

A Preliminary Study of Holocene Climate Change and Human Adaptation in the Horqin Region

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Abstract: Human activity during the Holocene in the Horqin region, northeastern China, has been widely documented. As an important proxy record of human activity, black carbon (BC) in sediments has been linked to climate change and human adaptation. A loess-paleosol section located in south Horqin was chosen for this study. Holocene climate change and human adaptation to the environment were discussed by analyzing BC, organic carbon (OC) and other proxies. The conclusions included: (1) before 3900 cal BP, human activity was closely related to the natural environment and cultural development was dominated by climate change. For example, the rapid decline of the agrarian Hongshan culture was caused by a slight decrease in temperature at ~5000 cal BP; (2) during 3900–3200 cal BP, the heavy dependence of human societies on nature gradually lessened and the ability of those human societies to adapt to the environment was enhanced. However, the farming-dominated Lower Xiajiadian culture was nonetheless replaced by the pastoralist Upper Xiajiadian culture due to an extremely cooling event at ~3200 cal BP; (3) during the late Holocene period, the marked influence of climate change on human activity might have lessened as a result of a clear improvement in human labor skills. After this, human living styles were influenced by cultural developments rather than climate change because humans had mastered more powerful means of productivity.

Key words: black carbon, climate change, human adaptation, archeological culture, the Holocene, Horqin Sandy Land

1 Introduction

The Western Liaohe River Basin in northeastern China, where Horqin Sandy Land developed, is watered by the Xar Moron River and its tributaries such as the Laoha River and Jiaolai River. Numerous archeological studies indicate that the Western Liaohe River Basin is one of the cradles of ancient Chinese civilization with a long history marked by remarkably distinctive local traditions (An, 1998; Li et al., 2006). Human activity developed rapidly in this region during the Holocene period, giving rise to the Xiaohexi, Xinglongwa, Zhaobaogou, Hongshan, Xiaoheyuan, Lower Xiajiadian and Upper Xiajiadian cultures (Deng, 1997; Xia et al., 2000; Hu et al., 2002; Mo et al., 2002; Li et al., 2003, 2006) (Table 1).

In the past several years, much attention has been paid for the sand dune activities which correspond to climatic variations during the Holocene in the Horqin region. However, previous studies yielded greatly different

results. Based on the study of Holocene dune activity in Horqin sand-field with ^{14}C and OSL chronology, Zhao et al (2007) thought that the dunes solidify and soils only developed between 7.5 and 2.0 ka. Yang (2010) suggested that Horqin dunes were stabilized during the period ~ 9.6–3 ka, and some differences exist in the timing of dune stabilization in the early Holocene (Yang et al., 2012).

Ren et al. (1997) reconstructed the evolutionary history of vegetation during the Holocene period through a high-resolution pollen analysis of peat profiles from Maili, Inner Mongolia, and based on plant remnant and pollen analysis of the relevant cultural layer at the Niuheiliang site, Mo et al. (2002) discussed the relation between human activity and paleoenvironment. Based on pollen analysis, Li et al (2013) reconstructed the climate change in inner Mongolia from 51.9–30.6 ka BP. Stable carbon isotopic composition of black carbon in surface soil was also used as a proxy for reconstructing vegetation and paleoclimate (Liu et al., 2012; 2013).

In our study, we aim to elucidate the relation between

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Table 1 Evolution sequence of ancient civilizations in the Western Liaohe River Basin (mainly based on Hu et al., 2002)

Age (cal BP)	Archaeological culture	Culture characteristic (s)
before 8150	Xiaohexi	gathering and hunting, fishing
8150–7350	Xinglongwa	gathering and hunting, primitive agriculture
7150–6150	Zhaobaogou	sedentary agriculture, fishing/hunting, gathering, domestication
6660–4900	Hongshan	advanced tillage agriculture with gathering
4800–4100	Xiaoheyuan	mainly fishing/hunting, agriculture depression
4100–3300	Lower Xiajiadian	advanced sedentary agriculture with developing animal husbandary
3200–2200	Upper Xiajiadian	pastoralism

climate change and human adaptation using BC records of loess samples from Horqin Sandy Land.

BC is a product of the incomplete combustion of both fossil and contemporary (biomass) fuels, arising from combustion residues (e.g. charcoal) and condensed carbonaceous products (Gelinás et al., 2001; Elmquist et al., 2004; Shao et al., 2012). BC particles are ubiquitously present in our environment, both suspended as aerosols in the atmosphere, and in liquid and solid media after deposition in soils, loess, and aquatic sediments (both lacustrine and marine) (Ahmed et al., 2009; Poot et al., 2009; Masiello et al., 1998; Wang et al., 2005). BC particles play an important role in biology, geochemistry and the environment (Schmidt et al., 2000). There is an increasing realization of the potential importance of BC in many global processes (Preston et al., 2006; Hsieh et al., 2008).

As a proxy record of the history of fire, BC as found in sediment samples has, over time, come to be recognized as having a major impact on the global atmospheric carbon cycle and, by extension, the recording of the history of fire (Bird et al., 1998; Lim et al., 1996; Gelinás et al., 2001; Poot et al., 2009; Muri et al., 2002). Fire is closely correlative with human activity, so BC can be linked to the intensity of human activity (Zhou et al., 1993; Xu et al., 2002).

2 Sampling and Method

2.1 Sampling

Horqin Sandy Land is in southeastern Inner Mongolia in the transition zone between the northeastern plains and the Inner Mongolian Plateau. This region is situated in a mid-latitude ecotone between a semi-humid zone and a semi-arid zone in northern China (location: 42°41'–45°45'N, 118°35'–123°30'E) (Fig. 1), and is characterized by a continental monsoon climate; mean annual temperature varies from 5.8–6.4°C, and annual precipitation from 343–451 mm.

The loess and paleosol samples used in this study were taken from a loess-paleosol section located at 34°34' N, 109°32' E near Xinwopu Village, Jiefangyingzi Town, Wengniute, Inner Mongolia, in southeastern Horqin Sandy Land. The profile was 2.94m thick in total. The upper 10cm of the location was a farmed soil layer, and the rest was a silt layer. The profile was sampled at an interval of 2cm, and there were a total of 148 samples. Sample numbers were named WNT-2011-3...WNT-2011-150 (Fig. 2).

2.2 Method

The thermal/optical reflectance method (TOR) has been

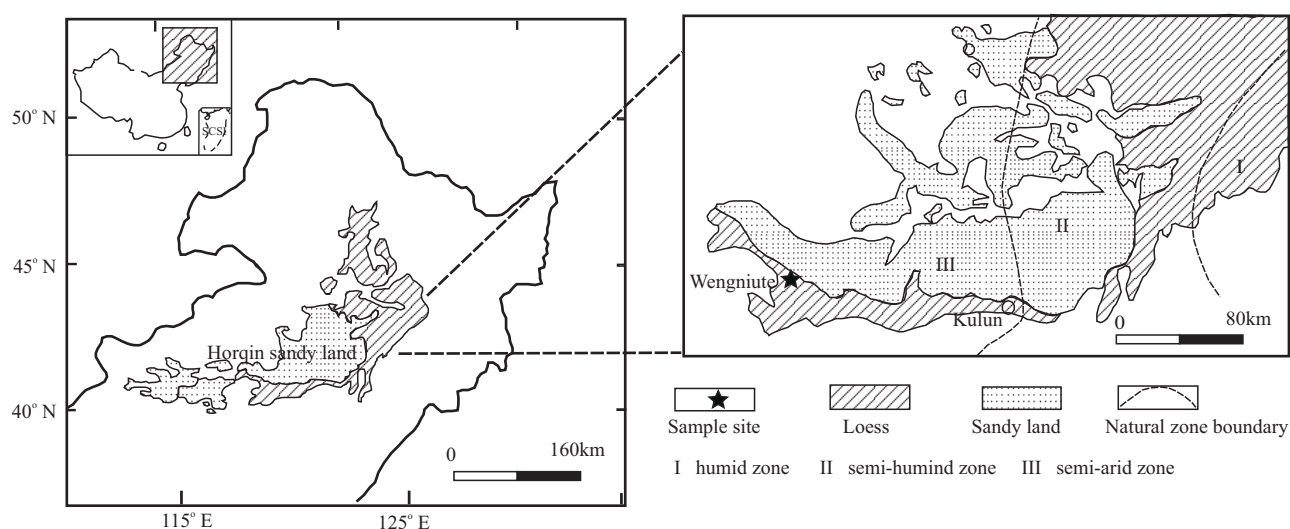


Fig. 1. The location of Horqin Sandy Land.

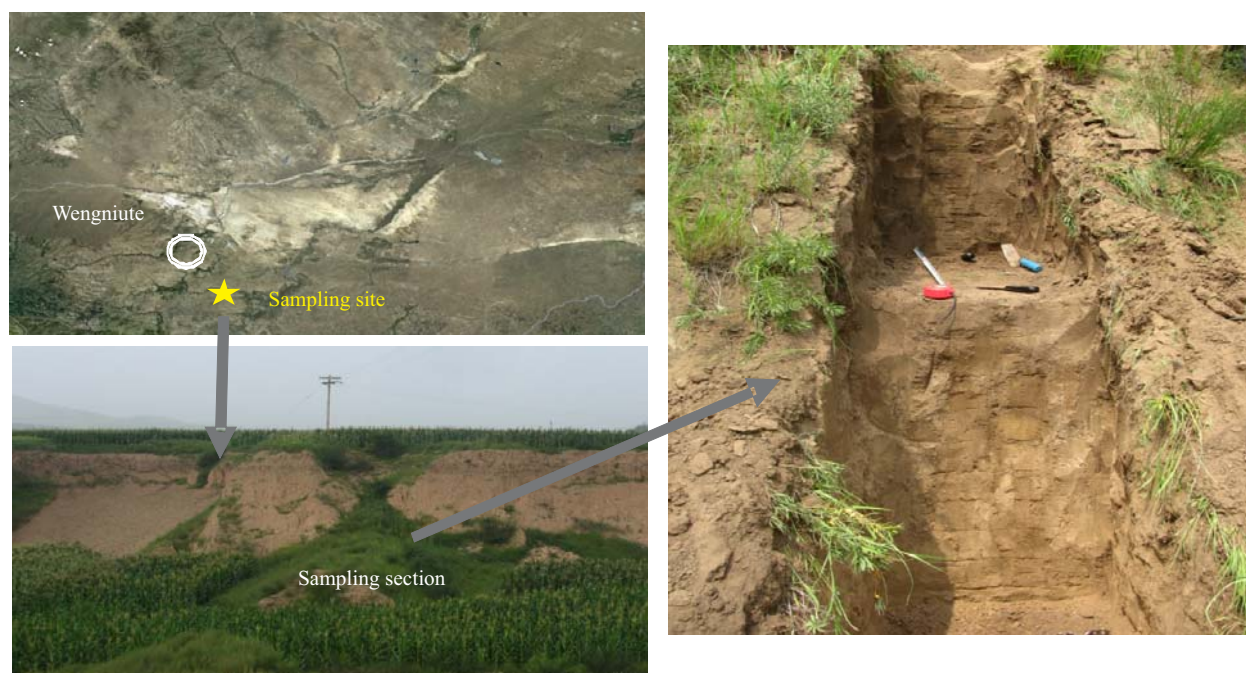


Fig. 2. The location of the section.

used in previous studies to quantify BC content based on the preferential oxidation of OC and BC compounds at different temperatures. It relies on the fact that organic compounds can be volatilized from the sample deposit in a helium (He) atmosphere at low temperatures, while BC is not oxidized and removed. Interagency monitoring of protected visual environments (IMPROVE) is one protocol that is most commonly used in black carbon analysis (Chow et al., 1993, 2001, 2004; Cao et al. 2008; Han et al., 2007ab, 2008ab, 2009; Wang et al., 2012).

The instrument used in this study was a DRI Model 2001 Thermal/Optical Carbon Analyzer. Carbonate and silicate were extracted by adding hydrochloric acid (HCl) and hydrofluoric acid (HF). The pretreatment procedures were determined as shown in Fig. 3.

After pretreatment, the residue was filtered on a quartz filter. A 0.526cm² punch from the sample filter was placed in a quartz boat and placed in the sample oven. The carbon compounds were converted to carbon dioxide (CO₂) by passing the volatilized compounds through an oxidizer (heated manganese dioxide, MnO₂). CO₂ was reduced to methane (CH₄) by passing the flow through a methanator (a hydrogen-enriched nickel catalyst), and the quantification of CH₄ equivalents was determined using a flame ionization detector (FID) (Huang et al., 2006).

First, with the oven temperature progressively heated to 120°C, 250°C, 450°C, and 550°C within in a pure helium (He) atmosphere, carbon was evolved from the filter punch, and four OC fractions were produced: OC₁, OC₂, OC₃ and OC₄. Then carbon was evolved from the filter

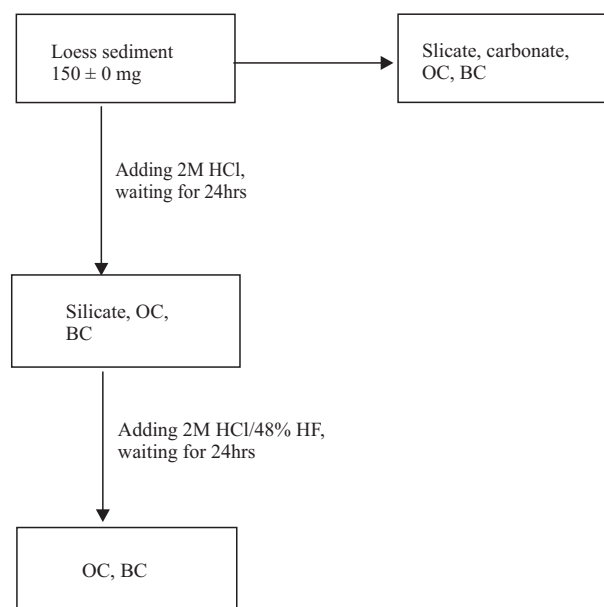


Fig. 3. Chemical pretreatment of loess samples.

punch in a He/oxygen (O₂) atmosphere (98%He/2%O₂) at 550°C, 700°C and 800°C, and three BC fractions were produced: BC₁, BC₂ and BC₃. Pyrolyzed organic carbon (POC) was also produced. Duplicate analyses of the same sample showed that the precisions of BC and OC are 94% and 95%, respectively.

Both magnetic susceptibility (SUS) and grain size were analyzed at the Institute of Geology and Geophysics, Chinese Academy of Sciences. SUS was measured using the Barrington MS2 magnetic susceptibility meter, and

grain size was measured with a Master Size 2000 Laser Particle Size Analyzer (Qin et al., 2005; Xiao et al., 2009).

3 Results

3.1 Chronology of the section

Twelve radiocarbon samples from this loess and paleosol section were dated with an Accelerator Mass Spectrometry (AMS) system at Beta Analytic Inc., United States. The positions of these radiocarbon samples were at 0cm, 10cm, 28cm, 48cm, 88cm, 118cm, 160cm, 186cm, 214cm, 250cm, 264cm and 292cm from the top of the section (Table 2, Fig. 4).

In order to determine the paleoenvironmental information, i.e. the age of a climate event, the period of climate change, etc., a precise time scale had to be established (Fig. 4).

3.2 The variation of BC

As shown in Fig. 5, the maximum BC content was

0.17%, the minimum was about 0.013%, and the mean was 0.06%. BC content exhibited similar trends to SUS values and OC content. BC content increased especially rapidly from 7700 to 7200 cal BP and from 6800 to 6300 cal BP. BC content thereafter rapidly reached high values at ~6000 cal BP. However, SUS and soil OC content exhibited high values at ~6500 cal BP.

BC content was characterized by three stages during 6000–5000 cal BP. At ~5000 cal BP, BC content decreased to its lowest value.

During the period 5000–3900 cal BP, BC content exhibited an increasing, fluctuating trend and reached its overall highest value of 0.17% at 4400 cal BP. Thereafter BC results began to decrease while fluctuating, reaching a lowest value for the period of 0.06% at ~3900 cal BP.

The period from 3900 to 3200 cal BP was characterized by several fluctuations, and BC content rapidly reached a maximum value of 0.14% at ~3800 cal BP. BC contents then began to decline and reached a minimum at ~3200 cal BP. Between 3200 and 2400 cal BP, BC contents exhibit

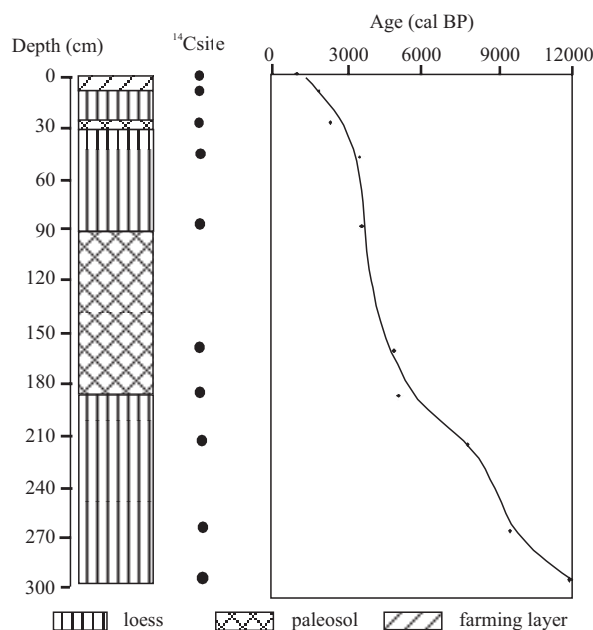


Fig. 4. Loess and paleosol stratigraphic and age–depth model of the section in the study area.

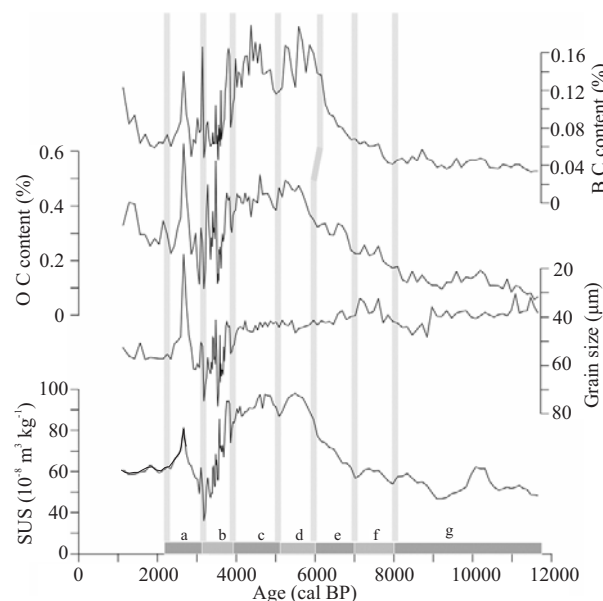


Fig. 5. BC content, SUS, grain size and OC of the section.

a. Upper Xiajiadian culture; b. Lower Xiajiadian culture; c. Xiaohewan culture; d. Hongshan culture; e. Zhaobaogou culture; f. Xinglongwa culture; g. Xiaohexi culture.

Table 2 AMS radiocarbon dates of samples

Sample number	Depth (cm)	Dating material	AMS ^{14}C (age/a. BP)	Calibrated ^{14}C age (2 σ) (cal BP)
WNT-2011I-3	0	Organic matter	1060 \pm 30 BP	1170–1050/ 1040–980
WNT-2011I-8	10	Organic matter	1910 \pm 30 BP	1990–1870
WNT-2011I-17	28	Organic matter	2280 \pm 30 BP	2430–2420/ 2360–2340
WNT-2011I-27	48	Organic matter	3250 \pm 30 BP	3630–3460
WNT-2011I-47	88	Organic matter	3310 \pm 30 BP	3690–3560
WNT-2011I-62	118	Organic matter	3040 \pm 30 BP	3380–3260
WNT-2011I-83	160	Organic matter	4290 \pm 30 BP	4970–4840
WNT-2011I-96	186	Organic matter	4430 \pm 40 BP	5310–5040/ 5010–4980
WNT-2011I-110	214	Organic matter	6950 \pm 40 BP	7940–7790/ 7770–7760
WNT-2011I-128	250	Organic matter	10390 \pm 50 BP	12540–12100
WNT-2011I-135	264	Organic matter	8380 \pm 40 BP	9530–9440
WNT-2011I-149	292	Organic matter	10150 \pm 50 BP	12040–11620

significant fluctuations. There was a surge in BC values from 3200 to 2900 cal BP, with a peak value occurring at ~3100 cal BP. After 2900 cal BP, BC content began to increase rapidly, reaching a peak value of 0.12% at ~2700 cal BP, and decreasing to a lowest value for this period of 0.04% at ~2400 cal BP.

Such a rapid increase in BC results was inconsistent with SUS values, which exhibited a steady fluctuation trend between 2000 and 1160 cal BP.

4 Discussions

Analysis of SUS, grain size and OC content in Horqin suggests that the climate during the early Holocene (11600–8000 cal BP) was dry and cold, and marked by low rainfall and poor soil conditions. Early on in the period from 8000 to 3200 cal BP, the climate shifted from cold/dry to moist/warm, and reached its highest levels at ~6000 cal BP. However, the high-intensity summer monsoon shifted at ~5000 cal BP, when a cold/dry event prevailed. The period from 3900 to 3200 cal BP was characterized by several centennial-scale climatic fluctuations, and an extreme climate event occurred at ~3200 cal BP (Fig. 6). A warm/moist event at ~2700 cal BP was accompanied by an increase in temperature and rainfall, a high degree of pedogenesis, and high vegetation densities.

(1) 11600–8000 cal BP

During this period, the climate was dominated by arid and cold conditions, resulting in low densities of vegetation cover. BC content is also low, though with some small fluctuations, suggesting that the frequency and geographical range of fires was small. The lowermost part in this sequence corresponded to the Xiaohexi cultural period. Based on archeological research (Deng, 1997; Hu et al., 2002; Li et al., 2003), gathering and hunting became

economically significant during the Xiaohexi culture (before ~8000 cal BP), suggesting that the level of human activity was low (Table 1). With an improvement in the climatic conditions, the Xiaohexi culture was replaced by the Xinglongwa culture.

(2) 8000–6000 cal BP

This period was characterized by an increase in BC content and temperature/rainfall, suggesting that the summer monsoon influenced this site strongly during this period. The increase in BC preceded that in the SUS and OC content at ~6000 cal BP, and this asynchrony suggested that BC content might be more closely determined by human activity. The intensity of human activity and the development of human civilization were closely associated with the development of the summer monsoon and the subsequent climate change. This period corresponds to the cultural periods of the Xinglongwa (8000–7000 cal BP) and Zhaobaogou cultures (7000–6000 cal BP). The former culture was replaced by the latter during a period of rapid improvement in climatic conditions. Archeological evidence (Table 1) indicated that, during the Xinglongwa period, gathering and hunting were the principal economic modes, though a preliminary development of primitive agriculture also occurred (Deng, 1997; Hu et al., 2002). Compared with the Xinglongwa culture, the Zhaobaogou culture was dominated by plough-tillage agriculture alongside fishing and hunting, gathering and the domestication of animals, indicating a population increase.

(3) 6000–5000 cal BP

During the period from 6000 to 5000 cal BP, an increase in SUS values and soil OC content was associated with very intense summer monsoon episodes and consequent high vegetation cover densities, indicating a warm/moist climate. The Hongshan culture, a significant archeological culture in China, arose. During this cultural period, tillage agriculture became dominant, although it coexisted with pastoralism, gathering and hunting (Deng, 1997; Hu et al., 2002; Mo et al., 2002; Teng, 2010) (Table 1).

Fluctuations in BC content were inconsistent with that of soil OC content from 6000 to 5000 cal BP, suggesting that human activity might have had a significant influence on BC content during this period. At ~5000 cal BP, a decline in BC content, considered indicative of a decline in human activity, signifies strong coincidence with the collapse of the Hongshan culture. This coincidence indicated that, during this period, human activity was highly dependent upon both climate and environment, and that a cold/dry event and environmental degradation around 5000 cal BP might cause the collapse of human cultures.

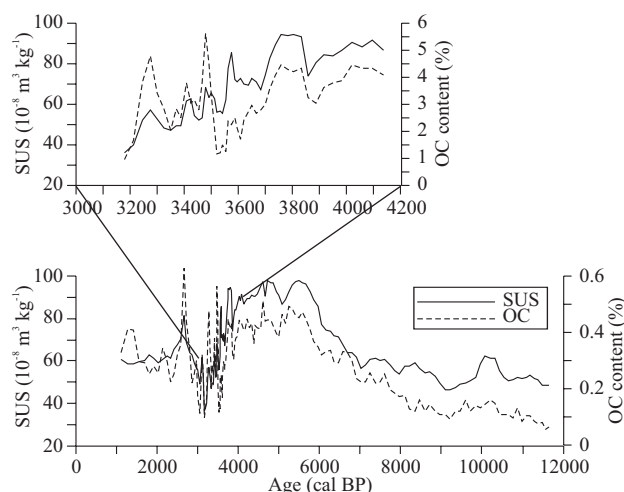


Fig. 6. Climatic fluctuations 3900–3200 cal BP.

(4) 5000–3900 cal BP

After the decline of the Hongshan culture, the climate appeared to have become warm/dry with high vegetation cover densities at ~4900 cal BP. In the archeological record, the Xiaohayuan culture replaced the Hongshan culture during a more benign climatic period, and fishing and hunting as well as agriculture became much more economically significant (Deng, 1997; Hu et al., 2002; Li et al., 2003). However, the period from 4400 to 3900 cal BP was characterized by a rapid decrease in BC content to its minimum, indicating a decay in human activity; it might be taken that, because of its high level of dependence upon climate change, a short-term deterioration in the climate might have caused human civilization to decline.

(5) 3900–3200 cal BP

BC content reached a high level almost on a par with that of the Hongshan culture at ~3800 cal BP, indicating that a suitable climate and rich vegetation had provided the optimal environment for enhancing human development. Archeological evidence suggested that the Lower Xiajiadian culture farmed intensively and that the keeping of livestock was also very popular (Deng, 1997; Li et al., 2006) (Table 1). Thereafter, BC content began to decrease, suggesting a decline in the frequency and geographical range of the use of fire. This decrease might be related to falling temperatures and the general deterioration in the climate.

The period from 3900 and 3200 cal BP was characterized by five climatic fluctuations; the fact that the Lower Xiajiadian culture did not disappear suggested that human adaptation to the environment had improved and, conversely, that a dependence on nature had lessened. Nonetheless, an extreme cold event (~3200 cal BP) still resulted in a decline in the Lower Xiajiadian culture, which was replaced by the Upper Xiajiadian culture. This represented a key transitional period in the archeological record from a predominantly agriculturally-based society to one based on pastoralism.

(6) 3200–2400 cal BP

At ~3100 cal BP (Fig. 5), an increase in summer monsoon events resulted in an increase in both temperature and precipitation, and the vegetation cover densities also began to increase, allowing the Upper Xiajiadian culture to develop. From 2800 to 2600 cal BP, a dramatic change was indicated by the SUS values and OC content, indicating intense summer monsoons and a warmer and wetter climate. However, the Upper Xiajiadian culture remained a pastoralist society (Deng, 1997; Li et al., 2006), indicating that human lifestyles were now dominated by cultural practices, and that the dependence of human activity on the environment had

declined.

(7) 2400–1160 cal BP

As Fig. 5 shows, during the period from 2350 to 1160 cal BP, the climate was most probably warm/dry. Under these climatic conditions, pedogenesis appeared to be weak. However, the vegetation cover densities and BC content were high, suggesting that human activity was expanding. It could reasonably be argued that, in this more highly developed civilization, human activity was able to adapt more readily to environmental change.

5 Conclusions

Based on a high-resolution timescale, and SUS, grain size, soil OC, and BC records in a soil-loess sequence at Wengniute, Inner Mongolia, our study focused on climate change and the characteristics of human adaptation in the Horqin region during the Holocene, reaching the following conclusions:

(1) The dependence of human activity on the environment was high, and climate change had a substantial impact on civilizations prior to 3900 cal BP. Therefore, a brief cold event resulted in a rapid decline of the Hongshan culture.

(2) During the period 3900–3200 cal BP, an increasingly effective human adaptation to the environment resulted in a decline in the dependence of human activity on that environment, and several climatic fluctuations did not seriously impact the Lower Xiajiadian agricultural culture. However, an extreme cold event (~3200 cal BP) still resulted in the decline of the Lower Xiajiadian culture, which was replaced by the Upper Xiajiadian pastoralist culture.

(3) The period 2800–2600 cal BP was characterized by intense summer monsoons, warmer/moister climatic conditions and a high degree of pedogenesis. However, the Upper Xiajiadian culture remained and thus represents a key transitional archeological period during which society moved from being predominantly agriculturally-based to one based on pastoralism. Such a development suggests that economic patterns were now dominated by the forces of human civilization, and that when that civilization reached a certain degree of sophistication, the influence of climate and the environment on the development of such prehistoric cultures was lessened.

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