Journal of Asian Earth Sciences 121 (2016) 1–8

Contents lists available at ScienceDirect

Journal of Asian Earth Sciences

journal homepage: www.elsevier.com/locate/jseaes

Holocene climate change evidence from high-resolution loess/paleosol records and the linkage to fire–climate change–human activities in the Horqin dunefield in northern China

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ARTICLE INFO

Article history:
Received 15 June 2015
Received in revised form 20 November 2015
Accepted 22 January 2016
Available online 9 February 2016

Keywords:
Black carbon
Holocene
Climate change
Human activity
Vegetation coverage

ABSTRACT

The combination of high-resolution sedimentary paleoclimate proxies of total organic carbon and magnetic susceptibility of a loess/paleosol section with black carbon (BC) records provides us with information about climate change and the linkage of fire–climate change–vegetation–human activities in the Horqin dunefield over the past 11,600 cal yr BP. We found that during 11,600–8000 cal yr BP (the early Holocene), the area was dominated by a dry climate. The vegetation coverage was low, which limited the extent of fire. The Holocene optimum can be placed between 8000 and 3200 cal yr BP, and during this period, anthropogenic fire was a key component of total fire occurrence as the intensity of human activity increased. The development of agricultural activities and the growing population during this period increased the use of fire for cooking food and burning for cultivation and land fertilization purposes. During 2800–2600 cal yr BP, a warm/moister climate prevailed and was associated with a high degree of pedogenesis and vegetation cover density, evident at 2700 cal yr BP. Fires may have contributed to human survival by enabling the cooking of food in the warm and wet climate. In the period since 2000 cal yr BP, fires linked to agriculture may have led to increased biomass burning associated with agricultural activity.

1. Introduction

The Horqin dunefield, situated in a mid-latitude ecotone in northern China, a semi-arid zone, is influenced by both the East Asian monsoon and the Westerlies (Fig. 1). Therefore, the dunefield is sensitive to variations in monsoon intensity. Archaeological records from this region indicate that human occupation has been continuous during the Holocene period (Yang et al., 2012).

In past decades, a great number of paleoclimatic scientists have investigated abundant geological records (including lake sediments and loess/paleosol sediment) near the Horqin dunefield in attempts to construct a detailed history of the East Asian monsoon and climate change variations during the Holocene (An et al., 2000; Dykoski et al., 2005; Janssen et al., 2012; Jiang et al., 2006; Jin et al., 2004; Spiro et al., 2009; Wen et al., 2010a, 2010b; Xiao et al., 2002). These studies have yielded a variety of results. Some studies have indicated that wet climate conditions appeared during the early Holocene (An et al., 2000; Jiang et al., 2006). An et al. (2000) proposed that the East Asian summer monsoon precipitation reached a peak in northeastern China approximately 10,000–8000 yr ago. Jiang et al. (2006) suggested that the summer monsoon influenced northern China most strongly between 10,500 and 6500 cal yr BP. In contrast, according to other records, the early Holocene was characterized by less rainfall, and the summer monsoon reached a peak during the mid-Holocene. For example, Zhao et al. (2007) concluded that dunes in the region stabilized widely between approximately 7.5 and 2.0 ka and that this dune activity was basically consistent with the timetable of Holocene climatic changes in northeastern China. Based on the archeological and geological evidence, analogous processes of climate change during the Holocene period have been reported by Hu et al. (2002) to have occurred in the Horqin region and the region of the West Liaohe River, i.e., changes from a relative cold and dry climate between 10 ka and 7.3 ka to a warm and wet climate during 7.3–2.8 ka and then a cool and dry climate since 2.8 ka. Because of the debate among many Quaternary scientists concerning climate change in this region during different Holocene periods, detailed records from various sources are required to obtain a clearer understanding of the history of climate change in northern China.

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http://dx.doi.org/10.1016/j.jseaes.2016.01.017
1367-9120/

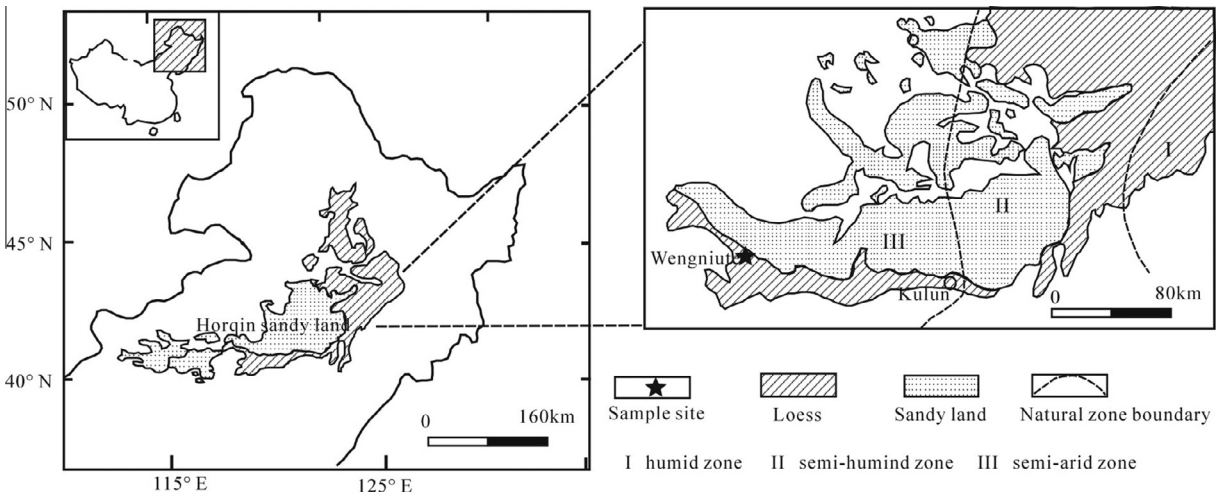

Fig. 1. Location of the Horqin dunefield.

Human activity developed rapidly in this region during the Holocene period, giving rise to the Xiaohexi, Xinglongwa, Zhaobaogou, Hongshan, Xiaoheyan, 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). Many studies have been focused on the linkage between Holocene climate change and human activities (Bowman et al., 2011; Carcaillet, 1998; Marlon et al., 2006; Tan et al., 2015; Wang et al., 2013; Whitlock et al., 2007). In the Chinese Loess Plateau in particular, the relationship between fires and climate changes have been discussed on orbital to millennial timescales (Huang et al., 2006; Tan et al., 2015; Wang et al., 2012b; Yang et al., 2001; Zhou et al., 2007). The results of these studies have contributed to our current research on the Horqin dunefield.

Fire occurrence in these mid-arid and arid regions was largely linked to climate change, which also influenced the vegetation types and coverage (Tan et al., 2015; Wang et al., 2012b). Humans are unique in being a fire-making species, so prehistoric human-made fires cannot be negligible. Charcoal, present as combustion residues in sediments (lake and loess), can provide information on past fire history (Ali et al., 2009; Clark, 1988; Huang et al., 2006; Whitlock et al., 2007; Yang et al., 2001). In previous paleoenvironmental work, charcoal and other proxies, e.g., total organic carbon (TOC), magnetic susceptibility, and pollen, have been used to analyze the linkage of fire–climate change–vegetation–human activities in North and South America, Europe, and Australia (Carcaillet, 1998; Huang et al., 2006; Marlon et al., 2006, 2009; Tan et al., 2015). In recent years, many scientists have studied fire charcoal records in East Asia, especially in China (Han et al., 2012; Long et al., 1998; Tan et al., 2015; Wang et al., 2012b, 2013; Zhou et al., 2007). However, more research is required to obtain a clearer understanding of the Asian monsoonal region because of the lack of charcoal data from sedimentary sources.

In this paper, we present detailed climate and anthropogenic records for the last 11,600 cal yr BP derived from loess sediment in Horqin sandy land. Our construction provides a detail history of Holocene climate change in this region. The relationship between climate and human activities is also discussed.

2. Study area

The Horqin dunefield is located in southeastern Inner Mongolia, in the transition zone between the northeastern Chinese plains and the Inner Mongolian Plateau (location: 42°41′–45°45′N, 118°35′–123°30′E) (Fig. 1). This region is approximately 400 km northeast of Beijing, with an area of approximately 50,000 km^2 and an elevation range of 180–650 m above sea level. In the summer, the dominant wind is southeasterly and brings humid air masses from the Pacific Ocean. In the winter, the prevailing wind is northwesterly, and the climate is cold and dry. This region is characterized by a continental monsoon climate. The mean annual temperature varies between 5.8 and 6.4 °C, and the mean annual precipitation varies between 343 and 451 mm.

Horqin Sandy Land sits in the Western Liaohe River Basin in northeastern China, which is fed by the Xar Moron River and its tributaries, the Laoha River and the Jiaolai River. Numerous archeological studies indicate that the Western Liaohe River Basin was one of the cradles of ancient Chinese civilization (An, 1998; Li et al., 2006).

3. Materials and methodology

3.1. Section

The loess and paleosol samples used in this study were taken from the loess/paleosol section (34°34′N, 109°32′E), near Xinwopu Village, Jiefangyingzi Town, Wengniute County, Inner Mongolia. The section is situated in a flat highland located on the edge of the southern Horqin dunefield, where savanna develops. Our profile also sits downwind of the Horqin dunefield, so aeolian deposition can reflect the occurrence of dust storms and climate changes in this sandy terrain.

The thickness of the loess/paleosol sequence is approximately 2.94 m in total. The upper 10 cm is a farmed soil layer, and the rest is a silt layer. A detailed description of the stratigraphy was made through field observations of the color and texture (Fig. 2; Table 1).

The section was sampled at depth intervals of 2 cm, and a total of 148 samples were obtained. The samples were named WNT-2011-3 through WNT-2011-150 (Fig. 2).

3.2. Indices of paleoenvironment and measurement methods

The thermal/optical reflectance method (TOR) has been used in previous studies to quantify black carbon (BC) and OC (organic carbon) content based on the preferential oxidation of OC and BC compounds at different temperatures. The method relies on the fact that organic compounds can be volatilized from sample deposits in a helium (He) atmosphere at low temperatures, while BC is not oxidized and removed. Interagency monitoring of protected visual environments (IMPROVE) is a protocol that is commonly