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The linkages with fires, vegetation composition and human activity in response to climate changes in the Chinese Loess Plateau during the Holocene

Zhihai Tan[a,b,*], Yongming Han[a,e], Junji Cao[a], Chun Chang Huang[c], Longjiang Mao[d], Zhao Liu[b], Zhisheng An[a]

[a] State Key Laboratory of Loess and Quaternary Geology, Key Laboratory of Aerosol Chemistry and Physics, Institute of Earth Environment, Chinese Academy of Sciences, Xi'an, Shaanxi 710075, PR China
[b] Department of Environment & Chemical Engineer, Xi'an Polytechnic University, Xi'an, Shaanxi 710048, PR China
[c] Department of Geography, Shaanxi Normal University, Xi'an, Shaanxi 710062, PR China
[d] School of Marine Science, Nanjing University of Information Science & Technology, Nanjing, Jiangsu 210044, PR China
[e] School of Human Settlements and Civil Engineering, Xi'an Jiaotong University, Xi'an, Shaanxi 710049, PR China

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ABSTRACT

Holocene paleo-records of the Chinese Loess Plateau loess–soil profiles were used to reconstruct wildfire patterns and landscape evolution. We examine black carbon and charcoal influx, combined with the Magnetic susceptibility, $\delta^{13}C$ values of soil organic matter, pollen counts and other paleo-environmental proxies to discuss interactions with biomass–climate during the Holocene. The history of fires from the charcoal and black carbon (BC, char and soot) influx at the two sites demonstrates a transition from climate-controlled low amplitude variations with peaks during the Early and Middle Holocene (11-3.1kyearsB.P.) to higher amplitude variability in fire occurrence decoupled from climate and tied to human activities during the Late Holocene (3.1-0kyearsB.P.). The difference in fire patterns was attributed to regional effective moisture and human land use over the entre Loess Plateau; meanwhile, fire activities observed during the Holocene are consistent with variations in vegetation composition inferred from $\delta^{13}C$ values in soil organic matter, pollen counts, and paleoclimate proxies. Regional wildfires rarely occurred on the desert steppe dominated by a weedy C_3 taxon (*Artemisia, Compositae,* and *Chenopodiaceae* dominated)during the late glacial period. A limited biomass would not meet fire propagation in the extreme colder and drier environment of the Loess Plateau during those periods, though. As the climate became ameliorated during the early Holocene, there was an increasing biomass and a sufficient contribution do to high fuel accumulation from C_4 taxon (*Gramineae*). As the middle Holocene progressed toward warmer and wetter conditions, fire events were less frequent on the steppe and forest-steppe (e.g. expansion of trees C_3,*Quercus, Corylus*) of the Loess Plateau. Subsequently, the number of local and regional fire events have largely increased with the colder and drier climate conditions (e.g. expansion of C_3 weedy), which have been decoupling with intensive anthropogenic burning for farming since the past 3kyr.

These data suggests that the regional fire patterns vary strongly along environmental gradients in the effective moisture and regional fuel availability as well as the spatial and temporal distributions of Neolithic burning practices over the Loess Plateau in response to the weakening East Asian monsoon during the Holocene.

1. Introduction

Fires play a key role in the evolution of the natural landscape and in the carbon cycle from the terrestrial biosphere to the atmosphere (Bowman et al., 2009). The extent and frequency of wildfires are closely related to seasonal climate variability (wet or dry), vegetation types and human activity (Conedera et al., 2009). The occurrence of fire is largely controlled by climatic changes (Archibald et al., 2008), and thus influenced by vegetation structure and productivity (Daniau et al., 2009; Pechony and Shindell, 2010); Fire occurrence in turn responded to climate condition through the evolution of vegetation and post-fire response at the millennium timescales (Moreira et al., 2011).

* Corresponding author. State Key Laboratory of Loess and Quaternary Geology, Key Laboratory of Aerosol Chemistry and Physics, Institute of Earth Environment, Chinese Academy of Sciences, Xi'an, Shaanxi 710075, PR China.
E-mail addresses: tonishtan@163.com (Z. Tan), Cao@loess.llqg.ac.cn (J. Cao).

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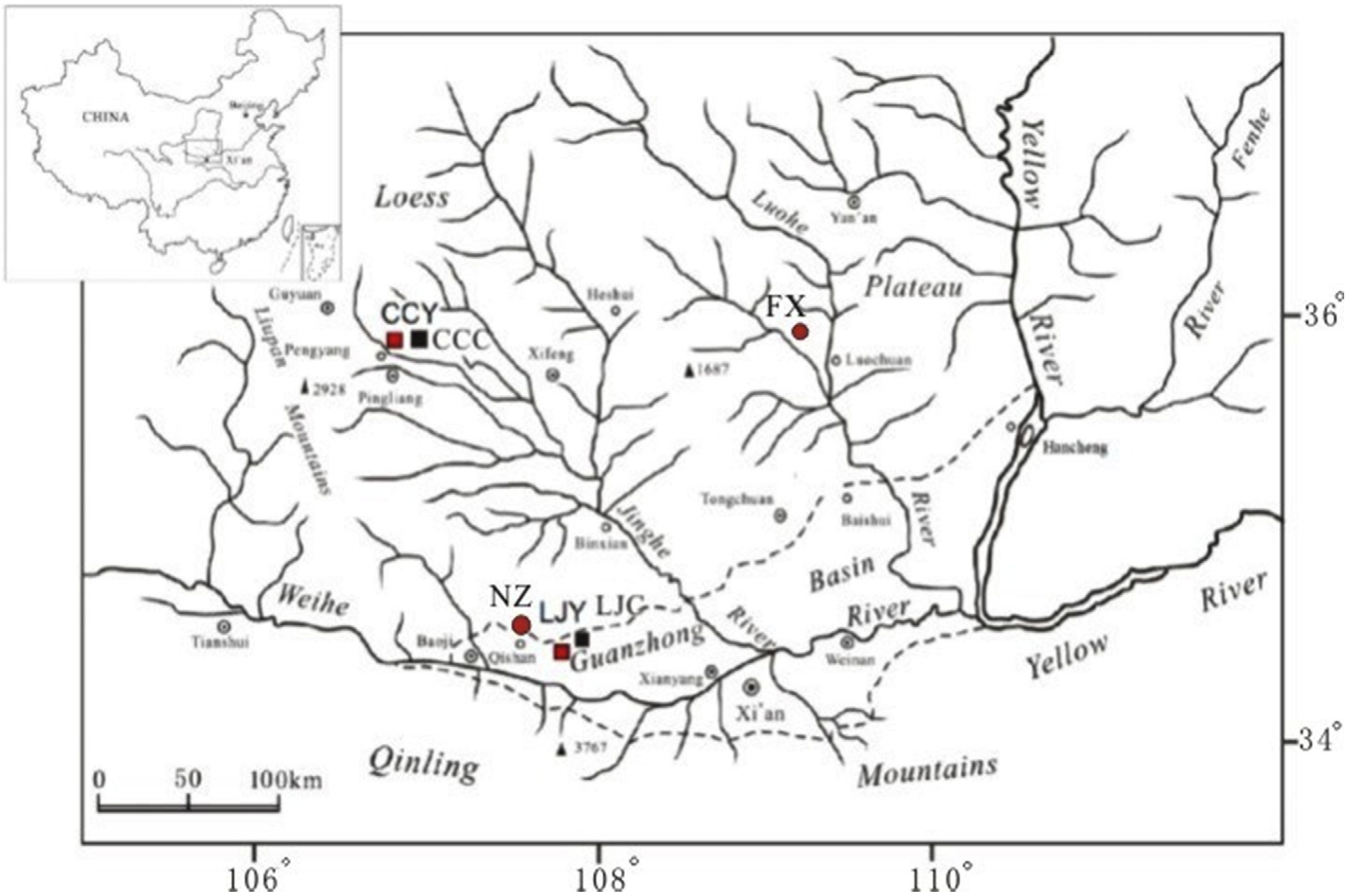

Fig. 1. Map showing the study region on the Loess Plateau. The study sites from black carbon and charcoal records are marked as boxes: Liangjiacun (LJC) site, Liangjiayao site (LJY, a previously-investigated site, Tan et al., 2015), and Nanguanzhang (NZ) site (Han, 2000) in the southern part of the Loess Plateau; Changchengchun (CCC)site, Changchengyuan site (CCY, a previously-investigated site, Tan et al., 2013)and Fuxian (FX) site (Cheng, 2011)in the northern part of the Loess Plateau; The pollen data used in the study sites from NZ and FX sites marked as circles.

Meanwhile, the vegetation composition and distribution of fire were greatly modified to human land farming on the Loess Plateau by the "slash and burn" method during the last thousand years (Huang et al., 2006; Tan et al., 2011).

The studies of wildfire history have rapidly developed during the past few decades. Currently, wildfire regimes were investigated throughout the world using biological geochemistry, remote sensing technology, atmospheric physics, environment modeling and other multi-disciplinary technologies (Kehrwald et al., 2013; Marlon et al., 2013). These studies greatly contribute to our understanding of the interaction between fire, vegetation and climate during Holocene. A key research focus initial is to understand the behavior of natural wildfires using historical database from remote sensing and tree ring studies (for the last fifty years only) or reports provided by governmental forestry departments from anthropogenic and natural ignitions (Kehrwald et al., 2013). Subsequently, an alternative source of evidence concerns fire regimes and its forcing driver from the reconstruction of past wildfire sequence, and also the study of wildfire history was from site-specific locations to establish intra- and inter-regional wildfire database (Haberle and Ledru, 2001; Huber et al., 2004; Higuera et al., 2007; Whitlock et al., 2007; Vanni'ere et al., 2008; Jiang et al., 2008; Marlon et al., 2009; Kaal et al., 2011; Han et al., 2012; X Wang et al., 2012). Recently, compilations of such records have produced useful global and regional syntheses of lateglacial to Holocene fire regimes from the Global Charcoal Database (Power et al., 2008; Daniau et al., 2012; Marlon et al., 2013). Most of their studies primarily focused on the correlation with fire and climate change at various scales, whereas few reports investigated the complex interaction between fire, and vegetation (fuel), climate and human activities.(Yang et al., 2001; X Wang et al., 2005; Huang et al., 2006; Zhou et al., 2007; Li et al., 2009; Tan et al., 2015; Miao et al., 2016a). Paleoecological research has shown that vegetation strongly mediates climate–fire relationship by altering landscape patterns of vegetation and fuels (Higuera et al., 2009). The occurrence and propagation of fires are strongly governed by the moisture content of the low fuel and sufficient high fuel accumulation. Recent studies show that wildfires could have occurred in relatively warm and dry climatic conditions during the early of Middle Holocene, whereas wildfire frequency was also an increase in cold and dry climatic conditions during the Late Holocene. This suggests that fuel characteristics also may be an important control rather than directly climate-determined influences on fire regimes in the semi-arid and sub-humid region (Christensen, 1993). However, there is no standard protocol attached to the charcoal and black carbon analysis from continental or marine sediment due to differences of regional scale. It is so difficult to establish comparisons between different paleo-environments throughout the world that a detailed understanding of the relations between fires, vegetation composition and climate change during the Holocene remains limited (Hawthorne et al., 2017; Tan et al., 2015; X Wang et al., 2013). Furthermore, there is no clear relation between fires, vegetation composition (C_3/C_4) and the distribution of human land use in response to the East Asian monsoon. We addressed this problem by investigating the interaction between wildfire, seasonal climate change and vegetation composition, as well as human land use at centennial-to-millennial time scales. The available charcoal and black carbon records will provide us an opportunity to examine the linkages with fire regime, the vegetation dynamics and human land use