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Stable carbon isotopic composition of black carbon in surface soil as a proxy for reconstructing vegetation on the Chinese Loess Plateau

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ABSTRACT

Black carbon (BC) is a continuum of carbon produced by incomplete combustion. Whether its stable carbon isotopic composition (expressed as $\delta^{13}C_{BC}$ values) can be used directly for paleovegetation reconstruction is still in debate. In the present study, we investigated surface soil from the Chinese Loess Plateau and collected samples from the following three transects: the Ruicheng–Jingbian, Lantian–Huanxian, and Qin'an–Dingxi, from east to west. The $\delta^{13}C_{BC}$ values for surface soil ranged from −27.9‰ to −21.9‰; the stable carbon isotopic composition of soil organic carbon (expressed as $\delta^{13}C_{SOC}$ values) ranged from −26.8‰ to −20.9‰. A strong positive correlation was observed between $\delta^{13}C_{BC}$ and $\delta^{13}C_{SOC}$ ($R = 0.88$, $P = 0.000 < 0.01$); the difference between the $\delta^{13}C_{BC}$ and $\delta^{13}C_{SOC}$ ($\Delta^{13}C_{SOC\text{-}BC}$) values ranged from −1.5‰ to +1.3‰, with an average of +0.2‰. The characteristics of vegetation on the Chinese Loess Plateau and its variation, indicated by $\delta^{13}C_{BC}$ and $\delta^{13}C_{SOC}$ values, were consistent with those of modern plants. It suggests that $\delta^{13}C_{BC}$ values for surface soil are controlled mainly by surface plants, and that therefore $\delta^{13}C_{BC}$ can indicate the vegetation effectively, within a precision range of ±1.5‰.

1. Introduction

Black carbon (BC) is produced by the incomplete combustion of vegetation and fossil fuels, and represents a continuum from partly charred material to graphite and soot particles, with no general agreement on clear-cut boundaries (Goldberg, 1985; Kuhlbusch, 1995; Schmidt and Noack, 2000; Czimczik et al., 2002; Masiello, 2004). BC is relatively inert and is distributed globally, including in the atmosphere, soils, ices, lake sediments and marine sediments, by water and wind via fluvial and atmospheric transport. As a product of fire, BC is not only a useful tracer for the earth's fire history (Bellen et al., 2012; Jiménez-Moreno et al., 2013), but also a good proxy recording paleoenvironmental information. The stable carbon isotopic composition of BC ($\delta^{13}C_{BC}$) is a promising proxy for paleoenvironmental research, as it has been applied widely across a range of disciplines for obtaining environmental and paleoenvironmental information (Bird and Cali, 1998; Clark et al., 2001; Turney et al., 2001; Yang et al., 2001; Jia et al., 2003; Hall et al., 2008; Zhou et al., 2009; Bird and Ascough, 2012; Liu et al., 2012). However, researchers still have different opinions on whether $\delta^{13}C_{BC}$ can be used in recovering information on paleovegetation directly.

In previous studies on $\delta^{13}C_{BC}$, some researchers (Clark et al., 2001; Yang et al., 2001; Jia et al., 2003; Ferrio et al., 2005; Pessenda et al., 2005; Zhou et al., 2009; Hall et al., 2008; Aguilera et al., 2009) used $\delta^{13}C_{BC}$ values of bulk material or isolated charcoal fragments to access the vegetation type directly; however, some experiments involving burning of plants revealed changes in the stable carbon isotopic composition during the combustion process (Bird and Grocke, 1997; Turekian et al., 1998; Czimczik et al., 2002; Krull et al., 2003; Ning et al., 2004; Hammes et al., 2006; Turney et al., 2006; Das et al., 2010; Bird and Ascough, 2012; Liu et al., 2012). In addition, further studies are needed to determine whether the BC in sediment records "local" environmental information potentially with some influence from exogenous BC. Therefore, in order to establish a sound basis for $\delta^{13}C_{BC}$ research, it is crucial to carry out systematic and detailed studies, especially modern process studies of BC, to investigate the correlation between surface soil $\delta^{13}C_{BC}$ values and surface plants, and the influence of the exogenous BC.

The aeolian loess-soil sequences in northern China have a high sedimentation rate and good continuity, and play an important role in paleoenvironmental reconstruction providing major records of global climate change along with records from deep sea sediments and ice cores (Liu, 1985; An et al., 1991; Liu and Ding, 1998; Guo et al., 2002). In the Chinese Loess Plateau, some progress has been made in the paleovegetation reconstruction using pollen and organic carbon isotope proxies. These studies prompted us to consider a multiple-proxy comparison for investigating the validity of BC isotope composition

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for recovering information on paleovegetation. In this study, we (i) systematically sample Chinese Loess Plateau surface soils; (ii) analyze the stable carbon isotopic composition of BC ($\delta^{13}C_{BC}$) and stable carbon isotopic composition of organic carbon ($\delta^{13}C_{SOC}$); (iii) examine the correlation between $\delta^{13}C_{BC}$, $\delta^{13}C_{SOC}$, and surface plants; and finally (iv) discuss the validity of $\delta^{13}C_{BC}$ in reconstructing vegetation in the Chinese Loess Plateau.

2. Geological background

The Chinese Loess Plateau is located in north-central China (33°41′–41°16′N, 100°52′–114°33′E) (Fig. 1). The plateau consists of thick deposits of loess and is bordered by several mountain ranges: from the Qinling Mountains (highest peak 3767 m a.s.l.) in the south to the Mu Us Sandland in the north, and from the Taihang Mountains and Luliang Mountains (highest watershed 1500 m a.s.1.) in the east to the Helan Mountains in the west. On the Loess Plateau, there are the Liupan Mountains (several peaks > 2500 m a.s.1.), Huanglong Mountains, and others.

The Loess Plateau currently has a typical continental monsoon climate, modified by latitude, longitude, and terrain. It straddles a warm temperate zone and a cool temperate zone from south to north, and the semihumid zone to the semiarid zone from east to west. At present, the climate of the Loess Plateau is mainly controlled

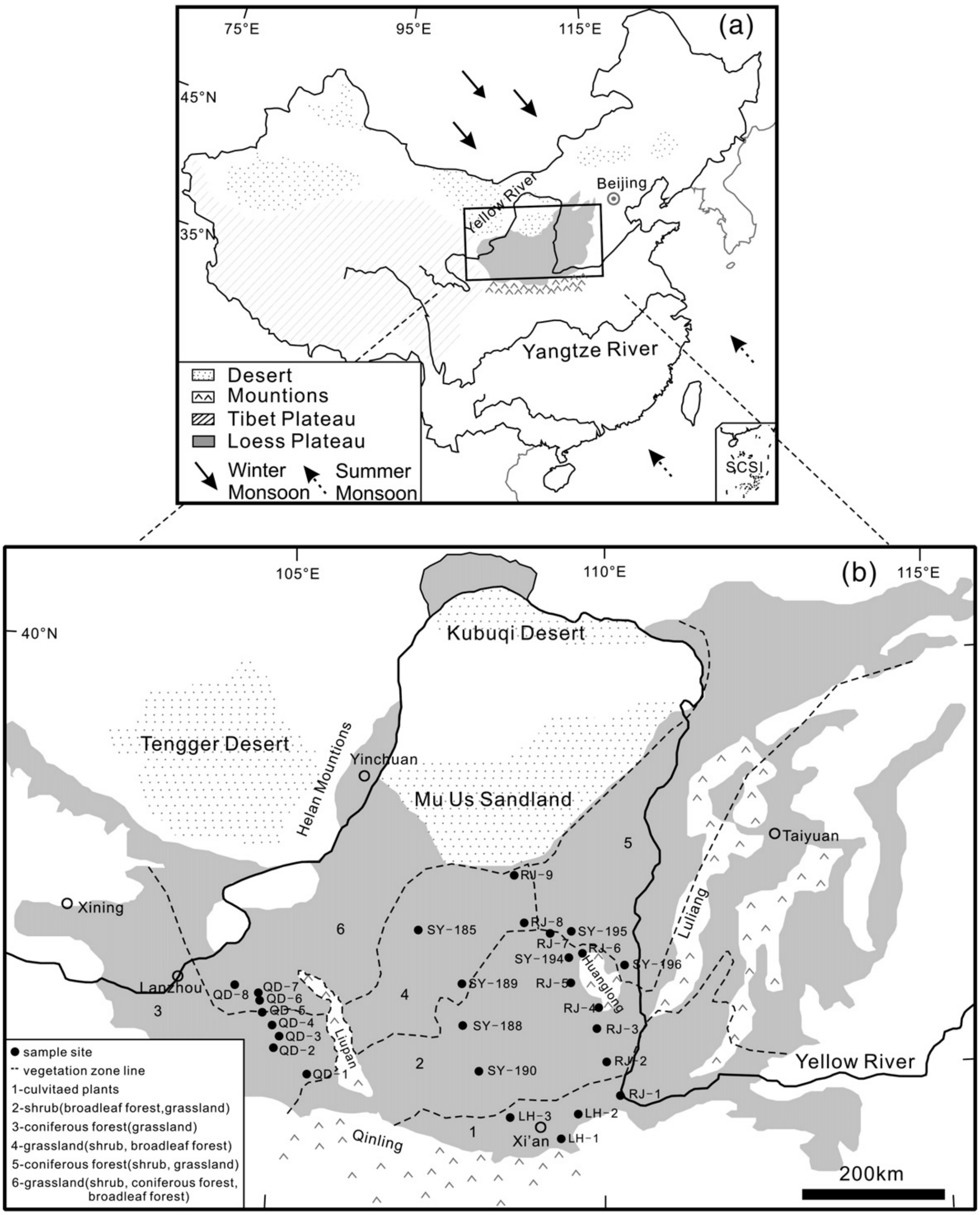

Fig. 1. Schematic map showing the position of the Chinese Loess Plateau (map is modified from Guo et al., 2002; Hao et al., 2008). The rectangle in (a) shows the locality of the Chinese Loess Plateau and the gray part in (b) shows the Chinese Loess Plateau. The deserts and mountains around and within the Loess Plateau are shown in (b).