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Microcodium in Chinese loess as a recorder for the oxygen isotopic composition of monsoonal rainwater

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ABSTRACT

Records of Asia Summer Monsoon (ASM) from the Chinese loess and the speleothem display distinct features. The very different proxies that were applied to the two archives may be responsible for this discrepancy. A direct comparison between the speleothem and the loess records under the same proxy system of rainwater $\delta^{18}O$ may help to resolve this puzzle. Here we show that the calcified microcodium in the loess deposits may record the oxygen isotopic composition of the summer rainwater. A microcodium based $\delta^{18}O$ record covering the past 140 kyrs was generated, which shows similar magnitude of the overall variation to that of the speleothem records. However, much weaker precession variability was registered in the microcodium record during the last interglacial period. Instead, the microcodium $\delta^{18}O$ record is more consistent with the widely used summer monsoon proxy of magnetic susceptibility in the loess deposits with clear glacial-interglacial pattern. This similarity may originate from the low sedimentation rate of the interglacial paleosol layer that preferentially record the peak ASM signals on the precession band. It is also possible that the orbital variability of ASM between the North China and South China is inherently different with more ice-volume related influence in the north. A longer microcodium $\delta^{18}O$ record in sequences of higher sedimentation rate and a reliable record of summer rainfall may help to resolve these possibilities.

1. Introduction

The dominant orbital cycles of summer precipitation, which is of great importance to decipher the driving force of monsoonal climate, have been found to be very different in region influenced by ASM (An et al., 2011, 2015; Bloemendal et al., 1995; Cai et al., 2015; Cheng et al., 2016; Clemens et al., 2010; Kathayat et al., 2016; Li et al., 2017; Nie et al., 2008, 2017; Sun et al., 2006; Wang et al., 2014). On the northern margin of the ASM influenced region, the records based on the loess-and-paleosol sequences from the Chinese Loess Plateau (CLP) display a coexistence of 100-, 41-, and 23-kyr periods with dominance of 100-kyr cycles after the mid-Pleistocene transition (Ding et al., 1995; Kukla et al., 1990; Liu, 1985; Liu et al., 1999; Sun et al., 2015). However, the speleothem stable oxygen isotopic records from the southern China reveal dominance of precession cycles (23-kyr) (Cheng et al., 2009, 2016; Wang et al., 2008; Yuan et al., 2004). This complexity may originate from the very different proxies applied to the two archives as the processes, besides the strength of ASM, that affect the proxy value, may be very different. Comparing the records of loess and speleothem under the same proxy system may have the potential to clarify this puzzle.

Oxygen isotope of rainwater is a widely used hydrological tracer for the intensity of ASM due to the preferential removal of heavy ^{18}O isotope from water vapor during condensation of cloud droplet (Dansgaard, 1964; Hu et al., 2008; Yuan et al., 2004). It is generally accepted that stronger ASM produces more negative $\delta^{18}O$ value of rainwater. Cave deposits in widespread regions across the East and South Asia show coherent variation of $\delta^{18}O$ (Cheng et al., 2016) that is consistent with the anticipated influence of precession and North Atlantic cooling on the intensity of ASM on orbital (Kutzbach, 1981) and millennial time scale (Lin et al., 2013, 2014, 2017; Wang et al., 2001), respectively. Following the same reason, the $\delta^{18}O$ value of rainwater on the CLP may also record the strength of ASM because the CLP is located on the northern margin of ASM influenced region

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so that the accumulative effect of precipitation in East Asia can be reflected.

Chinese loess is a typical calcareous soil (Liu, 1985) that contains abundant carbonate minerals for the $\delta^{18}O$ researches. It has been shown that the carbonate in loess is a mixture of pedogenic carbonate and detrital carbonate (Li et al., 2013). Thus, investigations on the oxygen isotopic composition of carbonate in the loess deposits are challenging and very limited (Chen et al., 1996; Han et al., 1997; Li et al., 2007; Sheng et al., 2002). Among these limited studies, most of the $\delta^{18}O$ records were generated from the carbonate nodules (Ding and Yang, 2000; Ji et al., 2017; Rao et al., 2006; Suarez et al., 2011) although other types authigenic carbonates are also abundant in the loess deposits. The best carbonate record of rainwater $\delta^{18}O$ should have a quasi-continuous distribution and a purely authigenic origin. However, the formation of carbonate nodules is related to the re-deposition of the leached carbonate in its overlying soil layer. Both of the leaching and the re-deposition require distinct climate conditions. A wet condition is needed for leaching while a much too wet condition may inhibit carbonate re-deposition. Thus, the distribution of carbonate nodule in the loess deposits is rather scattered with concentrated abundance at the bottom of paleosol layers (An et al., 1989). Evidences from trace metal compositions (Li et al., 2013) and intra-specimen variations of $\delta^{13}C$ and $\delta^{18}O$ (Yang et al., 2012) also suggest existence of significant amount of detrital carbonate in the carbonate nodule. The precipitation season of the carbonate nodule is also unclear while only the $\delta^{18}O$ of summer rainfall can reflect the strength of ASM. Thus, a continuously distributed pure authigenic carbonate that precipitates during the summer season is desired to reconstruct the $\delta^{18}O$ of monsoonal rainwater and thus the strength of ASM.

Recent works have shown that microcodium, a calcified plant debris, is rather continuously distributed in the loess deposits (Li et al., 2017). Trace element compositions of the microcodium show a purely authigenic origin with little detrital contamination (Li and Li, 2014). It has been shown that the microcodium can record the trace element composition of soil water that was controlled by summer monsoon intensity (Li and Li, 2014; Li et al., 2017). Thus, the microcodium in the loess deposits has great potential to record the $\delta^{18}O$ of monsoonal precipitation.

This work investigates the suitability of microcodium in Chinese loess as a recorder for the $\delta^{18}O$ of monsoonal rainwater. The $\delta^{18}O$ values of the modern and Holocene microcodium are used to constrain the seasonality of the microcodium records. A microcodium $\delta^{18}O$ record is generated on the central CLP covering the last interglacial-glacial cycles. The paleoclimate implication of the new record is also discussed associated with other summer monsoon proxies in the loess and cave deposits.

2. Material and methods

Holocene paleosol were collected from ten sites across the CLP (Fig. 1). The modern soil developed on the eolian deposits of late Holocene was also collected from Weinan site (109°29′E, 34°27′N) to the south margin of CLP. Samples of eolian deposits covering the past 140 kyrs were collected at 5-cm (~500 yr) resolution from the Xifeng section (107°47′E, 35°45′N) on the central CLP. Magnetic susceptibility (MS) of the samples was measured at low-frequency using Bartington Instrument MS2B meter to establish stratigraphy of the sections.

Different types of authigenic carbonate, namely microcodium, carbonate nodule, matrix carbonate, rhizoconcretion, and strawberry-like carbonate grains were picked from the sieved sediment (>75 μm) by hand under binocular microscope. For most of the samples, about twenty pieces of microcodium were picked to reduce the intra-sample variability. The picked carbonate of every sample was then crashed and mixed in a vial. The oxygen isotopic compositions of the mixed carbonate were analyzed by a MAT-253

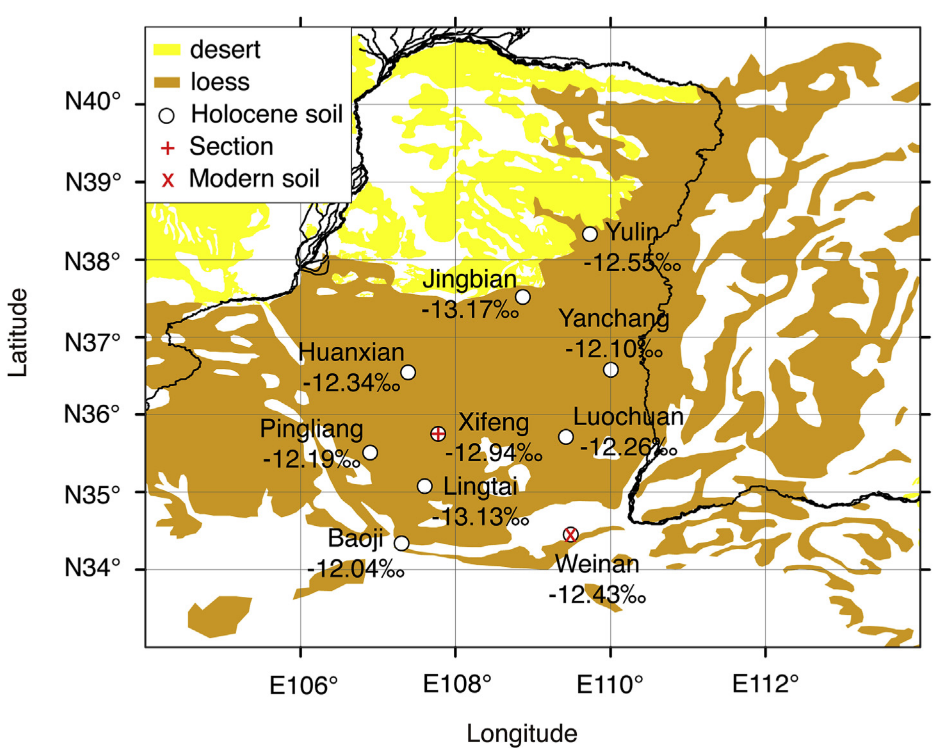

Fig. 1. Map showing the sampling sites on the CLP. The $\delta^{18}O$ values of microcodium from the Holocene paleosol across the CLP are also labeled.

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