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Palaeogeography, Palaeoclimatology, Palaeoecology 237 (2006) 359–369
PALAEO
www.elsevier.com/locate/palaeo

Stable isotope record in paleosol carbonates from the Chinese Loess Plateau: Implications for late Neogene paleoclimate and paleovegetation

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Received 23 May 2005; received in revised form 6 December 2005; accepted 8 December 2005

Abstract

Stable carbon and oxygen isotope analyses were conducted on pedogenic carbonates collected from a continuous, late Neogene terrestrial sequence located in Lantian, in the Chinese Loess Plateau. The sequence consists of 300 m of fluvial deposits (Bahe Formation) with a basal age of ca. 11 Ma overlain by ca. 50 m thick sequence of aeolian 'Red Clay' (Lantian Formation) deposited between 6.8 and 2.6 Ma.

Pedogenic carbonates from the fluvial part of the sequence (i.e., the Bahe Formation) show only slight variation in $\delta^{13}C$ and $\delta^{18}O$ values suggesting that no marked change in plant photosynthetic pathway or climate took place during ca. 10 – 6.8 Ma. The carbon isotope compositions imply a pure C_3 vegetation. However, most data are in the upper C_3 plant range suggesting that water stress conditions prevailed in the area.

A shift in both carbon and oxygen stable isotope curves occur at the boundary of the two formations where the sedimentation regime changed from fluvial to mainly aeolian. The $\delta^{13}C$ record shows more depleted values in the Lantian Formation with no indications of C_4 plant contribution in the soil carbonate except for the youngest sample at ca. 2.7 Ma. The formation boundary marks a general rise in $\delta^{18}O$ values. Moreover, the $\delta^{13}C$ and $\delta^{18}O$ values scatter more in the Lantian Formation compared to those measured from the Bahe Formation. As the shift in $\delta^{13}C$ and $\delta^{18}O$ values at the formation boundary is concurrent, we hypothesize that the reason for the changes in both values are mostly interrelated. The changes probably reflect increased summer precipitation related to the onset and/or intensification of the Asian monsoon system.

Sedimentological and fossil vertebrate analyses suggest that stable environments with relatively dry conditions prevailed during the time when the Bahe Formation was laid down. Slightly below the formation boundary there is a faunal turnover event implying a marked change into more humid and closed habitats. The paleoenvironmental patterns deduced from carbon and oxygen isotopes are in good agreement with the palaeoenvironments inferred from sedimentological and paleontological studies from the Lantian area.

Keywords: Neogene; China; Lantian; Pedogenic carbonate; Carbon and oxygen isotopes; Asian monsoon; Paleoenvironment

1. Introduction

The stable isotopic composition of oxygen and carbon in pedogenic carbonates has been used as a tool for

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doi:10.1016/j.palaeo.2005.12.011

obtaining information of terrestrial paleoenvironments. Oxygen isotope values of pedogenic carbonates reflect climatic factors such as temperature and precipitation, whereas carbon isotope values can be used to reconstruct the relative proportions of plants using C_3 and C_4 metabolic pathways (e.g. Cerling, 1984, 1991; Quade et al., 1989). The majority of the present-day plants are of C_3 type, comprising trees, temperate shrubs, and cool-season and high altitude grasses. C_4 plants include mainly warm season grasses that are adapted to light, warm, varying moisture conditions, as well as conditions of low atmospheric CO_2.

Isotope studies on soil carbonates and fossil tooth enamel show evidence of major expansion of C_4 grassland ecosystems in the late Neogene (8–4 Ma) in the Siwalik sequences (Quade and Cerling, 1995; Quade et al., 1995; Cerling et al., 1997), North America (Cerling et al., 1997), South America (MacFadden et al., 1994; Latorre et al., 1997), and Kenya (Kingston et al., 1994; Morgan et al., 1994). In most regions, the vegetation change has been linked to changes in precipitation (monsoonal climates) (Quade et al., 1989, 1995; Pagani et al., 1999) or alternatively to the global lowering of the atmospheric CO_2 partial pressure during the late Miocene (Cerling et al., 1997), or the compound effect of regional climatic factors and lowering of pCO_2 in the atmosphere (e.g. Fox and Koch, 2004; Sanyal et al., 2004).

Many studies have shown that the aeolian 'Red Clay' and the superimposed loess sequence in northern China constitute an important record for the evolution of East Asian paleoenvironments and atmospheric system. A significant amount of research has focused on the use of e.g. grain size, pedology, geochemistry, and magnetic properties (e.g. Sun et al., 1997, 1998; Ding et al., 1998, 2001; Guo et al., 2001; Lu et al., 2001; Liu et al., 2003) as proxies for the evolution of the Asian monsoon system, as well as for paleoclimatic and paleoecologic conditions through the late Neogene. Systematic carbon and oxygen isotope studies have been very limited and have almost entirely concentrated on the Pleistocene loess sequences (e.g. Wang and Zheng, 1989; Wang et al., 1997; Wang and Follmer, 1998; Liu et al., 2005). However, Ding and Yang (2000) investigated a 'Red Clay' and loess sequence in Lingtai covering the past 7.0 Ma and showed that the major expansion of C_4 plants occurred at around 4.0 Ma ago.

A long, terrestrial sequence in Lantian in the southeastern loess plateau offers a unique opportunity to trace the evolution of late Neogene environments in China. The sequence studied here consists of the fluvial Bahe Formation and the overlying aeolian 'Red Clay' deposits, named as the Lantian Formation. The sequence is well dated and covers a time span between ca. 11 and 2.6 Ma (Kaakinen, 2005).

Paleoenvironmental data in the study area have been previously generated from mammal fossils (e.g. Zhang et al., 2002; Qiu et al., 2003), sedimentology (Kaakinen and Lunkka, 2003), and taphonomy (Andersson and Kaakinen, 2004). The stratigraphic sequence includes abundant paleosols that commonly contain pedogenic carbonates. The purpose of this study is to report stable carbon and oxygen isotope values in pedogenic carbonates occurring across the late Neogene sequence in Lantian, and interpret these data in terms of environmental variables. Our aim is also to understand the nature of environmental change that is mirrored in the change of depositional regime from the Bahe Formation to the Lantian Formation. Additionally, our goal has been to examine whether there is a significant vegetation change from C_3- to C_4-dominated floras in the Lantian study area as demonstrated in several other late Neogene sequences (e.g. Quade et al., 1995; Cerling et al., 1997; Latorre et al., 1997).

2. Study area

The study area in Lantian is situated on the southeastern margin of the Chinese Loess Plateau in the northern foothills of the Qinling Mountains (Fig. 1). The east–west striking Qinling Mountain range makes up the southern boundary of the Loess Plateau and is the traditional dividing line between temperate and subtropical zones in China. The southern Qinling slopes maintain subtropical, evergreen forest habitat, while a warm–temperate, deciduous, broad-leaved forest occurs north of the mountains (Zhao et al., 1990).

The present climate in the Lantian region is influenced in the summer season by both Indian and East Asian monsoons that bring warm, moist air to the area fed from the tropical oceans while the Siberian – Mongolian monsoon is dominant during the winter season (Domrös and Peng, 1988). Currently, the mean annual precipitation is about 575 mm at Xian (World Climatological Normals). Nearly 60% of the annual precipitation occurs between July and October. The average annual temperature is 13.4 °C, while the mean air temperature is −0.5 °C in January and 26.3 °C in July.

The present study in Lantian is concerned with the late Neogene stratigraphic sequence that is exposed along the north-east facing slope of the Bailuyuan Plateau. The basal unit in the sequence, the Bahe Formation, consists of about 300 m of principally