Palaeogeography, Palaeoclimatology, Palaeoecology 440 (2015) 750–762

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

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

Stable carbon and oxygen isotopic evidence for Late Cenozoic environmental change in Northern China

Burcu Ciner [a,b,*], Yang Wang [a,b], Tao Deng [c], Lawrence Flynn [d], Sukuan Hou [c], Wenyu Wu [c]

[a] Department of Earth, Ocean & Atmospheric Science, Florida State University, Tallahassee, FL 32306, USA
[b] National High Magnetic Field Laboratory, Tallahassee, FL 32306-4100, USA
[c] Key Laboratory of Vertebrate Evolution and Human Origins, Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences, Beijing 100044, China
[d] Departmentof Human Evolutionary Biology, Harvard University, Cambridge, MA 02138, USA

ARTICLE INFO

Article history:
Received 5 February 2015
Received in revised form 5 October 2015
Accepted 6 October 2015
Available online 22 October 2015

Keywords:
Carbon isotopes
Oxygen isotopes
Tooth enamel
Yushe Basin
Paleodiet
Paleoenvironment

ABSTRACT

Stable carbon and oxygen isotope ratios of 311 enamel samples from a diverse group of herbivorous mammals including Equidae, Rhinocerotidae, Bovidae, Rodentia and Ochotonidaewere were analyzed in order to reconstruct the Late Cenozoic history of vegetation and environmental change in the Yushe Basin in North China. The $\delta^{13}C$ values of bulk and serial enamel samples from large mammals show a wide range of variation from −13.3‰ to 1.4‰, with a mean of −7.4‰ ± 3.5‰ (n = 294). This indicates that large herbivorous mammals in the area had a variety of diets since 6.5 Ma, ranging from pure C_3 to mixed C_3–C_4 and pure C_4 diets. In contrast, the $\delta^{13}C$ values of small mammals vary from −11.9‰ to −7.6‰, with a mean of −9.7 ± 1.1‰ (n = 17), indicating that rodents and ochotonids were feeding mostly on C_3 plants. Variations in $\delta^{13}C$ values within and between species reflect the variations in the habitat and the vegetation consumed by the animals. In general, horses had higher amounts of C_4 grasses in their diets than other contemporary taxa such as bovids, rhinos, rodents and deer, suggesting that horses exploited more open habitats such as grasslands while deer, rhinos and rodents may have preferred more C_3 vegetation, which is more indicative of forested environments. The carbon isotope data show that C_4 grasses have been an important component of horses' diets and of local ecosystems since ~6.5 Ma, confirming that the "late Miocene C_4 expansion" occurred in North China as it did in Africa, Indian subcontinent and the Americas. This supports a global factor as a main driver of the late Miocene C_4 expansion. The combined carbon and oxygen isotope data reveal major shifts in climate to drier and/or warmer conditions after ~5.8, ~4.1, ~3.3, and ~2.5 Ma, and significant shifts to relatively wetter and/or cooler conditions after ~6.4, ~5, ~3.5 Ma. The shifts to drier and/or warmer climate after ~5.8 Ma and ~2.5 Ma coincide with two major fauna turnover events. Intra-tooth $\delta^{13}C$ and $\delta^{18}O$ values are negatively correlated within individual modern teeth and some fossil teeth, displaying the characteristic pattern of the summer monsoon regime and confirming a strong monsoon influence in the area since at least the early Pliocene. The data also suggest that the C_4 abundance in the area has fluctuated over the past 6.5 Ma in response to changes in climate, with more C_4 grasses during warmer and/or drier periods and a reduced C_4 component at cooler and/or wetter times.

1. Introduction

The Himalayan–Tibetan Plateau (HTP), one of the most significant topographic features on Earth, is thought to be important in driving the modern Asian monsoons and affecting global atmospheric circulation, climate and erosion (e.g., Kutzbach, 1987; Webster, 1987; Molnar and England, 1990; Prell and Kutzbach, 1992; Molnar et al., 1993; An et al., 2001; Wang et al., 2012). However, the timing of the Tibetan uplift is still a hotly debated issue. The uplift of the HTP would have affected the west-to-east airflow across the northern hemisphere, increased the precipitation along the Himalayas, and prevented the entry of warm humid monsoonal air from the East Pacific Ocean and Indian Ocean into the large area behind the high mountains, resulting in drying in central Asia and a strong southeast-to-northwest precipitation gradient in East Asia. In addition, the high mountains serve as geographic barriers to biological migration (Barry and Flynn, 1990; Qiu, 1990). These changes in climate and geography caused by the uplift of the HTP would have had a profound effect on ecosystems and mammalian evolution in the region. Therefore, long-term records of vegetation, fossil mammals, and climate changes in China are not only important in understanding paleoecology and paleoclimate in East Asia but also may shed some light on the growth history of the Himalayan–Tibetan Plateau. Furthermore, understanding the past climatic conditions and how and why they change is crucial for predicting future changes in climate.

Stable carbon and oxygen isotope analyses of fossil mammalian tooth enamel have been established as an important tool in

* Corresponding author at: Department of Geological Engineering, Balikesir University, Balikesir, Turkey.
E-mail address: burcuciner@balikesir.edu.tr (B. Ciner).

http://dx.doi.org/10.1016/j.palaeo.2015.10.009
0031-0182/

paleoclimate research (e.g., Ericson et al., 1981; Lee-Thorp et al., 1989; Koch et al.,1992; Quade et al., 1992; Cerling et al., 1993; Wang et al., 1993; MacFadden et al., 1994; Quade et al., 1994; Wang and Cerling, 1994; Wang et al., 1994; Fricke et al., 1995; Lee-Thorp and Beaumont, 1995; Bochernens et al., 1996; Cerling et al., 1997a,b; MacFadden et al., 1999a,b; MacFadden, 2000a,b,c). Tooth enamel often preserves its original isotopic signatures that reflect the isotopic compositions of the diet and water ingested by an animal (Ayliffe et al., 1994; Bryant et al., 1994; Wang and Cerling, 1994; Fricke et al., 1995). Calcified tissues (i.e., bone, tooth enamel and dentine) are primarily made of hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$), which contains a small amount of structural carbonate (Wang and Cerling, 1994). Studies have shown a consistent carbon isotope fractionation between structural carbonate in hydroxyapatite and the diet (Lee-Thorp and van der Merwe, 1987; Lee-Thorp et al., 1989; Wang et al., 1994; Cerling et al., 1997a). As a result, the stable carbon isotope ratios ($\delta^{13}C$ values) of structural carbonate in hydroxyapatite from herbivores can be used to determine the proportions of C_3 and C_4 plants in their diets and the types of vegetation available for consumption in local ecosystems (e.g., Lee-Thorp et al., 1989; MacFadden and Cerling, 1994; Wang et al., 1994; Cerling et al., 1997a,b; Koch, 1998; MacFadden et al., 1999a,b; Kohn and Cerling, 2002; Wang and Deng, 2005; Wang et al., 2006; Wang et al., 2006; Wang et al., 2008a,b). The oxygen isotope ratios ($\delta^{18}O$) of enamel from large mammals are strongly correlated with the $\delta^{18}O$ of local meteoric water (e.g., Bryant et al., 1994, 1996; Kohn and Cerling, 2002; Wang et al., 2008a,b). Because the $\delta^{18}O$ of meteoric water is sensitive to climatic variables such as temperature, seasonality of rain, and the amount of rain (Dansgaard, 1964; Rozanski et al., 1992), the $\delta^{18}O$ of tooth enamel has been used as a proxy for paleoclimatic conditions during tooth growth (e.g., Longinelli, 1984; Koch et al., 1989; D'Angela and Longinelli, 1993).

Furthermore, carbon and oxygen isotopic analyses of serial samples collected along the length of a tooth can provide a detailed record of seasonal variations in diet and climate during the time of mineralization of the tooth (up to 2–3 years for horses) (e.g., Koch et al., 1995; Fricke and O'Neil, 1996; Sharp and Cerling, 1998; Balassee et al., 2003; Nelson, 2005; Sponheimer et al., 2006). When the $\delta^{18}O$ values of serial enamel samples from an individual tooth are plotted, they often show troughs and peaks reflecting the seasonal changes in the $\delta^{18}O$ of local meteoric water, with peaks generally representing the summer months (Fricke and O'Neil, 1996; Sharp and Cerling, 1998). However, in Asian summer monsoon regions, the $\delta^{18}O$ peaks would correspond to winter months because summer precipitation has lower $\delta^{18}O$ values than the winter precipitation in the Asian monsoon region (Araguas-Araguas et al., 1998; Johnson and Ingram, 2004; Biasatti et al., 2010).

In this study, we determined the stable carbon and oxygen isotopic compositions of both fossil and modern herbivores including *Equus* (horse), *Hipparion* (horse), rhinos, bovids (goat, gazelle, cow), rodents and *Ochotonoides* from the Yushe Basin in North China. The data were used to examine long-term changes in diets and environments of mammals in the area over the past 6–7 million years. The results from this study were also compared with the data from other localities in the region to improve our understanding of the development of C_4 ecosystems in North China and the effects of Tibetan uplift on regional climate and ecosystems.

2. Study area

Yushe Basin (37.07°N, 112.98°E, elevation of 1045 m) is located at the eastern margin of the Loess Plateau (Fig. 1) and near the boundary between the temperate deciduous forest and steppe vegetation zones today (Liu, 1988). The basin covers 1875 km^2, but outcrops are patchy and the fossils are from a smaller portion of the basin, mostly the Yuncu sub-basin (Tedford et al., 2013). The present-day climate in the Yushe Basin is strongly controlled by East Asian monsoons that result in a strong seasonality in temperature and precipitation, with most of the precipitation falling during the summer. The thick late Cenozoic deposits in the basin – the Yushe Group – contain many fossil horizons with different species of mammalian fossils, providing a long and detailed record of biological and geological events (Tedford et al., 1991).

The late Cenozoic sedimentary sequence in the basin spans an age range from the late Miocene to the Holocene (Qiu et al., 1987; Tedford et al., 1991; Flynn et al., 1995; Flynn and Wang, 1997; Flynn and Wu, 2001). It consists primarily of fluvial, alluvial and lacustrine sediments, with a minimum total thickness of 800 m. The Yushe Group has been divided into four formations, the Mahui, Gaozhuang, Mazegou and Haiyan formations (Fig. 1., Tedford et al., 1991; Flynn, 1997; Flynn et al., 1997), which is overlain by the Pleistocene loess deposits containing paleosols and calcerous nodules (Liu et al., 1985; Tedford et al., 1991).

The Mahui Formation lies on Triassic bedrock and includes many Baodean elements (i.e., the "*Hipparion* Fauna"), murids and *Stegodon*. It also has the last records of the browsing horse *Sinohippus*, the hyaena *Adcrocuta*, and the bear *Indarctos*, the first North China elephant *Stegodon*, and diverse pigs, giraffes and deer. The overlying Gaozhuang Formation includes early camels and canids, advanced hipparionine horses, and high crowned gazelles. The Mazegou Formation contains similar fauna including several additional taxa such as *Felis*, *Lynx*,

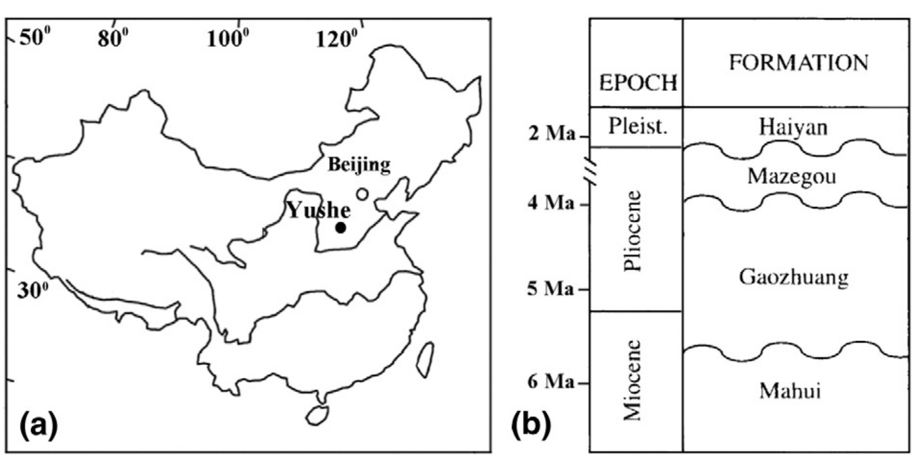

Fig. 1. (a) Location map and (b) chronostratigraphy of Yushe Basin, North China (modified from Flynn et al., 1997; Wang et al., 2006).