Quaternary International 399 (2016) 174–182

Contents lists available at ScienceDirect

Quaternary International

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

An integrated biomarker perspective on Neogene–Quaternary climatic evolution in NE Tibetan Plateau: Implications for the Asian aridification

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ARTICLE INFO

Article history:
Available online 23 May 2015

Keywords:
Neogene–Quaternary
Asian aridification
Biomarker proxies
Tectonic–climate
NE Tibetan Plateau

ABSTRACT

The long-term paleoclimate record in Asia and its comparison with the global climate record are of vital importance to understanding the coupling mechanisms between tectonics and climate. However, such long-term climate history in Asia revealed using the biomarker perspective has remained elusive. Here, we reconstruct the Neogene–Quaternary climatic history of the Northeastern (NE) Tibetan Plateau based on the integrated biomarker records of the Tianshui Basin and multiple published data from its surrounding localities. These comprehensive results indicate that the NE Tibetan Plateau did not have a consistent aridity trend until ~4 Ma. Before 4 Ma, the Neogene climate was generally humid although this pattern was temporarily interrupted by two drying intervals at ~14.5–~12.5 and ~10–~6 Ma. Each of the two drying intervals and the permanent aridification trend roughly correspond to one phase of global cooling and/or uplift event of the Tibetan Plateau, highlighting the importance and complexity of tectonic–climate interactions. However, our study indicates increasing influence of tectonic uplift on the NE Tibetan Plateau climate since late Pliocene.

1. Introduction

East Asia has a high population density, and quality of life depends critically on future climate change. Accelerated aridification in the future would be a disaster to Asian peoples and ecosystems. So, a clear understanding of Asian climatic history is key background knowledge for predicting future climate trends. Furthermore, such knowledge is also critical to understanding the coupling mechanisms among the tectonic activities, regional and/or global climate change (Raymo and Ruddiman, 1992; Rea et al., 1998; An et al., 2001; Molnar et al., 2010; Miao et al., 2012; Xie et al., 2012; Hough et al., 2014; Li et al., 2014), and the ecosystem evolution (Chang et al., 2008; Deng et al., 2011). For example, the extraordinarily thick-boned fish in the Qaidam Basin of NE Tibetan Plateau probably resulted from the extreme arid condition, in response to the tectonic uplift of the Tibetan Plateau during the Pliocene (Chang et al., 2008). However, although many recent studies focused on initiation of interior Asian desertification (An et al., 2001; Guo et al., 2002; Sun et al., 2010; Qiang et al., 2011) and Northern Hemisphere aridification (Eronen et al., 2012), few studies discussed the detailed climatic history of Asia since the Neogene from the biomarker perspective. In the NE margin of the Tibetan Plateau, an unusually continuous late Cenozoic stratigraphic record and mammal fossils buried in the series of sedimentary basins, such as the Longzhong Basin, provides a unique opportunity to interpret its climatic history and tectonic uplift, and the potential interactions between the two in this area. Given the advantages of the biomarker method and specific late Cenozoic deposition, its biomarker perspective not only sheds fresh light on the Neogene–Quaternary environmental change in NE Tibetan Plateau margin, but also has the potential for discussion of the mechanism of climate change in this area. In this study, we present a detailed climatic history of NE Tibetan Plateau since 22 Ma based on our biomarker proxy records of Neogene–Quaternary sediments from the Tianshui Basin and several published biomarker documents from its surrounding localities (Xie et al., 2003; Wang et al., 2004; Zhong et al., 2007; Bai et al., 2009; Zeng et al., 2011; Wang et al., 2012b) (Fig. 1). These integrated *n*-alkanes results illustrate the

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http://dx.doi.org/10.1016/j.quaint.2015.04.020
1040-6182/

climatic history of the NE Tibetan Plateau since the Neogene. Furthermore, the possible interconnections among Neogene–Quaternary climate change in our studied area, regional tectonic uplift, and global cooling have also been considered to shed light on the issue of tectonic–climate interactions.

2. Geological setting and data integration

The NE Tibetan Plateau is situated at the frontier of the Tibet block extending to the northeast. It is bounded by the Kunlun-Qinling, Altyn Tagh and Qilian-Haiyuan Faults, and contains a number of large intermontane basins such as the Qaidam and broad Longzhong Basins (GRGST, 1984; Fang et al., 2005; Li et al., 2014) (Fig. 1). Geographically, NE Tibet lies at the junction of the Eastern Monsoon, Northeastern Arid, and Tibet Cold regions, and is very sensitive to Asian environmental change. Among these basins, excellent Cenozoic successions are well preserved with climate information and abundant mammalian fossils (GRGST, 1984; Wang et al., 2012a; Deng et al., 2013), which provide better constraints on magnetostratigraphy. These Cenozoic sediments are more than 1000 m thick in the NE Tibetan Plateau.

All biomarker data was combined from the Longzhong Basin and Liupan Shan areas of the NE Tibetan Plateau. In detail, Yanwan, Yaodian, QA-I, Lamashan (see Table 1) and Dadiwan sections were analyzed in the Tianshui Basin, while the Maogou, Tawan, Yuanbao, Jiuzhoutai sections and Chaona section were chosen from the Linxia-Lanzhou Basins and eastern front of Liupan Shan, respectively. Their depositional age spans the entire Neogene and Quaternary, and detailed biomarker information has been reported by Bai et al. (2009), Peng et al. (2012), Wang et al. (2012b), Xie et al. (2003), Zeng et al. (2011), and Zhong et al. (2007). In brief, the Linxia basin is a sub-basin of the Longzhong Basin, and its Miocene lithology is dominated by mudstone and sandstone fluvial and lacustrine deposits (Fang et al., 2003). Another sub-basin of the Longzhong Basin is the Lanzhou basin, located in the eastern part of Linxia basin. Its Cenozoic lithology can be divided into the Neogene fluvial/lacustrine mudstone and sandstone, and Quaternary eolian loess (Zhang et al., 2014). The Tianshui Basin, situated in the southeastern corner of the broad Longzhong Basin, is surrounded by the Western Qinling Mountains to the south, the Liupan Shan Mountains to the east, and the Huajia Ling Mountains to the north. Its late Cenozoic sediments are divided into the Ganquan Formation, Yaodian Formation, Yangjizhai Formation, and Lamashan Formation (Li et al., 2014). In the Liupan Shan area, the Chaona section is composed of late Miocene red clay and a Quaternary loess-paleosol sequence (Bai et al., 2009).

Table 1
The biomarker data of Yanwan, Yaodian, QA-I and Lamashan sections in the Tianshui Basin.

Yanwan				Lamashan				Yaodian			
Age (Ma)	ACL	CPI	C_{31}/C_{27}	Age (Ma)	ACL	CPI	C_{31}/C_{27}	Age (Ma)	ACL	CPI	C_{31}/C_{27}
6.3	29.36	1.20	1.05	2.7	29.38	2.24	0.90	7.7	29.57	1.97	1.23
6.9	28.96	1.17	0.60	2.8	29.47	2.99	1.26	8.3	29.58	1.35	1.19
7.1	29.36	1.51	1.01	2.9	29.31	2.65	0.86	9.3	29.36	3.24	1.15
7.7	29.30	1.44	1.03	3.2	29.96	3.06	2.12	10.4	29.44	1.35	1.11
8.1	29.60	1.59	1.42	3.4	29.61	1.64	1.37	11.2	28.76	1.11	0.48
8.6	29.41	1.57	1.21	4.2	29.96	2.35	2.26	12.3	29.50	1.17	1.18
9	29.45	1.56	1.17	5	29.41	1.34	1.04				
9.5	29.25	1.32	0.96	5.4	29.19	1.11	0.67				
9.8	29.65	1.44	1.48	6.8	29.19	1.10	0.60	QA-I			
10.2	29.13	1.35	1.04	7.4	28.99	1.25	0.55				
10.7	28.31	1.13	0.30	7.85	29.32	1.23	0.81	11.5	29.46	1.34	0.97
10.8	28.88	1.12	0.63	8	29.74	2.09	1.42	13.7	29.03	1.16	0.66
11.3	29.09	1.33	0.90	8.4	29.64	1.46	1.38	16.5	29.11	1.16	0.73
11.9	28.62	1.12	0.48	9.05	30.02	2.03	3.27	17.1	28.97	1.21	0.67
12.4	28.80	1.18	0.63	9.7	29.80	1.43	1.76	20	28.98	1.12	0.61
12.7	29.03	1.10	0.63	9.9	29.57	1.60	1.62	21.2	29.16	1.18	0.80
12.8	29.33	1.31	0.91	10.5	29.80	1.42	1.66	22	28.44	1.12	0.33
13.2	29.03	1.18	0.63								
13.9	29.22	1.25	0.89								
14	28.94	1.21	0.60								
14.2	29.16	1.12	0.81								
14.7	28.91	1.26	0.62								
15.1	28.83	1.20	0.54								
16.2	28.93	1.15	0.60								
16.5	28.84	1.15	0.52								
16.8	29.18	1.23	0.86								

Note
$ACL = (27 \times C_{27} + 29 \times C_{29} + 31 \times C_{31} + 33 \times C_{33})/(C_{27} + C_{29} + C_{31} + C_{33})$.
$CPI = \sum C_{23} - C_{35}(odd)/\sum C_{22} - C_{34}(even)$.

3. Materials and methods

The Yanwan, Yaodian and QA-I biomarker distribution has been reported by Peng et al. (2012), while the new Lamashan data is analyzed from the Lamashan section, which is located in the southern part of the Tianshui Basin (Fig. 1). The Lamashan section is about 393 m thick with Zebra beds, which is considered as the marker layer in the Tianshui Basin. Field investigation indicates that sediments of this section are mostly gray–green mudstones and yellow–brown or reddish-brown mudstones. The detailed lithologic properties and magnetostratigraphic age (>11.1–2.6 Ma) have been reported by Wang et al. (2012a). Seventeen new samples were sampled from Lamashan based on differences in sedimentary characteristics, such as lithology, color, and degree of pedogenesis. The Lamashan samples were extracted with Soxhlet and ultrasonic methods in the Key Laboratory of Gas Geochemistry, Institute of Geology and Geophysics and Institute of Tibetan Plateau Research of CAS, respectively. Both labs show the similar *n*-alkane distribution.