Earth-Science Reviews 139 (2014) 213–230

Contents lists available at ScienceDirect

Earth-Science Reviews

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

Revisiting the Paleogene climate pattern of East Asia: A synthetic review

Cheng Quan [a,*,1], Zhonghui Liu [b], Torsten Utescher [c,d], Jianhua Jin [e], Junwu Shu [f], Yongxiang Li [g,**], Yu-Sheng (Christopher) Liu [h,***,1]

[a] Research Center of Paleontology and Stratigraphy, Jilin University, Changchun 130026, China
[b] Department of Earth Sciences, The University of Hong Kong, Hong Kong, China
[c] Steinmann Institute, Bonn University, Bonn 53115, Germany
[d] Senckenberg Research Institute, Frankfurt 60325, Germany
[e] School of Life Sciences, Sun Yat-sen University, Guangzhou 510275, China
[f] State Key Laboratory of Palaeobiology and Stratigraphy, Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, Nanjing 210008, China
[g] School of Earth Sciences and Engineering, Nanjing University, Nanjing 210093, China
[h] Department of Biological Sciences and Don Sundquist Center of Excellence in Paleontology, East Tennessee State University, Johnson City, TN 37614, USA

ARTICLE INFO

Article history:
Received 1 May 2013
Accepted 15 September 2014
Available online 20 September 2014

Keywords:
Paleogene climate pattern
East Asia
Planetary wind system
Monsoon or monsoon-like climate
Continentality
Rain shadow effect

ABSTRACT

East Asian Paleogene climates have long been regarded as controlled by the planetary wind system, which might result in a climate pattern with three latitudinally distributed zones. Two humid zones located separately in the north and south were lithologically designated by coals and oil shales, while an arid zone in the middle was represented by red beds and evaporites. Because the middle arid zone was located along ~30° N paleolatitude, its presence had been further linked with a then subtropical high. However, this long-standing model has recently been challenged by growing evidence from petrology, sedimentology, paleontology, paleobiogeography, paleoclimatology, and climate modeling. Here we review the primary data from these disciplines and reinterpret their climate significances to revisit the East Asian climate pattern during the Paleogene. Petrologically, while the occurrence of coals and/or oil shales is accepted as an indicator for overall humid climates, that of red beds and/or evaporites is highly equivocal to exclusively indicate perennial arid climates unless their origins are carefully investigated. In reality, generic red beds merely represent an oxidizing environment, not essentially associated with a single specific climate type. Meanwhile evaporites, although typically precipitated in arid environments, may be deposited in either perennial dry or seasonal/monsoonal climates. There is no solid evidence so far to convincingly support that the landscape of the so-called middle arid zone was dominated by desert and/or steppe under a then subtropical high during most of the Paleogene. The plant function type study additionally suggests that the "middle arid zone" appears to be lack of xerophytic vegetation, even though some xerophytic or sclerophyllous plant taxa did sporadically occur. Interestingly, paleozoological data show that the Paleogene mammalian faunas were somewhat equably distributed over East Asia, strongly suggesting the evident absence of a critical biogeographical or climatic barrier stretched across the "middle arid zone" as the planetary wind model implied. In contrast to the planetary wind model, monsoonal or monsoon-like Paleogene climates have been broadly reported from the northern, middle, and southern East Asia, as well as adjacent regions of Russia and Kazakhstan. If only the indicators for humid climates are considered, simply due to the uncertainty of those for perennial arid climates, East Asia must have had a relatively dry region in the continental interior during the late Eocene to Oligocene transition, likely caused by the continentality and/or the rain shadow effect along with the global cooling. The monsoonal interpretation is highly in agreement with the evidence from floras, faunas, basin analyses, and modeling experiments, and well explicates the Paleogene climate distribution and seasonal dynamics of East Asia. However, further studies will be largely needed to verify whether, uniformly according to the modern criteria, the Paleogene climates of the East Asia interior can be accurately attributed to the arid category.

* Correspondence to: C. Quan, Research Center of Paleontology and Stratigraphy, Jilin University, 938, Xi-minzhu Str., Changchun 130026, China. Tel.: +86 431 8850 2598; fax: +86 431 8850 2427.
** Correspondence to: Y. Li, School of Earth Sciences and Engineering, Nanjing University, 22, Hankou Road, Nanjing 210093, China.
*** Correspondence to: Y.S.C. Liu, Department of Biological Sciences, 309 Brown Hall, East Tennessee State University, Box 70703, Johnson City, TN 37614-1710, USA. Tel.: +1 423 439 6920; fax: +1 423 439 5958.
E-mail addresses: quan@jlu.edu.cn (C. Quan), yxli@nju.edu.cn (Y. Li), liuc@etsu.edu (Y.-S.(C.) Liu).
[1] The first and last authors contributed equally to this study.

http://dx.doi.org/10.1016/j.earscirev.2014.09.005
0012-8252/

Contents

1. Introduction

East Asia represents one of the most important regions in understanding Paleogene climates and the origin of major animal and plant taxa, in that it is a biogeographical center of a large number of modern of these taxa (Wolfe, 1985; Russell and Zhai, 1987; Meng and McKenna, 1998; Manchester, 1999; Bowen et al., 2002; Ting et al., 2011; Nie et al., 2012; Shi et al., 2012; Meng and Wang, 2014). However, our knowledge on the Paleogene climates from this vast region is still extremely poor (e.g., Wolfe, 1985; Sewall et al., 2000; Shellito and Sloan, 2006; Huber and Caballero, 2011; Huber and Goldner, 2012). In many previous studies, East Asian Paleogene climates were subdivided into three categorically latitudinal zones controlled by the planetary wind system (Fig. 1) (e.g., Liu, 1997; Wang et al., 1999; Guo et al., 2008; Z. Zhang et al., 2012). Lithologically, two humid zones located separately in the south and north are characterized by the occurrence of coals and/or oil shales, while the third broad arid zone resided in the middle and flanked by the two humid zones is largely designated by the widespread red beds and/or evaporites along ca. 30° N paleolatitude (ranging between ~25° N and ~35° N), allegedly driven by the then subtropical highs (Fig. 1) (Liu, 1997; Wang et al., 1999; Guo et al., 2008; Z. Zhang et al., 2012). In an ideal model of the modern atmospheric circulation, the surface zone of atmospheric high pressures is located in the subtropics of both northern and southern hemispheres. These high pressure systems are produced by vertically descending branches of the Hadley cell. However, the distribution of these subtropical highs is highly subject to the continent–sea configuration, land topography, and the thermal gradient between the polar and equator regions (Rohli and Vega, 2008; Brierley et al., 2009; Johanson and Fu, 2009; Huber and Goldner, 2012). That is, the subtropical highs are not continuously distributed and steadily spread along ~30° latitudes, the position would be shifted under particular global climate conditions (Lamb, 1982; Lu et al., 2007; Johanson and Fu, 2009; Hasegawa et al., 2012).

On the other hand, advances on petrogenesis have suggested that some of these lithological climate indicators are probably not as conclusive as we previously thought. While coal and oil shale are cogent evidence of humid climates (Mancuso and Seavoy, 1981; Parrish et al., 1982; Cecil, 1990; Suárez-Ruiz et al., 2012a; Thomas, 2013), red beds and/or evaporites are rather equivocal indicators for perennial arid climates (McBride, 1974; Schreiber, 1988; Renaut and Long, 1989; Sonnenfeld and Perthuisot, 1989; Alcocer and Escobar, 1996; Alcocer and Hammer, 1998; Parrish, 1998; Schreiber and Tabakh, 2000; Warren, 2006; Dupont-Nivet et al., 2007; Warren, 2010; Craggs et al., 2012; D. Wang et al., 2013). Consequently, the Paleogene planetary wind model, with a subtropical high-driven arid zone across middle paleolatitudes (middle China), has been deeply challenged in recent years from various disciplines, such as petrology, sedimentology, paleobotany, paleozoology, paleobiogeography, paleoclimatology, and modeling experiments (Tong, 1989; Leopold et al., 1992; Tong et al., 1996; Chen et al., 2000; Tong et al., 2002; White and Dettman, 2007; Gao et al., 2009; Quan et al., 2011; Wang et al., 2011; Huber and Goldner, 2012; Quan et al., 2012a, 2012b; D. Wang et al., 2013; Q. Wang et al., 2013).

In contrast to the planetary wind model, quantitative Eocene climate studies based on plant fossils have shown that the mean annual precipitations over China, including areas in the so-called middle arid zone, could be not less than 730 mm (Tong et al., 2002; Shi et al., 2008; Quan et al., 2012a), much higher than the threshold 500 mm, which is regarded as a precipitation boundary between semi-arid and subhumid climates (Sun and Wang, 2005). Moreover, recent paleoclimate reconstructions have also suggested that the Paleogene monsoon in East Asia must have already been developed in northeastern (Shi et al., 2008; Quan et al., 2011; Quan et al., 2012b), middle (Tong et al., 2002; Sun et al., 2009), and southern China (Guo, 1985; Leopold et al., 1992; White and Dettman, 2007), as well as in adjacent regions of Russia and Kazakhstan (Akhmetiev, 2010).

Here we review up-to-date sedimentological, paleontological, and paleoclimatological data to revisit the Paleogene climate pattern of East Asia, with particular attention paid to China. The critical question to ask is which climate type, namely planetary wind or monsoon, dominated this vast region during the Paleogene. This question is essential to understanding the Paleogene climates of East Asia, where the dearth of data has seriously impeded paleoclimate understanding in a global context (Shellito and Sloan, 2006; Huber and Caballero, 2011; Huber and Goldner, 2012). By reviewing selected proxy data and reinterpreting their climate significances, our results demonstrate that monsoon or monsoon-like climates, instead of the planetary wind system with three