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Eocene prevalence of monsoon-like climate over eastern China reflected by hydrological dynamics

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ABSTRACT

Hydrological dynamics of sedimentary basins are essential for understanding regional climatic pattern in the geological past. In previous qualitative studies lithologically depending on the occurrence of featured sedimentary rocks, the Eocene climate of China had been subdivided into three latitudinal zones, with one subtropical high-controlled arid zone throughout middle China, and two humid zones respectively in the north and south. However, recent advances on mammalian fauna distribution, plant fossil-based quantitative paleoclimatic reconstruction, and modeling experiment jointly suggest that the relatively humid monsoonal climate might have prevailed over the territory. Here we examine and compare sedimentary sequences of 10 Eocene sections across eastern China, and hence the lake level fluctuations, to discuss the nature of climate type. Our results show that, instead of the categorically zonal pattern, the hydroclimate dynamics is intensified landward. This is demonstrated by the fact that, in contrast to the wide developed coal layers around the periphery, evaporites are growingly occurred endocentrically to the central part of middle China. However, although we have had assumed that all evaporites are indicator of extreme aridity, the highly oscillated climate in the central part of middle China was humid in the majority of the Eocene, distinct from permanent arid as seen in deserts or steppe along modern horse latitude. From the upcountry distribution pattern of the Eocene hydrological dynamics, it appears that the relatively dry climate in central China was caused by the impact of continentality or rain shadow effect under monsoonal, or monsoon-like climate.

1. Introduction

The Eocene represents one of the most pronounced greenhouse periods in the Cenozoic, characterized by the equably distributed hot and humid climate (Greenwood and Wing, 1995; Clementz and Sewall, 2011). The warm global temperature, as much as 5–12 °C higher than today that leading to ice-free poles for the majority of the epoch (Huber and Sloan, 2001; Bijl et al., 2009), allowed air masses holding more water vapor, and enhanced polarward moisture transportation from extremely wet tropics along a shallow gradient (Fricke, 2003; Greenwood et al., 2010; Clementz and Sewall, 2011). However, the regional hydrological dynamics distribution, and hence the climatic pattern during the Eocene, are intangibly known, especially in the vast territory of East Asia such as China, in which conflicting explanations are produced (e.g., Qiu, 1996; Tong et al., 1996; Liu, 1997; Wang et al., 1999; Sun and Wang, 2005; Lu et al., 2007; Huber and Caballero, 2012; Quan et al., 2012a).

Previous lithology-based qualitative climatic studies suggest that there were two humid zones respectively in the north and south marked by the occurrences of coal and/or oil shale, and one broad arid zone stretched throughout middle China from west to east implied by the wide spread red beds and/or evaporites (Fig. 1) (Liu, 1997; Wang et al., 1999; Sun and Wang, 2005). Because this arid zone was located around 30°N paleo-latitude, it was further identified with the Eocene subtropical high (Liu, 1997; Wang et al., 1999), probably with landscapes resembling deserts and steppes along modern horse latitudes (Zhang et al., 2012). However, latest large-scale quantitative climatic reconstruction depending on the paleobotanical assemblages (Quan et al., 2012a) and the numerical simulation experiment (Huber and Caballero, 2012) both suggest that monsoonal climate might have been more or less developed under a relatively humid environment over China during the Eocene. From a paleoclimatic perspective, these new results corroborate those of mammalian fossil investigations, which deduce that the Eocene mammalian faunas are equably distributed in a humid climate over the

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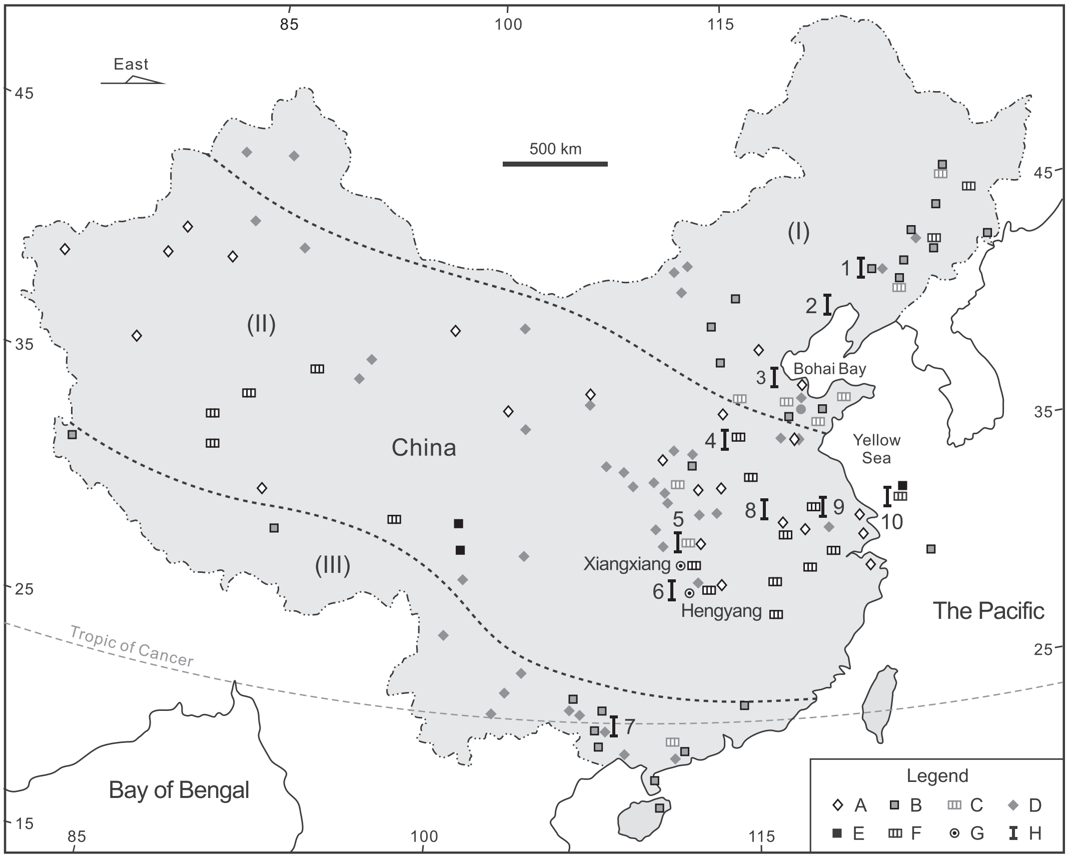

Fig. 1. Location of selected Eocene sections and associated lithological and paleontological data. Site numbers as in Table 1. Climatic zone subdivision (I–III) and related lithological data are from previous studies (Liu, 1997; Wang et al., 1999; Sun and Wang, 2005; Zhang et al., 2012). I – humid warm temperate to subtropical zone; II – middle arid zone (subtropical highs); III – tropical to subtropical zone. A – evaporites; B – coal; C – oil shale; D – mammalian fauna; E – newly found coal site; F – newly found oil shale site; G – important plant fossil or stratigraphic site; H – selected sections investigated in the present study. Mammalian data are mainly based on Tong (1989); data of newly found coal and oil shale sites are available online of data available on the website of National Geological Archives of China at http://www.ngac.cn/.

country, without an unambiguous latitudinal zonal pattern (Qiu, 1996; Tong et al., 1996). Apparently, in such a discrepancy, depicting the distribution of hydrological dynamics is crucial in understanding the Eocene climatic pattern of China.

Sedimentologically, stratigraphic succession of terrestrial deposits provides a substantial record of perturbations in lake system responding to associated climatic changes, and helps to decrypt the regional hydroclimatic dynamics in the geological past by comparing sedimentary sequences of different areas (Frakes, 1979; Janasson, 1983; Renaut and Long, 1989). In this paper, we examine profiles from several representative Eocene basins of eastern China to find out the overall distribution of lake water dynamics, which conduces to the comprehensive understanding of the Eocene climatic pattern thereof. Our results reveal that middle China, previously considered as an arid zone controlled by a subtropical high, is of high hydroclimatic dynamics in the Eocene, far from permanent arid as seen in deserts or steppe along the horse latitude. Moreover, integrated analyses further suggest that it appears without a distinguished arid zone obstructing across middle China during the Eocene, supporting that a monsoonal, or monsoon-like climate must have had dominated this vast region.

2. Method and material

2.1. Mudstone facies

Diagenetically, the mudstones, including mudrock, clay, shale, and other fine-grained rocks, give critical insight into sedimentation processes of the basin, such as the lake level changes and oxygen level identifications (Janasson, 1983; Aplin et al., 1999; Potter et al., 2005). Among various physical properties of mudstone, the rock color is basically controlled by water depth, and subsequently by the redox condition (Janasson, 1983; Parrish, 1998; Aplin et al., 1999). For a given facies, color of mudstone is decisive in environment determination, as shown by cycles of either marine or terrestrial muddy shoreline deposits (Abdul Aziz et al., 2003; Potter et al., 2005). In general, the color of mudstone tends to be darkened with deepening of the water body. Ferrous iron and organic matter are responsible to the darkened rock color, from gray, gray–green to black, under the reducing environment (Aplin et al., 1999; Abdul Aziz et al., 2003). When the lake depth turns to be shallow, ferric iron is accountable to the reddened rock color under the oxidizing environment (McBride, 1974; Parrish, 1998; Potter et al., 2005). In other words, the water depth plays the key role for redox condition, and thus the color variation of mudstone (Aplin et al., 1999; Potter et al., 2005). Therefore, we here briefly summarize the characteristics of mudstone in continental sedimentary facies, and use it as the indicator of hydrological dynamics.

Fluvial facies are deposited in oxidizing environment in most cases, in which the color of mudstone is red in either humid or arid climate (McBride, 1974; Parrish, 1998). Likewise, alluvial fan is also definitely in the oxidizing environment, where the mudstone could be red in both climate types (van Houten, 1973; Parrish, 1998). However, the mudstone is impure and occasionally comprising sandstone, conglomerate, charcoal, and fossil plant fragments in humid climate, while in arid climate, the mudstone is mainly