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Eocene monsoon prevalence over China: A paleobotanical perspective

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ABSTRACT

Proxy-based quantitative estimates of Eocene climates can be made from marine isotope records for ocean conditions or fossil plants for terrestrial environment. However, our understanding about Eocene terrestrial climates is derived mainly from North America and Europe, and little is known about East Asia. Previous qualitative paleoclimate studies briefly revealed three climatic regimes across China during the Eocene with a planetary wind-dominated subtropical to tropical arid zone in the central part (i.e., the subtropical highs), which was flanked by the subtropical climate zone in the north and tropical climate zone in the south. But such a pattern of paleoclimatic zonation still requires a test from quantitative study. Based on analyses of 66 plant assemblages, carefully selected from 37 fossil sites throughout China, we here report the first large-scale quantitative climatic results and discuss the Eocene climatic patterns in China. Our results demonstrate that the Eocene monsoonal climate must have been more or less developed over China, judging from the presence of apparent seasonality of both temperature and precipitation revealed by our quantitative estimation. This appears not to support the previously claimed Eocene planetary wind-dominated climate system, at least in the region of eastern China. In addition, the research indicates that, with a slight declining trend of MAT during the Eocene, the winter temperature substantially dropped in tropical southern China during the middle to late Eocene interval. This might be related to the development of a weak Eocene Kuroshio Current in the southwestern Pacific, and/or a significantly enhanced paleo-winter monsoon from Siberia.

1. Introduction

The Eocene environments, as generally understood, are characterized by distinct warm climates with overall global temperatures believed to be much higher than those in any other periods of the Cenozoic (Greenwood and Wing, 1995; Zachos et al., 2008; Huber and Caballero, 2011). The temperatures reached the highest levels in the Cenozoic during the Paleocene–Eocene Thermal Maximum and Eocene Thermal Maximum 2 (Wing et al., 2005; Zachos et al., 2008), and then decreased to a long-lived climatic optimum in the middle Eocene followed by an “ice-house” with small ephemeral ice-sheets in the early Oligocene (Zachos et al., 2008; Eldrett et al., 2009). Eocene climatic conditions have been well reported from proxies of either isotopes from surface-and-deep oceanic deposits or continental minerals and floras from both North America and Europe (Greenwood and Wing, 1995; Mosbrugger et al., 2005; Wing et al., 2005; Zachos et al., 2008; Greenwood et al., 2010; Utescher et al., 2011). However, little is quantitatively known from East Asia, except for several studies in China (e.g., He and Tao, 1997; Su et al., 2009; Yao et al., 2009; Wang et al., 2010; Quan et al., 2011, 2012). Because quantitative paleoclimatic estimates are essential to understand these long-term climate conditions, the paucity of studies from East Asia evidently prevents us from understanding and modeling the Eocene climates in a global context (Shellito and Sloan, 2006; Huber and Goldner, 2012).

As a vast country in East Asia, China preserves abundant Eocene palyno- and mega-floras (Fig. 1), but unfortunately no large-scale quantitative study has been conducted on the distribution of the Eocene climatic pattern in China. Based on data from the Chinese Eocene palynofloral assemblages, Song et al. (1983) qualitatively subdivided the Eocene climates of China into three zones, i.e., a humid warm temperate to subtropical zone in the north (Zones I in Fig. 1), an arid zone in the middle (Zone II), and a tropical to subtropical zone in the south (Zone III). This three-zone recognition was later supported by evidence from megafossil plants and lithological records (Guo, 1985; Liu, 1997; Sun and Wang, 2005). Although these studies have provided a possible general Eocene climatic pattern in China, it is still largely unclear about the details of Eocene climates over this vast region in East Asia due to the absence of large-scale quantitative reconstructions. Therefore, a critical question is to know what kind of climatic system, planetary wind or monsoon,

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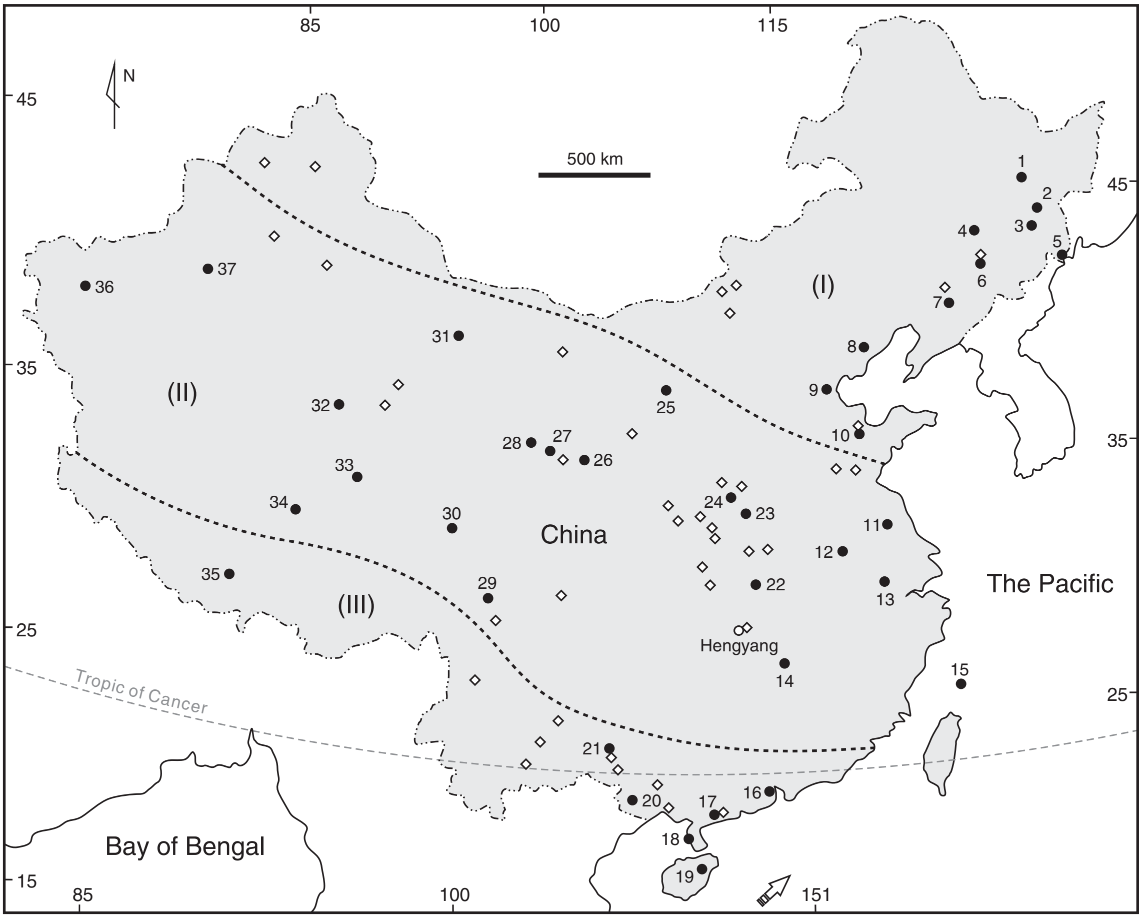

Fig. 1. Location of plant fossil sites. Each site may include several plant fossil assemblages. Site numbers as in Table 1. Climatic zone subdivision (I–III) modified from previous qualitative studies (Song et al., 1983; Guo, 1985; Liu, 1997; Sun and Wang, 2005): I—humid warm temperate to subtropical zone; II—middle arid zone (subtropical highs); III—tropical to subtropical zone. Solid circle—Eocene site yielding either mega- or microfossil plants; open diamond—Eocene mammalian fauna (data mainly from Tong, 1989). Arrow shows the Kuroshio Current.

prevailed during the Eocene, especially in central China. Moreover, the qualitative results, though important, are not always suitable for climate modeling experiments, which heavily depend upon quantitative climatic estimates (Shellito and Sloan, 2006; Huber and Goldner, 2012).

We here quantitatively reconstruct the Eocene climates by using fossil plants, including both megafossils and palynomorphs from China. Our results show that the distribution of Eocene climates is fairly even, but seasonality appears prominent, indicating a more or less developed monsoonal climate over China.

2. Methods and material

2.1. Selections and age control of fossil plant assemblages

The Eocene deposits are widely distributed throughout China, and are generally dominated by non-marine facies except the southern margin of the Tibetan Plateau. The continental strata with plenty of plant fossils are mainly fluvial, lacustrine in origin in eastern China, but in central-western China there contains red-beds and evaporites. The majority of these strata, however, lacked extensive geochronological investigations (Li, 1984). As a result, ages of many of these floras were initially assigned only to a wide geological range based on assemblages, such as to an epoch or system level. This apparently reduces the resolution of paleoclimatic results, or even casts doubt on their validity in paleoclimatic modeling. Fortunately, recent interdisciplinary studies significantly improve the age constraints in many Eocene localities (e.g., Huang et al., 1998; Wang et al., 1999; Miao et al., 2008; Shi et al., 2008; Pei et al., 2009). This provides opportunities to reconstruct paleoclimates in a better resolution at the stage level.

Although dozens of Eocene sections have been reported, 66 plant assemblages from 37 localities with well-defined ages are included in the present study (Table 1). Except for a few localities, the assemblages are selected only when at least 1 (for most cases, >2) of the following criteria well matches the age indicated by plant assemblage, i.e., 1) polarity chron studies, which were carried out in many of the localities; 2) geochemical dating, either by isotopic dating on volcanic intercalations near the fossil beds or by fission-track dating on the fossiliferous rock complexes; 3) vertebrates, especially mammals, which are main age markers in the subdivision of Chinese Cenozoic terrestrial sediments; 4) invertebrates, which are available and well studied in many localities; and 5) intensive biostratigraphical correlations between adjacent basins.

2.2. Quantitative paleoclimate reconstructions

Although several plant fossil-based methods have been developed and well used in recent decades for quantitative reconstruction of paleoclimates (e.g., Wolfe, 1979; Wing and Greenwood, 1993; Greenwood et al., 2004; Su et al., 2010; Spicer et al., 2011), the coexistence approach (CA) is applied in this study. Choice of the CA is because this approach is organ-independent and eligible to both palyno- and mega-plant fossils (Mosbrugger and Utescher, 1997; Utescher et al., 2007; Bruch et al., 2011; Utescher et al., 2011). The CA assumes that climatic tolerances of a fossil plant are not significantly different from its nearest living relatives (NLRs) when its modern affinity is determinable