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Late Miocene southwestern Chinese floristic diversity shaped by the southeastern uplift of the Tibetan Plateau

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ABSTRACT

In southwestern China and Southeast Asia modern geology and topography have been influenced strongly by the collision between the Indian and Eurasian plates. The southeastern margin of the Tibetan Plateau is well known for its high biodiversity and diverse vegetation types. While the present diversity is explained by the geological history of this region, to date no study has looked at how past vegetation was shaped by geological and topographical history. In this study, we focus on three coeval late Miocene leaf assemblages from Yunnan: Lincang, Xiaolongtan and Xianfeng. The palaeoelevation of these three sites is reconstructed using enthalpy as a palaeoaltimeter. Enthalpy at the fossil site is reconstructed based on leaf physiognomy; the difference between this enthalpy and enthalpy at sea-level is used as a proxy for altitude. The palaeoaltitudes are resolved as 214 ± 901 m asl for Lincang, 530 ± 901 m asl for Xiaolongtan, and 1936 ± 901 m asl for Xianfeng. The floristic components of these floras are analysed for their geographical elements. There is a gradient in the percentage of tropical genera between the three floras from Lincang, at the lowest elevation, to Xianfeng, at the highest level. For Lincang, this percentage exceeds the threshold used to define present day tropical regions. Our results demonstrate that there was already a floristic differentiation in Yunnan during the late Miocene. Floras with tropical affinities were at low altitude, whereas floras with temperate affinities were at high altitude. With the later uplift of southern Yunnan, floras with tropical affinities retreated to the south where they are still present. The uplift framework reconstructed in this paper gives a tectonic context for further studies on the impact of uplift on biodiversity.

1. Introduction

In recent years many studies have focused on the southeastern extension of the Qinghai–Tibetan Plateau (Clark and Royden, 2000; Schoenbohm et al., 2004; Clark et al., 2005a,b; Shen et al., 2005; Schoenbohm et al., 2006a,b; Westaway, 2009; Bai et al., 2010; Searle et al., 2011; Wang et al., 2011). This southeastern Tibetan borderland is mostly situated in Yunnan, southwestern China (Fig. 1) and has been studied extensively because important mechanisms of the India–Eurasia collision, such as the extrusion of Indochina, took place in this region (Tapponnier et al., 1990; Leloup et al., 1995; Replumaz et al., 2001; Replumaz and Tapponier, 2003). The impact of the regional tectonics on past climates has been studied in several papers: Kou et al. (2006) demonstrated the influence of the uplift of mountain ranges on Yunnan precipitation; Zhang et al. (2012) demonstrated how the uplift of the Ailao mountains influenced the winter monsoon; Xie et al. (2012) and Su et al. (2013) showed how the uplift of Gaoligong and Nu mountains influenced precipitation in western Yunnan. Several palaeobotanical studies have provided a detailed palaeoclimatic background for this province during the late Cenozoic (Wu et al., 2009; Xia et al., 2009; Jacques et al., 2011a; Sun et al., 2011, 2012; Xing et al., 2012; Zhang et al., 2012; Su et al., 2013). The modern diverse floristic composition of Yunnan province has been explained by the geological history of the province (Zhu, 2012, 2013a). Palaeovegetation reconstructions of China show an imbrication of several vegetation types in Yunnan since the late Miocene (Jacques et al., 2011c, 2013) hypothetically linked to a complex landscape (Jacques et al., 2011c). However, no study has really looked at the impact of the local geology on the floristic differentiation of Yunnan in the past.

Several phylogeographic studies based on molecular sequences have demonstrated the importance of the geological history of Yunnan on the plant population and diversification in this region. For example, the evolution of the drainage system influenced the diversity pattern of *Terminalia franchetii* (Zhang and Sun, 2011) and *Buddleja crispa* (Yue et al., 2012), while the uplift of the Qinghai–Tibet Plateau can explain the floristic evolution of the region and its origin from a Tethysian flora (Sun and Li, 2003) and tectonic movement and river dynamics the formation of endemic species in Yunnan (Qiu et al., 2011). Yunnan

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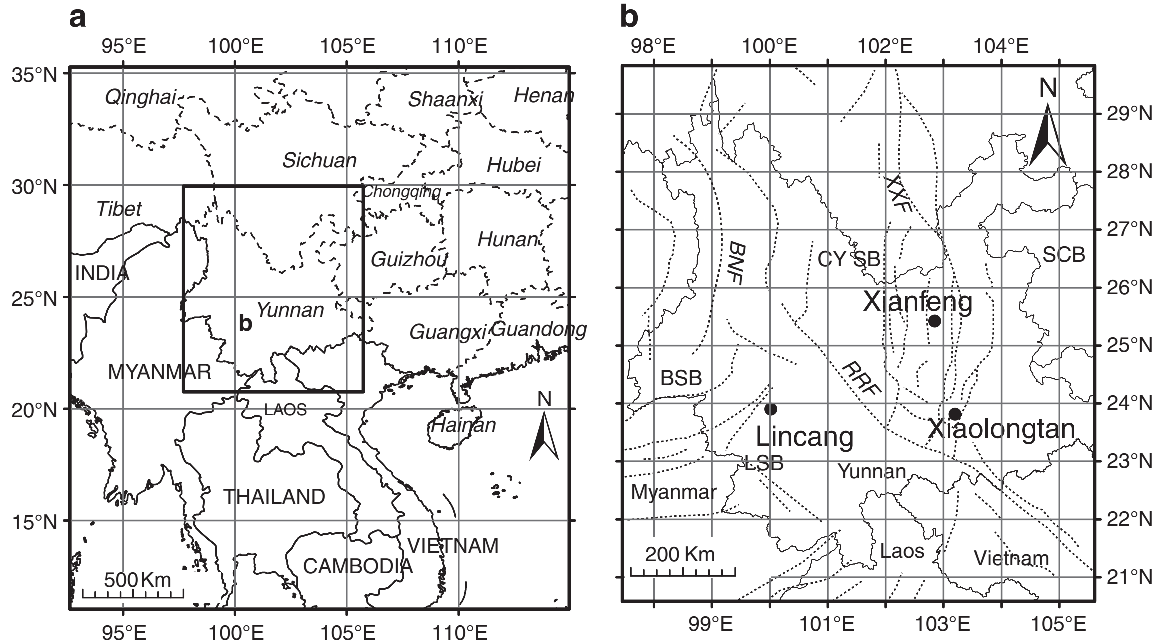

Fig. 1. Location of the three fossil sites. a. General map of Southeast Asia. b. Location of the three fossil sites in Yunnan and main fault systems (dashed lines) of the region. BNF, Bangong–Nujiang Fault; BSB, Baoshan Sub-block; CY SB, Central Yunnan Sub-block; LSB, Lincang Sub-block; RRF, Red River Fault; SCB, South-China Block; XXF, Xianshuihe–Xiaojiang fault system.

is one of China's biodiversity 'hotspots': its surface only accounts for 4% of the Chinese territory, but supports half the species of vascular plants, birds and mammals present in China (Wu and Zhu, 1987). Moreover, most vegetation types of China can be found in this province. Consequently, Yunnan is an ideal region to study the impact of tectonics on floristic composition and structure because: (1) the diversity of vegetation types occurring in Yunnan ranges from tropical forest in the south to alpine meadow in the northwest (Li and Walker, 1986); (2) the complex tectonic history of the province, where modern altitudes range from almost sea level to more than 6000 m asl within a distance of approximately 850 km. These marked vegetation and altitude differentiations can enhance the visibility of the changes.

Despite the important relationship between uplift and biodiversity, research in this field lacks a good time and space framework for the uplift. Several studies provide insight into the uplift history of Yunnan (Schoenbohm et al., 2004, 2006a; Cao et al., 2011), but they all give relative, instead of absolute, altitude. In this paper, we propose an original approach: reconstruct absolute palaeoaltitudes of the studied fossil sites in order to discuss Yunnan floristic changes in a strong tectonic context. Using enthalpy as a palaeoaltimeter (Forest et al., 1999) gives the palaeoaltitude at a fossil site, and palaeoenthalpy is obtainable from fossil leaf assemblages.

Here we focus on the late Miocene. The Miocene is a critical time slice to investigate because the modern tectonic regime in Yunnan province was established by around 8 to 10 Ma (Royden et al., 2008), as a result of a long period of extrusion of Indochina (Replumaz and Tapponier, 2003; Royden et al., 2008; Yang and Liu, 2009). First we reconstructed the geological and tectonic context of the three fossil sites in terms of palaeoaltitude. We then analysed the floristic differences between three late Miocene floras of Yunnan. Finally, we looked at possible links between geological patterns and floristic patterns.

2. Material and methods

2.1. Geological settings

The major tectonic structures in Yunnan Province (Fig. 1) are the Red River Fault, which shows minor activity in the late Cenozoic (Schoenbohm et al., 2006a), and the Xianshuihe–Xiaojiang fault system (Shen et al., 2005; Royden et al., 2008; Taylor and Yin, 2009), which became active at around 8 to 10 Ma (Royden et al., 2008). In the Neogene, the tectonic activity of Yunnan Province is characterised by a general extensional context (Schoenbohm et al., 2006a). Modern GPS velocity data indicate a surface regional clockwise rotation around the eastern Himalayan syntaxis (Shen et al., 2005). The geological structures of Yunnan have sometimes been used to explain the modern phytogeography of Yunnan: the geological structures correspond to the accretion of different geological blocks or terranes, the two major ones being the Yangtze Block and the Lincang Terrane. According to Zhu (2013a), there is a biogeographical line at the border between these two blocks.

2.2. Palaeofloras

The three leaf assemblages studied here are: the Lincang flora (Guo, 2011; Jacques et al., 2011a), the Xiaolongtan flora (Zhou, 1985; Tao et al., 2000; Xia et al., 2009) and the Xianfeng flora (Xing et al., 2012) (Fig. 1). The Lincang flora is situated on the Lincang Terrane, whereas Xiaolongtan and Xianfeng are both situated on the South China Terrane, or Yangtze Block, north of the Red River Fault (RRF; Fig. 1). The coordinates of the studied sites are indicated in Table 1. The Lincang flora belongs to the Bangmai Formation, which is dated as being of late Miocene age by stratigraphic correlation between sediment deposits in Yunnan and the plant fossil composition of these layers (Guo, 2011; Jacques et al., 2011a), while both the Xiaolongtan and Xianfeng floras belong to the Xiaolongtan Formation, also dated as late Miocene by mammal fossils (Dong, 2001) and palynology (Wang, 1996). Thus, both the Bangmai Formation and the Xiaolongtan Formation are considered as late Miocene; and, according to the available geological and stratigraphical evidence (Group of the Regional Stratigraphic Table of Yunnan, 1978; Bureau of Geology and Mineral Resources of Yunnan Province, 1990; Zhang, 1997), the three floras are considered as coeval.

These three floras yielded rich fossil assemblages with Fagaceae and Lauraceae as dominant families (Zhou, 1985; Xia et al., 2009; Guo, 2011; Xing et al., 2012). Overall, 73 morphotypes were recognised from the Lincang flora, 54 from Xiaolongtan and 54 from Xianfeng. Compositionally, they reflect a warm and humid late Miocene climate in Yunnan (Xia et al., 2009; Jacques et al., 2011a; Xing et al., 2012). CLAMP palaeoclimate reconstructions give mean annual temperatures (MATs)