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Late middle Eocene fossil wood of Myanmar: Implications for the landscape and the climate of the Eocene Bengal Bay

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ABSTRACT

The late middle Eocene Pondaung Formation, Myanmar, has yielded a diversified assemblage of silicified wood including some of the earliest recorded Dipterocarpaceae. However, mid-Palaeogene fossil wood from Asia remains rarely described. We present here three additional species of fossil wood from the upper member of the Pondaung Formation, including a new species of *Menispermoxylon* (*M. mowglii* nov. spec.) with successive cambia and included phloem, and two specimens of the fossil genera *Glutoxylon* (*G. burmense* Chowdhury) and *Heritieroxylon* (*H. arunachalensis* Lakhanpal, Prakash et Awasthi). These three fossil species are related to modern taxa of mangrove and coastal forests in the Bengal Bay and complete the floral assemblage already identified in the Pondaung Formation. The late middle Eocene fossil woods of Myanmar followed a toposequence with mangroves along the seashore, riparian elements similar to those of modern Terai ecosystem in the upper delta plain, and dry dipterocarp forests in the upstream areas of the drainage basin. The latter two assemblages and their association in the landscape are typical of monsoonal areas with significant rainfall and a marked dry season, thus confirming recent studies showing that the Bengal Bay has experienced a significant monsoonal regime as early as 40 Ma ago. The climatic parameters obtained by two quantitative botanical approaches on the Pondaung fossil wood, the coexistence and wood anatomical approaches, suggest similar-to-modern rainfall amount, marked dry season, and warmer annual temperature for the Eocene of Myanmar. They thus support the hypothesis that monsoonal rainfall at that time may have been favored by Eocene greenhouse conditions. However, despite the homogeneity of the Pondaung floral assemblage, several resulting climatic parameters, such as the mean annual temperature (for the coexistence approach) or the mean annual rainfall (for the wood anatomical approach), display large but incomplete uncertainty intervals or unlikely values (for the coexistence and wood anatomical approaches respectively). These limitations can be attributed to the lack of super-warm and super-seasonal stations in their modern databases. It thus indicates that results from both quantitative approaches should be interpreted with caution for palaeo-monsoon reconstruction.

1. Introduction

The late middle Eocene Pondaung Formation of central Myanmar has yielded a significant amount of silicified wood specimens, attributed to 13 fossil species (Privé-Gill et al., 2004; Licht et al., 2014a). These species are closely related to modern representatives of the genera *Amesiodendron* Hu, *Acrocarpus* Wight & Arnott, *Bauhinia* L., *Bombax* L., *Cynometra* L., *Ficus* L., *Saraca* L., *Schima* Reinwardt, *Shorea* Roxburgh, *Sonneratia* L.f., and *Terminalia* L., and are interpreted as representing different ecotones of a dry dipterocarp forest similar to those of sal (*Shorea robusta* Gaertner) forests of the modern Indian foreland (Licht et al., 2014a).

Though fossil wood specimens have been occasionally reported in the Asian Palaeogene fossil record (e.g. Bande and Prakash, 1986; Bande, 1992; Mehrotra, 2000; Srivastava, 2011; Srivastava and Mehrotra, 2013), palaeobotanical data from the Palaeogene of Asia are dominated by fossil pollen, leaves, and fruits assemblages, datings of which are usually poorly constrained (see e.g. Morley, 2000; Utescher and Mosbrugger, 2007; Quan et al., 2012; Wang et al., 2013 for recent compilations). The upper member of the Pondaung Formation contains an abundant late middle Eocene (Bartonian) fauna (Marivaux et al., 2005; Tsubamoto et al., 2005; Métais et al., 2007; Head et al., 2013);

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the magnetostratigraphic polarity of these deposits (Benammi et al., 2002) and recent U/Pb and fission-track ages of detrital zircons (Tsubamoto et al., 2002, 2011; Zaw et al., 2015) indicate a correlation with the chron C38n, dated between 40.1 and 38.6 Myr (Gradstein et al., 2012). Pondaung deposits are thus contemporary with the end of the Middle Eocene Climatic Optimum (MECO), the most prominent transient warming episode of the middle Eocene, and its subsequent cooling event (Bohaty and Zachos, 2003; Villa et al., 2008; Bijl et al., 2010; Bosboom et al., 2014). Both events are yet poorly documented in continental Asia and are known from few sites (Quan et al., 2011; Song et al., 2013; Bosboom et al., 2014). Studying the Palaeoflora of the Pondaung Formation is thus critical for understanding the late Eocene Asian climate, and the evolution of the late Eocene monsoons (Quan et al., 2012; Wang et al., 2013; Licht et al., 2014b). This paper strengthens the reconstruction of the late middle Eocene woods of Myanmar initiated by Privé-Gill et al. (2004) and Licht et al. (2014a) through the description of three additional fossil wood taxa from the Pondaung Formation. It then proposes a reconstruction of the late middle Eocene Burmese landscape and climate based on qualitative and quantitative analyses of the fossil floral assemblage.

2. Palaeoenvironmental context

The Pondaung Formation is a thick sequence of continental deposits in the Central Myanmar Basin reaching more than 2000 m of thickness (Pivnik et al., 1998). It crops out extensively along the eastern flank of the Indo–Burman Ranges, which now separate the Central Myanmar Basin from the Bengal Bay (Fig. 1A; Bender, 1983). At the time of Pondaung deposition, the Indo–Burman Ranges had not emerged and central Myanmar was the locus of small deltas opening into the Indian Ocean, supplied by the unroofing of the volcanic arc that extended along the eastern flank of the Central Myanmar Basin (Fig. 1B; Licht et al., 2013; Licht et al., in press). The upper member of the Pondaung Formation (upper 500 m of the section) has yielded numerous continental vertebrate remains, including a large and diverse community of fossil primates (Jaeger et al., 1999; Takai et al., 2001; Beard et al., 2009; Chaimanee et al., 2012). Outcrops of the upper member consist in fossiliferous sandstones and reddish mudstones with numerous palaeosols, representing the alluvial deposits of a deltaic floodplain (Licht et al., 2014c). Shrinking and swelling features and evidence of Gilgai microtopography development in palaeosols indicate a seasonal, water-stressed climate and are incompatible with the presence of a dense forested cover in the Pondaung floodplain (Licht et al., 2014c). These features suggest that a portion of the Pondaung fossil wood taxa may have been supplied from upstream areas of the Eocene drainage system. This is corroborated by the co-occurrence in most of the sites of fossil taxa similar to those of modern Bengalese littoral forests and mangroves (*Acrocarpoxylon ungeri* Gottwald, *Sonneratioxylon caseolarioides* Shete et Kulkarni, *Cynometroxylon holdenii* (Gupta) Prakash et Bande), together with taxa related to modern inland dry dipterocarp woods (*Ficoxylon mogaungense* Licht, Boura et De Franceschi, *Bauhinium paleomalabaricum* Prakash et Prasad, *Shoreoxylon panganense* Licht, Boura et De Franceschi, *S. burmense* Prakash, *S. deomaliense* Prakash et Awasthi, *Terminalioxylon coriaceum* Prakash et Awasthi, *Bombacoxylon pondaungense* Licht, Boura et De Franceschi, *Schimoxylon benderi* Licht, Boura et De Franceschi, *Sapindoxylon burmense* Licht, Boura et De Franceschi and *Acrocarpoxylon siwalicus* Yadav; Licht et al., 2014a). The latter forest assemblage comprises numerous specimens with well-marked growth rings and suggests a wet, yet strongly seasonal climate, modern dry dipterocarp forests being associated to monsoonal areas with intense rainfall and a marked dry season (Gautam and Devoe, 2006). Strong seasonality during the time of Pondaung deposition is confirmed by growth arrest lines in mammalian fossil lower jaws (Jaeger et al., 2004). Isotopic analyses of Pondaung gastropod shells and fossil tooth enamel, together with climatic models, confirm a strong monsoonal climate in the late middle Eocene of Myanmar, intensity of which has not been precisely quantified (Licht et al., 2014b).

3. Materials and methods

Samples come from two fossiliferous localities of the upper member of the Pondaung Formation, Nyaungpinle (Bahin village, Myaing Township-Magway Division, Myanmar) and Mogaung (Mogaung village, Pale Township-Sagaing Division) (Fig. 1; detailed map of the localities and GPS coordinates in Licht et al., 2014a). They were collected on the ground together with vertebrate remains and are completely silicified. Sections of the fossil wood were prepared following the standard techniques (Hass and Rowe, 1999) and described following the IAWA

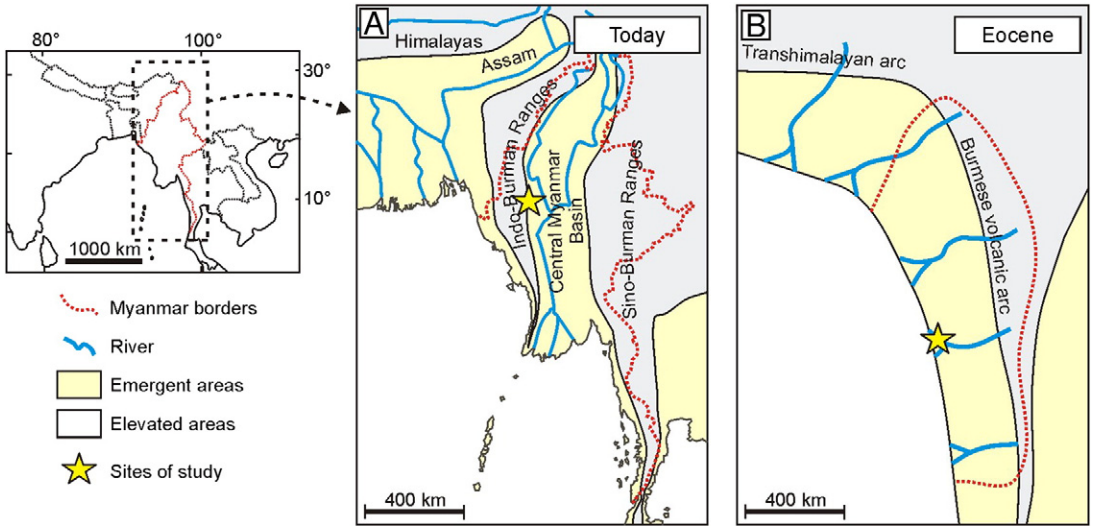

Fig. 1. Simplified map of the study area (A) and palaeogeographical reconstruction of the area in the Eocene (B; after Licht et al., 2013). A detailed map of all localities (with GPS coordinates) is available in Licht et al. (2014a). Note that the studied sites in the Eocene are located south relative to their modern position due to the Cenozoic northward displacement of central Myanmar along the Sino–Burman Ranges (Estimates vary from 300 to about 1100 km; Mitchell, 1993; Curray, 2005; Morley, 2009).