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Global warming and South Indian monsoon rainfall—lessons from the Mid-Miocene

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ABSTRACT

Precipitation over India is driven by the Indian monsoon. Although changes in this atmospheric circulation are caused by the differential seasonal diabatic heating of Asia and the Indo-Pacific Ocean, it is so far unknown how global warming influences the monsoon rainfalls regionally. Herein, we present a Miocene pollen flora as the first direct proxy for monsoon over southern India during the Middle Miocene Climate Optimum. To identify climatic key parameters, such as mean annual temperature, warmest month temperature, coldest month temperature, mean annual precipitation, mean precipitation during the driest month, mean precipitation during the wettest month and mean precipitation during the warmest month the Coexistence Approach is applied. Irrespective of a ~3–4 °C higher global temperature during the Middle Miocene Climate Optimum, the results indicate a modern-like monsoonal precipitation pattern contrasting marine proxies which point to a strong decline of Indian monsoon in the Himalaya at this time. Therefore, the strength of monsoon rainfall in tropical India appears neither to be related to global warming nor to be linked with the atmospheric conditions over the Tibetan Plateau. For the future it implies that increased global warming does not necessarily entail changes in the South Indian monsoon rainfall.

1. Introduction

Asian monsoon is a substantial component of the global climate system, which affects half of the world's population (An, 2000; Lovett, 2010). This large-scale atmospheric circulation comprises the Indian and East Asian monsoon subsystems, both characterised by seasonal reversing winds and precipitation changes associated with asymmetric heating of land and sea. Temporal and spatial variability in these atmospheric circulations can result in severe droughts or floods with profound socioeconomic impact on large, densely populated regions (Webster et al., 1998; Cook et al., 2010). Accordingly, monsoon prediction models have a high priority in many Asian countries and global warming incites the question: will the Asian monsoon strengthen or weaken in the future (DelSole and Shukla, 2002; Ashfaq et al., 2009; Cook et al., 2010)?

Climate proxies from critical times of changing monsoon intensity are important for a better understanding of the driving forces (Overpeck and Cole, 2007). The development of the Asian monsoon system is considered to be related to the Himalayan uplift and dated to the beginning of the Neogene (Raymo and Ruddiman, 1992; Guo et al., 2002). In particular, growth of the Tibetan Plateau has been cited as being a trigger for an Asian monsoon intensification (Molnar et al., 1993). The Neogene monsoon history is mainly reconstructed from chemical and physical weathering rates recorded in widely continuous marine sequences of the Indus Fan, Bengal Fan and South China Sea which, depending on the source physiography and sediment, indicate drier or wetter climates (Clift et al., 2008; Wan et al., 2010). These climate proxies display long-term variations of the East Asian monsoon in the catchment area of the Perl and Yangtze rivers (South China) as well as of the Indian monsoon in the catchments of the Indus and Ganges–Brahmaputra river systems (Himalaya; Clift et al., 2008; Wan et al., 2010). The overall trend is one of gradually increasing monsoon strength from the beginning of the Neogene to 10 Ma (Late Miocene) with an unusually dry period at the Early/Middle Miocene transition (16.5–15 Ma; Clift et al., 2008).

The southwest Indian state of Kerala is popularly known as the "Gateway of summer monsoon" over India (Krishnakumar et al., 2009) and receives locally more than 75% of the rain by the Indian monsoon (Simon and Mohnakumar, 2004). Herein, we present an Early/Middle Miocene pollen flora from the siliciclastic Ambalapuzha Formation at the coastal cliffs of Varkala in SW Kerala, which represents the first terrestrial precipitation proxy from the time before 10 Ma for entire southern India. It corresponds to a global warming event at ~17–15 Ma (Middle Miocene Climate Optimum, MMCO; Zachos et al., 2001), when the global annual surface temperature was on average about ~3–4 °C higher than present and equivalent to the warming predicted for the next century by the mid-range scenarios of the IPCC Fourth Assessment Report (You et al., 2009;

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You, 2010). Therefore and since the general conditions such as palaeogeography and paleobathymetry were not greatly different from today, this global warming episode represents a possible analogue of future climate change (You, 2010).

The state of current knowledge of the Asian monsoon systems during this crucial time interval of climate change is only inferred from marine sediments (Clift et al., 2008; Wan et al., 2010). However, these proxies neither provide direct information to the seasonal distribution of temperature and rainfalls nor to the monsoon over tropical India. In order to quantify the climate seasonality in SW-India during the MMCO the Coexistence Approach (Mosbrugger and Utescher, 1997) is applied to the Varkala pollen flora.

2. Geological setting and stratigraphy

The studied outcrop is located in the Kerala Basin (SW-India) at the coastal cliffs at Varkala (Fig. 1). It exposes a 21-m-thick siliciclastic succession of the Ambalapuzha Formation conformably overlying carbonates of the Quilon Formation (Vaidyanadhan and Ramakrishnan, 2008). Elevation and denudation of the Western Ghats were the source for the siliciclastics (Campanile et al., 2008). Palynofloras from these deposits document their deposition in marginal marine brackish lagoons as well as brackish and freshwater swamps (Ramanujan, 1987). Exceptional is the mixed siliciclastic–carbonatic Quilon Formation, which is interbedded between siliciclastics of the underlying Mayyanad Formation and the overlying Ambalapuzha Formation (Vaidyanadhan and Ramakrishnan, 2008; Fig. 2). It represents a marine ingression during the Burdigalian (Reuter et al., 2011). Calcareous nannoplankton from the Quilon Formation indicates nannoplankton zone NN3 (Reuter et al., 2011). The herein studied siliciclastics follow directly above the Quilon Formation with a conformable contact (Vaidyanadhan and Ramakrishnan, 2008) pointing to a late Burdigalian to early Langhian age (Fig. 2).

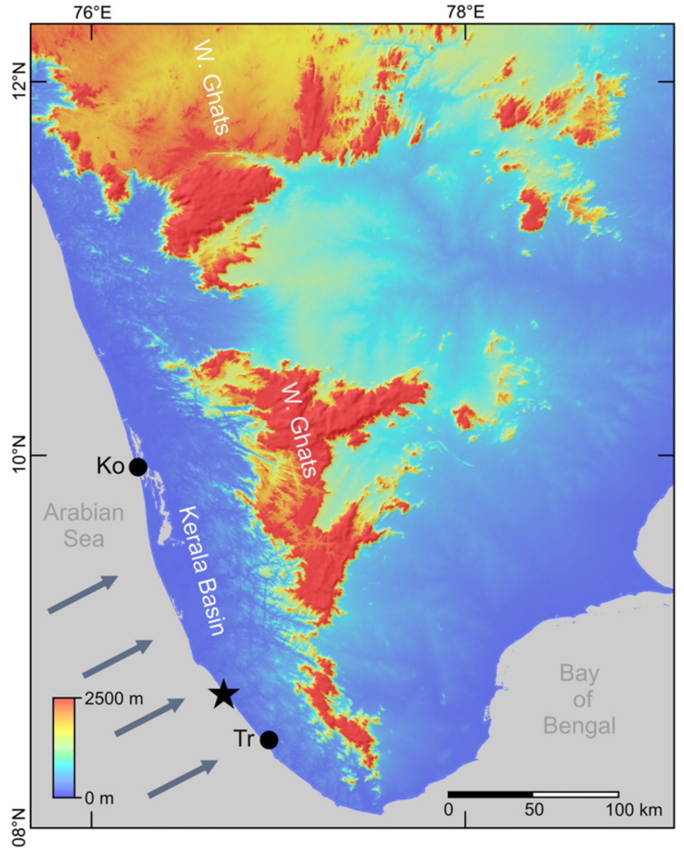

Fig. 1. Digital elevation model of southern India (Jarvis et al., 2008). The black asterisk locates the studied outcrop at Varkala (N 08°43′47″, E 076°42′30″) and the black dots indicate the position of the meterological stations Kochi (Ko) and Trivandrum (Tr). Blue arrows represent the SW-monsoon.

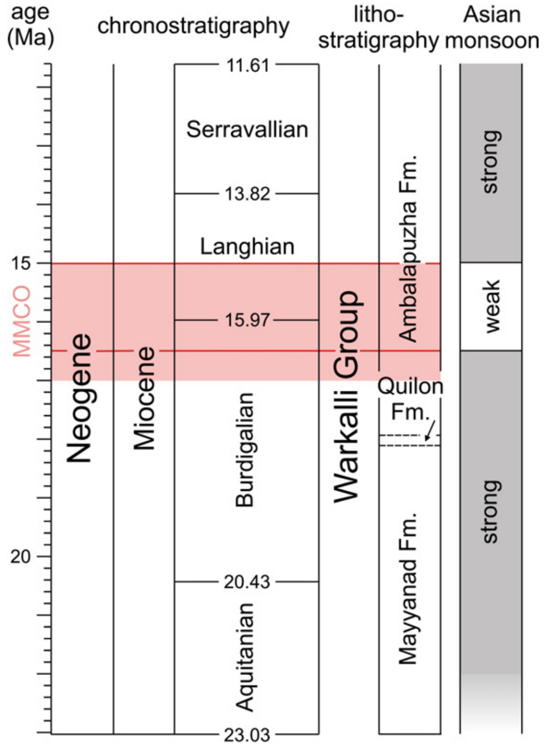

Fig. 2. Stratigraphic chart of the Varkala pollen flora. Correlation of the studied section with global chronostratigraphy (Gradstein et al., 2004), lithostratigraphy (Vaidyanadhan and Ramakrishnan, 2008), biostratigraphy (Reuter et al., 2011) and Asian monsoon intensity over northern India (Clift et al., 2008). The solid red lines mark the stratigraphic interval for the studied sediments, the red bar indicates the Middle Miocene Climate Optimum (MMCO).

In the studied section sediments range from bright yellow quartz sands to black sandy clays. Parts of the section exhibit lamination and flaser bedding due to interbedded laminae and lenses of well-sorted fine-grained quartz sands with finer grained dark grey muddy siliciclastics. In contrast, metre-thick yellow sand deposits show shallow inclined planar layers of well-sorted coarse-grained sand and fine gravel. Characteristically, the upper surfaces of these beds are erosive or modified by lateritic pedogenesis. Bioturbation is common in the sand as well as in the clay facies and predominantly represented by crab burrows. *Diplocraterion* ichnofossils can be associated in the clays as well as thin vertical rootlets of <20 cm length. Wood fragments occur in clay as well as sand facies.

3. Materials and methods

Eight samples were taken from dark grey and black sandy clays with a high amount of wood and/or rootlets. The samples were washed and processed with concentrated hydrochloric and hydrofluoric acid to eliminate silica and $CaCO_3$. Afterwards, the residues were prepared with concentrated glacial acetic acid before acetolysis was performed. At least 200 identified pollen grains were counted from each sample. Their identification stays at family and genus level to avoid parataxonomy.

The Coexistence Approach (CA; Mosbrugger and Utescher, 1997) was used for palaeoclimatic reconstructions. This method uses climatic tolerances of all nearest living relatives (NRLs) known for a fossil flora by assuming that the tolerances of a fossil taxon are not significantly different from its modern counterpart. The maximum overlap of the environmental tolerances of all the nearest living relatives is the coexistence interval (CI). By enquiring the Palaeoflora Database (Utescher