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Low-latitude vegetation and climate dynamics at the Paleocene-Eocene transition – A study based on multiple proxies from the Jathang section in northeastern India

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ABSTRACT

We present a multi-proxy study of an upper Paleocene-lower Eocene succession from the paleo-equatorial region. The study is carried out on a coal-bearing, shallow-marine succession exposed at Jathang, east Khasi hills, Meghalaya, northeastern India. The succession was deposited in a low-energy, coastal marsh-bay complex. Dinoflagellate cyst biostratigraphy yields a late Paleocene to early Eocene age for the section. The deposits of the lower part of the succession represent a transgressive systems tract (TST) defined by seven parasequences, each starting with bay sediments deposited during transgression, followed by a shallowing-upward bay fill-marsh deposit. In the vertical succession, each parasequence acquires an increasingly marine character, culminating in a maximum flooding surface at the Paleocene-Eocene boundary. It is followed by four shallowing upward parasequences deposited in a highstand systems tract (HST). Enhanced chemical weathering and high terrestrial supply are testified by raised SiO_2 and Al_2O_3 contents and high percentages of terrestrial palynomorphs. The pollen flora recovered from the Jathang section was used for quantitative paleoclimate and vegetation reconstructions. The Coexistence Approach was applied based on Nearest Living Relatives (NLRs) of sixty fossil species recorded at different stratigraphic levels. Seven climate variables were determined for the fossil assemblages, and, as a measure of the seasonality of climate, the number of dry months was estimated. Our study shows that during the Paleocene there existed warm, seasonally dry tropical climate conditions with mean annual temperature at ca. 24–26 °C and mean annual precipitation at ca. 700–1800 mm, and with a dry season of 5–6 months. Particularly warm and wet, perhumid climate conditions with 26–27 °C and 2200–3200 mm mean annual precipitation with a dry period of 2–3 months were reconstructed for the latest Paleocene-earliest Eocene interval. The study shows a distinct vegetational turnover from palm-dominated, seasonally dry tropical forest during the Paleocene to highly diversified dicotyledonous megathermal rainforest during the latest Paleocene-early Eocene. The present study demonstrates that the reduced duration of the dry period during the latest Paleocene-earliest Eocene, due to a more active hydrological cycle, played a major role in determining the climate and shaping the vegetation cover in the paleo-equatorial region. There is evidence from our data that seasonality of rainfall is the determining factor for the tropical forest vegetation pattern of the equatorial region rather than mean annual rainfall condition. As the main trigger for the observed step-wise changes of the hydrology along the studied succession, the fast northward movement of the Indian Plate is inferred.

1. Introduction

The currently observed trend of increasing average mean surface temperature is a well-documented phenomenon and continues to occupy a central position in discussions on environmental issues. The last 150 years have seen a rise in atmospheric CO_2 concentration from 280

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to 400 ppm and an increase in ambient temperature (IPCC, 2007). Current trends indicate that this rise in both CO_2 and temperature is expected to continue, attaining levels that will, without any doubt, affect both flora and fauna, including mankind. There have been efforts to detect analogues that may expose the long-term effect of global warming on the bio-geosphere and to enable a more precise prediction of future climate. These attempts however, have been hampered by the absence of such analogues from the recent past. Climate model scenarios based on numerical simulations related to a significant increase in CO_2 level expected for the not so distant future are difficult to validate using data from the recent past. The early Paleogene greenhouse climate in deep time geological records offers an understanding of a longer-term effect of raised CO_2 on ecosystems. The Paleocene-Eocene Thermal Maximum (PETM), a well-studied extreme, globally warm event, followed by several small scale hyperthermal events, provides an important context within which to study temperature and precipitation data for a globally warm climate state.

Obtaining quantitative paleoclimate estimates for the early Paleogene greenhouse climate is one of the most crucial aspects of paleoclimate research during the last few decades. In contrast to the unambiguous records of the high temperature state of polar and high latitudinal regions during the Paleocene-Eocene interval, divergent hypotheses have been suggested for the climate at low latitudes (D'Hondt and Arthur, 1996; Huber, 2008). Past changes in the hydrological regime i.e. precipitation/evaporation, that mainly determine the continental climate in tropical regions, are a challenging issue. Quantitative data based on continental, paleobotanical proxies involving precipitation and its seasonal patterns are scarce (Anupama et al., 2000; Barboni et al., 2003; Vincens et al., 2007). Model simulations of future warming generally suggest warming mainly at higher latitudes (Masson-Delmotte et al., 2006; Cohen et al., 2014). However, there are discrepancies in terms of tropical precipitation changes (Allen and Ingram, 2002; Clark, 2004; Meehl et al., 2000; Williams et al., 2015). While the radiative forcing induced by the increase of greenhouse gases is spatially relatively uniform, tropical precipitation exhibits large variations between simulations, producing both positive and negative rainfall anomalies (Chou and Neelin, 2004; Chou et al., 2008). In order to better validate simulations of precipitation patterns in the tropical region anticipated for future climate scenarios, well-resolved quantitative precipitation data for the Paleocene-Eocene intervals from multiple tropical locations are required.

During the late Paleocene - early Eocene, the northern part of the Indian Plate occupied a near-equatorial position (Scotese and Golanka, 1992; Sluijs et al., 2008). This period also witnessed marine transgression along the coastal zone of India, initiating carbonate sedimentation. A humid climate during the late Paleocene to earliest Eocene led to the development of peat swamps in the coastal areas of the northeastern and western margins of the Indian subcontinent (Prasad et al., 2013). In the northeastern region of India, in the Garo-Khasi-Jaintia Hills, the Paleocene-Eocene sedimentary successions consist of thin pinching and discontinuous but workable coal seams. The rich plant fossils present in this coal offered a unique opportunity to investigate floral and faunal changes during the Paleocene-Eocene transition in a tropical setting. Coal and lignite bearing deposits of the Indian subcontinent have yielded a large number of pollen, megaflora, insects, marine fishes and a variety of mammalian fossils (Dutta and Sah, 1970; Kar and Kumar, 1986; Samant and Phadtre, 1997; Tripathi et al., 2000; Sahni et al., 2004; Bhandari et al., 2005; Prasad et al., 2006; Sahni et al., 2006; Rose et al., 2006; Garg et al., 2008; Prasad et al., 2009; Clementz et al., 2010; Prasad et al., 2013; Shukla et al., 2014; Srivastava and Prasad, 2015; Kumar et al., 2016). Most of the late Paleocene-early Eocene successions of northeastern India represent coastal to shallow marine deposits. The Jathang section in northeastern India is a coastal deposit of late Paleocene-early Eocene age and is thought to include the pre and post PETM events (Prasad et al., 2006). The basic stratigraphy and sedimentological analysis of the Jathang section were presented in Prasad et al. (2006). In the present study, the section is further interpreted in terms of parasequences and systems tract analysis in response to sea level changes to provide a depositional framework. The geochemical analysis was carried out to understand the intensity of weathering in the provenance area during the Paleocene-Eocene. A Carbon isotopic study was carried out in order to identify major shifts in the $\delta^{13}C$ values. Being coastal marine in nature, the Jathang section has both marine and terrestrial biotic components. This provides us with an opportunity to investigate changes in the terrestrial plant communities in relation to changes in the CO_2 concentration, temperature and precipitation.

Nearest Living Relatives (NLRs) of most of the early Paleogene fossils are already known (Prasad et al., 2009). Based on the assumption that Cenozoic plant taxa have similar climatic requirements to their NLRs, the Coexistence Approach (CA) was applied on the recovered fossil pollen flora from Jathang, East Khasi Hills, Meghalaya, northeastern India to obtain a quantitative climate reconstruction across the Paleocene-Eocene transition from a paleo-equatorial region.

In detail, the following questions are addressed: How was tropical plant diversity of the paleo-equatorial belt affected by markedly warm climates during the late Paleocene and early Eocene? How did temperature and precipitation evolve throughout the late Paleocene and early Eocene in a paleo-equatorial region? How did the ecosystem respond to climate changes across the Paleocene-Eocene transition?

2. Geological setting, stratigraphy and sedimentology

The separation of the Indian landmass from Gondwanaland, its movement from southern high latitude across the equator to the subtropical zone of the Northern Hemisphere, and its final collision with Asia (at 50 Ma ± 10 Ma) resulted in large-scale continental plate reorganization. The Assam-Arakan Basin in India was initiated during the late Campanian with sedimentation starting in the southern part of the Meghalaya region (Garg et al., 2006; Singh and Swamy, 2006). The southern fringes of the Shillong Plateau, collectively known as South Shillong Plateau, comprise the Garo-Khasi-Jaintia hilly tract in Meghalaya (Fig. 1). Sedimentation started with coarse-grained clastics at the base, known as Mahadeo Formation (Campanian-Maastrichtian), in a rift-related coastal setting, later on converting into prominent carbonate platform condition represented by the Sylhet Limestone Formation. The Sylhet Limestone Formation, consisting of three horizons of fossiliferous limestone interposed by two bands of sandstone, witnessed several phases of sea-level fluctuations during the depositional history of the Shillong Plateau (Raja Rao, 1981; Wilson and Metre, 1953). All the three limestone units contain datable larger benthic foraminifera in association with calcareous algae (Jauhri and Agarwal, 2001; Nagappa, 1959; Wilson and Metre, 1953). In the Jathang Hill of the Mawsynram area, only the lower most Lakadong Limestone Member and Lakadong Sandstone Member are present (Table 1). Both members occur as small outcrops and commonly occupy the top of the hillocks in the area (Figs. 1, 2). The section is 26 m thick, consisting of 3.5 m light grey to dark grey coloured hard and compact limestone of the Lakadong Limestone Member at the base containing larger benthic foraminifera and calcareous algae, while the 20.5 m thick overlying Lakadong Sandstone Member is the uppermost lithological unit in the study area (Figs. 1, 2). The Lakadong Sandstone Member of Jathang comprises a succession of mudstone, sandstone, carbonaceous shale, and coal (Fig. 2). Three lithofacies were identified which are cyclically repeated.

Mudstones make up 10–20 cm thick horizons. Essentially they represent clayey siltstones within sand layers. They display millimetre-scale alternations of sand and silt layers, sometimes with small ripple bedding pointing to deposition in a shallow bay under low-energy conditions.

Sandstones make up 50 cm to 2 m thick horizons. They exhibit low-angle crossbedding, parallel bedding, and bands of rippled layers. Thick