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Abrupt shifts in the Indian monsoon during the Pliocene marked by high-resolution terrestrial records from the Yuanmou Basin in southwest China

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ABSTRACT

A 650-m-thick sequence of fluvio-lacustrine sediments from the Yuanmou Basin in southwest China was analyzed at 20-cm intervals for grain-size distribution to provide a high-resolution terrestrial record of Indian summer monsoon variations during the Pliocene. The concentrations of the clay and clay-plus-fine-silt fractions are inferred to reflect the water-level status of the lake basin related to the intensity of the Indian summer monsoon and high concentrations reflect high lake levels resulting from the intensified summer monsoon. The frequency of individual lacustrine mud beds is considered to reveal the frequency of the lakes developed in the basin associated with the variability of the Indian summer monsoon and an increased frequency of the lakes reveals an increased variability of the summer monsoon. The proxy data indicate that the Indian summer monsoon experienced two major shifts at 3.57 and 2.78 Ma and two secondary shifts at 3.09 and 2.39 Ma during the Pliocene. The summer monsoon displayed a general trend of gradual intensification during the period of 3.57–2.78 Ma, coeval with an accelerated uplift of the Tibetan Plateau, implying a close link between the monsoon intensification and the plateau uplift. At 2.78 Ma, the summer monsoon was markedly weakened, synchronous with the formation of extensive Northern Hemisphere ice sheets, denoting a quick response of the monsoon regime to the Northern Hemisphere glaciation. The variability of the summer monsoon decreased at 3.09 Ma and increased at 2.39 Ma, presumably suggesting that variations of the Indian monsoon would be modulated by the initiation and periodic fluctuations of ice-sheet covers in Northern Hemisphere high latitudes.

1. Introduction

The Pliocene represents a period when Earth's boundary conditions underwent dramatic changes, such as the onset of Northern Hemisphere glaciation (Shackleton et al., 1995; Kleiven et al., 2002), the uplift of the Tibetan Plateau (An et al., 2001), and closure of Panamanian (Haug and Tiedemann, 1998) and Indonesian (Cane and Molnar, 2001) seaways. During this period, the global climate system experienced significant reorganizations in response to changes in Earth's boundary conditions (Zachos et al., 2001).

The Indian monsoon, an integral part of the global climate system, has been extensively studied through investigations of marine sediments from the Indian Ocean and the Arabian Sea (Clemens and Prell, 1990; Clemens et al., 1991; Kroon et al., 1991; deMenocal et al., 1991; Hovan and Rea, 1992; Chen et al., 1995; Gupta and Thomas, 2003; Gupta et al., 2004). During the Pliocene, however, the Indian monsoon variability and its possible causes have remained an enigma, because the resolution of the proxy records from marine sediments is limited and few terrestrial records related to the Pliocene history of Indian monsoon variations are available.

In the present study, we provide a terrestrial sedimentary sequence from the Yuanmou Basin in southwest China. The sequence covers the entire Pliocene with an average temporal resolution of ~45 yr cm^{-1}. The proxy records would greatly contribute to a better understanding of the process of Indian monsoon variations during the Pliocene and physical links between the Indian monsoon regime and other subcomponents of the global climate system.

2. Yuanmou Basin

The Yuanmou Basin (25°42′N, 101°53′E), a north–south stretched fault basin, lies 110 km northwest of Kunming, Yunnan Province, southwest China (Fig. 1). It has an area of 187 km^2 with a length of 30 km and a maximum width of 9 km (Li, 1993). The elevation of the basin ranges from 980 to 1400 m above sea level, while the surrounding mountains rise above the basin floor 1200–1400 m on the east and 200–400 m on the west. The Longchuan River flows through the basin from south to north toward its

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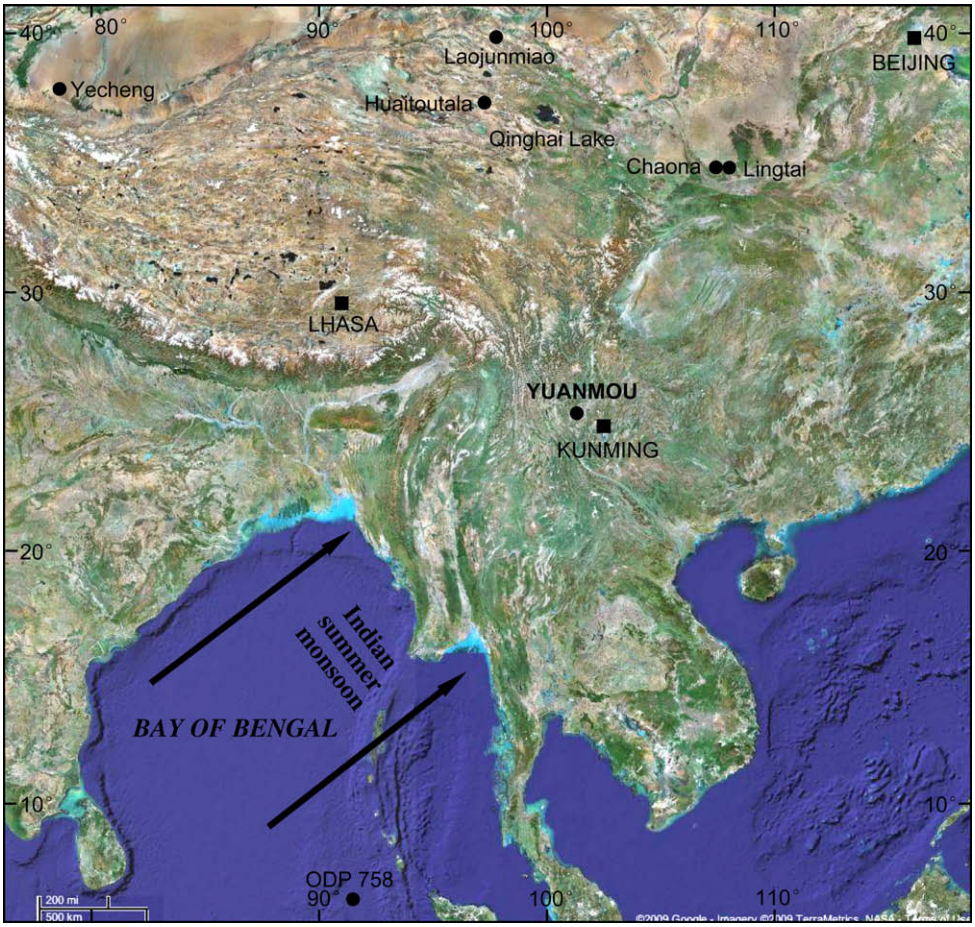

Fig. 1. Map (from http://maps.google.com) showing locations of the Yuanmou Basin and other terrestrial and marine records mentioned in the text. The bold arrows represent generalized wind directions of the Indian summer monsoon that brings rainfall from the tropical Indian Ocean to southwest China.

confluence with the Jinsha River, the uppermost reaches of the Yangtze River.

The basin is located in the south subtropical zone. The climate of the basin is controlled by the Indian monsoon in summer and by the southern stream of the westerly winds in winter (Li, 1993). Mean annual temperature is 21.9 °C, and mean annual precipitation is 614 mm with more than 80% of the annual precipitation falling in May–October. Mean annual evaporation reaches 3640 mm.

The Yuanmou Basin, one of the most representative Late Cenozoic sedimentary basins in China, was followed with interest as early as in 1920s when mammalian fossils were found from the basin (Colbert, 1940). During the subsequent decades, extensive investigations on the mammalian fauna were carried out, and fossils of *Equus* sp. of the latest Pliocene age (Bien, 1940) and *Enhydriodon* cf. *falconeri* of late Pliocene age (Chow, 1961) were discovered. In 1965, the discovery of two hominid incisors of *Homo erectus yuanmouensis* (Hu, 1973; Li et al., 1976; Qian et al., 1984) rejuvenated geologists' attention to the basin. Until now, however, most of the researches have been focused on the paleontology, sedimentology, lithostratigraphy and magnetostratigraphy (e.g., Qian and Zhou, 1991; Zhang et al., 1994; Urabe et al., 2001). Little attention was paid to the relation between the evolution of the lake basin and variations of the Indian monsoon.

3. Material and method

The sedimentary section selected for the present study extends east–west in the southern part of the Yuanmou Basin and passes by Gantang and Maoyi villages (therefore designated GM section) (Figs. 2 and 3). It is exposed in erosional gullies and attains a thickness of 644 m with its base on the right bank of the Longchuan River.

3.1. Lithostratigraphy

The GM sedimentary sequence generally consist of brownish-red to greyish-brown fluvio-lacustrine mud and sands intercalated by frequent, greenish-grey and blackish-grey lacustrine mud beds and occasional, fluvial granule layers (Figs. 3 and 4). Lacustrine mud beds reach thicknesses of 0.4–5 m with the greenish-grey beds intervening from the base to the top of the section and the blackish-grey beds appearing only in the upper 271 m. The fluvio-lacustrine mud and sands, predominant deposits in the basin, generally display two sedimentary types, i.e., massive fluvial and laminated lacustrine mud and sands. Most of the granule layers are 40–80 cm thick with a few exceptions (1–4 m thick) at the depths around 170, 325, 430 and 472 m. The strata of the GM sequence tilt towards northeast to east and dip at 5–12°. Investigations in the field suggest that the GM section shows no signs of erosional hiatuses or faults.

3.2. Magnetostratigraphy

Paleomagnetic studies of the GM section were carried out to provide an age scale for the sedimentary sequence (Zhu et al., 2008). After orientated in situ with a magnetic compass, block