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A 20,000-year high-resolution pollen record from Huguangyan Maar Lake in tropical–subtropical South China

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ABSTRACT

A high-resolution pollen record from Huguangyan Maar Lake near the South China Sea spanning the past 20,400 yr BP has been presented, aimed to provide an improved understanding of the response of the regional vegetation in tropical–subtropical South China to climatic variations since the late Last Glacial Maximum. The results reveal the strong control of the Asian summer monsoon (ASM) strength on vegetation via orbitally-induced variations in Northern Hemisphere summer solar insolation. The trend of climatic evolution of the region consists of change from a warm temperate–northern subtropical climate (20,400–18,700 cal yr BP) to a southern subtropical climate (16,500–11,500 cal yr BP) during the last deglaciation, followed by a stepwise environmental shift from a tropical climate (11,500–8200 cal yr BP), to a southern subtropical climate (8200–6600 cal yr BP) and finally to a middle–northern subtropical climate. The Bølling–Allerød warming is characterized by the highest percentages of evergreen *Quercus* but the lowest percentages of xerophytic Gramineae throughout the record, suggesting intensified warm, wet conditions during 15,000–13,000 cal yr BP. By contrast, the Younger Dryas is characterized by a marked decrease in subtropical evergreen broad-leaved plants but a significant increase in herbaceous taxa, representing a brief cold reversal during 13,000–12,000 cal yr BP. The occurrence of two major cooling events at 8.2 and 6.6 kyr BP, both of which are characterized by dramatic decreases in tropical evergreen broad-leaved plants, is supposed to be linked to a distinct weakening of the ASM and southward migration of the Intertropical Convergence Zone associated with marked declines in Atlantic Meridional Overturning Circulation. The subsequent brief intervals of high herbaceous pollen percentages but low percentages of tropical taxa correspond to high El Niño/Southern Oscillation (ENSO) activity, supporting a link between the weakening of solar isolation-driven ASM strength and a gradual intensification of ENSO.

1. Introduction

The Asian summer monsoon (ASM), an integral part of the global climatic system, affects about 60% of the world's population as well as the associated ecosystems. Thus, there is an urgent need to improve our understanding of its dynamics and potential future evolution. Over the past several decades, significant progress has been made in investigating the ASM variability in northern and central China based on multi-proxy paleoclimatic analyses of loess–paleosol sequences (An et al., 1991; Chen et al., 1997; Guo et al., 2000; Hao et al., 2012; Sun et al., 2015), lake sediments (Yang et al., 2004; Jiang et al., 2006; Xiao et al., 2008; Zhang et al., 2011; An et al., 2012; Chen et al., 2015) and cave deposits (Wang et al., 2001, 2005; Dykoski et al., 2005; Cheng et al., 2016). In tropical–subtropical South China, however, high-resolution paleoclimatic records are sparse, hindering detailed regional comparisons and a more complete understanding of the regional behavior of the ASM.

Huguangyan Maar Lake (HML) has proven to be an ideal site for recording high-resolution paleoclimatic and paleoenvironmental changes since the last glaciation in South China (Liu et al., 2000; Mingram et al., 2004; Yancheva et al., 2007; Wang L. et al., 2012; Duan et al., 2014; Wang et al., 2016). A striking resemblance between the HML paleo-proxies (e.g., magnetic susceptibility, *S*-ratio, and Ti content) (Yancheva et al., 2007), Chinese speleothem $\delta^{18}O$ records (Wang et al., 2001; Dykoski et al., 2005), Ti records from the Cariaco Basin, off the coast of Venezuela (Haug et al., 2001), and North Greenland ice-core (NGRIP) $\delta^{18}O$ records (Rasmussen et al., 2006) over the interval of the Bølling–Allerød (BA) warming, the Younger Dryas (YD) event, and the Preboreal has revealed a remarkably strong global-scale teleconnection during the last deglacial–Holocene transition. Yancheva et al. (2007) initially proposed that higher magnetic mineral concentrations and

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higher Ti content during cold climates (e.g., the pre-BA, the YD, and the later Holocene) at HML may have resulted from intensified eolian inputs transported by the East Asian winter monsoon (EAWM). However, subsequent geochemical and mineral magnetic analyses together with microscopic observations indicated that variations in Ti content are primarily associated with variations in summer monsoon-induced vegetation density that may have restricted erosive input of local pyroclastic rocks to the catchment (Zhou et al., 2009; Shen et al., 2013). Wu et al. (2012) further proposed that higher chlorophyll *a* values, higher TOC content and Sr/Rb ratios during the early Holocene may denote higher summer monsoon precipitation. Our recent integration of the results of mineral magnetic, geochemical, and X-ray diffraction analyses confirmed that the two magnetically depleted intervals corresponding to the early Holocene optimum and the BA warming are largely due to intense dissolution of detrital iron-bearing minerals associated with significantly-enhanced diagenetic alteration (Wang et al., 2016). All of these recent studies strongly suggest that the HML paleo-proxies primarily reflect an ASM evolution history for tropical–subtropical South China, although the phase relationship between the summer and winter monsoon, as well as the possible impact of solar radiation and El Niño–Southern Oscillation (ENSO) activity on climatic variability in tropical–subtropical South China, remains unclear (Wang et al., 2007; Wang L. et al., 2012; Wu et al., 2012; Jia et al., 2015; Wang et al., 2016).

Pollen analysis is one of the most widely-used techniques for qualitative and quantitative reconstructions of past vegetation and environments and has also played a critical role in deciphering climatic variations of the HML record on various temporal scales. A preliminary pollen analysis revealed that the coldest period since the last glacial period occurred at 24–27 cal kyr BP (Lu et al., 2003). Recent palynological results suggest an early Holocene climatic optimum and relatively dry conditions during the mid- and late Holocene in the HML area (Wang et al., 2007), and a major fall in annual mean temperature of 2–3 °C during the Last Glacial Maximum (LGM) compared with the present (Wang S.Y. et al., 2012). It should be noted that all of these pollen results are based on the problematic chronological model of Mingram et al. (2004) and Yancheva et al. (2007) which lacks precise ^{14}C age control for the time interval of 8300–3800 yr BP, a critical interval of climatic evolution during the Holocene (Wu et al., 2012; Jia et al., 2015). The rather low-resolution pollen sampling and insufficient age constraints used in these studies hamper detailed pollen-based regional comparisons of vegetation and environmental changes (Mingram et al., 2004). Thus, a precisely-dated high-resolution pollen study is essential for a thorough understanding of the regional vegetation response to climatic changes and forcing mechanisms in tropical–subtropical South China. To this end, we performed high-sampling-resolution pollen analyses of the HML sediments from a new suite of cores with well-constrained AMS ^{14}C and ^{137}Cs age determinations.

2. Site, materials, and chronology

HML (21°9′N, 110°17′E, Fig. 1), located on the Leizhou Peninsula in the southernmost part of mainland China, is the deepest maar lake among the Leiqiong volcanic cluster. Climatically, the site lies in the transition zone between the southern subtropical zone and the tropical north. A south–north shoal, which may emerge during dry seasons, divides this small lake into two parts. The bi-lobate lake, surrounded by a high tephra wall, has a diameter of ~1.7 km and a maximum water depth of ~20 m. The mean annual temperature and annual precipitation for Zhanjiang (15 km from HML) are 23.1 °C and 1600 mm, respectively. The natural vegetation in the area is dominated by tropical semi-evergreen seasonal rain forest (Zheng and Lei, 1999).

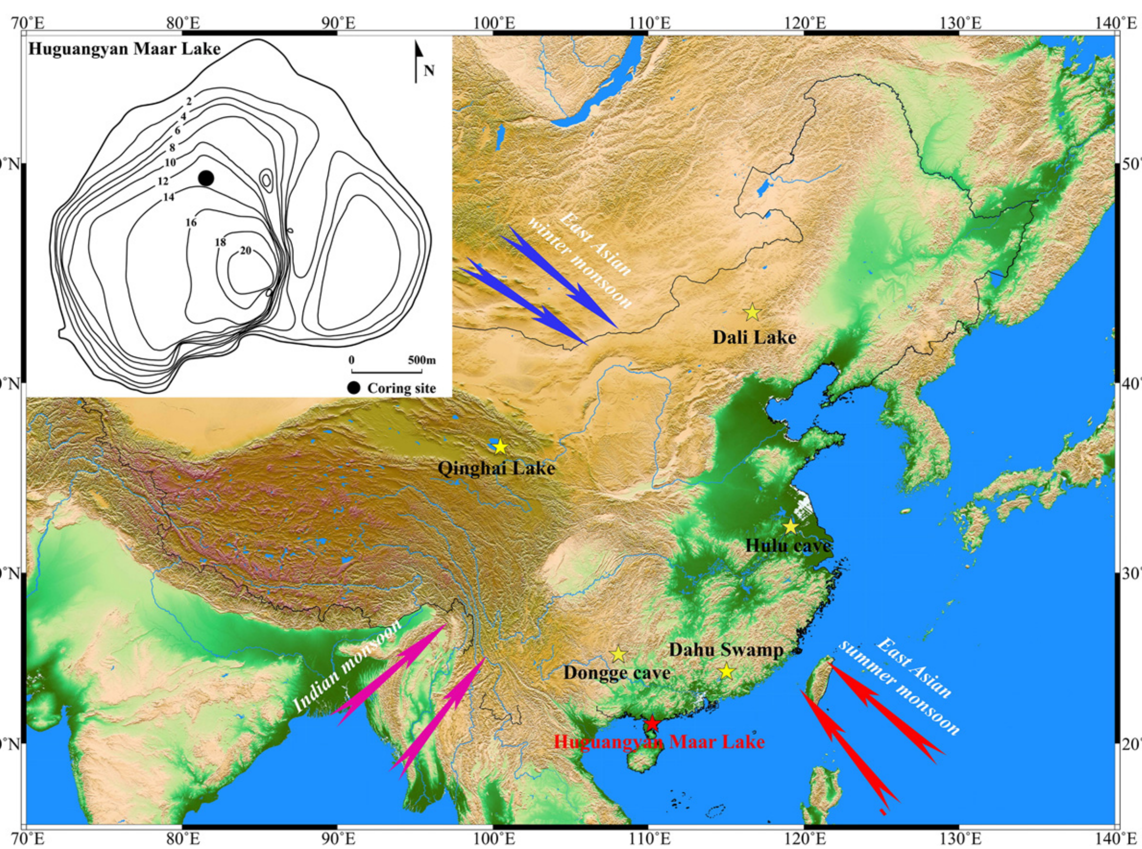

Fig. 1. Topography and atmospheric circulation systems of China. Arrows denote the wind directions of the East Asian summer monsoon (red), the East Asian winter monsoon (blue), and the Indian monsoon (Magenta). Stars mark the locations of Huguangyan Maar Lake (red), Hulu Cave (Wang et al., 2001), Dongge Cave (Dykoski et al., 2005; Wang et al., 2005), Dahu Swamp (Zhou et al., 2004), Dali Lake (Liu S.Z. et al., 2015), and Qinghai Lake (Shen et al., 2005) (yellow). The inset map shows the bathymetry of Huguangyan Maar Lake and the location of the coring site (solid circle).