Palaeogeography, Palaeoclimatology, Palaeoecology 461 (2016) 1–11

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

journal homepage: www.elsevier.com/locate/palaeo

Vegetation and climate history inferred from a Qinghai Crater Lake pollen record from Tengchong, southwestern China

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ARTICLE INFO

Article history:
Received 12 January 2016
Received in revised form 25 June 2016
Accepted 17 July 2016
Available online 19 July 2016

Keywords:
Holocene
Indian Summer Monsoon
Paleovegetation
Pollen analysis
Qinghai Crater Lake

ABSTRACT

A palynological investigation of a 514 cm long continuous core section from Qinghai Crater Lake, western Yunnan Province, southwestern China, was performed in order to reconstruct regional vegetation and climate from 15.8 cal kyr BP to the present. The results show that the area was covered with deciduous broadleaved forest dominated by deciduous *Quercus* between 15.8 and 12.8 cal kyr BP, suggesting slightly cold and dry conditions. From 12.8 to 8.3 cal kyr BP, the vegetation continued to be dominated by deciduous broadleaved forest, but there was also a sudden increase in *Castanopsis*/*Lithocarpus* and a slight drop in deciduous *Quercus* and *Alnus*, reflecting a gradual increase in both temperature and humidity. During the period 8.3–4.6 cal kyr BP, the mixed deciduous forests became more diverse and dense, with thermophilous and hygrophilous species expanding to their maximum extents, implying a warm and rather humid climate. From 4.6 to 0.5 cal kyr BP, the vegetation was succeeded by open mixed deciduous forest dominated by *Alnus*, with a retreating evergreen broadleaved forest, indicating a cool and slightly dry climate. After 0.5 cal kyr BP, the vegetation became less diverse and more open, but evergreen broadleaved trees increased their spread markedly, suggesting that the climate had become warmer and drier. In recent decades, human activity resulted in a large increase in *Alnus* and *Pinus* around this lake basin. Specifically, we concluded that the warm and moist climate detected between 8.3 and 4.6 cal kyr BP may have occurred in response to the high sea surface temperatures and high sea levels in the Bay of Bengal existent at that time.

1. Introduction

The Indian Summer Monsoon (ISM) plays a vital role in the climates of both Asia and Africa; it is an important component of the tropical ocean-atmosphere-land interactions which supply moisture and heat from the tropical Indian Ocean to extratropical regions. Many geoscientists have therefore investigated paleomonsoonal patterns in the Arabian Sea (Sirocko et al., 1993; Fleitmann et al., 2003; Divakar and Malmgren, 2005; Thamban et al., 2007), the Indian subcontinent (Demske and Tarasov, 2009; Leipe et al., 2014; Raj et al., 2015), the Bay of Bengal (Rashid et al., 2011; Ahmad et al., 2012; Ranasinghe et al., 2013; Contreras-Rosales et al., 2014) and the Tibetan Plateau (Herzschuh et al., 2006; Morrill et al., 2006; Wang et al., 2010; Kramer et al., 2010; Zech et al., 2014). Most of these studies indicate that the ISM suddenly intensified during the first part of the Early Holocene, then weakened gradually from the Early to Mid Holocene (Hodell et al., 1999; Neff et al., 2001; Gupta et al., 2003; Wang et al., 2005, 2010; Leipe et al., 2014).

Yunnan Province in southwest China, located on the southeastern margins of the Tibetan Plateau (TP), is a region strongly influenced by the ISM. It is therefore a key region for Chinese paleomonsoonal studies. Much paleoenvironmental research has been carried out in Yunnan Province over the last few decades (Wu et al., 1998; Yu et al., 1990; Shen et al., 2006a; Cook et al., 2012; Song et al., 2012; Chen et al., 2014a; Xiao et al., 2014a, 2014b; Zheng et al., 2014a; Yao et al., 2015). Paleoclimatic records from Lake Xingyun (Chen et al., 2014a) and Lake Qilu indicate that the strength of ISM reached its maximum during the first half of Early Holocene, and then weakened gradually. Pollen records from Lake Erhai delineate a warm and humid climate condition between 8.4 and 6.4 cal kyr BP in response to the Holocene Climate Optimum (HCO) (Shen et al., 2006a). Interestingly, evidence from Lake Shudu (7.2–4.0 cal kyr BP) (Cook et al., 2012), the Haligu Wetlands (8.7–2.4 cal kyr BP) (Song et al., 2012) and Lake Tiancai (6.1–3.4 cal

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http://dx.doi.org/10.1016/j.palaeo.2016.07.017
0031-0182/

kyr BP) (Xiao et al., 2014b) in northwestern Yunnan suggest that the HCO lasted into the Late Holocene. Scholars have attributed these discrepancies in conclusions to low temporal resolutions, age uncertainties, different proxies and human activities (Chen et al., 2014a, 2014b; Xiao et al., 2014b; Zhao et al., 2011). Nonetheless, these different conclusions do all reflect the response of the local environment to ISM dynamics. Additionally, the bulk of ISM paleomonsoonal research has drawn upon evidence taken from northwestern/northern Yunnan Province, with little paleoclimatic research conducted in southwestern/western Yunnan.

Qinghai Crater Lake is located in the Tengchong area of southwestern Yunnan, western Gaoligong Mountains and received monsoonal precipitation directly from the Bay of Bengal (Fig. 1a) (An et al., 2011; Chen et al., 2014b). It is therefore uniquely sensitive to changes in the ISM, though very careful attention should be paid to the dating of any climatic/environmental proxies identified (Liu et al., 2015). Xiao et al. (2015) have revealed the variations in vegetation, fire and climate history since 18,500 cal yr BP in Qinghai Crater Lake by pollen and charcoals records, and considered the HCO occurred between 8450 and 4280 cal yr BP. In this study, we also present a Late Pleistocene and Holocene pollen record from Qinghai Crater Lake. Our first objective was to use fossilized pollen data from the Qinghai Crater Lake and surface pollen to quantitatively reconstruct the area's paleoclimate and paleovegetation. Secondly, we aimed to compare the potentially different responses and sensitivities exhibited by our reconstructed regional vegetation and climate data with other records from the ISM domain and adjacent regions. Thirdly, we hoped to explain the dating of the duration of the HCO in the Qinghai Crater Lake.

2. Geographical setting of the study area

Qinghai Crater Lake (25°07′57″N, 98°34′18″E), an enclosed crater lake at an altitude of 1849 m above sea level (asl), is located in the western Gaoligong Mountains in Tengchong County, southwestern Yunnan Province (Fig. 1b). The lake is fed by rainfall and groundwater, without any river inputs (Wang et al., 2002). The lake has a surface area of ~0.25 km^2, with a maximum water depth of 5.9 m, and a catchment area of 1.5 km^2 (Wang and Dou, 1998) (Fig. 1c).

The climate of the study area is principally controlled by the southwesterly ISM and its warm and humid airflow from the Indian Ocean and Bay of Bengal (Fig. 1a). Thus the climate can be simply divided into a wet season and a dry season. Based on meteorological data recorded at Tengchong (25.01°N, 98.30°E, 1654.6 m asl) between 1981 and 2010, the mean annual temperature (MAT) and mean annual precipitation (MAP) are 15.4 °C and 1532 mm, respectively (Fig. 1d; http://cdc.nmic.cn/home.do). Statistical data also show that ~85% of annual precipitation falls between May and October. The warmest month is August, with a mean temperature of 20.2 °C, and the coldest month is January, with a mean temperature of 8.6 °C.

The study area's modern vegetation cover comprises subtropical evergreen broadleaved forest, with a distinct, seasonal wet-dry alternation. Due to the area's altitudinal gradients and complex topography, its

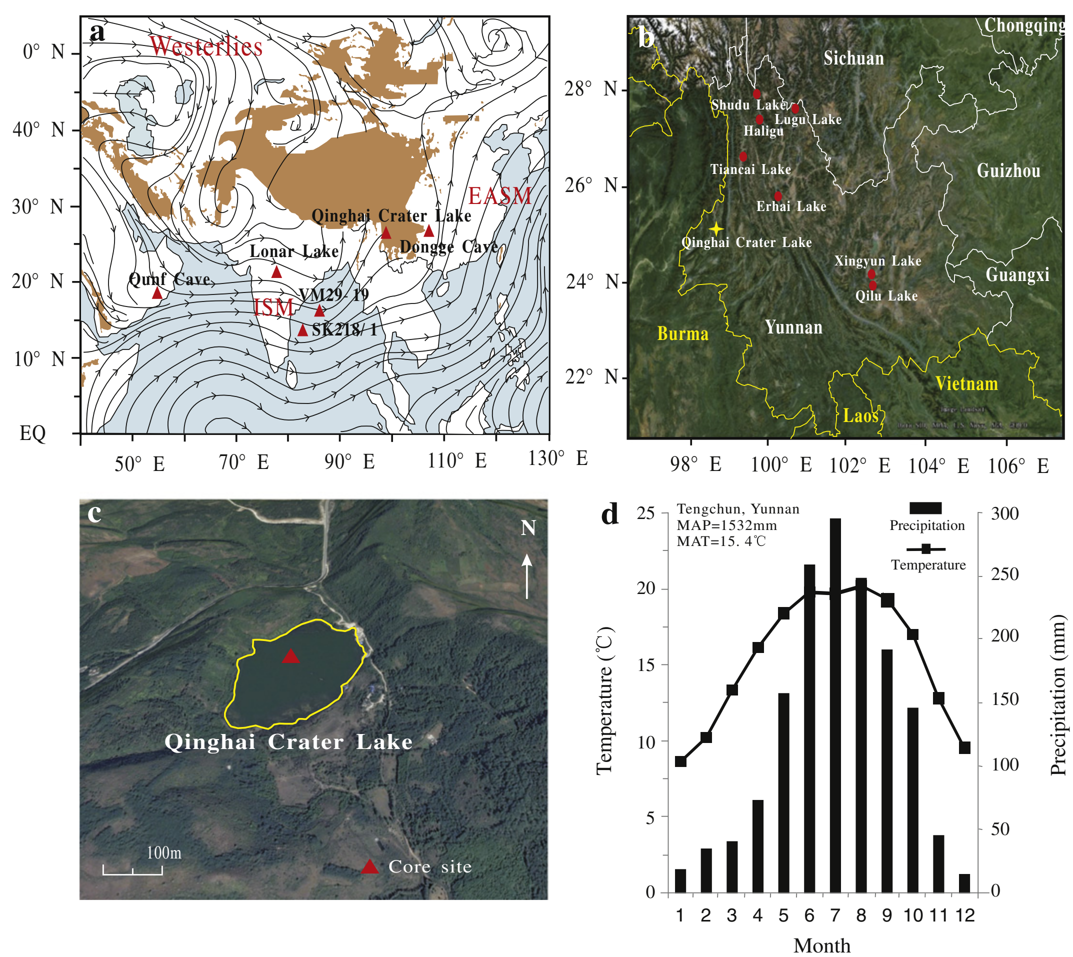

Fig. 1. (a) Overview map showing the study area and atmospheric circulation sysems (ISM, Indian Summer Monsoon; EASM, East Asian Summer Monsoon; Westerlies), and June–July–August mean 850-hPa streamlines for the period 1970–2000 (Chen et al., 2014b). The red triangles indicate Qinghai Crater Lake and other sites referenced in the text. (b) Satellite image of Yunnan Province showing the location of Qinghai Crater Lake and the other sites referenced in the text. (c) Hydrologic and topographic settings around Qinghai Crater Lake. The red triangle indicates the location of the drilling core. (d) Mean monthly temperatures and precipitation values measured at the nearby Tengchun meteorological station.