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Diatom-based inference of Asian monsoon precipitation from a volcanic lake in southwest China for the last 18.5 ka

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A B S T R A C T

Diatom in the volcanic lake provides proxy evidence for pH changes that are characterized by variations in the percentage of acidophilous diatom species. The information regarding the hydrology of the lake, derived from a previous publication and survey of one year on the lake, indicate that pH is low during the wet season and higher during the dry season. Therefore, variations in lake water pH may be considered as a proxy record for past changes in precipitation. In the sediment, high/low relative abundance of acidophilous diatom species indicates high/low precipitation. The diatom record of the past 18.5 ka BP shows that precipitation decrease during the periods 17.0–15.0, 13.3–11.3, and 0.7–0.3 ka BP corresponding to the Heinrich Event 1 (H1), the Younger Dryas cold event (YD), and the Little Ice Age (LA). A marked precipitation increase between 15.0 and 14.5 ka BP occurred at the end of H1 and before the Bølling-Allerød (BA), which indicates a strong pre-Bølling wetting. The start of the Holocene is recorded at 11.3 ka BP. The climate was the wettest between 11.3 and 7.5 ka BP., then the wetter between 7.5 and 3.4 ka BP. Between 3.4 and 0.7 ka BP, the precipitation decrease in general, but in the period from 1.3 to 0.8 ka BP the precipitation was higher corresponding to the Medieval Warm Period (MWP). Our results support the hypothes that the Indian Summer Monsoon (ISM) was strongest during the Early Holocene.

1. Introduction

Southwestern China is in close proximity to the Tibetan Plateau, making it a key region to reconstruct environmental effects and past dynamics of the southwest summer monsoon (Xiao et al., 2015). The dominant trends in Asian monsoon variability parallel changes in Northern Hemisphere summer insolation, with a general warming trend from the last glacial maximum (LGM) to the Holocene Megathermal, and then cool and dry conditions until the present-day (Overpeck et al., 1996; Morrill et al., 2003; Wang et al., 2010; Xiao et al., 2015).

In the past decades, progress in reconstructing palaeomonsoons, especially during the Holocene Epoch, have been made based mainly on evidence from cave deposits, lake sediments and peat deposits (Chen F.H., et al., 2014). One of the key hypothesis that was proposed was that the strongest monsoon occurred during the early Holocene and was induced by peak summer insolation (Kutzbach, 1981; Ruddiman, 2008). Evidence from cave deposits, lake sediments records, peat deposits supported this hypothesis (Hong et al., 2003; Zhou et al., 2004; Wang et al., 2005, 2008; Shen et al., 2006; Chen F.H., et al., 2014). However, other researchers have reached different conclusions regarding the Holocene Optimum (peak monsoon precipitation) in different regions (Xiao et al., 2006). An et al. (2000) first proposed the hypothesis based on various climatic records from China of an asynchronous Holocene Optimum in different regions of China and found that the Indian Summer Monsoon (ISM) was strongest during the Early Holocene, and the Holocene Optimum in southwestern China appeared ca. 11,000 yr ago. However, more recently some records from the Indian Summer Monsoon regions have been interpreted as indicating that the Holocene ISM maximum occurred during the middle to Late Holocene. Chen X., et al. (2014) analyzed diatoms from the sediment record of a small treeline lake in southwest China, spanning the last 12.2 ka, and inferred a strong monsoon intensity

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in the middle Holocene (9.4–4.6 ka BP), and a weak monsoon intensity after 4.6 ka BP. Pollen records from the Yunnan region demonstrated that the warmest and wettest climate occurred in the mid-Holocene from wetland, lake sediments (Song et al., 2012; Xiao et al., 2014a). Xiao et al. (2015) analyzed the pollen record from Lake Qinghai, and proposed that the Holocene Climatic Optimum occurred from 8450 to 4280 yrs BP based on the abundance of evergreen broadleaved trees and tropical arbors and the low frequency of fire. Wang et al. (2016) showed that the Holocene climatic optimum was between 7600 and 5600 cal yr BP bases on the pollen and diatom records of Lake Lugu on the Yunnan Plateau. Herzschuh et al. (2009) indicated that warm and wet conditions prevailed between 14,600 and 6600 cal yr BP from pollen record of Lake Koucha on the northeastern Tibetan Plateau.

In order to resolve some of the controversies and uncertainties highlighted above, well-dated records with unambiguous ISM proxies (such as of precipitation) are necessary for reconstructing the history of the ISM. Separation of precipitation and temperature may further our understanding of summer monsoon evolution. Diatoms are widely used for tracking indirectly climate changes that cause altered limnological conditions such as temperature, light, nutrients and pH (Battarbee et al., 2002; Lotter and Birks, 2003). Here we present a detailed diatom record spanning the last 18.5 ka BP from Lake Qinghai, a volcanic dammed lake in southwestern China. In this lake, it has been shown that the lake water pH varies seasonally and that it is linked to precipitation as its values are low during the wet season and increase during the dry season (Wang et al., 2002). Considering that diatom assemblages are very sensitive to changes in pH, they may be used as indirect indicators for the amount of precipitation falling on Lake Qinghai. Our record covers the complete time interval from 18.5 ka BP to the present, with an average time resolution of ~45 years. In this paper, we will analyze the relationship between diatom assemblage composition and past precipitation changes, and explain the possible mechanisms driving the interaction between the shifts in the diatom flora and the intensity of the southwest monsoon on decadal to millennial timescales since ~18500 cal a BP in southwestern China.

2. Core site and local climate conditions

Lake Qinghai (25°07′48″–25°08′6″ N, 98°34′11″–98°34′16″ E) is located in Tengchong County, Yunnan Province, Southwestern China (Fig. 1). It is a volcanic lake with an elevation of 1885 m a.s.l, an area of 0.25 km^2 and a catchment area of 1.5 km^2 in 1990. In 2010, the maximum and mean water depths were 8.1 and 5.2 m, respectively. The lake is recharged by direct precipitation, groundwater and surface runoff from the catchment, and currently there is no natural outflow (Wang et al., 2002; Zhang et al., 2015; Xiao et al., 2015). Lake Qinghai has a continuous supply of acid spring groundwater. Measurements of lake water pH were taken during both the dry and wet seasons. They showed that the pH is low during the wet season (~6.5) and higher during the dry season (~6.9) (Wang et al., 2002).

The study region is characterized by a subtropical humid monsoonal climate. From October to May, the Tibetan High dominates and prevents humid air masses from entering the region, while the plateau acts as a barrier to the Mongolian cold anticyclonic pressure system (Wu et al., 1980; Zhang et al., 2015). From May onwards, the temperature rises but monsoon precipitation does not normally begin until June (Zhang et al., 2015). The mean annual air temperature is approximately 15.4 °C, with monthly averages of temperatures in July and January of 19.8 °C and 8.6 °C, respectively. The annual precipitation is approximately 1506 mm, with an average of 19.9 mm in January and 291.3 mm in July, and the rainy season between May and October accounts for 85% of the total mean annual precipitation. The average annual evaporation is about 1575 mm (Wang and Dou, 1998; Wang et al., 2002; Zhang et al., 2015; Xiao et al., 2015).

In 2010, a 832-cm-long sediment core (core TCQH1) was retrieved from a water depth of 6.3 m using a UWITEC piston corer from the central part of the lake (Fig. 1b). In addition, a short gravity core, 44-cm long, that preserved the sediment-water interface was retrieved nearby the location of the long piston core. The long and short cores were then sectioned at 1 cm intervals and samples were kept <4 °C until analysis.

3. Sampling and analytical methods

Diatom samples of sediment core were taken every 2 cm and prepared following standard procedures (Battarbee et al., 2001), and diatoms were counted using an Olympus BX51 microscope with an oil immersion objective (magnification ×1000). A

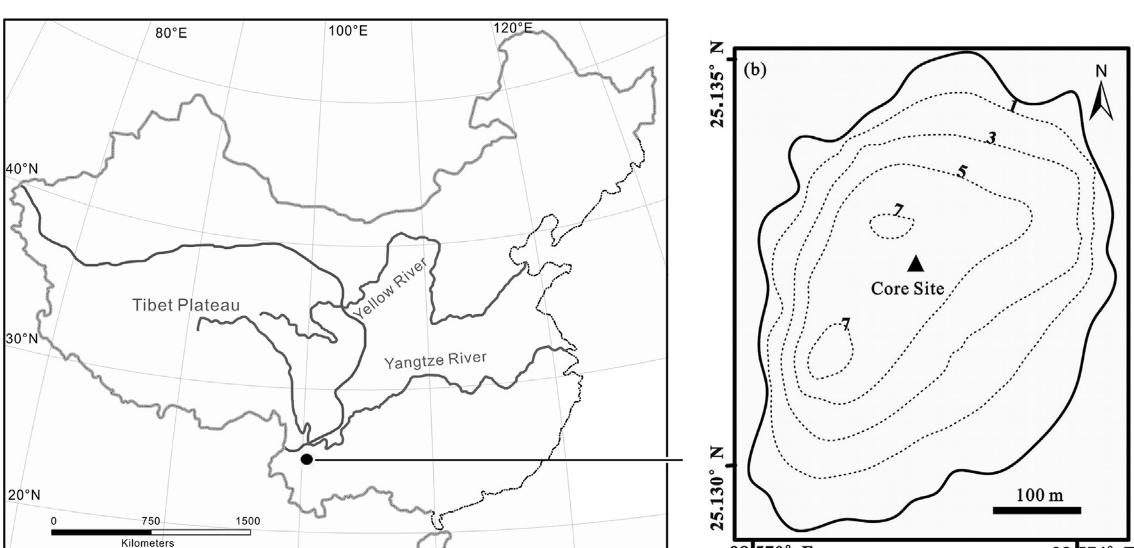

Fig. 1. a) Location of Lake Qinghai in SW China, b) lake bathymetry and coring site.