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Late Holocene monsoon climate as evidenced by proxy records from a lacustrine sediment sequence in western Guangdong, South China

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ABSTRACT

The study of a 300-cm-thick exposed lacustrine sediment section in the Hedong village in Zhaoqing area which is located in sub-tropical west Guangdong Province in South China, demonstrates that the lacustrine sedimentary sequence possibly contains evidence for exploring variation of Asian monsoon climate. Multi-proxy records, including the humification intensity, total organic carbon, and grain size fractions, reveal a general trend towards dry and cold conditions in the late Holocene that this is because of a decrease in solar insolation on an orbital scale. Three intensified Asian summer monsoon (ASM) intervals (~3300–3000 cal yr BP, ~2600–1600 cal yr BP, and ~900–600 cal yr BP), and three weakened ASM intervals (~4000–3300 cal yr BP, ~3000–2600 cal yr BP, and ~1600–900 cal yr BP) are identified. Our humification record (HD_{cal}) shows a good correlation on multi-centennial scale with the tree ring $\Delta^{14}C$ record, a proxy of solar activity. A spectral analysis of HD_{cal} reveals four significant cycles, i.e., ~1250 yr, 300 yr, 110 yr, and 70 yr, and most of these cycles are related to the solar activity. Our findings indicate that solar output and oceanic–atmospheric circulation probably have influenced the late Holocene climate variability in the study region.

1. Introduction

The Asian monsoons (AM) consist of two subsystems: the East Asian monsoon (EAM) and the Indian monsoon (IM). These two monsoon systems can influence the life and production activities of 60% of the global population (Hong et al., 2006), so adequate monsoon prediction techniques are essential. However, we do not fully understand the relationship between the two monsoon systems. Scientists have not been able to exactly determine the factors that influence the two monsoon systems. Previous studies have presented controversial results on the existence of an inverse–phase relationship of climate variations between the two monsoons (Hong et al., 2005, 2010; Stebich et al., 2011; Zhang et al., 2011). More paleoclimate data are urgently needed to investigate the possible forcing mechanisms of the two monsoon systems.

Gao et al. (1962) proposed that the center of the tropical monsoon area is located in the Nanling Mountains (24°00′–29°00′N, 110°00′–120°00′E) and the area to the south. In this region, the climate is subjected to both the EAM and IM systems (Fig. 1A). Therefore, detailed climatic studies of this area will help our understanding of the influences of the AM systems. In this study, we present a climatic record derived from lacustrine sediments in western Guangdong Province. We use these data to explore the history of AM variations in the late Holocene, and investigate possible forcing mechanisms.

2. Study site

Zhaoqing administrative region is located in western Guangdong Province. This area has a tropical monsoon climate. Both the EASM and ISM can influence the precipitation in this region (Fig. 1A). Local humidity and temperature conditions mean that the flora of this region is monsoon forest, dominated by evergreen broad-leaved trees. The natural vegetation of this region has been decimated by modern anthropogenic activity. The annual average temperature at present is 22.2 °C, and the annual precipitation is 1648 mm. In May 2010, we performed field investigations in this region. The exposed section and preliminarily drilled cores revealed that lakes existed in the past near Hedong village in Baizhu town (Fig. 1B and C). However, an increase in human activity has caused many to dry up. Our investigation found that the buried lacustrine sediment in this region is more than 5 m thick at its maximum. Marshy sediments were widely distributed during the late Holocene. We selected a 300-cm-thick exposed section to investigate the historical climate in the region (Hedong section, 22°54.191′N–112°20.132′E, ~10 m a.s.l) (Fig. 1C). We took samples at 2-cm intervals to analyze the total organic carbon (TOC), humification degree (HD), and grain size distribution.

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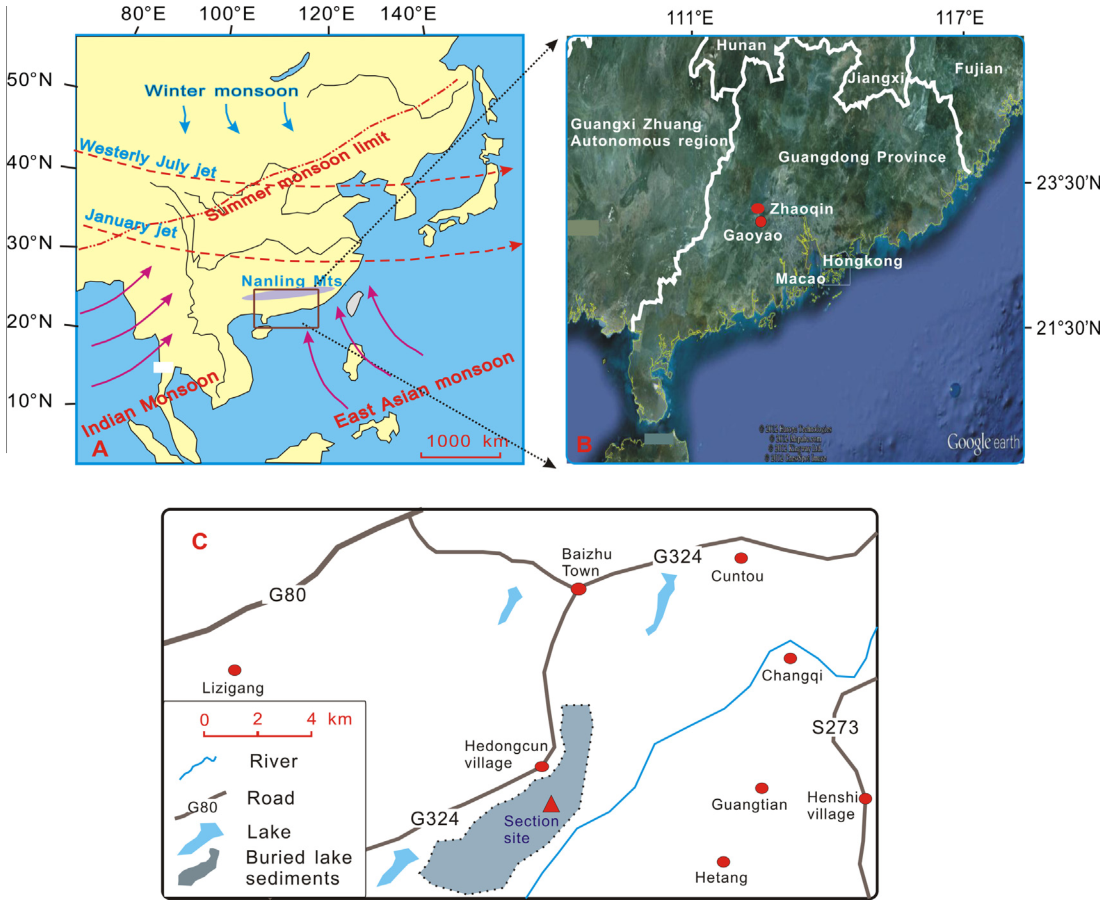

Fig. 1. (A) Climatic background of the study region, and (B) the location of Zhaoqing area in western Guangdong, (C) the section site at the Hedong village of Baizhu town. The distribution of the buried lacustrine sediments around the section site is tentatively indicated.

3. Materials and methods

Eight organic-rich samples that contained plant fragments were collected for conventional radiocarbon dating. We calculated the ages with a half-life of 5568 yr, and calibrated the results to calendar ages using the Calib 6.0 program and the Intcal 09 dataset (Reimer et al., 2009). The chronology of the section was established using a linear interpolation between the neighboring age levels and the basic (non-Bayesian) age-depth modeling software developed by Blaauw (2010).

The bulk samples were ground and homogenized for the TOC measurements. After treating samples with 1 N HCl, we measured the TOC using a CE Model 440 elemental analyzer. We used the fraction below 60 μm to measure the HD. After being treated with 0.1 mol/L NaOH and boiled for 1 h to extract humic acid, the solution was filtered and diluted. We used a UV-1901 spectrophotometer to measure the absorbance of the solution at a wavelength of 520 nm. The analytical accuracy was 1%. We expressed the absorbance relative to the absorbance of distilled water (defined as 0%), and used it to express HD. We have previously proposed a method to correct measurements of HD as per unit of organic matter to indicate humification intensity (Zhong et al., 2010). In this study, we use the TOC to calibrate the HD (HD_{cal}). This is defined as $HD_{cal} = HD/(M_{sample} \times TOC)$, where HD_{cal} is the corrected absorbance value, HD is the raw absorbance value, and M_{sample} is the weight of the sample. A higher (or lower) HD_{cal} represents a stronger (or weaker) humification intensity.

To analyze the grain size, we pretreated the sample with 10–20 mL of 30% H_2O_2 to remove organic matter, and then with 10 mL of 10% HCl to remove carbonates. We added approximately 2 L of deionized water. After 24 h, we treated the sample residue with 10 mL of 0.05 M $(NaPO_3)_6$ on an ultrasonic vibrator for 10 min. The Malvern Mastersizer 2000 analyzer automatically yields the percentages of the related grain size fractions of a sample, with a relative error of less than 1%.

4. Results

4.1. Lithology and chronology

The lithology of the Hedong section is primarily composed of dark gray or black peaty materials (including organic-rich silt and peat or plant remains), intercalated with layers of light gray silt and gray yellowish fine sand (Fig. 2). The lacustrine sediments concentrate between 60 and 300 cm from the top of this section. The upper 60 cm of the section is characterized by cross bedding gray green fine sands (60–25 cm depth) and by gray yellow silt or fine sand (0–25 cm depth) that may be of fluvial and proluvial origins, respectively.

The radiocarbon dating results of the section are listed in Table 1 (also Fig. 2). The bottom of the section was determined to be 4370 cal. yr BP, and the average resolution of the section (300–60 cm depth) was approximately 48 yr/sample. As illustrated in Fig. 2, the sedimentation rate in the layer dominated by dark gray peaty material or abundant plant remains is relatively higher than that in the gray white silt layers.