Palaeogeography, Palaeoclimatology, Palaeoecology 418 (2015) 65–74

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

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

Diatom-based inference of variations in the strength of East Asian spring wind speeds since mid-Holocene

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ARTICLE INFO

Article history:
Received 1 July 2014
Received in revised form 30 October 2014
Accepted 12 November 2014
Available online 20 November 2014

Keywords:
Diatom
East Asian spring wind
Mid-Holocene
Lake Jingpo
Northeast China

ABSTRACT

Lake Jingpo is located in Ning'an County, Southeast Heilongjiang Province, northeast China and is strongly influenced by the East Asian monsoon system. Diatom analysis of the last 5000 cal. yr BP according to the results of AMS ^{14}C dating provides a detailed history of paleoenvironment changes. The relative abundance of diatom species, *Asterionella formosa*, *Aulacoseira*, *Cyclostephanos*, *Stephanodiscus* and *Discostella* species can be used as a proxy of spring wind speed, which is supported by the results of seasonal diatom and reviews of literature on the autoecologies of these species. In the sediment, high relative abundance of *A. formosa*, *Aulacoseira* species indicates high wind-driven turbulence of the water column. The diatom record of the past 5000 years shows that the spring wind speed shifted from weak to strong to weak. In our result, the relative abundance of *Aulacoseira* species decreased sharply, while that of small-cell *Cyclotella* sensu *lato* (including *Stephanodiscus*, *Cyclostephanos* and *Discostella*) increased since 2000 cal. yr BP. The broad alternations between these species are probably keyed to mean temperature and wind variations that control lake circulation and stratification. Our results support the hypotheses that abiotic drivers affect the size structure of planktonic communities and that a warmer climate favors small-sized diatom cells. The change in the ratio of *A. formosa* and *Aulacoseira* species to *Cyclostephanos*, *Stephanodiscus* and *Discostella* species (AA/SC) basically correspond to change of the spring insolation (May) at 45°N. Abundance of diatoms in Lake Jingpo roughly corresponds to changes in the Mid- to Low-Latitude Circulation Index of the northern hemisphere as indicated by NH_4^+ concentration from the GISP2 ice-core, the strength of the Asian summer monsoon as recorded from Hani Peat in Northeastern China, and from a stalagmite found in the Dongge cave in southern China. The results are important in demonstrating the sensitivity of diatoms to climate change, and providing proxy evidence for spring wind speed marked by shifts of diatom type.

1. Introduction

The climate of northeast (NE) China is controlled by the East Asian monsoon system that controls much of the Asian climate variations by seasonal reversal of winter and summer monsoons (Wang et al., 2012a,b). During winter, the region is dry, very cold and lakes are ice-covered from the middle of November to the end of the following April (Chu et al., 2005). During summer, the region is warm and lakes are thermally stratified (Wang et al., 2012a,b). Strong northerly winds are common in the spring season and promote the mixing of the water column and the occurrence of dust storms (Liu, 1985). Climate is generally regarded as an important factor influencing the occurrence of dust storms. Studies have shown that spring (March–May) is the season with most frequent dust storms in China, accounting for more than 80% of the annual dust storm frequency. However, reconstruction of the spring wind speed is rare, a result of the lack of suitable proxy records, especially during the Holocene. Therefore, there is a clear need to develop high-resolution-independent proxy records suitable for the reconstruction of the strength of spring winds.

Lakes are widely distributed worldwide and normally undergo a long history of evolution. As a result, lake sediments generally possess continuous and often high resolution records that provide abundant information regarding regional environmental and climatic variations, which can be used in global change studies (Battarbee, 2000; Shen et al., 2013). Among the biological proxies found in lake sediments, diatoms are excellent indicators of environmental conditions and have been widely used to reconstruct Holocene climate variability (Smol and Cumming, 2000; Battarbee et al., 2001; Mackay et al., 2003). Diatoms are primary producers within the food chain, and occur worldwide, growing in almost all aquatic environments (Smol et al., 2001). Climate influences diatoms either directly (e.g. via changes in lake-water temperature, mixing regime, length of ice cover) or indirectly (e.g. by controlling, for example, habitat availability and quality, catchment and aquatic vegetation, water transparency, or nutrient supply) (Moser et al., 1996; Lotter et al., 2010). The relative diatom abundance of *Aulacoseira* species and *Cyclotella* species from the Huguang Maar Lake can be used as a proxy of the strength of winter

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http://dx.doi.org/10.1016/j.palaeo.2014.11.009
0031-0182/

monsoon winds (Wang et al., 2008). In this study, the aim was to describe changes in the diatom community in the sediment and to track changes in the intensity of spring winds.

Jingpo Lake (43°46′–44°03′N, 128°27′–129°03′E, Fig. 1) is located in Ning'an County, Southeast Heilongjiang Province, NE China. It is a lava-blocked lake formed about 10 ka BP (Wang and Dou, 1998). The lake covers an area of 90 km^2, with an average water depth of 25 m and a maximum water depth of 90 m. The lake is surrounded by hills and low mountains with a bedrock of granite, perlite and basalt (Wang and Dou, 1998). The climate of the Jingpo Lake catchment shows remarkable seasonal variation, warm–humid in the summer months and cold–dry in the winter months (Li et al., 2011). In summer, it is influenced by the Asian summer monsoon. Summers are also very moist as 85% of the annual precipitation falls between April and September (Chu et al., 2005). The average temperature of the warmest month is about 20.5 °C. In winter, the Siberian High causes very cold, north to northwesterly winds, and the temperature is very low. The average temperature of the coldest month (January) is about −21.9 °C. The mean annual temperature is 2.5 °C (Wang and Dou, 1998).

2. Materials and methods

2.1. Sampling and sediment analysis

In August 2012, three long lake sediment cores (43°59′16.41″N, 129°02′04.97″E, 350 m a.s.l.) (Fig. 1) were retrieved from the northeastern part of Jingpo Lake at a water depth of 30 m using UWITEC (Austria) coring equipment. In the laboratory, the longest sediment core JPC (1272 cm) was sampled at 2 cm intervals for further analyses.

2.2. Diatom analysis

Diatom analysis focuses on the upper sediment (0–1154 cm). A total of 290 diatom samples were taken at 4 cm intervals in JPC, and 80 diatom samples were taken at 0.5 cm in the short core. Diatom samples were treated using HCl and H_2O_2 (Battarbee, 1986). Two replicate sub-samples are potentially available from each sample. Diatom valves were enumerated on each of two prepared slides from each sample. Diatoms were identified using oil immersion at 1000× magnification using an Olympus microscope (BX51). Identification was performed using manuals such as: Krammer and Lange-Bertalot (1986, 1988, 1991a,b), Reichardt (1999), and Zhu and Chen (2000). Diatom absolute concentrations were estimated by counting a known area on a pipetted smeared slide, made from a 0.1–0.2 mL aliquot from a 50 mL ‘well-mixed’ suspension of 0.3–0.4 g dry sediments. Diatom-based biostratigraphic zones were established by cluster analysis using constrained incremental sum of squares (CONISS; Grimm, 1993). To explore the temporal patterns of the diatom data, detrended correspondence analysis (DCA) was performed using the program CANOCO 4.5 (ter Braak and Šmilauer, 2002). Diatom abundances were square-root transformed in an attempt to stabilize their variances (Ter Braak and Šmilauer, 2002). DCA was performed using a normalized data set using species/taxon abundances >1% of the total count.

2.3. Core chronology

40 samples at 1 cm intervals were analyzed for ^{210}Pb and ^{137}Cs using EG and G Ortec well-type coaxial low background germanium detectors (HPGe GWL-120-15) at the State Key Laboratory of Lake Science and Environment at the Nanjing Institute of Geography and Limnology, Chinese Academy of Science.

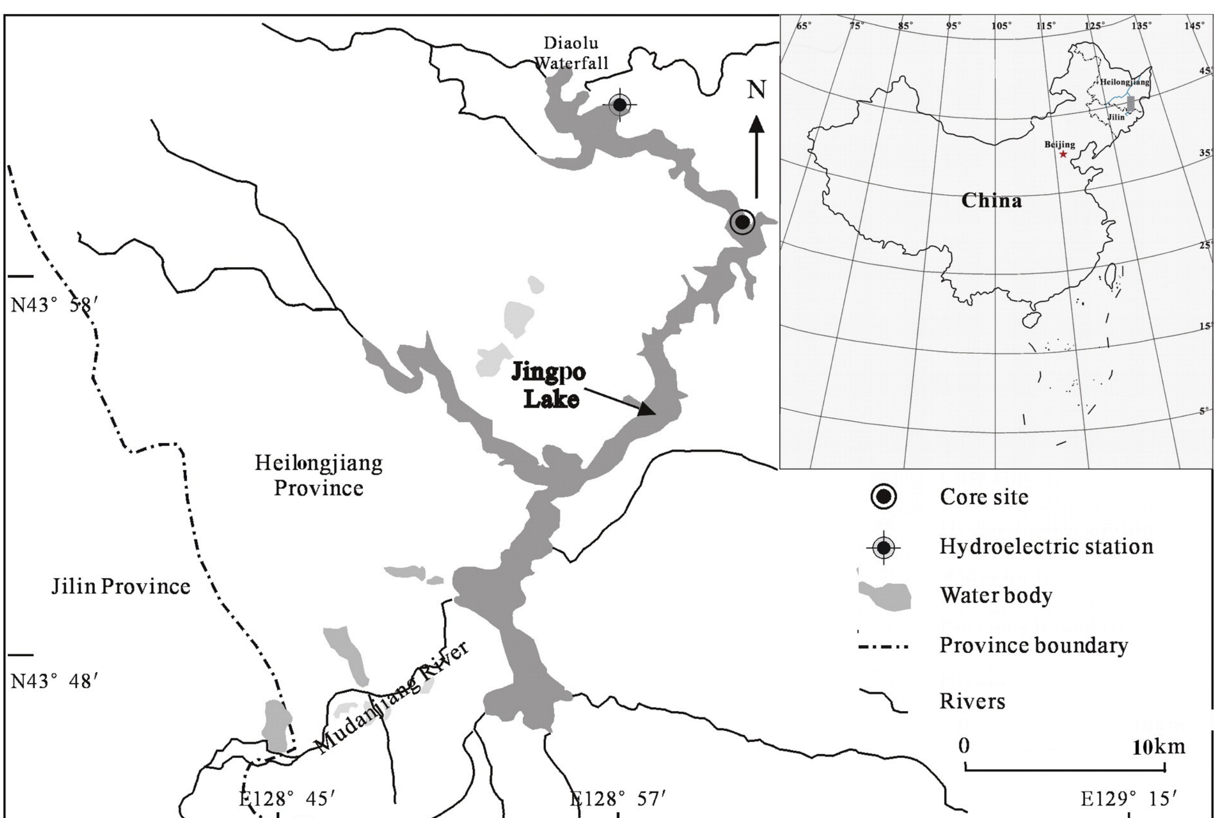

Fig. 1. Location of Jingo Lake, core site.