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Younger Dryas Event and Cold Events in Early-Mid Holocene: Record from the sediment of Erhai Lake

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Abstract: Three cold events (the Younger Dryas, 9.4 ka cal BP, 5.8 ka cal BP) since the 13 ka cal BP in Erhai (EH) Lake catchment, Yunnan Province, were analyzed using the Total Organic Carbon (TOC) series of the EH core. By comparison of the EH core, Qinghai Lake core and Guliya ice core, differences of these cold events were determined. Erhai Lake's responses to the global cold events were lagged in time and weakened in intensity in comparison with Qinghai Lake's. The latitude location of Erhai Lake and the obstruction of Tibetan Plateau may in part explain the differences. However, the remarkable cold event of 8.2 ka cal BP in the Guliya ice core was absent in the records of Erhai Lake and Qinghai Lake. Power spectrum analysis of the TOC proxy series shows that there were three kinds of millennial cycles, i.e. 5 ka, 2.3 ka, and 1.5 ka, in climate changes in Erhai Lake, which reveal the responses of climate to sub-orbit cycles.

Key words: Younger Dryas; Holocene; cold event; Erhai Lake

Introduction

Importance of millennial scale climate change has been recognized since the Younger Dryas (YD) event and Heinrich event were discovered in 1930s and 1990s, respectively. Climate fluctuations, mainly cold events, at this scale provide the research backgrounds for climate change at decade-century scale, as it is more closely related to people's life and production [1−2].

The YD event, in the process of the climate warming-up after the Last Glacial Maximum (LGM), was well recorded in lake sediment, loess and ice cores [3−7] in China. It happened suddenly and temperature dropped by a large range. The Holocene was a warm period after this cold event, however, it was found as earlier as in the 1970s that the glacier advance also existed in that time, climate in the Holocene was unstable [8]. Since the1990s the high resolution ice cores and sediments in deep sea have been used to determine the time of cold events, the results show that there does exist some comparability in the times given by different environmental proxies [9]. Being the important palaeoclimate proxies in terrene, lake sediment possesses the merits of abundant information, continuous time serial and high resolution. Previous researches in China mainly focus on lake sediment in the mid-high latitudes, and study on lake sediment in the low latitudes, however, is feeble, which limits the analysis of the spatial and temporal characteristics and the driving mechanism of millennial-scale cold events. Hereby, this paper provides the sediment record of Erhai Lake in Yunnan Province of Southwest China, and compares it with the climate records in different regions to discuss characteristics of the YD event and cold events in the early-mid Holocene and their periodic law.

1 General physical situation of Erhai Lake catchment

Erhai Lake in Dali Bai Autonomous Prefecture, Yunnan Province, with an area of 2785 km^2, located in the boundary between the southeast fringe of Tibetan Plateau and the northwest fringe of Yunnan Plateau, is in the low latitude belt of 25°25′−26°10′ N. The catchment is influenced mainly by the southwest summer monsoon, as well as partly

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by the westerlies and the local climate of the Tibetan Plateau. The modern climate of the catchment belongs to the western kind of subtropical plateau monsoon climate, dominantly characteristic of distinctively seasonal variations in the whole year, with the winter half-year (Nov.−Apr.) being the dry season and the summer half-year (May−Oct.) being the rainy season [10].

The longest inflow to the lake is the Miju River, which rises from the mountains in the southwest of Heqing County, and the second one is the Boluo River located in the southeast part of the lake. There are 18 streamlets running from the Cangshan Mountain to the west part of the lake, and other short and small rivulets to the east part. The natural outflow is the Xier River at the southwest part, having a typical canyon riverbed with the length of 23 km and the fall of 610 m. It flows into the Yangbi River, belonging to Lantsang-Mekong Rivers water system (Fig. 1).

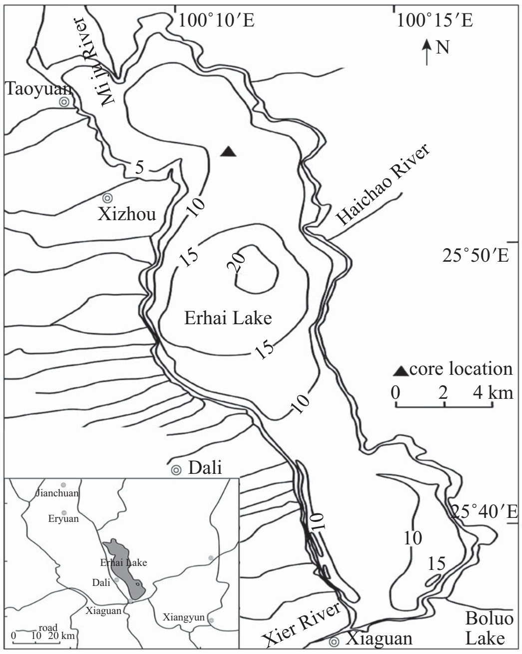

Fig. 1 Situation of Erhai Lake and the location of EH core

2 Sampling and experimental analysis

A continuous sediment column (named EH core), with the length of 661cm, was obtained in April 2001 by a UWITEC sampling system (sampling platform and piston corer) in the deep (10.8 m) water area of north Erhai Lake. For the upper sediment column is soft, the samples above 145 cm was taken out by extruding pole and the samples below 145 cm was gotten by dissecting the corer tubes. The core lithology changes from gray silty clay below 60 cm to yellowish brown clay above 60 cm, with a change to brownish red clay above 10 cm. The column was incised at an interval of 1cm in the field, kept sealed, and then transported to laboratory. Indoor experimental analyses of the sediment include total organic carbon (TOC), total nitrogen (TN), diatom, pollen, grain size, chemical elements and magnetic susceptibility. The age was tested at the Radiocarbon Lab of Tokyo University in Japan, using the organic substance at 7 different depths of the core, among which three samples were tested twice, and the resultant ages were their means. After calibration of ^{14}C, the age serial of the core was constructed by linear interpolation between the dated depths. The bottom age is 12950 a cal BP, which exceeds the normal lower limit (11000 a cal BP) of the Holocene, and reaches the upper limit of late-Pleistocene.

Shen *et al*. [11] studied the environmental change and human activity in Erhai Lake catchment since 13 ka cal BP based on the comprehensive environmental proxies, and Yang *et al*. [12] discussed the evolution of human activity manner in early ages by the serial of pollen change. Their results show that the local climate transformed from cold-wet to warm-wet in the period of 12950−8399 a cal BP, and the transition happened in 10329 a cal BP. In the mid-Holocene, climate was warm and wet, and the optimum appeared in 8399−6371 a cal BP. In 6371 a cal BP, the human activity might begin. The primary human activity was selective deforestation, till 2139 a cal BP farming agriculture was developed widely.

3 Cold events in Erhai Lake catchment and the comparison with other regions

TOC in the lake sediment comes from both endogenetic and exgenetic organic matter, generally representing the lake productivity and the changes in the regional biomass of the catchment. Recently, TOC is widely used as the information source of palaeoclimate fluctuations [13].

When temperature rises, the productivities in lake and catchment would be raised, thus TOC content increases, and vise versa. TOC is chosen to be the proxy of cold events in this paper for its sensitivity to temperature changes.

The response characteristic of Erhai Lake to global change is uncovered by comparing the time series of the EH sediment with other palaeoclimate serials in different monsoon areas, including the Guliya ice core in western Tibetan Plateau, influenced by the Indian Ocean monsoon, and the Qinghai Lake core in eastern Tibetan Plateau, mainly influenced by the southeast summer monsoon.

Comparing among the δ18O curve of the Guliya ice core [14], the total pollen concentration curve of the Qinghai Lake core [7] and the TOC curve of the Erhai Lake core since 13 ka cal BP (Fig. 2), it can be concluded that three global cold events (the YD, 9–10 ka cal BP, 6–7 ka cal BP) were embodied in Erhai Lake, while there were some particularities in its response manner.

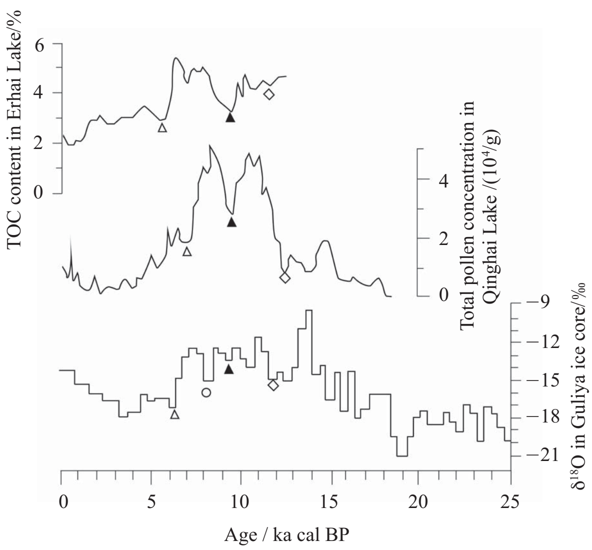

Fig. 2 Comparison of the 5-point running average curves of the TOC in Erhai Lake, the total pollen concentration in Qinghai Lake [7], and the curve of the δ18O concentration in the Guliya ice core [14] (diamond: the YD; solid/open triangle: 9–10/6–7 ka cal BP cold event, respectively)

As to the YD event (diamond), it was not evident in Erhai Lake, and the range of temperature decline small. The maximum cooling of this event appeared in 12.8 ka cal BP in the Qinghai Lake core, in 12 ka cal BP in the Guliya ice core, and in 12.5 ka cal BP in the Erhai Lake core, respectively.

As for the cold event of 9–10 ka cal BP (solid triangle), the occurring time was consistent in the three cores, with the maximum cooling in 9.4 ka cal BP. It was obvious in both the Erhai Lake and the Qinghai Lake cores, however, in the Guliya ice core, the range of temperature decline was small and the duration was short.

With regard to the cold event of 6–7 ka cal BP (open triangle), it happened in the mid-Holocene, reflecting the different ending time of the Holocene optimum for different regions. The maximum cooling appeared in 5.8 ka cal BP in the Erhai Lake core and in 6.2 ka cal BP in the Guliya ice core, while in 7 ka cal BP in the Qinghai Lake core, with the earliest in time and the largest in cooling range.

4 Millennial-cycle of climate changes

The power spectrum analysis of EH TOC series shows that three cycles, 5 ka, 2.3 ka and 1.5 ka, passed the significance test of the confidence level of 80% (Fig. 3). The 1.5 ka cycle has been found in deep sea sediments and the Greenland ice core, and Wang *et al.* [9] has pointed out that there were 6–7 cold periods in the past 10 ka, whose interval was 1.5 ka, basically consistent with the D/O cycle frequency in ice age. The statistic research about cold events in the Holocene by Fang *et al.* [15] affirmed the 2.3 ka climate change cycle. And besides, in Fig. 3 the 5 ka cycle passed the significance test, whose energy value is the highest, which might reflect the Heinrich or Bond cycle in the last glacial. The above analysis illustrates the millennial-cycle consistency between the global climate change and the response of Erhai Lake catchment.

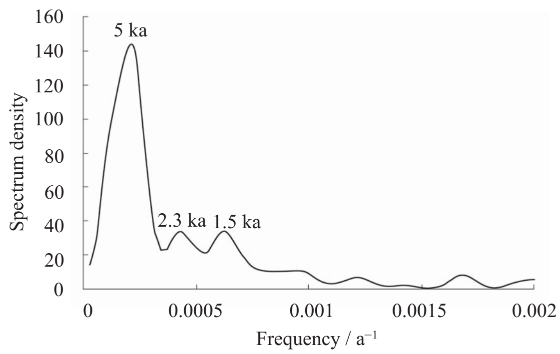

Fig. 3 The power spectrum of TOC proxy in the EH core

5 Conclusion and discussion

There were three cold events since 13 ka cal BP in Erhai Lake, whose maximum cooling appeared in 12.5 ka cal BP, 9.4 ka cal BP and 5.8 ka cal BP, respectively. Comparing to Qinghai Lake, they were later in time and weaker in intensity, especially the event in 6–7 ka cal BP lagged time about 1.2 ka. In addition, TOC proxy in Erhai Lake didn't climb up quickly at the same rate as the pollen proxy in Qinghai Lake after entering the Holocene, and also its ending time of the Holocene optimum was also much later. In Erhai Lake the optimum lasted longer than the others, which may result partly from its geographic situation. For Erhai Lake lies in the southern subtropical belt of 25°25′–26°10′N, where the solar radiation is intensive, regional climate is warm and biomass is huge. While Qinghai Lake lies in the temperate zone of 36°32′–37°15′N, whose baselines of temperature and biomass are also lower, so global warming affects Erhai Lake region much less than Qinghai Lake region. Similarly, because Erhai Lake lies in the low latitude region, and its north faces the obstruction of the Tibetan Plateau, the cold airs from the mid-high latitudes has been greatly weakened when they reach Erhai Lake, resulting in its lagged and insensitive responses to the global cold events.

The cold event happened in 8.2 ka cal BP is evident in deep sea records of the area surrounding North Atlantic Ocean [16], lake sediments [17] and tree rings [18]. Additionally, the Greenland ice core [19] record proves that the event was the coldest one in the post-glacial period. It is not evident in both the Erhai Lake and Qinghai Lake cores, but prominent in the Guliya ice core (open circle in Fig. 2), which suggests that there were some regional characteristics in recording palaeoclimate fluctuations. The geographic situation and the sensitivity of environmental proxies, as well as the complex coupling effects between atmospheric general circulation and underlying surface circumstance in that time may be the explanations.

The power spectrum analysis of TOC proxy evidences the 5 ka, 1.5 ka, and 2.3 ka cycle of regional climate change in Ehai Lake, reflecting its response to the sub-orbit cycle.

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