The two-step monsoon changes of the last deglaciation recorded in tropical Maar Lake Huguangyan, southern China

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Abstract The concentrations of biogenic silica, total organic carbon, total nitrogen and total hydrogen inferred from the sediments of tropical Maar Lake Huguangyan, southern China, provide a climate record of the last deglaciation with century resolution. The records fully demonstrate the existence of the two-step shape of the last deglaciation in tropic East Asia, and they point out noticeable differences between the low and high latitudes in the Northern Hemisphere. Thus, the Bølling first warming at the last deglaciation in the low latitude may have preceded that of the high latitude, whereas the cooling of the Younger Dryas occurred synchronously in the two regions. These results likely suggest that the links between the low and high latitude climates in the Northern Hemisphere during this period are complexity.

Keywords: tropic, last deglaciation, Maar Lake, complexity.

The two-step character of the last deglaciation has been well documented in high latitudes[1, 2], such as Greenland, the North Atlantic, which has also been reported from other regions in the world and has been considered as a worldwide phenomenon[3]. However, recent results also suggest other different evidence. The Antarctic Cold Reversal (ACR), a period of cooling that appears in many Antarctic stable isotope records, has not been compared with the Younger Dryas (YD) in North Atlantic[4]. Pollen records of deglacial sequences from northwest Nelson, New Zealand demonstrate that there was no significant temperature decline associated with the YD, glacial advances at this time were either the product of increased snow accumulation under enhanced precipitation regions or random variation rather than the result of a regional thermal decline[5]. The oxygen isotope records from planktonic foraminifera from the cores in the South China Sea have indicated that the sea surface temperature has not decreased during the YD period[6]. These facts show that the geographical extent and character of climatic oscillations of the last deglaciation are not well known. Therefore, it is important to find more paleoclimatic records of the last deglaciation in extensive space for understanding extremely abrupt changes in Earth's climate.

This note is based on AMS ^{14}C data and climate proxy from the sediments of Maar Lake Huguangyan, southern China, and presents good evidence that the two-step shape of the last deglaciation also existed in the low latitude of East Asia. In addition, there is evidence show that the Bølling first warming at the last deglaciation in the low latitude may have preceded that of the high latitudes, whereas the cooling of the YD occurred synchronously in the two regions.

1 Materials and methods

Maar Lake Huguangyan is located in Leizhou Peninsula (21°9′N, 110°17′E), near the Pacific Ocean in the east and the South China Sea in the south. The present area is characterized by a warm and rainfall summer caused by summer monsoon, typhoon and other tropical storms, a cold and dry winter by winter monsoon. Average annual temperature is 23℃ and precipitation is 1 600 mm. Maar Lake Huguangyan is a typical thermal explosion volcanic basin sealed completely by a low tephra ring of pyroclasstic material, the lake surface area is 2.1 km^2, the maximum depth of the lake reaches 21 m. From February to April in 1997, Chinese-German researchers drilled out seven cores (A, B, C, D, E, F, and G) in Maar Lake Huguangyan using Usinger technique. The profile studied in the present work was from 682 to 990 cm depth of core B, the lithological sequence is here described in descending order:

682—748 cm dark gyttja, with highly organic, and less terrestrial plant residues;

748—796 cm grey sandy gyttja, with poorly organic;

796—894 cm dark gyttja, with highly organic, and autochthonous diatom;

894—990 cm grey sandy gyttja, with poorly organic.

The samples were taken at intervals of 10 cm. After samples had been dried in CHRIST RETA 1-16 freeze dry system for 48 h at the temperature of −30℃, the concentrations of biogenic silica, total organic carbon, total nitrogen and total hydrogen in the samples were analyzed. Biogenic silica contents were measured using the same method as reported by Mortlock and Froelich[7], the concentrations of total organic carbon, total nitrogen and total hydrogen were determined by a Vario EL elemental analyzer after removing inorganic carbon. Three AMS ^{14}C samples were measured in AMS ^{14}C Laboratory, Peking University, among which two datings on leaves were from depths of 759 and 845 cm, one dating on bulk sample from the depth of 912 cm.

2 Results and reconstruction of paleoclimate

Biogenic silica (B_{SiO_2}) derived from the input of diatom to the lake sediments reflects changes in diatom productivity in the lake and provides information regarding changes in paleoclimatic conditions[8, 9], warm surface-water of the lake would further promote the propagation of diatoms, increase in precipitation rates would increase the transport capacity of the nutrients to lake, thereby enhancing the diatom productivity. The amounts of total organic carbon (TOC) are organic matter signals of bio-productivity, which is dominantly controlled by climate, i.e. high TOC values imply warmer and wetter paleoclimatic conditions, whereas low values indicate colder and drier conditions[10, 11]. Nitrogen and hydrogen contents in lake sediments are mainly derived from organic matter, the C/N ratios may indicate the source of organic matter, and imply environmental and climatic conditions[12]. In Huguangyan, the present temperature and precipitation are dominantly controlled by summer monsoon, though the Tropic Convergence Zone also affects this region, its influence is unstable. Thus in the long-time scale, we interpret the biogenic silica, total organic carbon, total nitrogen (TN) and total hydrogen (TH) from the sediments of Maar Lake Huguangyan as proxies for summer monsoon changes.

From the data indicated in fig. 1, it can be seen that along vertical profile B_{SiO_2}, TOC, TN, TH contents vary almost synchronously, and relate to lithological variation. The two-step shape of the late deglaciation is reflected in the proxy curves: two deglacial steps towards high values at the Bølling-Allerød (B/A) and early Holocene warmer and wetter interval; one cold and dry event, corresponding the YD, interrupted the deglacial warming. During B/A and Early Holocene the summer monsoon became strong resulting in warmer and wetter climatic conditions, but the monsoon climate system was unsteady, and the summer monsoon behaved minor fluctuations. The proxy records also show that the intensity of the summer monsoon was greatly reduced in the YD period, and the onset and end of YD demonstrated the character of the abrupt transition, indicating the rapid reorganization of atmospheric circulation in the monsoon climate system in short time.

Pollen data from the same core show[1)] that middle subtropical deciduous-latifolious-needle mixed forest dominated before the B/A period was replaced by tropical forest in the B/A period, but temperate zone vegetation dominated during the YD period, and followed by a rapid shift to south subtropical and tropical forest in the early Holocene. This result is well correlated to our geochemical proxies described above.

3 Discussion and conclusion

Our records show striking similarities in shape with the record of $\delta^{18}O$ from the GRIP2 that documents the extremely rapid climatic oscillations in high latitudes during the last deglaciation[13] (fig. 1). Surpassingly, the warming at the end of the last glacial period in both tropical Huguangyan and Greenland reaches their maxima at the same time, and afterward, major and minor climatic fluctuations

1) Lu, H. Y., Liu, J. Q., Liu, T. S. et al., Palynological records since last glacial from Maar Lake Huangguangyan, Southern China, 1999.

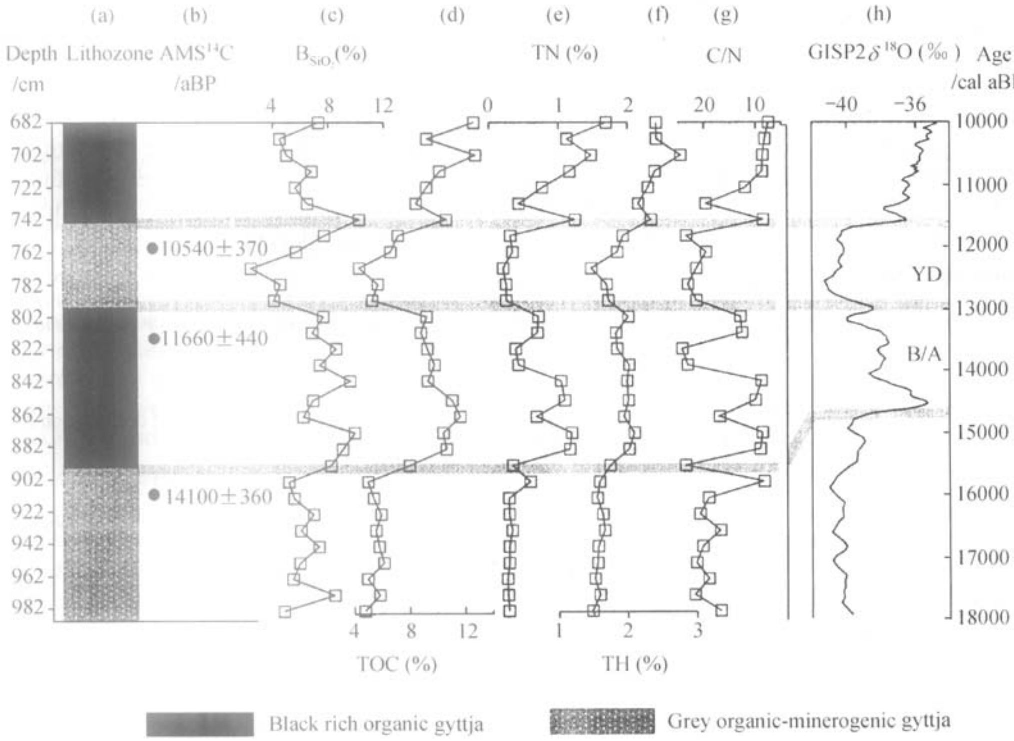

Fig. 1. The data set of core B from Maar Lake Huguangyan during the last deglaciation and comparison with GISP2 $\delta^{18}O$ record. (a) Sediment profile; (b) AMS ^{14}C ages; (c) biolgenic silica (B_{SiO_2}); (d) total organic carbon (TOC); (e) total nitrogen (TN); (f) total hydrogen (TH); (g) C/N; (h) GISP2 $\delta^{18}O$ curve.

in both the regions seem to be well in phase. Especially, at the YD period, climatic changes in both regions were synchronous. It is shown here that the last glacial period was terminated by an abrupt warming event in the Huguangyan at about 16 000 cal aBP (this age has been obtained by linear interpolated age model by a sedimentation rate, and calibrated to calendar ages by CALIB version 3.0.3c[14]), this warming leads the Greenland's. The same transitions also observed in the western Arabian Sea[15], tropical Bolivian ice cores[16], and a global atmospheric methane record[17] seem to reveal that in region the first warming of the last deglaciation in low latitudes of the Northern Hemisphere leads that in high latitudes.

This comparison of the Huguangyan and Greenland climatic records is indicative of the complexity of the links between low and high latitude climates in the Northern Hemisphere during the last deglaciation. This result has important implications for our understanding of the mechanisms linking climate between low and high latitudes in the Northern Hemisphere. It is generally accepted that abrupt deglacial warming in the Northern Hemisphere was accompanied by the onset of North Atlantic Deep Water (NADW) formation, whereas a circulation pattern marked by reduced NADW formation accounts for cold conditions during the YD interval[18]. Benson et al.[19] have found that the western North America also underwent similar climatic oscillations recorded in the North Atlantic, and suggested that the oscillations in the strength and pattern of the NADW caused the variations of temperature and moisture content of air passing over the North Pacific. Our results do not completely support the NADW model, and propose the idea that the low and high latitude link operated differently during the initial stage of the deglaciation, and the initial response to initial forcing maybe occur in the low latitude. From published paleoclimatic data, the two-step character of the last deglaciation is well recognized in many sites, but mechanisms and processes of climatic variations are not yet clear now, which probably involve Milankovich forcing[20], the ocean's thermohaline circulation[21], atmospheric forcing[22] and so on. In recent years, many climatologists believe that the key to unlocking the mysteries of ice ages in the tropics may be found, the hydrological cycle[23] and atmospheric carbon dioxide [24] driven by tropic ocean maybe have played an important role in the global climatic changes.

We think that the main value of our study stems from the data themselves. It is shown that Bϕlling/Allerϕd-Younger Drys oscillation of the last deglaciation well documented in high latitudes is also recorded in the sediments from tropic Maar Lake Huguangyan, southern China. But it also points out an important phenomenon that the first warming of the last deglaciation in the low latitude of the Northern Hemisphere leads that in high latitudes. We obviously recognize the need for finding more high-resolution records in extensive site with accurate absolute dating in order to improve understanding of the mechanism of climatic variations of the last deglaciation.

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