Periodicity of Holocene climatic variations in the Huguangyan Maar Lake

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Abstract There exist five primary periods of 2 930, 1 140, 490, 250 and 220 a in the Holocene climatic variations in the Huguangyan Maar Lake, according to the energy-spectrum and filter analyses of high-resolution time sequences (10—15 a) of the sediment dry density. The peak values of the three temperature-decreasing periods with the 2 930 a cycle occur at about 7 300, 4 250 and 1 200 Cal. aBP. There are 7—8 temperature-decreasing periods with the 1 140 a cycle, and the climate fluctuation range is largest in the early Holocene, and reduces gradually in the middle and late Holocene. The millennial-scale climatic change in the Holocene may adjust the global water cycle and the thermohaline circulation intensity through the harmonic tones of the earth's precession cycle, which in turn influences the global climate change.

Keywords: Maar Lake, Holocene, climatic periodicity.

Since the millennial-scale climate fluctuations were discovered in the ocean, continent, and the ice core sediments[1—7], the explanation of this phenomenon, which cannot be explained by the Milankovitch Theory, has become the key to understanding the succession process of the climate system. Many researchers had attempted to explain it with hypothesis of "the suborbital cycle"[8] or the salinity oscillating mechanism[9, 10], but the 12 000—6 000 a "suborbital cycle"[8] has great difference with the millennial-scale climate fluctuation. Since there is no large ice cap around the northern region of the North Atlantic in the Holocene, it seems impossible for the instability of ice cap to cause the thermohaline current's millennial-scale change[11]. Some researchers tried to explain the periodicity of the Holocene climate change with mechanisms such as solar activities and vocanical activities[13], but because there are no enough detailed studies on the period, frequency and phase of the Holocene high-resolution climate fluctuation in different regions, no consensus of recognition has been reached yet on the mechanism and cause of the Holocene climatic instability[14].

On the basis of energy-spectrum and filter analyses of high-resolution time sequences (10—15 a) of the sediment dry density in the Huguangyan Maar Lake[15], Zhanjiang City, Guangdong Province, this note will focus on discussing the periodicity of the Holocene climatic variations in the tropical South China. This research work will provide new evidence for exploring the factors influencing Holocene climatic change.

1 Materials and methods

2 550 samples' dry density of Core B of the Huguangyan Maar Lake was measured. The procedures are as follows: Firstly sub-sample the freezing core samples at 1 cm intervals with a 7.6 cm diameter round steel-slice. In case that the periphery material may be polluted by the core tubes or storage plastic tubes, the periphery sediment need to be scraped away with a 1 cm high mouth-open glass vessel of 7 cm in diameter. Then put the sample in an already weighed plastic box and get the total weight. After that, put it into the refrigerator to freeze for at least 12 h, and then put it into the freezing air dryer to dry under vacuum, low temperature conditions for 48 h. Weigh the dried sample and subtract the plastic box's weight from it, then the dry density is got after being divided by the sample's volume. The measurement accuracy was examined in two ways: (ⅰ) Take samples of a fixed quantity with the pipes of one-off injectors in a special drilled 1-m-long core paralleling Core B, and use the same freezing and drying methods to measure the samples' dry density. 200 dry density data of the paralleling samples were obtained. The average error was 0.022 g/cm^3; the standard deviation was 0.036. (ⅱ) Choose 100 samples already frozen and dried for 48 h to freeze and dry for another 48 h. Comparison of the sample's weight of 48 and 96 h showed that the two weights were almost the same, which suggests that the samples can be completely dried off after 48 h.

(ⅰ) Climatic implication reflected from the sediment dry density. Sediment dry density has been applied very well in the palaeoclimatic change research in oceans and lakes. Studies on the relationships between the sediment dry density and pollen content in Monticcio Maar Lake, Italy show that the dry density decreases while the temperature increases[16]. As we all know, there are diverse kinds of factors influencing the dry density of lake sediment, and the climatic implication of sediment dry density in different lakes may be different too. It is the most effective way to contrast the proxy-data with clear climatic implication to the dry density of the same profile, to determine the environmental implication of the sediment dry density. The pollen record of lakes is one of the most distinguished proxies in reflecting the climate change. The sediment dry density of the Huguangyan Maar Lake is closely related to the pollen content of different plant species. In the low latitude region, the pollen contents of broad-leaf plant *Fagus*, which is adaptive to the wet-cool climate, and the herbage plant Gramineae, which is adaptive to the cold climate, are in remarkable positive correlation with the sediment dry density. The correlation coefficient is 0.58 and 0.62 respectively. In the tropical-subtropical region, the pollen contents of *Castanopsis* and Hamamelidaceae are in remarkable negative correlation with the sediment dry density, and the correlation coefficient is −0.46 and −0.61 respectively. Fig. 1, which describes the corresponding relationship between the pollen content of two typical plants (Gramineae and Hamamelidaceae) and the sediment dry density, shows that the dry density is increasing while the climate is getting colder, and the dry density is decreasing while the pollen content of tropical-subtropical forest vegetation increases. Additionally, the sediment dry density of the Huguangyan Maar Lake decreases with the increase of the organic matter's content and the

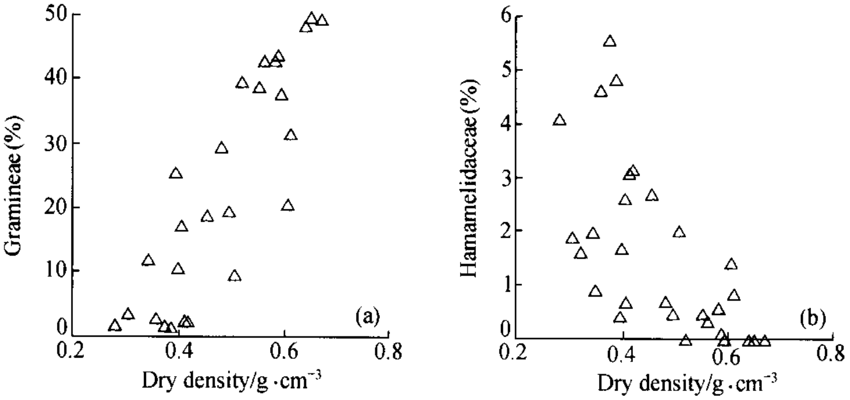

Fig. 1. The corresponding relationship between the pollen content and the dry density of the Huguangyan Maar Lake sediment. (a) The corresponding relationship between the Gramineae pollen content and the dry density; (b) the corresponding relationship between the Hamamelidaceae pollen content and the dry density.

increase of the terrigenous detritus content$^{1,2)}$. The corresponding relationship indicates that in the warm period, the sediment dry density is low with high coverage thriving vegetation, abundant organic matter on the land surface, and less terrigenous detritus carried to lakes. But in the cold period, the sediment dry density is high with less woody plant, and more herbage plants, decreasing organic matter productivity on the land surface, and comparably more terrigenous detritus carried to lakes by the seasonal precipitation. The variations of the sediment dry density directly reflect the process of the climate change.

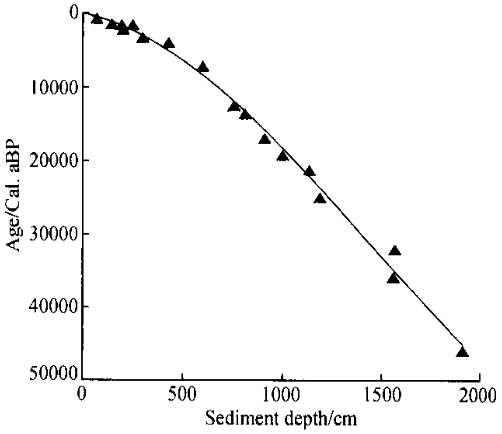

Fig. 2. The curve of the sediment depth varying with the AMS ^{14}C ages.

(ii) Construction of the time sequence of the Huguangyan Maar Lake sediment. There are 44 well-preserved samples of terrestrial plant's bulk, leaves, and fruits in Core B of the Huguangyan Maar Lake. Some samples of Core B were dated by the AMS^{14}C Laboratory of Peking University, others of Core B and the samples of Core C were dated by GFZ-Germany. The 17 age data calibrated by chronology and its variation with the sediment depth are shown in fig. 2. The AMS^{14}C ages after 20 000 years are calibrated by ref. [17], and the ages before 20 000 years are calibrated by ref. [18]. The relationship between the calibrated ages and the sediment depth is described as this fitting equation:

$$Y = -94.872 + 4.78879X + 0.0174769X^2 - 3.94772E - 0.6X^3,$$

where Y is the calibrated ages (Cal. aBP), X is the sediment depth (cm). The sedimentation time span of each sample (1 cm) in the Holocene layers is about 10—15 years.

2 Analysis of the periods of Holocene climatic variations

Energy spectrum analysis of the time sequence, which consists of 1 024 interpolated sediment dry

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density data with isochronal intervals (10 years), shows that self-correlation coefficient r_1=0.92 (r_1=R_1/R_0) indicates the perfect continuity of the sequence. The periods passing through the red-noise examination are 220, 250, 490 and 2 930 a with a confidence of 90% and 75%, the periods passing through the white-noise examination are 1 140 and 2 930 a with a confidence of 75% (fig. 3).

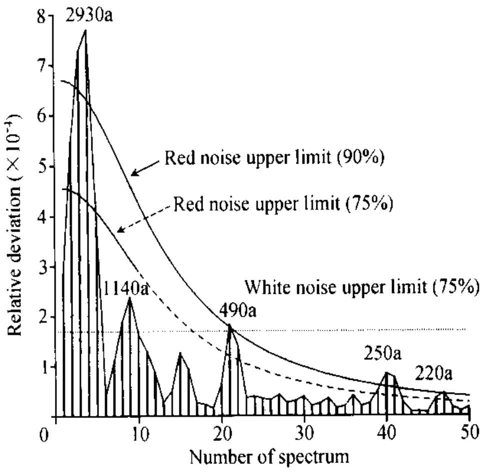

Fig. 3. The energy spectrum curve of the sediment dry density of the Huguangyan Maar Lake in the Holocene.

The primary periods of 2 930, 1 140, 490, 250 and 220 a are separated from the climate curve by the FFT method[19] (Fast Fourier Transform) (fig. 4). Corresponding with the 2 930 a primary period, there are 3 remarkable temperature-decreasing periods in the Holocene, whose peak values occur at about 7 300, 4 250 and 1 200 Cal. aBP, respectively. The climatic fluctuation range with the 1 140 a period is largest in the early Holocene, and then reduces in the middle and late Holocene. Corresponding with the 1 140 a period, there are 7—8 remarkable temperature-decreasing periods, whose peak values occur at about 9 830, 8 680, 7 530, 6 290, 5 040, 3 830, 2 680, 1 640 and 680 Cal. aBP, respectively. There is a trend with the other three short periods of 490, 250 and 220 a, i.e. the climatic fluctuation range is small in the early Holocene (about 8 500—6 000 Cal. aBP) and increases gradually during the late Holocene.

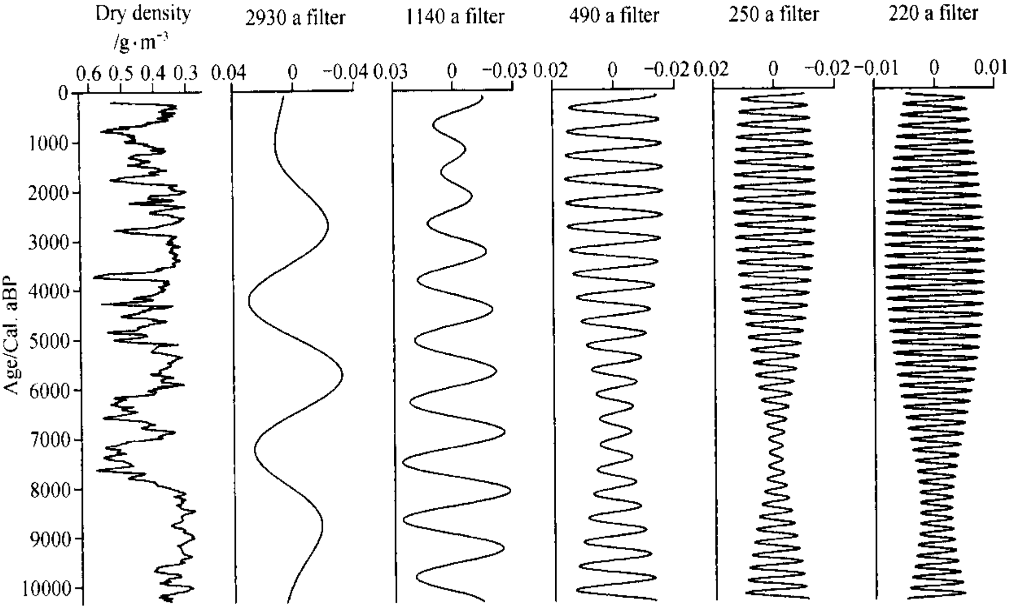

Fig. 4. The climatic fluctuation and its trends of the primary periods in Holocene in the Huguangyan Maar Lake.

3 Discussions and conclusions

The 2 930 and 1 140 a primary periods of the climatic change in the Huguangyan Maar Lake are somewhat similar to the 1 450 and 1 150 a periods[20], which were discovered in the high-resolution paleoclimate record of Core 74KL in the Arabian Sea. The 2 930 a period is a double period of 1 450 a. According to the climate record during the Holocene and the ice ages in the Greenland Cores[2] and the

North Atlantic[6], the periodical variations of 1470 and 1 500 a show that the Holocene climatic fluctuation seems to follow the millennial-scale climatic fluctuation of the ice ages. However, the fluctuation range (signal) is weakened during the Holocene.

There is no unanimous recognition about what factors caused the millennial-scale climatic change in the Holocene. Sirocko[20] believes that three periods are actually the harmonic tones (2 930×8= 23 440; 1 450×16=23 200; 1 150×20=23 200; 1 150×20=23 000) of the earth's precession cycle (23 070 a), it is the nonlinear response of the monsoon system to the solar radiation precession cycle. Many high-resolution nonlinear models also indicate that the climate change always evolves in the pattern of the harmonic tones' precession cycle[21]. Bianchi[22] believes that the variations of the ocean current conveyer strength may be the leading factor to the millennial-scale climate change. Simultaneously, he believes that the variation of the solar activities does not seem to be the leading factor forcing the millennial-scale climate change, for the contents of ^{14}C and ^{10}Be have no periodic change of 1 500 a in the Greenland ice core records. Since there are no large ice caps or sheets around the North Atlantic in the Holocene, the mechanism of using the ice-melting water to force the variations of the ocean current conveyor strength is restricted[11]. Meanwhile, studies on the thermohaline circulation of the present North Atlantic reveal that the decade-year interior oscillations of the thermohaline circulation are existing[22], which are caused by the adjustment of the global water cycle[23—25], not by the melting and injection of the ice caps' freshwater. The millennial-scale climate change in the Holocene may adjust the global water cycle and force the thermohaline circulation's variation through the harmonic tones of the earth's precession cycle (23 070 a), which in turn influences the global climate change. The variations of primary periods of 2 930 and 1 140 a recorded in the Huguangyan Maar Lake are the responses of the global millennial-scale climate change in the tropical South China. The 1 450 a period, which commonly exists in the ocean and ice core records in other regions, appears as its double period (2 930 a). It is still unknown what causes this regional features.

The century-scale periods (490, 250 and 220 a) recorded in the Huguangyan Maar Lake are somewhat different from the 775 and 102 a / 84 a periods of Core 17 940 from the South China Sea[4]. Wang believed that the 102 a / 84 a period probably reflects the variations of the solar activities[4]. Further research should be made on the factors causing the century-scale climatic variation periods recorded in the Huguangyan Maar Lake.

Corresponding to the 2 930a primary period, there are three remarkable dry and temperature-decreasing periods in the Holocene, and their peak values occur at about 7 300, 4 250 and 1 200 Cal. aBP. They are consistent with the present main cold events in East China[7, 26, 27], especially the dry-cold event occurring at about 4 250 Cal. aBP. This event was not only recorded in the continental sedimentary environment in Asia and Africa[7], but also corresponds perfectly with the *Pulleniatina* cold event in the Chinese margin sea environmental record[27], and even influenced the evolution and development of the palaeoanthropology culture in North China1). Cold event at 7300 Cal. aBP. was recorded in many continental sediments in China[7, 28]. Through the energy spectrum and filter analysis of paleoclimatic record in Huguangyan Maar Lake, we can make an advance in understanding which primary period controlled a certain cold event occurring in the Holocene. Thus, it will provide important basic data for us to study the process and mechanism of the climate change.

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