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Lake Taihu Record of Paleoenvironmental Changes over the Past 14000 Years*

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Abstract: *Two sediment cores, one 396 cm long from west Taihu Lake, another 246 cm long from east Taihu Lake, are interpreted from the analysis of their magnetic susceptibility, total organic carbon, total nitrogen, total pigments, organic carbon isotope, hydrogen index, saturated hydrocarbons, ^{14}C dating and surficial sediment conditions. The west Taihu Lake core is the longest one studied in this lake so far, and has provided us the most complete environmental and climatic information for this lake. The results from the west Taihu lake core indicate that Taihu Lake has undergone the following stages: from ca.14 300 to 13 300 aB.P. Taihu Lake was in low lake-level, and there existed exposed features from the proxies reflecting arid paleoclimate. From ca. 13 300 to 12 400 aB.P. an arid transitional stages occurred with a slightly warmer and wetter climate. From ca.12 400 to 10 900 aB.P. a period of large climatic fluctuation occurred and from 10900-10 000 aB.P. a warm period developed with deep water and strongly reducing sediments. During ca.10 000-7 200aB.P., a cool transitional period alternating with a warm climate occurred. It was warm and wet during 7 200-5 700aB.P.; some proxies changed violently in 5 050aB.P., reflecting obvious changes in material source and a probable interruption of sedimentation. The east Taihu Lake history from ca. 6 550 to 6 450 aBP, the climate was cold and dry, and gradually turned warm and wet in ca. 6 450-6 050 aBP. It was warm and wet in ca. 6 050-5 800 aBP and had a cold tendency in 5 800-ca. 5 000 aBP. An abrupt change occurred at ca. 5 000 aBP, and the lake sediment in the uppmost part was disturbed by wave action indicating shallow water conditions.*
Keywords: *Taihu Lake, 14Ka, Paleoenvironmental Evolution, Lake Record*

1. Introduction

Taihu Lake (31°30′N, 120°30′E), the third largest freshwater lake in China, sits in the lower reaches of the Yangtze River. It covers an area of 2 428 km^2 and has a mean depth of 1.89 m (Sun

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1993). The lake is situated in the flat Yangtze River Delta (below 5 m in elevation), which is higher in the west and lower in the east. The water from Taihu Lake drains eastward into the East China Sea by the Lou, ·Wusong and Dong rivers, and in recent years, these rivers have silted up and the Wusong river became the only outlet from Taihu Lake to the sea.

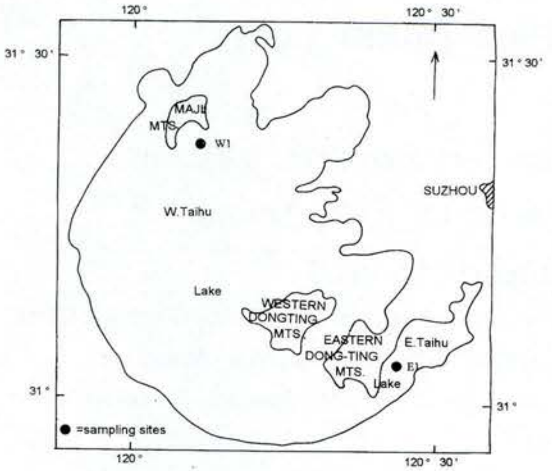

Fig. 1 Core sites of Taihu Lake

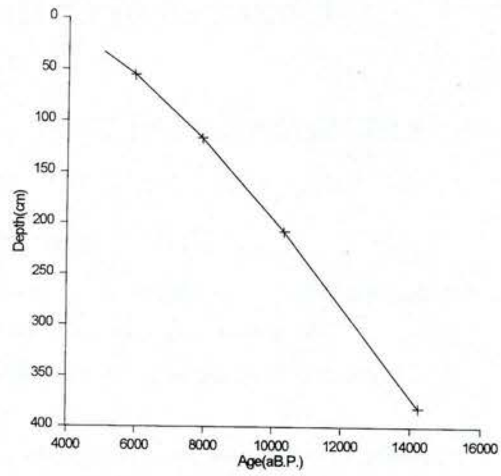

Fig. 2 Age-depth curve of west Taihu Lake core

Taihu Lake sits in one of the most populated and developed region of China. The history of this lake and the adjacent region has been studied in the past decade, and a series of papers were published (Shi 1993, Sun 1993). Previous studies of Taihu Lake on paleoenvironmental and paleoclimatic change were emphasized on the lithological associations, grain size, magnetic susceptibility and paleontologic proxies , the studied core from west Taihu Lake was only about 280cm and the age was 11 000 years. (Wang *et al.* 1996, William and Liu 1996). In this paper, organic carbon isotope, hydrogen index, pigments and ^{14}C dating etc. from the sediments of two Taihu lacustrine cores were studied to assess paleoenvironmental changes during the last 14 000 years in Taihu Lake.

2. Materials and methods

Two cores were collected in November of 1995 using a gravity corer. The west Taihu Lake core was taken to the southeast of Majishan Island and was 3.96 m long, the water level is about 2.26m. The core from the central part of east Taihu Lake (Fig. 1) was 2.46 m long, the water level is 1.12 m. Both of the cores were sectioned at 2 cm intervals and stored below 4℃. The analyses conducted on the sediment samples included total organic carbon (TOC) and total nitrogen (TN), organic carbon isotope ($\delta^{13}C_{org}$), magnetic susceptibility ($\times$ lf, $\times$ hf), pigments and saturated hydrocarbons. The chronology of the cores were established by the ^{14}C dating method (Kar 1986).

^{14}C age was measured using a Quantalas 1220 liquid scintillometer. The results are as follows:

West Taihu Lake: 5 936±44aB.P. (50-60cm); 7 899 ± 110aB.P. (108-124cm); 10 299 ± 123aB.P. (202-211cm); 14 188±865aB.P. (374-384 cm). The chrono-sequence is determined by these ^{14}C data. The bottom age of the east Taihu Lake core was commonly treated as 6 550 aBP (William and Liu 1996), and by the use of the age, we can still put forward some preliminary results on this core.

The content of total organic carbon (TOC) was determined by potassium dichromate volumetry (Yu and Wang 1980). Owing to the small content of the inorganic nitrogen, the total nitrogen (TN) was used instead of total organic nitrogen. TN was determined by the method of persulphate-UV-VIS spectrophotometry (Qian *et al.* 1990)

Low magnetic susceptibility and high magnetic susceptibility (× lf, × hf) was determined using Bartington Company MS_2 magnetic susceptibility meter. Frequency dependent susceptibility (× fd) is calculated as × fd =(× lf- × hf)/ × lf. Organic carbon isotope ($\delta^{13}C_{org}$) was determined using a Finnigen-251 mass spectrograph. Sedimentary pigments (chlorophyll (CD), total carotenoid (TC), Oscillaxanthin (Osc) and Myxoxanthin (Myx)) were determined by Hp8452 uv-vis spectrophotometry according to the method used in the paper of Swain (Swain 1985). Hydrogen index (HI) was determined using a Rock-Eval thermolysis meter.

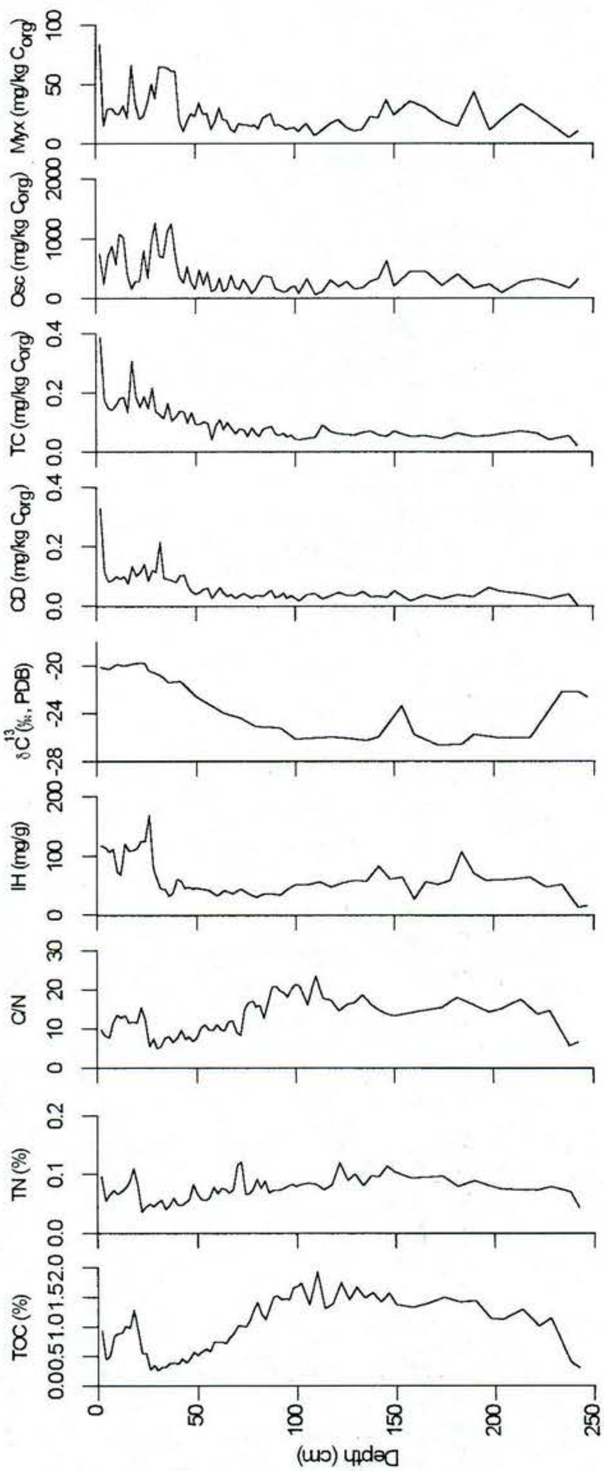

Fig. 3 The distribution of the proxies from east Taihu Lake core since 6 500 aB.P.

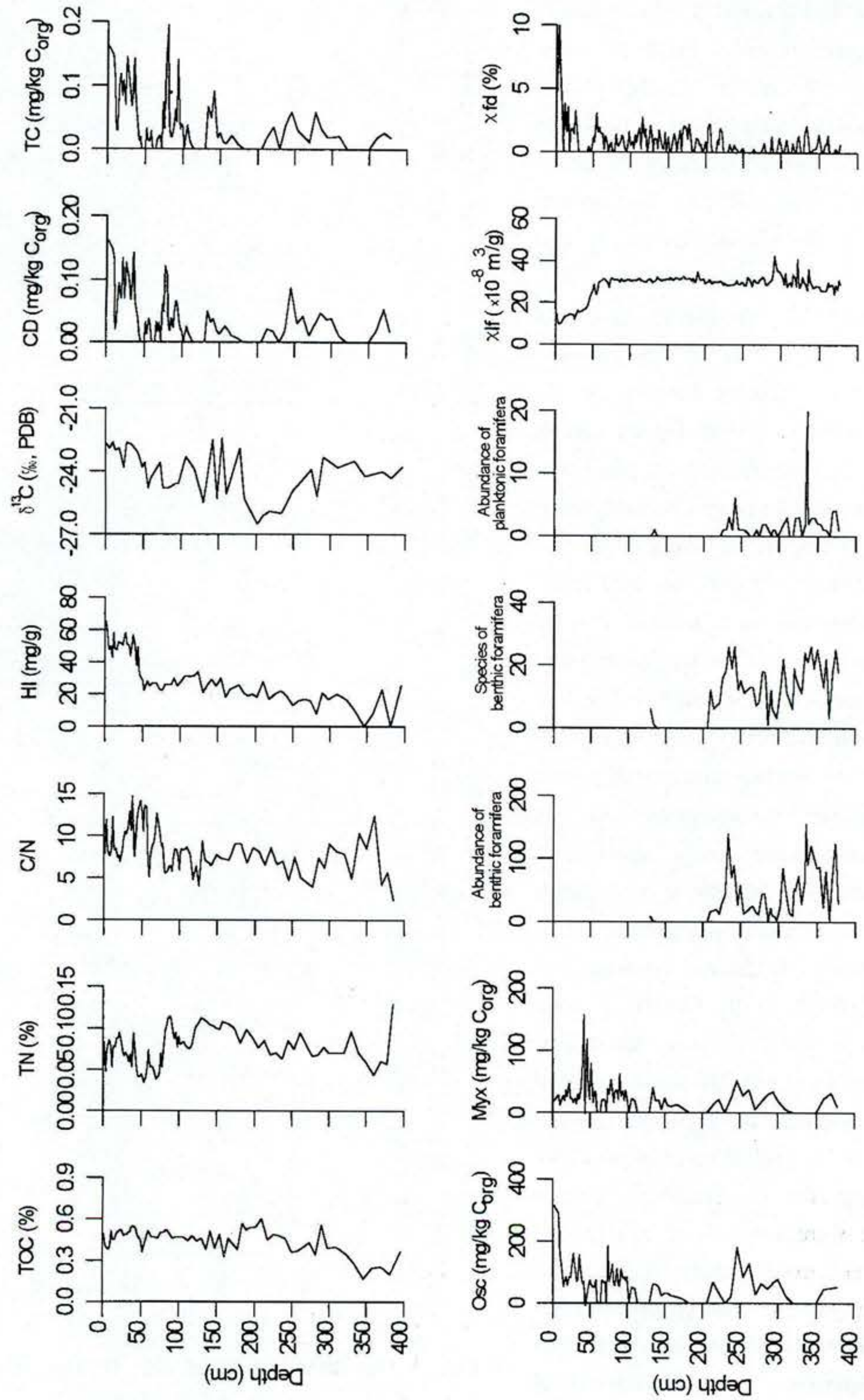

Fig. 4 The distribution of the proxies from west Taihu Lake core since 14 000 aB.P.

The analysis of saturated hydrocarbons has been done on the surface sample from both cores: extraction was carried out in a soxhlet solution (500ml; (2:1) CH_2Cl_2/MeOH) for 72 hours. The extracts were fractionated on an activated silica/alumina column. The saturated hydrocarbons were washed in petroleum ether and analyzed using a GC-MS (HP5890 capillary gas chromatograph-HP5989 with a quadrupole mass spectrograph).

3. Results

Results of analyses of the proxies from the two core samples are shown in figure 3 and 4.

The TOC concentrations in the west Taihu Lake in 396-325cm were less than 0.3 % and had a relatively constant value more than 0.3 % in 325-0 cm. In the east Taihu Lake core the TOC concentrations increa-sed gradually from 0.2 % to 1.8 % in the 246-110cm, and generally maintained a high value in this layer, then it began to decrease gradually to 0.2 % at 35 cm. There existed a sudden change during 35-20cm, it increases from 0.2 % to 1.2 %, a 6 fold increase in counts.

The nitrogen concentrations could be divided into three stages in the west Taihu Lake core. During 325-396 cm and 0-80 cm TN levels showed a relatively low value, the average value is closer to 0.05 %, but there was an increasing tendency from 40cm to 0cm. The higher value stage in the whole core occurred in 80-325 cm with average value about 0.09 %. In the east Taihu Lake the nitrogen concentrations were relatively low in lake sediments, it varies slightly with average value about 0.07 %.

The HI coincided well with TOC in the Taihu Lake sediments. An abrupt change in HI occurred at 25-35 cm in the east core and 40 cm in the west core. We also found the zero value at 346 and 382 cm in west Taihu Lake sediments.

The low frequency magnetic susceptibility ($\times$ lf) from the sediments appeared at ca. 30×10^{-8} $m^3\cdot kg^{-1}$. Generally speaking, this was relatively low in lake sediments, and it varied only slightly. The value of high frequency magnetic susceptibility was similar to that of low frequency magnetic susceptibility. The distinct decrease of magnetic susceptibility appeared at 35-45 cm in the west Taihu Lake core; There was a high value at 280-340 cm. The peak value of frequency magnetic susceptibility occurred in the top 5 cm and may be related to human activities.

The content of organic carbon isotopes ($\delta^{13}C_{org}$) in the west Taihu lake core could be divided into the following stages. In 396-280 cm it had an average value about -24.0 ‰ and varied slightly. it was of low value in 180-280 cm, and ranged from -25-26.3‰. During 50-180 cm it fluctuated violently. In 50-30cm it increased from –25 ‰ to –23 ‰. In the east core it could be divided into four stages. In 246-220 cm it decreased from –23 ‰ to –26 ‰, and during 220-100cm it was an obvious negative stage and it varied slightly except an high point in 155cm. There was a gradually increasing tendency in 100-200 cm from –26 ‰ to –20 ‰. During 20-0 cm it was about –20 ‰ and almost had no change.

The results showed that the pigment concentrations were generally low at 246-40 cm with peaks at 125-225 cm in east Taihu Lake, esp. the content of oscillaxanthin and myxoxanthin. From 40 cm to 0 cm in the core the pigments increased. Total sedimentary chlorophyll (CD) increased from 0.05 $\mu g \cdot g^{-1}$ at 55 cm to 0.3 $\mu g \cdot g^{-1}$ at 15 cm, a six fold increase. Both oscillaxanthin and myxoxanthin increased about 6 fold during this same period. At a depth of 15-20 cm, the total sedimentary pigment suddenly declined. This decline is associated with a dramatic reduction in both the concentration of myxoxanthin and oscillaxanthin, particularly the latter. At a depth of 5-15 cm, oscillaxanthin recovered while myxoxanthin remained low. In the top few centimeters of the core (0-2 cm) this pattern reversed and oscillaxanthin was replaced by myxoxanthin. The results from the west core showed that the pigment concentrations were generally low and fluctuated frequently. In the stage of 50-100 cm, 140-160 cm and 210-300 cm all the pigment concentrations showed high values, the marked increasing trend occurred at 40cm, chlorophyll and total carotenoid increased from 0.03 $\mu g \cdot g^{-1}$ at 40 cm to 0.1 $\mu g \cdot g^{-1}$ at 15 cm. Oscillaxanthin also increased during this same period. In the top few centimeters of the core (0-2 cm concentrations of CD, TC and Osc increased to the highest point of the entire core section.

4. Discussion

According to the chronological sequence, the Taihu lake area has undergone many changes in its palaeoenvironment and palaeoclimate history .

4.1 East Taihu Lake

(1) ca. 6 550-6 450 aB.P. (246-220 cm): TOC, TN, HI and the content of pigments were low. The low TOC and TN suggest a climate condition, which led to little aquatic vegetation cover. The lake level seemed to be low and the low preservatin potention gave rise to the low HI. The value of $\delta^{13}C$ was high. The factors, which control the change of the content of ^{13}C in the lake sediments are complex. However, as far as the Taihu lake which is mainly fed by allochthonous organic matter origin is concerned, the content of C3 plant in the terrigenous vegetation will play an important role on the content of ^{13}C in the lake sediments. High $\delta^{13}C$ usually coincides with a cold climate and *vise versa*. Therefore all of the above proxies suggest a cold and dry climate for the period 6 550-6 450 aB.P.

(2) ca. 6 450 - 6 050 aB.P. (220-145 cm): TOC, TN, HI and the content of pigments increased. The value of $\delta^{13}C$ decreased, suggesting a slightly warmer and wetter climate. It seems that a sudden event occurred at ca. 6 100 aB.P. when the temperature decreased, corresponding with the high $\delta^{13}C_{org}$ and low HI.

(3) ca. 6 050-5 800 aB.P. (145-95 cm): TOC, TN and HI were very high. Meanwhile the value of $\delta^{13}C_{org}$ declined indicating a distinct very warm and wet climate.

(4) ca. 5 800-5 050 aB.P. (95-35 cm): TOC, TN and HI decreased gradually, and the value of $\delta^{13}C_{org}$ increased, suggesting a cold tendancy. However, the pigment evidence suggests that there were very few changes in this period.

(5) ca. 5 050-present (35-0 cm): A shift at 5 500-5 000 aB.P.(40-35 cm) for all the proxies occurred, suggesting a sedimentary hiatus ca.5 000 aB.P. The uppermost part of the core, i.e. ca. 2 600 aB.P.-present (20-0 cm), seems to be disturbed by wave action, and the Pb-210 dating results are difficult to interpret. The proxies suggested a dry and cold climate. The C/N ratio was high from the east Taihu lake sediment, suggesting that the organic matter mainly came from vascular plants and not from phytoplankton. The pigment content was high, and the water level was low.

4.2 West Taihu Lake

(1) ca. 14 300-13 300 aB.P. (396-335 cm): HI was low, with a zero value at two depths in the core, suggesting the sediment was probably exposed above the water in this period. The content of both TOC and TN, as well as the magnetic susceptibility were low. The value of $\delta^{13}C_{org}$ was high. All the proxies suggested the climate was dry, and the water level was low, thus it would appears that lake primary production was low.

(2) ca.13 300-12 400 aB.P. (335-300cm): The HI content gradually increased and magnetic susceptibility had a high value and TOC increased with HI. It seems the palaeoclimate ameliorated during this period. The value of $\delta^{13}C_{org}$ was high all through this period, and this may be the result of marine transgression, because the value of $\delta^{13}C_{org}$ in marine sediments which averaged at -18～-22‰ was usually higher than that in terrigenous sediments(-23～-29‰).

(3) ca. 12 400-10 900 aB.P. (300-230 cm): All the proxies appeared high-low-high, suggesting the climatic fluctuation as warm-cold-warm, in which the TOC, TN, C/N, HI and pigment contents were very low at the depth of 275 cm, while the value of $\delta^{13}C_{org}$ was high, and the concentration of foraminifera and magnetic susceptibility were also low, suggesting a cold and dry period. This period was also found from the other records in adjacent areas of east China (Wang and Yang 1996).

(4) ca. 10 900-10 000 aB.P. (230-200 cm): This is obviously a warm period. $\delta^{13}C_{org}$ was low, suggesting good vegetation growth . HI increased. TOC, pigment contents were all high indicating a wet climate.

(5) ca.10 000-9 500 aB.P. (200-175 cm): The high value of TOC, TN suggest the warm climate in the early Holocene. However the pigment content was still low during this period. Thus the lake condition did not seem to be improved.

(6) ca. 9500-7200 aB.P. (175-100 cm): This is a frequent fluctuation stage. The high value of TOC and pigment contents suggest a slightly warmer and wetter period.

(7) 7 200-5 700 aB.P. (100-50 cm): This is the warmest period in the core. All the proxies were high, esp. the pigment content. This warm period was also documented in a lot of records from east China (Shi 1993).

(8) 5 700- 0 aB.P. (50-0 cm): There was a shift in TOC, HI, $\delta^{13}C$, and χlf in 50-40 cm. especially the HI and the pigment content. It is reasonable to speculate that the algae began to develope. Our study from the other authors suggest a sedimentary hiatus. The east and west part of Taihu lake might have become one at this period.

4.3 Surface samples

We found that the distribution range of the carbon number of the normal alkane in the surface sediments in the core from the East Taihu Lake is C_{16}-C_{33}, the major peak is C_{17}, C_{29}. The value of L/H is 0.63, C_{31}/C_{17} is 0.95, OEP is 3.38, Pr/Ph is 0.59. According to the total ion chromatogram of the saturated hydrocarbons of the aquatic plants in the East Taihu lake, we found that its range of the carbon number distribution is C_{15}-C_{35}, the major peak is C_{29}, the value of L/H is 0.42, C_{31}/C_{17} is 1.44, OEP is 3.22. The East Taihu Lake core has relatively higher content of carbon and lower content of nitrogen, C/N is 13.08. Comparing surface sediment with emerged plant, the following conclusion was drawn: the mainly original organic matter of the sediment in the East Taihu lake is largely from vascular plants. It is an oligo to meso-trophic lake dominated by macrophyte-type vegetation.

The distribution range of the carbon number of the normal alkane in the surface sediments in the West Taihu Lake is C_{15}-C_{33}, the major peak is C_{17}, the L/H is 1.04, C_{31}/C_{17} is 0.40, the odd to even predominate index (OEP) is 1.65, the ratio of pristane to phytane (Pr/Ph) is 0.80. According to the hydrocarbon total ion chromatography of the blue- green algae in the West Taihu Lake, we found that its range of the carbon number distribution is C_{16}-C_{34}, the major peak is C_{17}, the value of L/H is 4.85, C_{31}/C_{17} is 0.01, OEP is 1.55, Pr/Ph is 2.55. The West Taihu Lake core has relatively higher carbon content and higher nitrogen content, C/N is only 7.95. Comparing surface sediment with blue-green algae, the following conclusion was drawn: the mainly original organic matter of the sediment in the West Taihu Lake is blue-green algae. It is a eutrophic lake, and an algae dominated lake. The increase of χlf may be related to the human activities or dynamic turbulence or both.

5. Conclusions

The postglacial lacustrine sediment was not deposited untill 6 550 aB.P. in east Taihu Lake, suggesting a 6 500 years history for the Holocene east Taihu lake. The climate was slightly warmer and wetter in 6 450-5 800 aB.P.. There existed a dry tendancy in 5 800-5 050 aB.P. All the proxies suggested an abrupt change ca 5 050 aB.P., coinciding with the sedimentary hiatus at 30-35 cm (ca. 5 000-5 500 aB.P.). The material source may have changed. The modern east Taihu Lake is characterized by high carbon and low nitrogen. The high C/N ratio suggests the organic matter may derive from the vascular plants. The pigment contents are high and the lake level is low.

The west Taihu Lake core has registered the climate history of Taihu area in the past 14 300 years. The lake level was low and the sediment was probably exposed from14 300-13 300 aB.P., suggesting a dry climate. The 13 300-12 400 was a transitional stage of slightly warmer and weter conditions. The proxies suggested a cold and dry climate at ca. 11 500 aB.P.(270-280 cm), corresponding with the Younger Dryas record. A distinct warm and wet period occurred in 10900-10 000 aB.P., characterized by a reducing sedimentary environment and deep water. The 10 000-7

200 aB.P. was a tranditional period alternating with warm and cold climates. The climate was warm and humid in 7 200-5 700 aB.P. There was an abrupt change of proxies in 5 700-4 900 aB.P., when the algae began to bloom with a sedimentary hiatus. The modern environment (4900aB.P.-present) is characterized by an oxidized sedimentary environment and thriving algae. The lake productivity is high at present. It is a eutrophic lake characterized by cyanobacteria such as *Microcystis* species.

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