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Human impact recorded in the sediment of Honghu Lake, Hubei, China

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Abstract: Vertical profiles of the total organic carbon (TOC), total nitrogen (TN), phosphorus, susceptibilities, elements and partical size were analyzed in a short ^{137}Cs-dated sediment core collected from Honghu Lake, China. The average sedimentation rate was 1.55 mm/a. The results indicated that trophic status of Honghu Lake in the historical period had experienced three stages. Before 1840 the lake was characterized with lower productivity, TOC was less than 9.92 g/kg; TN was 0.902 to 1.24 g/kg. During about 1840—1950, population increased quickly, there was an obvious change in TOC with an average of 13.0 g/kg. Since 1950, human impacts have accelerated the lake eutrophication and nutrients enriched in the sediment with TOC of 21.7 to 93.1 g/kg, TN of 1.77 to 8.78 g/kg. The heavy metal concentration profiles presented similar distribution trends except Pb and Mn. The results from elements analyses indicated that Honghu Lake had not been polluted by heavy metals except lead.

Keywords: Honghu Lake; lake deposit; human impact

Introduction

Hubei Province, in the east-central China, possessing thousands of water bodies in the past, is one of the richest districts of China in terms of lake number. Lakes in this area are increasingly subject to human impacts, including residential and agricultural development, urbanization, road and railroad construction. Much of the anthropogenic influence has occurred during the 20th century (Yang and Cai, 1997).

Honghu Lake is the biggest lake of Hubei Province. Rapid population growth and associated human activities, such as cultivation and fishery, have had negative impacts on the Honghu Lake water and sediment quality(Yang and Cai, 1995).

To assess the impact of humans, it is necessary to establish proper baseline conditions against which change can be measured(Mooney and Dodson, 2001). Lake sediments can serve as information archive of environmental changes through time (Mônica and Carlos, 2002), as each layer of buried sediments represents a record of the environmental conditions related to a period in the past(Von Guten *et al.*, 1997). However, long-term limnological data are lacking for Honghu Lake. Paleolimnological methods may provide insights into the historical condition of Honghu Lake.

Vertical profiles of the concentration of heavy metals and organic matter in dated sediment cores can be used to perform historical studies that seek relationships with the evolution of adjacent terrestrial ecosystems and the emission sources. This evolution is often influenced by significant changes such as industrial development, deforestation, mining and the increase in population and energy consumption (Palanques *et al.*, 1998).

Several papers have reported geochemical studies on Honghu Lake sediments. Yang and Cai (1995, 1997) studied the chemical characteristics of sedimentary cores in Honghu Lake, but the age of sediment was not mentioned. Nutrients in Honghu Lake sedimentary core were also reported in Cheng's paper and the human impact on lake system was discussed (Cheng, 2001; Cheng *et al.*, 2004, 2005). The purposes of this study were to understand the vertical distribution of organic matter and heavy metals associated to the lacustrine sediments, and to evaluate the influence of human impact on the relative contribution of organic matter sources and heavy metals to the lake sediments.

1 Physical environment

Honghu Lake is a relatively large (344 km^2), and shallow water body located at 29°49′N, 113°17′E in Wuhan, Hubei Province, east-central China. The lake lies on Jianghan plain of the Yangtze valley. The lake has a polygon shape, straight in the banks and flat in the bottom. The land inclines from west to east with its central part slightly lower than the surroundings. The water level is 25 m asl. The site is exposed to wet monsoon. Rainfall is moderately high, with a mean of 1343 mm/a. The precipitation from April to June accounts for about 56% of the annual total rainfall, and the evaporation exceeds precipitation on the yearly average values. Mean annual temperature is 16.6℃. The total surface area of Honghu Lake was about 760 km^2 in the early 1950s, but the subsequent portioning and reclamation work in the 1960s and 1970s around the lake caused the continual shrinkage

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of the surface area of the lake to 350 km^2 in 1979 (Zhao *et al.*, 2001; Wang and Dou, 1998). Historically, this region suffered frequent flood damage by the Yangtze or the Hanjiang rivers. However, this situation has changed greatly due to the construction of an integrated flood control and drainage system consisting of dikes, drainage channels, pumping stations, and irrigation and drainage culvert gates. Those facilities were completed in the middle of the 20th century(Yang and Cai, 1995).

2 Materials and methods

2.1 Sediment core

A sediment core was taken from Honghu Lake during the autumn of 2002 using a gravity corer. We determined latitude and longitude with a global position system. The location was near Cheng's(2004). It was sectioned at 0.5 cm intervals above 50 cm depth, and then at 1 cm intervals from 50 cm to the bottom. The slices were oven dried at 60℃ for approximately 72 h. Samples were partitioned for the analysis of sediment chemistry, physics and radioactivity dating. In this paper only the above 40 cm was discussed.

2.2 Physical and chemical analysis

Samples for the determination of metals were dissolved in acid solution utilizing microwave digestion(EPA Method 3052). Approximately 0.125 g of dry samples was dissolved in 0.5 ml HCl, 6 ml HNO_3 and 3 ml HF solution utilizing microwave digestion at 180±5℃ for 10—15 min. Then the digestion solution was transferred to polytetrafluoro ethylene beaker and 0.5 ml hydrochloric acid was added. The acid was evaporated to almost dryness(≤ 200℃), and the residue was redissolved with 2.5 ml 1:1 HNO_3, 0.25 ml H_2O_2 and 5 ml water. The extracts were analyzed by ICP-AES (Leeman Labs Profile). Accuracy was assessed including sub samples of the national institute of standard and technology reference material(SRM 1646a).

Total organic carbon is a measure of organic matter production, and it was determined using the concentrated sulfuric acid-potassium dichromate digestion method. Total nitrogen was measured by the Kjeldahl technique. Total phosphate (TP) was measured by colorimetric analysis and the sample was treated with molybdenum blue reagent. The content of organic phosphate (OP) was calculated using the formula developed by Institute of Soil Science, Chinese Academy of Sciences(1978), and Professional Committee of Agricultural Chemistry of Chinese Society for Soil Sciences(1983).

Low field DC susceptibility magnetism was measured in magnetometer to provide a record of mineral content and an estimate of mineral erosion and dust and spray outfall onto the deposit. Sediment grain size was determined for each sediment sample using Malvern Mastersizer 2000.

3 Results and discussion

3.1 Dating

The age of the sediment layers was determined by ^{137}Cs dating method (Fig.1). ^{137}Cs as a product of radioactive fallout shows typical concentration peaks for 1963 from the testing of nuclear weapons and 1986 from the Chernobyl disaster.

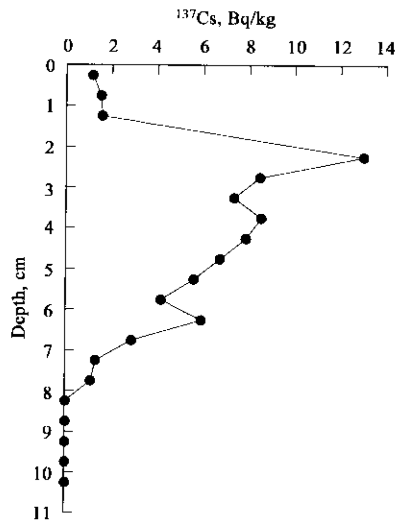

Fig.1 Dating results of ^{137}Cs for Honghu Lake core

At sampling location in the lake, ^{137}Cs was detected at 7.75 cm firstly and reached its first peak at 6.25 cm attributed to 1963. Near to the surface layer, at the depth of 2.25 cm it is another peak of ^{137}Cs corresponding to Chernobyl accident occurred at 1986. Using depths recorded in 1963 as the datum levels, the average sedimentation rate is calculated to be 1.55 mm/a. The sedimentation is comparable to 1.29 mm/a of Cheng's core based on ^{14}C data (2004). Thus the upper 40 cm sediment represents about 260 years deposit time.

3.2 Erosion

In Fig.2, the results of physical measurements related to erosion including susceptibility and cations for Honghu Lake core are presented. The concentration of castions showed the following variations: Al=38.5—98.8 g/kg; Ca=14.3—150 g/kg; Fe=24.1—60.6 g/kg; K=10.5—27.6 g/kg; Mg=8.9—17.7 g/kg; Na=3.2—7.1 g/kg. In general, the metals concentration profiles display similar distribution trends except calcium. Calcium concentration increases sharply from the depth of 5 cm to 0 cm. Susceptibility values are lower in the top 10 cm sediment.

A correlation matrix (Table 1) shows that susceptibility is positively associated with potassium, magnesium, iron, and aluminum relative to erosion

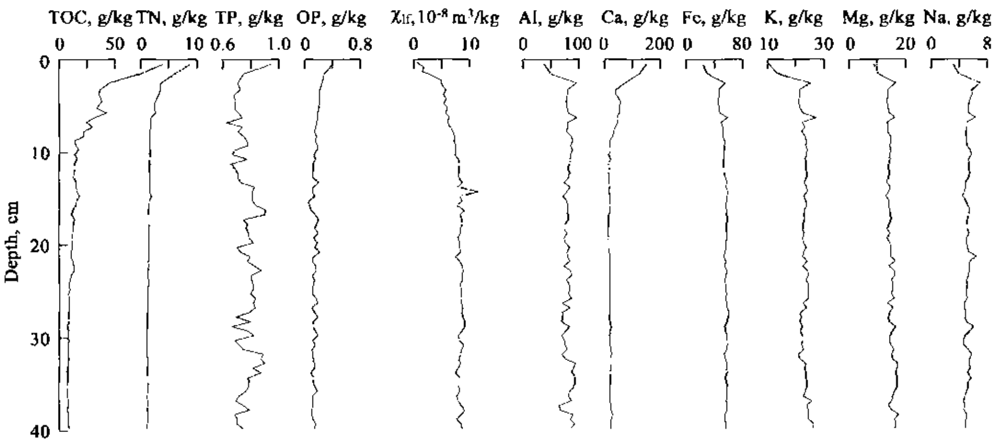

Fig.2 Results of selected chemical and physical measurements of HN core

and negatively associated with calcium. The good correlations found among all the cations except calcium indicate that there may be a common source for them(e.g., erosion) except calcium that may have a different source (e.g. water plant). Same results were reported by Yang and his colleagues, who suggested that newly dead water plant may contribute to the extraordinary high content of calcium in the surficial sediment (Yang, 1996). Since the construction of drainage system in 1950s, lots of macrophyte has brought part of Honghu Lake into the condition of swamp(Cheng *et al.*, 2005). The relatively low values for theses cations except calcium since 1950s may relate to a great degree of water flow onto the site and the flushing of the swamp surface.

Table 1 Correlation coefficients between metals and nutrients and x_{lf}

	TOC	TN	TP	OP	Co	Cr	Cu	Fe	K	Mg	Mn	Na	Ni	Pb	Zn	Al	Ca
TN	**0.959**																
TP	0.002	0.105															
OP	**0.646**	**0.631**	-0.097														
Co	**−0.845**	**−0.873**	-0.017	**−0.476**													
Cr	**−0.473**	**−0.5**	0.014	**−0.353**	**0.608**												
Cu	**−0.765**	**−0.804**	0.056	**−0.51**	**0.864**	**0.439**											
Fe	**−0.875**	**−0.887**	0.014	**−0.539**	**0.921**	**0.504**	**0.952**										
K	**−0.672**	**−0.74**	**−0.191**	**−0.533**	**0.727**	**0.401**	**0.71**	**0.738**									
Mg	**−0.633**	**−0.645**	0.013	**−0.382**	**0.72**	**0.307**	**0.535**	**0.606**	**0.72**								
Mn	-0.081	-0.008	**0.208**	0.064	0.144	0.01	0.119	0.206	-0.07	0.201							
Na	**−0.184**	**−0.266**	-0.167	**−0.141**	**0.365**	**0.208**	**0.245**	**0.203**	**0.366**	**0.463**	**−0.200**						
Ni	**−0.882**	**−0.857**	0.095	**−0.555**	**0.879**	**0.486**	**0.893**	**0.962**	**0.66**	**0.634**	**0.276**	**0.143**					
Pb	**0.636**	**0.692**	**0.191**	**0.557**	**−0.413**	**−0.362**	**−0.325**	**−0.42**	**−0.516**	**−0.526**	**0.142**	-0.222	**−0.458**				
Zn	**−0.642**	**−0.569**	**0.23**	**−0.283**	**0.676**	**0.221**	**0.758**	**0.797**	**0.414**	**0.487**	**0.496**	**−0.035**	**0.839**	-0.112			
Al	**−0.45**	**−0.527**	**−0.151**	**−0.289**	**0.64**	**0.327**	**0.435**	**0.478**	**0.798**	**0.819**	**−0.131**	**0.526**	**0.421**	**−0.424**	0.193		
Ca	**0.939**	**0.923**	0.028	**0.64**	**−0.832**	**−0.534**	**−0.8**	**−0.874**	**−0.701**	**−0.512**	0.085	**−0.242**	**−0.84**	**0.583**	**−0.537**	**−0.46**	
χ_{lf}	**−0.597**	**−0.551**	0.143	**−0.497**	**0.497**	**0.44**	**0.547**	**0.613**	**0.439**	**0.361**	**0.113**	0.048	**0.634**	**−0.372**	**0.465**	**0.214**	**−0.648**

Note: Highlighted values indicate significant probability ($P<0.05$ or $P<0.01$)

3.3 Lake trophic status

The decrease of TOC concentrations with depth in the sediments of Honghu Lake indicates possible changes in organic matter delivery and preservation. The TOC concentrations increase from 21.7 at 8 cm to 93.1 g/kg at 0 cm in sediments(corresponding to 2002 to 1950), and decrease from 8 cm to 25 cm with an average of 13.0 g/kg. Constantly low values (below 9.92 g/kg) are found for sediments deposited from 25 cm to 40 cm, prior to 1840 (Fig.2). The TN profile roughly parallels the TOC concentration profile. TN concentration is stable ranging from 0.902 to 1.24

g/kg in sediments deposited from 25 cm to 40 cm, prior to 1840, and slowly increase from 1.20 to 1.77 g/kg in sediments deposited from 25 cm to 6.5 cm, then increase sharply from 1.77 to 8.78 g/kg in sediments deposited from 6.5 cm to 0 cm corresponding to 1963 to 2002 (Fig.2). OP concentrations generally decline with increasing depth in the profile and values are stable below 8 cm depth (Fig.2). TP concentration oscillates all over the core, but shows an increase in the top 4 cm. TP concentration reaches a peak concentration(0.946 g/kg) at 0 cm.

Honghu Lake core displays a general decrease in total organic carbon concentration with greater depth in the profile. The TOC concentration values of the pre-1950 sediments are similar to those of other moderately productive lakes, and the values of the post 1950 are markedly higher than most modern lakes except city lake (Jin *et al.*, 1990). Increased delivery of organic matter to the lake system could be responsible for the increase burial.

Generally before 1840 the lake was characterized with lower productivity. During about 1840—1950 there was an obvious increase of organic production due to population increase. The population increased from 4.60×10^6 in 1753—1766 to 33.80×10^6 in 1851 (Yang, 1998). Since 1950s large amounts of carbon, nitrogen, phosphorus has accumulated in the sediment. The accumulation of these nutrients was considered to be the discharge of sewage water from multiple sources and cultivation of the lake (Cheng, 2001).

OP concentrations increase with decreasing depth in the profiles. Survey studies have demonstrated a positive correlation between the total P content of surficial lake sediments and water column P concentration (Brenner and Binford, 1988) or phosphorus loading (Sondergaard *et al.*, 1996). Up core increases in the total P concentration of Honghu Lake sediments profiles may reflect increasing P loading through time. Alternatively, higher total P concentrations in very recent deposits of some lakes have been attributed to diagenetic factors. Sondergarrd *et al.*(1996) suggest that higher total P in uppermost deposits is, in part, a consequence of high concentrations of temporarily stored, organic-bound P. They argued that, given time these high total P concentrations would decline as nutrients are released to overlying waters. In our studies, the ratio of OP and total P concentration decreases with the increase of depth in the top 7 cm, then become steady. It is possible that higher total P concentrations in very recent deposits of Honghu Lake are contributed to both diagenetic factors and human impact.

Although TP concentration shows an increase in the top 4 cm and reaches a peak at 0 cm, the TP concentration value between 4 cm and 12 cm is low. In the past decades there were too much aquatic plants (Chang, 2001) in Honghu Lake. These plants may uptake nutrients such as phosphorus and nitrogen from the sediment through roots, and only inorganic phosphorus are bioavailable.

Susceptibility magnetism values are positively associated with potassium, magnesium, iron, and aluminum and negatively with TOC concentration. This indicates that sediment accumulation is much influenced by organic autochthonous input(John *et al.*, 1995). The rapid increases in trophic status appear to be increasing aquatic plant abundance within the last decades. This could be of the population increases and sewage input around Honghu Lake. Another reason could be that the fishes who utilize aquatic plants as food were separated from Honghu Lake after the construction of water gate(Song *et al.*, 1999).

3.4 Heavy metal pollution

In Fig.3, the results of heavy metal profiles for Honghu Lake core are presented. The concentration of metals presents the following variation: Co=7.2—35.9 mg/kg; Cr=43.0—209 mg/kg; Cu=22.9—53.8 mg/kg; Mn=776—1173 mg/kg; Ni=20.9—63.5 mg/kg; Pb=24—45 mg/kg; Zn=88—132 mg/kg; Ti=2.3—6.3 mg/kg. The heavy metal concentration profiles present similar distribution trends except Pb and Mn. Pb concentration increases sharply from the depth of 5 cm to 0 cm. Mn values are more variable in the whole core. The importance of understanding the origin of material from different sources has been discussed in the literature. For example, according to Mônica and Carlos(2002), variations in mineral content can have a marked effect on heavy metal concentrations in an environment, and for distinguishing between natural and anthropogenic sources. The elemental concentrations can be normalized by the concentrations of a refractory constituent of the mineral material. Here titanium is used for this purpose. The vertical pattern of concentrations of lead presents increased concentration near the sediment surface (Fig.3). One possible explanation of this fact is that lead is not only from natural source. To confirm this hypothesis and to avoid any errors due to the elemental composition of sediments (the presence of dead body of water plant), we calculated the ratios between Co, Cr, Cu, Mn, Ni, Pb, Zn and Ti concentration.

Honghu Lake M/Ti ratios are shown in Fig.4 since 1950s (represents about the top 8 cm sediment). The M/Ti ratios of Pb, Cu, Zn, Mn present maximum values between the 1980s and 2000s. These maximum values are an indication of human intervention processes in the lake, showing that the origin of metals is not only from natural processes. Combined with the vertical profiles of trace elements concentrations(Fig. 4). Honghu Lake is obviously polluted by lead. The concentrations of lead in surfical sediment were above

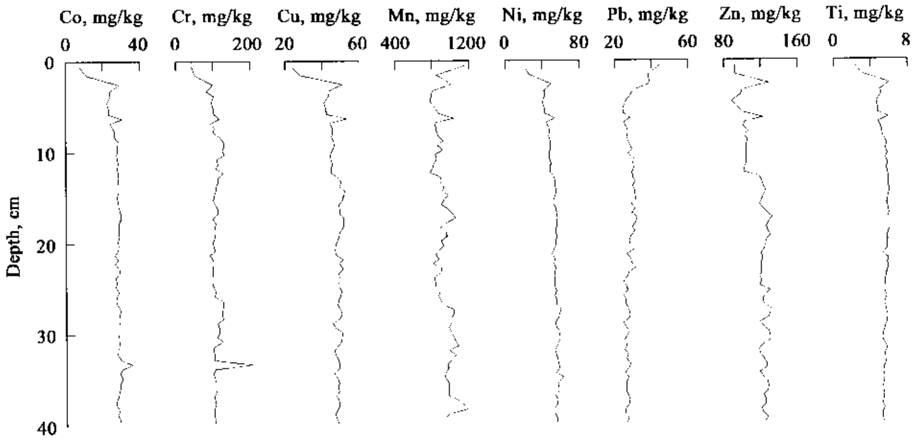

Fig.3 The vertical profiles of microelements of Honghu Lake sediment

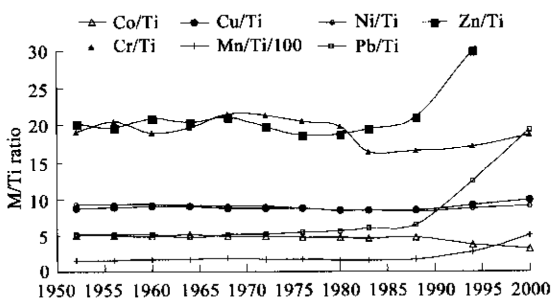

Fig.4 The vertical profiles of trace elements of Honghu Lake sediment

sediment quality guidelines that reflect TEL(threshold effect level for lead is 35 mg/kg)(MacDonald *et al.*, 2000).

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