Bias and association of sediment organic matter source apportionment indicators: a case study in a eutrophic Lake Chaohu, China

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Abstract

The sources of sediment organic matter (SOM) could be explained by various indicators. To test their biases and associations, the present study determined multiple indicators for SOM source apportionment, including elemental analysis (carbon and nitrogen, and their stable isotope $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$), n-alkanes compositions as well as derivative indicators (e.g., terrigenous to aquatic ratio), and carbon isotopes of n-alkane in Lake Chaohu, a eutrophic lake. The spatial variation of anthropogenic effects could be revealed by SOM elemental variations. The n-alkanes of all samples have a bimodal distribution with the 1st peak at n-alkane with 17 carbon (C17) and the 2nd predominant peak at C29. The parity advantage index of n-alkanes indicated that the sediments have mixed characteristics of both endogenous and terrigenous sources. Some n-alkanes indicators also revealed eutrophication characteristics of dominant algae in Lake Chaohu. SOM received a mixed contribution of plankton (I), low-latitude terrestrial high-grade plants (II) and microbial material (III) as indicated by isotopic compositions of long-chain n-alkane. Multiport element model (MEM) showed the contribution of self-generated sources of organic matter in Lake Chaohu is more than 50%, indicating the historic serious eutrophication in Lake Chaohu. The main sources of SOM in the eastern part of the lake are algae and terrestrial input, with little input from microbes, and the contribution from algae decreased from west to east. The multiple indicators' judgment by MEM and principle component analysis (PCA) was of ecological significance and proposed because they offered scientific tools for disclosing the historic variations of SOM as well as their sources.

Keywords: Sediments organic matter; Source apportionment; Lipid molecular biomarkers;

Isotope fingerprinting; Lake Chaohu.

1. Introduction

Lake sediment cores are high-resolution information databases that record ecosystem evolution, climate change and human activities (Haworth and Lund, 1984). With the study of sediment cores, the history of pollution and eutrophication of a lake ecosystem could be reconstructed, and the response of the lake ecosystem to human activities could also be explored (Yang et al., 2008; Zhang et al., 2010; Chen et al., 2011). Although water analysis a conventional and real-time way of monitoring eutrophication currently, its history data is often missing (Kong et al., 2016). To disclose the eutrophication of a lake, long-term monitoring not only provide convincing results, but also tells us what influencing factors lead to the eutrophication and gives early warning signals of a critical transition (Wang et al., 2012). Furthermore, sediment buries algal-derived organic matter from dissolved phase to particle phase and some biomarkers preserves intact information (Yang et al., 2008; Zhang et al., 2010; He et al., 2016a).

Some traditional methods, including elemental (Chen et al., 2002), pigment (Reuss et al., 2005) and pollen analyses (Xiao et al., 2007), are widely used for sediment organic matter (SOM) source apportionment. During recent years, new technical methods such as lipid monomer molecular biomarkers and stable isotope fingerprinting substantially contributed to SOM source apportionment. Thus, it is possible to study the environmental change and biological evolution of an aquatic ecosystem from the macro-level into molecular level (Fu and Sheng, 1996; Waterson and Canuel, 2008). The lipid compounds, including n-alkanes, fatty acids, ketones, alcohols, aldehydes, sterols, and terpenes, are typical biomarkers of SOM

and are widely used in source apportionment (Meyers and Ishiwatari, 1993; Sheng et al., 1999; Zhang et al., 1999b; Ficken et al., 2000; Meyers, 2003; Muri et al., 2004; Lin et al., 2005). For example, n-alkanes from plankton and bacteria are characterized by low carbon number and non-discernable parity advantage, whereas n-alkanes from terrestrial high-grade plants are characterized by high carbon number and appreciable parity advantage (Eglinton and Hamilton, 1967; Cranwell, 1973; Grimalt and Albaigés, 1987; Yao and Sheng, 2002). A high ratio of short to long carbon chains (L/H) of the homologous biomarkers (such as n-alkanes) is often indicative of the dominant inputs of algae and bacterial organic matter (Zhang et al., 1999a). The predominance of monocarboxylic acids and dicarboxylic acids in the fatty acids of sediment indicates aquatic plankton as the primary SOM source and the lipids as the main component, respectively (Volkman et al., 1980; Xiang et al., 1997). Some lipid biomarkers are only from certain organisms. For instance, the dinoflagellate sterols (phytosterone and androstenol derivatives) are biomarkers of dinoflagellates in SOM (Fu and Sheng, 1996; Schubert et al., 1998). The stable isotope composition of lipid biomarker monomers substantially increases resolution and decreases deviation for source apportionment (Hayes et al., 1990; Hayes, 1993a; Lin et al., 2005). Sometimes, those indicators could cause confusion and contradiction because SOM sources were very complex and controlled by multiple factors. It is wise to simultaneously use a variety of indicators for the comprehensive and accurate apportionment of SOM sources. Then, some statistical analysis such as principle component analysis could be employed to simplify those indicators into one or two, to unravel each indicator and reduce the confusions, and to select those consistency indicators.

Lake Chaohu (30°58'~32°06'N/116°24'~118°00'E) is the fifth largest freshwater lake in China (Figure 1), with an area of 760 km² and an average depth of 3 m. With the rapid development of the social economy in the catchments, it has become one of the most hypereutrophic lakes in China since the 1980s (Xu et al., 1999; Xu et al., 2003). Our studies during recent years have shown that Lake Chaohu also suffers from severe contamination by persistent organic pollutants (POPs) such as organochlorine pesticides (OCPs) (Kong et al., 2013), polycyclic aromatic hydrocarbons (PAHs) (Qin et al., 2013), phthalate esters (PAEs) (He et al., 2013b), and polybrominated diphenyl ethers (PBDEs) (He et al., 2013a). The severe eutrophication and associated algal bloom in Lake Chaohu would have important effects on its SOM that would further impact the residues and distributions of lipophilic POPs in the sediment (Xu et al., 2003; Liu et al., 2012). Therefore, the study of SOM sources would also have an important implication to the environmental effects of the lake water eutrophication and to the POPs in the sediment. The objectives of this study were to: (1) identify the source of SOM based on the multiple indicators, including the contents of total organic carbon (TOC) and total nitrogen (TN), the C/N ratio, lipid molecular biomarkers and isotope fingerprinting, and (2) compare those SOM source apportionment results to make a suggestion on the use of multiple indicators.

Fig. 1 Location of Lake Chaohu and sampling sites

2. Methods

2.1. Sample collection and pretreatment

The sampling locations and methods were referred in previous study (He et al., 2013a).

In brief, fourteen sediment samples were collected by a stainless steel Ponar grab sampler (<15 cm based on the angle of that system) from Lake Chaohu on August 8th and 9th, 2009. To minimize the sampling error caused by that tool, a composite sampling, which was mixed thoroughly with the sub-sample, were finally collected. The locations of the sampling sites are shown in Figure 1. The sampling sites EL1, EL2, EL3, and EL4 are located in the eastern part of Lake Chaohu (excluding the drinking water source (WR) area), whereas the sites EL5, EL6, EL7, EL8, and EL10 are located in the WR area. The sediment samples from R1, R2, and R3 were obtained from four inflow rivers located east of the lake, whereas WL was located in the western part of the lake. The sediment samples were placed in sealed bags and taken back to the laboratory. After air-drying, the plant tissues, shells and other benthic organisms were removed from the sediments, and then the sediments were milled to pass a 200-mesh (74 μ m) sieve.

2.2. Sample Analysis

2.2.1 Analysis of total organic carbon (TOC) and total nitrogen (TN)

Sediment samples were ground to 100 mesh (150 μ m) with an agate mortar. The samples were tested for C and N content by the Elementar Vario EL III at the Institute of Geochemistry, CAS in Guangzhou. Before analysis of TOC, an aliquot of 0.1 g of sediment was placed in a test tube, carbonates were removed by adding excess HCl (10%). After 24 h, the sample was washed three times with deionized water. Then, the sediment was placed in a drying oven at 60 °C until constant weight. TN was analyzed without adding HCl.

2.2.2 Analysis of total carbon and nitrogen isotopes

Approximately 2 mg of sediment sample were placed into a clean tin boat, and then

measured in the electronic balance (Sartorius 4503). The boat was placed in the Gas Chromatography-Isotope Ratio Mass Spectrometer (Thermo Finigan Delta Plus XL) for analysis. The instrument's standard deviation is ± 0.5 ‰. The standards used in this study are NBS-22 for $\delta^{13}\text{C}$ and IAEA-N-1 for $\delta^{15}\text{N}$. The $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values that are expressed as ‰ are the $^{13}\text{C}/^{12}\text{C}$ and $^{15}\text{N}/^{14}\text{N}$ deviations of the sample compared with the standard, respectively. Their calculation formulas are as follows (Zanden and Rasmussen, 1999):

$$\delta^{13}\text{C}(\text{‰}) = \frac{^{13}\text{C}/^{12}\text{C}_{\text{sam}} - ^{13}\text{C}/^{12}\text{C}_{\text{sta}}}{^{13}\text{C}/^{12}\text{C}_{\text{sta}}} \times 1000 \quad (1)$$

$$\delta^{15}\text{N}(\text{‰}) = \frac{^{15}\text{N}/^{14}\text{N}_{\text{sam}} - ^{15}\text{N}/^{14}\text{N}_{\text{sta}}}{^{15}\text{N}/^{14}\text{N}_{\text{sta}}} \times 1000 \quad (2)$$

where $^{13}\text{C}/^{12}\text{C}_{\text{sam}}$ and $^{15}\text{N}/^{14}\text{N}_{\text{sam}}$ are the carbon and nitrogen isotope ratios of the samples, respectively, and $^{13}\text{C}/^{12}\text{C}_{\text{sta}}$ and $^{15}\text{N}/^{14}\text{N}_{\text{sta}}$ are the carbon and nitrogen isotope ratios of the standards, respectively. Positive values of $\delta^{13}\text{C}$ or $\delta^{15}\text{N}$ indicate enrichment of the heavy isotope (^{13}C or ^{15}N) in the sample compared to the standard, whereas negative values of $\delta^{13}\text{C}$ or $\delta^{15}\text{N}$ express the enrichment of the light isotope (^{12}C or ^{14}N) in the sample compared to the standard. The standard for $\delta^{13}\text{C}$ is the carbon of calcite shells in the Cretaceous Pee Dee belemnite (PDB standard) from South Carolina, United States. The standard for $\delta^{15}\text{N}$ is atmospheric N_2 .

2.2.3 Analysis of *n*-alkanes

Approximately 8 g of sediment sample were extracted using 25 mL of a mixture solution n-hexane : acetone (1:1, v/v) in a microwave-assisted extraction (MAE) system MARS 5 (CEM Corp., Matthews, NC, USA) with the following instrument conditions: working power 1,200 W, temperature increase to 100 °C within 10 min, hold at 100 °C for 10 min, and

decrease to ambient temperature within 30 min. The extracted solution was concentrated to approximately 1 mL on a rotary evaporator at 35 °C and transferred to the top of a glass column that was packed with 12 cm of silica gel and 12 cm of neutral alumina for cleanup. The n-alkanes were eluted with 20 ml n-hexane. After concentrated into 1 mL, n-alkanes were determined by GC-MS (Agilent GC6890/5973 MSD). The GC conditions were as follows: HP-5MS capillary column (30 m × 0.250 mm), high-purity Helium as the carrier gas, inlet temperature of 280 °C, and injection volume of 1 µL without split injection. The initial column temperature began at 60 °C, was heated to 310 °C at a rate of 8 °C min⁻¹ and was held constant for 17 min until the sample had completely eluted. The MSD conditions were: 70 eV for EI ionization source, 45 ~ 600 amu of mass range, 2341 V for multiplier voltage, ion source temperature at 246 °C, and selected ion monitoring (SIM) mode. N-alkanes were analyzed with even numbers of carbons producing standard markings, and the odd carbon n-alkanes were deduced according to the even carbon markings. The internal standard substance was C₂₄D₅₀.

2.2.4 Analysis of n-alkanes carbon isotopes

The n-alkanes extracts were determined by UK VG Instruments IsoPrime Gas Chromatography-Stable Isotope Ratio Mass Spectrometry at the State Key Laboratory of Environmental Geochemistry, Institute of Geochemistry, CAS. The measurement process uses a mixture of calibration standards (C₁₂ ~ C₃₂) from Indiana University to calibrate the instrument. Using a DB-5MS capillary column of molten silicon (50 m × 0.25 mm × 0.25 µm), the sampling temperature program was set. Initial temperature was 70°C, maintained for 2 min, increased to 290°C at a rate of 3 °C min⁻¹, and retained for 15 min at the end of the

analysis. The internal standard substance was CO₂ of known isotopic composition with an error range of $\pm 0.3\%$. Carbon isotope ratios of n-alkanes were calculated using the PDB standard. The formula are the same as for the total carbon and nitrogen isotopes. The results are the average of two repetitive measurements with an error range of $\pm 5\%$.

2.3 Date processing

2.3.1 Indicator calculation

Multiple lipid molecular indicators were calculated to identify the sources. The quantitative parameters of n-alkanes could also indicate some sources. For instance, n-alkanes with lower carbons (e.g., C17) and n-alkanes with higher carbons (e.g., C31) have potential sources from algae and herbs, respectively (Colombo et al., 1989; Fang et al., 2010), and the ratio C17/C31 could discriminate aquatic-algae- and terrestrial-high-grade-plant-derived SOM. Except for the peak group distribution analysis of n-alkanes, some ratios (Eq. (3) to (10)) of the quantitative parameters of n-alkanes and the carbon preference index (CPI, Eq. (11) and (12)) were employed as follows:

$$L/H = \frac{\Sigma C_{21-}}{\Sigma C_{22+}} \quad (3)$$

$$A1 = \frac{L/H}{1 + L/H} \quad (4)$$

$$TAR_{Hc} = \frac{C_{27} + C_{29} + C_{31}}{C_{15} + C_{17} + C_{19}} \quad (5)$$

$$A2 = \frac{TAR_{Hc}}{1 + TAR_{Hc}} \quad (6)$$

$$A3 = \frac{C_{17}/C_{31}}{1 + C_{17}/C_{31}} \quad (7)$$

$$AAB/AM = \frac{2C_{17}}{C_{23} + C_{25}} \quad (8)$$

$$A4 = \frac{AAB/AM}{1 + AAB/AM} \quad (9)$$

$$\text{LDH/LDW} = \frac{2\text{C31}}{\text{C27}+\text{C29}} \quad (10)$$

$$\text{CPI1} = \frac{\sum_{i=15}^{2n+1} \text{C}_i (2 \sum_{i=14}^{2n} \text{C}_i + \text{C}_{24})}{2 \sum_{i=14}^{2n} \text{C}_i \sum_{i=14}^{2n+2} \text{C}_i}, (n=11) \quad (11)$$

$$\text{CPI2} = \frac{\sum_{i=25}^{2n+1} \text{C}_i (2 \sum_{i=24}^{2n} \text{C}_i + \text{C}_{34})}{2 \sum_{i=24}^{2n} \text{C}_i \sum_{i=24}^{2n+2} \text{C}_i}, (n=16) \quad (12)$$

$$\text{Paq} = \frac{\text{C23}+\text{C25}}{\text{C23}+\text{C25}+\text{C29}+\text{C31}} \quad (13)$$

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168 where L/H is the ratio of total content of n-alkanes with no more than 21 carbons (ΣC_{21-}) to
 169 the total content of n-alkanes with no less than 22 carbons (ΣC_{22+}); both terrestrial alkane
 170 ratio for hydrocarbons (TARHc) could estimate the relative contribution of terrestrial and
 171 algal sources of SOM (Cranwell et al., 1987); AAB/AM is the ratios of the aquatic algae- and
 172 bacteria-derived n-alkanes (AAB, C17) to aquatic macrophyte-derived n-alkanes (AM, C23
 173 and C25) and A4 denotes the algal organic matter; LDH/LDW is the ratio of land herbs (LDH,
 174 C31) to land woody plants (LDH, C27 and C29), estimating the relative proportion of organic
 175 matter input from herbaceous and woody plants (Marzi et al., 1993; Meyers, 2003). CPI1 and
 176 CPI2 are used for origin assessment of lipids with short-chain and long-chain, respectively
 177 (Muri et al., 2004). In addition, the Paq value is a proxy, usually used to distinguish the
 178 relative contributions of terrestrial high-grade plants, aquatic plants, and submerged and
 179 floating plants to lake sediment. When $\text{Paq} < 0.1$, terrestrial high-grade plants or emergent
 180 plants are the main SOM sources; when $0.4 < \text{Paq} < 1$, submerged and floating macrophytes
 181 are the main SOM sources; when $0.1 < \text{Paq} < 0.4$, it indicates mixed SOM sources of above

plants (Ficken et al., 2000). In addition, we also calculate other indicators A1, A2, A3, and A4, which denote the fractional abundance of short-chain n-alkanes in the total n-alkanes, terrestrial SOM in the total SOM, herb-derived SOM in the total SOM, aquatic algae- and bacteria-derived n-alkanes in the total n-alkanes, respectively. Those indicators is used to calculate relative contribution of various biological sources (e.g., plankton source) in the multiport element model (Ou et al., 2013) and to construct indicators' association in the principle component analysis.

2.3.2 Multiport element model (MEM) and principle component analysis (PCA)

To quantitatively determine the contribution ratio of different biological sources for the bimodal distribution pattern with long-chain n-alkanes as dominant components, the MEM based on the analysis of the relative abundance and $\delta^{13}\text{C}$ values of long carbon chain n-alkanes is usually applied (Collister et al., 1994). Given that the long carbon chain n-alkanes in sediment are from a mixture of the plankton source (I), terrestrial high-grade plants source (II), and microbial sources (III) (Walker and Colwell, 1976; Damsté et al., 1999; Pearson and Eglinton, 2000; Ou et al., 2013), the equation is as follows:

$$\delta_{i,j} = \frac{\sum_{k=1}^K X_{i,k} W_{j,k} \delta_{j,k}}{\sum_{k=1}^K X_{i,k} W_{j,k}} = \sum_{k=1}^K F A_{i,j,k} \delta_{j,k} \quad (14)$$

where $W_{j,k}$ is the abundance of n-alkane from the biological source k in the sample j ; $X_{i,k}$ is the ratio of the i -th n-alkane to all n-alkanes in the k -th biological source; K is 3 in the present study, indicating three biological sources I-III were considered; $\delta_{j,k}$ is the carbon isotopic composition of the biological source k in sample j , which is constant (-28.3‰, -30.8‰, and

-34.0‰ for sources I, II, and III); and $\delta_{i,j}$ is the weighted average of the carbon isotopic composition of the i -th n-alkane in sample j . Further deduction shows that fractional abundance $FA_{i,j,k}$ denotes the relative contribution of each biological sources. Because the calculation procedure was detailedly described in previous study (Collister et al., 1994), we only briefly stated here: the fractional abundance of each biological sources were adjusted by iterative spreadsheet model in Microsoft Excel to make the calculated $\delta_{i,j}$ as closely as the observed $\delta_{i,j}$.

The statistical analysis and the PCA were conducted with SPSS v20 software. A significant value was assigned with $p < 0.05$. The PCA was employed to identify the associations among elemental analysis, n-alkanes, their indicators, and carbon isotopes of n-alkane congeners. PCA also required that the indicators should be detected in specific locations. We excluded some indicators with low detection rate such as $\delta^{13}\text{C}_{13}$, $\delta^{13}\text{C}_{29}$, $\delta^{13}\text{C}_{30}$, and $\delta^{13}\text{C}_{31}$.

3. Results and discussion

3.1. Source apportionment of SOM using multiple indicators

3.1.1. Element composition

The TN and TOC in lake sediments are mainly controlled by the primary productivity of the lake, terrestrial input and the preservation of organic debris in the sediment (Meyers, 2003; He et al., 2016a; He et al., 2016b). There was a significantly positive correlation between TOC and TN contents in the Lake Chaohu sediment ($p = 0.013 < 0.05$), indicating that TN strongly associated with organic carbon matter. Sediment organic matter sources can be

divided into endogenous and exogenous. The former is mainly from the lake bacteria, algae, aquatic plants, and other large aquatic organisms, and the latter mainly is from terrestrial high-grade plants and human activities. Degradation products of low-grade aquatic organisms such as algae are rich in protein, but have less cellulose content, and their C/N ratios fall into the range of 4 to 12 and are generally less than 10. In contrast, terrestrial high-grade plants are rich in lignin and have less protein, and their C/N ratios are generally in the range 20-30, or even as high as 45-50 (Meyers, 2003). Therefore, the C/N ratio can be used to quantitatively estimate aquatic sediment organic carbon (CA), organic nitrogen (NA), terrestrial organic carbon (CT) and organic nitrogen (NT) (Qian et al., 1997). In the present study, we assumed that CA/NA and CT/NT values were assigned as 4 and 26 based on previous studies (Qian et al., 1997), TOC only included CA and CT, and TN only included NA and NT. Thus, we could quantitatively evaluate NA, NT, CA, and CT (Table 1).

Table 1. C/N ratio, NA, NT, CA, CT, NA/TN and CA/TC ratio calculations of the sediment from Lake Chaohu

The average TN content was $0.14 \pm 0.04\%$, with the highest value (0.18%) at site EL4 in the eastern lake and the lowest value (0.06%) at site R2 in the Xiaozhegaohe River. The average TOC content was $1.39 \pm 0.83\%$, with the highest value (3.31%) at site EL6 in the eastern source area and the lowest value (0.45%) at site R2, indicating that high primary productivity was found in Lake Chaohu and varied with different lake locations. The algal organic matter content in the western area was higher than that in the eastern part. The average C/N ratio was 11.85 ± 7.10 . The highest C/N ratios were 25.46 and 24.43 at sites EL6 and R1, respectively, which were indicative of terrestrial organic matter as the main sources.

The C/N ratios for other samples were less than 10 except for site R3, indicating that algae was the main source of SOM. The contents of autogenous nitrogen showed the same result. In samples except for EL6 and R1, the contribution rates of autogenous nitrogen were more than 0.70, with an average of 0.81 ± 0.04 . This might be attributed to the bloom and sedimentation of cyanobacteria, which had a strong nitrogen-fixing ability in Lake Chaohu.

3.1.2. Carbon and nitrogen isotopes ($\delta^{13}\text{C}$ and $\delta^{15}\text{N}$)

The carbon isotopic composition ($\delta^{13}\text{C}$) can reflect the processes of photosynthesis and assimilation of carbon sources (Sternberg et al., 1984). The terrestrial C3 plants usually are more enriched in lighter carbon isotopes (^{12}C), and $\delta^{13}\text{C}$ values between $-34\text{‰} \sim -22\text{‰}$, with an average of approximately -27‰ . The C4 plants sequester carbon in different ways, which causes the enrichment of heavier carbon isotopes (^{13}C). The $\delta^{13}\text{C}$ values for the C4 plants are between $-19\text{‰} \sim -9\text{‰}$, with an average of approximately -13‰ . Aquatic plants can be grouped into floating and submerged plants according to the carbon sources of photosynthesis. The $\delta^{13}\text{C}$ values for the aquatic floating plants (including phytoplankton and floating leaf plants), which have CO_2 as the carbon source for photosynthesis, are close to the values of terrestrial C3 plants ($-34\text{‰} \sim -22\text{‰}$) (Stuiver, 1975; Lin and Wang, 2001). However, the $\delta^{13}\text{C}$ values are $-20\text{‰} \sim -12\text{‰}$ for the aquatic submerged plants with HCO_3^- ($\delta^{13}\text{C}$ of 1‰) as the carbon source of photosynthesis (Lin and Wang, 2001). For the aquatic emergent plants with CO_2 as the primary carbon source and HCO_3^- as the secondary carbon source, the $\delta^{13}\text{C}$ values are $-30\text{‰} \sim -24\text{‰}$. If the lake sediments receive mainly exogenous contributions of the organic matter, the $\delta^{13}\text{C}$ distribution would be more like that of terrestrial C3 and C4 vegetation. If the main $\delta^{13}\text{C}$ contribution is from endogenic sources, the $\delta^{13}\text{C}$ distribution

would be more related to the lake productivity. The nitrogen isotope ($\delta^{15}\text{N}$) composition in sediments could reflect the use of nitrate in the aquatic environment (Teranes and Bernasconi, 2000). The most common nitrogen source for algal photosynthesis is NO_3^- , whereas that for terrestrial plants is N_2 fixed in the soil from the air. The $\delta^{15}\text{N}$ values for terrestrial plants are usually approximately 1 ‰, and those for algae are approximately 8 ‰ (Emerson and Hedges, 1988; Herczeg et al., 2001; Lücke et al., 2003; Ni et al., 2011). However, the increasing use of agricultural fertilizers and urban sewage would also lead to increased nitrogen load and $\delta^{15}\text{N}$ values in sediment (Costanzo et al., 2005; Zhou et al., 2007).

The $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values in the surface sediments from Lake Chaohu are reported in Figure 2. The $\delta^{13}\text{C}$ values varied from -26.5 ‰ to -23 ‰, with a mean of $-24.60\text{‰} \pm 0.85\text{‰}$, indicating the typical mixed source characteristics of phytoplankton, terrestrial C3 plants or aquatic floating plants, and emergent plants. Considering that the floating leaf plants and emergent plants in Lake Chaohu are gradually extinct due to the impacts of severe eutrophication during the past decades (Xu et al., 1999), we could exclude the occurrence of aquatic floating and emergent plants and conclude that SOM in Lake Chaohu is mainly derived from phytoplankton and terrestrial C3 plants. The $\delta^{13}\text{C}$ values for three river samples (R1, R2 and R3) are lighter than those for the lake samples. This indicated that the organic matter in the inflow river sediments were more affected by the terrestrial C3 plants, whereas the organic matter in the lake sediments was substantially influenced by phytoplankton, especially in the western lake samples (WL) and in the eastern water area samples (EL10) (Figure 2).

Fig. 2 Scatter plot for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ in the sediments from Lake Chaohu

The $\delta^{15}\text{N}$ values in the sediment ranged 2 ‰ ~ 9 ‰, with an average of $5.84\text{‰} \pm 2.03 \text{‰}$. The $\delta^{15}\text{N}$ values for three river sediment samples (R1, R2 and R3) varied within the range of 2 ‰ ~ 5.5 ‰, whereas those from the lake sediment samples were in the range 5 ‰ ~ 9 ‰ (Figure 2). This suggested that the SOM in Lake Chaohu had mixed characteristics of terrigenous and algal sources, which is consistent with the results of the $\delta^{13}\text{C}$ data. The relationship between the $\delta^{13}\text{C}$ values and C/N ratios can be used to further distinguish the SOM sources of terrestrial C3 plants or aquatic algae. Figure 3 shows that SOM in samples, excluding EL6 and R1 was mainly from lacustrine algae.

Fig. 3 Scatter plot for $\delta^{13}\text{C}$ and C/N in the sediments from Lake Chaohu (after Meyers et al., 2003)

3.1.3. The n-alkane congeners' composition and indexes

The n-alkane, one important lipid biomarker, is widely used for SOM source apportionment because they are widely distributed in organisms and more stable than the total organic matter (Fang et al., 2014). The sources of n-alkanes in lake sediments consists of aquatic biological activity, terrestrial plants, and anthropogenic activities: the aquatic biological activity sources include bacteria, algae, other aquatic organisms, and macrophytes (e.g., floating, submerged, and emergent plant; the sources of terrestrial plants include terrestrial C3 and C4 plants; anthropogenic sources include the incomplete combustion of n-alkanes in oil, coal, straw, wood, and other biomass sources (Pearson and Eglinton, 2000; Zhang et al., 2005; Harji et al., 2008).

The n-alkane congeners' relative composition (Figure 4) could unravel the sources of

SOM because the different sources had their own unique n-alkane congeners' relative compositions. The sources of algae and photosynthetic bacteria can be revealed by the n-alkanes with 15~20 carbons (C15 ~ C20), and the n-alkanes with 17 carbons (C17) dominated that n-alkane carbon number distribution. In addition, those n-alkanes derived from algae and bacteria exhibited an appreciable odd carbon advantage. However, some cyanobacteria are C19-based, and the odd carbon advantage is not readily apparent (Cranwell et al., 1987; Ou et al., 2012). The emergent and floating plants and other large non-exogenous vascular plants have the greatest abundance of n-alkanes with 21, 23, and 25 carbons (C21, C23, and C25). And the terrestrial plants were the sources of n-alkanes with 27, 29, and 31 carbons (C27, C29, and C31). The n-alkanes derived from non-exogenous plants also exhibited an appreciable odd carbon advantage (Meyers, 2003). C27 and C29 represent the input of woody plants, and C31 indicates the input of herbaceous plants. Furthermore, the sources of incomplete biomass combustion contain plenty of short-chain n-alkanes (C < 22) and do not have a discernable advantage parity (Yi and Zhiping, 2002).

The contents and characteristic parameters of n-alkanes and their relative percentage content distribution in the sediment from Lake Chaohu are summarized in Table 2 and shown Figure 4, respectively. In brief, 29 n-alkane congeners from C10 to C38 were detected. The n-alkanes in all of the sediment samples had bimodal distributions showing the long-chain and short-chain n-alkanes as the dominant and supplementary components, respectively. However, the short chain n-alkanes in the two river sediment samples (R1 and R3) had no distinct peaks (Figure 4). The highest peaks for the short-chain and long-chain n-alkanes were C17 and C29, respectively, for all of the sediment samples except for the river site R2, which

had C16 as the peak carbon of short-chain n-alkanes (Figure 4). There was no discernable advantage parity for the short-chain n-alkanes ($CPI1=1.0-1.7$, average 1.3), and there was an appreciable odd carbon advantage for the long-chain n-alkanes ($CPI2=1.9-4.6$, average 2.7) (Table 2, Figure 4). The bimodal distribution (Figure 4) and the Paq values (range 0.1–0.2) (Table 2) showed that the sources of n-alkanes in the sediments had the characteristics of a mixture. The C17 peak might be contributed by bacteria, algae or lower aquatic bio-derived lipids, or the incomplete combustion of biomass (Cranwell et al., 1987; Zhang et al., 2005), whereas the C29 peak might be derived from terrestrial C3 plants such as trees and shrubs in the Lake Chaohu basin. A height comparison of the two peaks suggests that terrestrial high-grade plants had more contribution to the n-alkanes than bacteria, algae and other low-grade aquatic organisms. The ratios of L/H and C17/C31, and the TARHc values, also showed that the source of n-alkanes in the sediments was dominated by terrestrial high-grade plants (Table 2). In addition, the terrestrial high-grade plants had more contribution to the n-alkanes in the river sediments (TARHc = 9.4) than in the lake sediments (TARHc = 3.3).

Table 2 The contents and characteristic parameters of n-alkanes in the sediment from Lake Chaohu

Fig. 4 Relative percentage content of n-alkanes in the sediments from Lake Chaohu. The n-alkanes were normalized to the most prominent n-alkanes (C29 = 100%)

3.1.4 Carbon isotopes of n-alkane congeners

The lipid compounds derived from plankton typically have a heavier carbon isotopic composition (Duan et al., 1997). In Lake Chaohu, the average of carbon isotope of n-alkane

with short carbon chains are -28.1‰, indicating that plankton is contributing the organic matter with short chains. Because the biosynthesis of n-alkanes are similar to fatty acids, carbon isotopic compositions of n-alkanes can refer to fatty acids'. The average $\delta^{13}\text{C}$ of C23 n-alkanes in all samples (-30.3‰) is consistent with the value of bound long-chain fatty acids (-30.3‰) and is fairly consistent with other literature values of -30.8 ‰ (Duan et al., 1997). This is an indication that these low-latitude terrestrial sources are of high-grade plant origin (II) and are also a major source of n-alkanes. C25 ~ C29 n-alkanes in the samples have lighter carbon isotopic compositions, with an average $\delta^{13}\text{C}$ value of -31.1 ‰. A light carbon isotopic composition indicates that it originates from microorganisms. Lacustrine sediments derived from photosynthetic bacteria and chemically autotrophic bacteria contain the heaviest carbon isotope composition of lipids (-34.0 ‰) (Freeman et al., 1990). Therefore, the $\delta^{13}\text{C}$ value of -34.0‰ can represent n-alkanes of the biological source (III) from microbes. N-alkanes in sediment can be provided by petroleum contaminants and rock weathering products (IV), but this causes the composition of n-alkanes to be skewed towards low-carbon-number chains, unlike the studied samples. Thus, the biological source (IV) is not considered in MEM analysis in following section.

Table 3. N-alkane carbon isotope compositions of Lake Chaohu sediments at each point (‰)

3.2. Inconsistent source apportionment of SOM among multiple indicators

The measurement and calculation of the above indicators show that the organic matter is derived from a variety of biological sources: (1) the traditional analysis of carbon and nitrogen content shows that the main source of organic matter in Lake Chaohu is algae, which

is supplemented by terrestrial input; (2) the bulk carbon and nitrogen isotope analyses show that the contribution of algae to organic matter in Lake Chaohu is substantial, and the impact of terrestrial input is barely discernable; (3) the results of n-alkane composition analysis indicate the contribution of terrestrial input is the more prominent sources of SOM. Actually, there should be consistent source of SOM to the same lake among all the indicators. Thus, we deduced that some bias exists among those indicators.

To further investigate the inconsistency, the end-member contribution rate of organic matter among those indicators were calculated using MEM. The CA/TC value in Table 1 and A1, A3, and A4 in Table 2 represent the contribution ratio of biological source (I). The ratios of biological sources (II) and (III) were evaluated using MEM (Table 4). The contribution rate of three biological sources of organic matter in sediments of Lake Chaohu should be > 0 . But MEM results showed some negatives and inconsistency of contribution ratios, indicating that the four selected contribution rates (CA/CT, A1, A3, A4) used to estimate the actual situation are biased. Of above four fractional abundance values, CA/TC is intrinsically the most appropriate and reasonable because this indicator associated with the bulk organic matter. However, other n-alkane indicators was only a part of the bulk organic matter, resulting in underestimating (A1 and A3) or overestimation (A4) of biological source (I). Those inconsistencies were caused by different analytical perspectives. For instance, the elemental analysis offers low-resolution results and generally discloses the overall sources of SOM (Chen et al., 2002). Although carbon and nitrogen isotopes make up some drawbacks of elemental analysis, they still reflect overall sources of SOM (Hu et al., 2006). In contrary, results from n-alkanes composition only denote sources of one group of SOM as well as

carbon isotopes of n-alkane congeners (Ou et al., 2012; Fang et al., 2014). Generally, the sources of the bulk SOM would be consistent with that of part of SOM only when that part dominated the bulk. Furthermore, there is a large uncertainty when using the distribution characteristics of n-alkanes for the source apportionment of SOM because some overlap exists in the n-alkane distributions of different types of organisms. This makes it difficult to distinguish the specific biological source in a mixture of n-alkanes in lake sediments. For instance, fungal spores have C₂₇-, C₂₉- and C₃₁-based n-alkane peaks, and some aquatic algae can also produce C₁₄ ~ C₃₂ n-alkane compounds (Gelpi et al., 1970; Albro, 1976; Weete, 1976; Huang et al., 1996; Ou et al., 2012).

Table 4 Multiport element model estimates of the carbon isotope compositions of long chain n-alkanes in the sediments of Lake Chaohu

Some transport and reaction processes in the environment might cause the bias of multiple indicators. Through diagenesis effect, organic matters such as n-alkanes usually generate small carbon isotopic fractionation (Xiao and Liu, 2010; Ni et al., 2011), but their n-alkanes content composition varied with biological sources (Li et al., 2017). Furthermore, selective degradation of $\delta^{13}\text{C}$ -enriched organic matter might cause $\delta^{13}\text{C}$ shift in bulk organic matter. Typically, lipids (n-alkanes) were more slowly degraded than carbohydrates and amino acids, which resulting in the lipids' lower $\delta^{13}\text{C}$ than total SOM (Hayes, 1993b). Because of the preferential degradation of nitrogen-containing organic matter, n-alkane composition changed litter while C/N ratio changed a lot (Sampei and Matsumoto, 2001). Consequentially, we would found the fractionation C/N and alkane composition.

3.3. Association of multiple indicators revealed by PCA

PCA was employed to investigate association of multiple indicators. PCA accounted for 61.9% of total variance with the first two axes (37.1% and 24.8%). According to PCA loading plot of PC1/PC2 in Fig. 5a, PC1 was more positively associated with n-alkanes with higher carbon chain, whereas n-alkanes with higher carbon chain scattered in the negative direction of PC1, indicating that PC1 could distinguish the high-grade plants and algae by the positive and negative directions, respectively. This was also proved by the n-alkanes indicators such as L/H, A1, TARHc, A2, AAB/AM, and A4. The n-alkanes indicators could also be classified into two groups by PC1. L/H, A1, A2, C17/C31, A3, AAB/AM, and A4, belonged to aquatic algae source indicators, whereas TARHc could denote terrestrial high-grade plants. The PC2 seemed to associate with aquatic algae and microorganism in its positive direction as indicated by its linkage with the C17-19 n-alkanes, C17/C31, A3, and carbon isotope compositions of n-alkanes. Furthermore, PC2 also associated with organic matter derived from land woody plants and aquatic high-grade plants (e.g., submerged and floating macrophytes) as indicated by LDH/LDW and paq, respectively. Interestingly, PC2 could also discriminate the odd carbon advantage for both short-chain and long-chain n-alkanes as indicated by CPI1 and CPI2. After identifying the PC1 and PC2, the sampling sites were discriminated in Fig. 5b. Both PC1 and PC2 also discriminated the terrestrial and aquatic elements (C, N). Furthermore, the high-grade plants denoted by n-alkanes with higher carbon chain associated with aquatic elements (CA, NA), jointly indicating the SOM origins from aquatic high-grade plants. In summary, PCA unraveled the potential associations among the source apportionment indicators. We could select some key indicators for general estimation

SOM sources. Nevertheless, the combining usage of discriminative indicators helped to obtain more credible source apportionment of SOM, which is highly recommended from the present study.

Fig. 5 PCA plot (loading (a) and score (b)) of element analysis, n-alkanes, their indicators, and carbon isotopes of n-alkane congeners.

3.4. Ecological implication to multiple indicators' judgment on SOM sources

After investigating the bias of individual indicators and constructing multiple indicators' association by MEM and PCA, we could geographically identify the SOM sources in Lake Chaohu. The MEM results showed that the main sources of organic matter in the eastern part of the lake are algae and terrestrial input, with little input from microbes (Table 4). The average contribution rate of algae is $54 \pm 7\%$, and the rate decreased from west to east. Due to the impact of the rivers, the contribution of terrestrial organic matter increases, and this becomes the dominant source of organic matter. The compositions of organic matter in the eastern part are consistent with samples nearby in the eastern area of the lake. The contribution of self-generated sources of organic matter in Lake Chaohu is more than 50%, indicating serious eutrophication of Lake Chaohu, which is consistent with the actual water quality (Xu et al., 2003; Jiang et al., 2014). According to PCA (Fig. 5b), it seemed that SOM in EL1-4 had aquatic algae and microorganism sources. EL6 and R2, and WL and R3 had similar sources, respectively. Their SOM seemed to derive from land herbaceous plants.

In addition, with a comprehensive analyses of multiple indicators, we can fully identify the maturity, biological sources, and depositional environments of SOM to reveal rich

information associated with paleoclimate and paleoenvironments (Sessions et al., 1999; Ménot-Combes et al., 2002). Multiple indicators' judgment in Lake Chaohu also geographically discloses the historic characteristics of SOMs as well as their sources. The SOM source appointment can help to explain the severe eutrophication, associated algal bloom, and also residues and distributions of lipophilic POPs in the sediment (Xu et al., 2003; Liu et al., 2012). Furthermore, the inconsistency source appointment from multiple indicators is attributed to some transport and reaction processes (e.g., diagenesis effect, preferential degradation) in the environment (Sampei and Matsumoto, 2001). Because of SOM molecules' diverse transformations in the sediment or during settling from water phase, it is wise to simultaneously use a variety of indicators for the comprehensive and accurate apportionment of SOM sources.

4. Conclusions

Based on the comparison study of multiple indicators of SOM from Lake Chaohu, we concluded that: (1) Elemental analysis together unraveled the high primary productivity of Lake Chaohu. The differences between the eastern and western parts could be discriminated by SOM content as well as contribution of algae. (2) The n-alkane congeners' relative patterns of all samples have a bimodal distribution with the 1st peak at n-alkane with 17 carbon (C17) and the 2nd predominant peak at C29. Its parity advantage index and Paq values indicate that the sediments have mixed characteristics of both endogenous and terrigenous sources, whereas the L/H ratio, C17/C31 ratio and TARHc show the n-alkanes of Lake Chaohu sediments being dominated by terrestrial high-grade plants. (3) Isotopic

compositions of long-chain n-alkanes in sediments indicate that organic matter in sediments received a mixed contribution of the plankton source (I), a source of low-latitude terrestrial high-grade plants (II) and microbial sources (III). MEM showed the contribution of self-generated sources of organic matter in Lake Chaohu is more than 50%, indicating the historic serious eutrophication in Lake Chaohu. The main sources of organic matter in the eastern part of the lake are algae and terrestrial input, with little input from microbes, and the contribution from algae decreased from west to east.

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Figure and Table Captions

Fig. 1 Location of Lake Chaohu and sampling sites

Fig.2 Scatter plot for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ in the sediments from Lake Chaohu

Fig. 3 Scatter plot for $\delta^{13}\text{C}$ and C/N in the sediments from Lake Chaohu (after Meyers et al., 2003).

Fig. 4 Relative percentage content of n-alkanes in the sediments from Lake Chaohu. The n-alkanes were normalized to the most prominent n-alkanes (C29 = 100%)

Fig. 5 PCA plot (loading (a) and score (b)) of element analysis, n-alkanes, their indicators, and carbon isotopes of n-alkane congeners.

Table 1. C/N ratio, NA, NT, CA, CT, NA/TN and CA/TC ratio calculations of the sediment from Lake Chaohu

Table 2 The contents and characteristic parameters of n-alkanes in the sediment from Lake Chaohu

Table 3. N-alkane carbon isotope compositions of Lake Chaohu sediments at each point (‰)

Table 4 Multiport element model estimates of the carbon isotope compositions of long chain n-alkanes in the sediments of Lake Chaohu

Table 1. C/N ratio, NA, NT, CA, CT, NA/TN and CA/TC ratio calculations of the sediment from Lake Chaohu

		C%	N%	C/N	NA%*	NT%*	CA%*	CT%*	CA/TC
WL	Centre of western lake	1.28	0.17	7.53	0.14	0.03	0.57	0.71	0.45
EL1	Eastern lake	1.16	0.15	7.73	0.12	0.03	0.50	0.66	0.43
EL2	Eastern lake	0.99	0.12	8.25	0.10	0.02	0.39	0.60	0.39
EL3	Eastern lake	0.93	0.11	8.45	0.09	0.02	0.35	0.58	0.38
EL4	Eastern lake	1.27	0.18	7.06	0.16	0.03	0.62	0.65	0.49
EL10	Eastern source area	1.41	0.17	8.29	0.14	0.03	0.55	0.86	0.39
EL6	Eastern source area	3.31	0.13	25.46	0.00	0.13	0.01	3.30	0.00
R1	Shuangqiaohe River	3.42	0.14	24.43	0.01	0.13	0.04	3.38	0.01
R2	Xiaozhegaohe River	0.45	0.06	7.50	0.05	0.01	0.20	0.25	0.45
R3	Dazhegaohe River	1.33	0.13	10.23	0.09	0.04	0.37	0.96	0.28
Average of the rivers		1.73	0.11	14.05	0.05	0.06	0.20	1.53	0.25
Average of the lake		1.58	0.15	10.76	0.11	0.04	0.44	1.14	0.35
Average of western lake		1.28	0.17	7.53	0.14	0.03	0.57	0.71	0.45
Average of eastern lake		1.09	0.14	7.87	0.12	0.02	0.46	0.62	0.42
Average of eastern source area		2.36	0.15	16.88	0.07	0.08	0.28	2.08	0.20

*TOC = CA + CT, TN = NA + NT, CA / NA = 4, CT / NT= 26。

Table 2 The contents and characteristic parameters of n-alkanes in the sediment from Lake Chaohu

Area	Western	Eastern				Eastern water source		River		
Sampling site	WL	EL1	EL2	EL3	EL4	EL10	EL6	R1	R2	R3
Σn-alkanes	1824.3	1442.0	1038.1	1358.2	1747.1	1865.9	932.9	5058.7	773.9	2027.8
LMaxC	C17	C17	C17	C17	C17	C17	C17	C17	C16	C17
HMaxC	C29	C29	C29	C29	C29	C29	C29	C29	C29	C29
L/H	0.2	0.4	0.5	0.5	0.3	0.2	0.4	0.1	0.5	0.2
A1	0.16	0.30	0.31	0.32	0.21	0.18	0.27	0.08	0.32	0.14
TARHc	5.9	2.0	1.9	1.9	3.5	4.5	3.2	16.5	2.7	8.9
A2	0.15	0.33	0.34	0.35	0.22	0.18	0.24	0.06	0.27	0.10
C17/C31	0.2	1.0	0.8	0.8	0.5	0.4	0.4	0.1	0.4	0.2
A3	0.19	0.51	0.44	0.46	0.32	0.29	0.28	0.08	0.29	0.14
AAB/AM	1.0	2.2	1.8	2.0	1.3	1.6	1.6	0.6	2.3	0.9
A4	0.49	0.69	0.64	0.67	0.56	0.62	0.61	0.37	0.70	0.47
LDH/LDW	0.9	0.6	0.7	0.7	0.7	0.9	0.9	1.1	1.1	0.8
CPI1	1.2	1.5	1.2	1.3	1.6	1.7	1.2	1.1	1.0	1.1
CPI2	2.2	3.5	2.5	2.5	3.2	3.3	2.8	2.1	2.2	3.2
paq	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1

LMaxC: Short carbon chain primary carbon peak

HMaxC: Long carbon chain primary carbon peak

Table 3. N-alkane carbon isotope compositions of Lake Chaohu sediments at each point (‰)

	WL	EL1	EL2	EL3	EL4	EL	EL10	EL6	EWS	R2	R3	River
C13	-26.29	-31.02	-30.10	-29.71	-29.22	-30.01	-29.10	-30.67	-29.89	-30.45		-30.45
C14	-30.17	-29.22	-28.72	-28.68	-29.07	-28.92	-29.04	-29.61	-29.33	-29.12	-29.43	-29.28
C15	-28.64	-28.99	-28.25	-28.65	-29.19	-28.77	-29.55	-28.67	-29.11	-29.22	-28.33	-28.78
C16	-28.05	-28.25	-27.81	-28.14	-28.54	-28.19	-28.25	-27.46	-27.85	-28.46	-26.89	-27.68
C17	-28.87	-28.39	-27.28	-27.50	-29.53	-28.17	-31.17	-29.68	-30.42	-29.58	-30.14	-29.86
C18	-26.31	-24.86	-27.60	-27.91	-27.54	-26.98	-27.63	-28.63	-28.13	-28.66	-27.94	-28.30
C19	-24.93	-23.72	-25.44	-25.89	-25.71	-25.19	-25.77	-27.72	-26.75	-25.96	-26.14	-26.05
C20	-29.42	-28.61	-28.43	-28.62	-27.68	-28.33	-28.20	-29.58	-28.89	-28.64	-28.62	-28.63
C21	-27.17	-28.55	-27.96	-28.62	-28.33	-28.37	-28.69	-28.11	-28.40	-28.01	-28.29	-28.15
C22	-29.19	-28.74	-28.93	-28.94	-29.38	-29.00	-29.93	-27.80	-28.86	-27.82	-29.09	-28.45
C23	-30.43	-29.75	-28.96	-30.35	-28.91	-29.49	-31.42	-30.41	-30.91	-31.27	-31.68	-31.47
C24	-31.01	-27.36	-28.42	-28.52	-30.05	-28.59	-29.77	-28.48	-29.13	-30.89	-30.28	-30.58
C25	-32.33	-30.19	-29.99	-30.65	-30.09	-30.23	-30.00	-31.47	-30.73	-31.69	-31.08	-31.38
C26	-32.25	-31.02	-29.72	-30.12	-30.48	-30.34	-30.38	-31.83	-31.11	-31.20	-32.10	-31.65
C27	-31.72	-29.70	-29.64	-30.05	-29.48	-29.72	-32.12	-31.76	-31.94	-31.11	-30.87	-30.99
C28	-32.04	-31.49	-29.70	-30.30	-30.49	-30.50	-32.56	-30.98	-31.77	-31.19	-31.60	-31.39
C29		-31.08	-31.16	-31.93	-32.43	-31.65		-32.33	-32.33	-32.89	-31.95	-32.42
C30			-29.37	-27.79		-28.58						
C31			-28.89	-29.66		-29.27		-30.50	-30.50			
Average of all	-29.30	-28.88	-28.76	-29.05	-29.18	-28.96	-29.60	-29.76	-29.78	-29.77	-29.65	-29.74
Average of short-train	-27.76	-27.96	-27.95	-28.19	-28.31	-28.10	-28.60	-28.90	-28.75	-28.68	-28.22	-28.57
Average of long-train	-31.28	-29.92	-29.48	-29.83	-30.16	-29.74	-30.88	-30.62	-30.81	-31.01	-31.08	-31.04

Table 4 Multiport element model estimates of the carbon isotope compositions of long chain n-alkanes in the sediments of Lake Chaohu

		WL	EL1	EL2	EL3	EL4	EL10	EL6	R2	R3	Mean
carbon isotope of n-alkanes ΣC_{21-}		-27.76	-27.96	-27.95	-28.19	-28.31	-28.60	-28.90	-28.68	-28.22	
CA/TC	I%	45	43	39	38	49	39	0	45	28	36
	II%	25	65	78	70	33	44	91	34	51	55
	III%	30	-8	-17	-8	18	17	9	21	21	9
A1	I%	17	30	32	32	22	19	28	34	14	25
	II%	79	89	91	80	82	78	47	52	76	75
	III%	3	-20	-23	-13	-3	3	26	14	10	0
A3	I%	19	51	44	46	32	29	28	29	14	32
	II%	76	50	67	56	63	60	46	60	77	62
	III%	5	-1	-12	-2	5	11	26	11	9	6
A4	I%	49	69	64	67	56	62	61	70	47	61
	II%	18	17	30	18	21	5	-7	-7	18	13
	III%	33	14	6	15	23	33	46	37	36	27
Average of A3 and A4	I%	34	60	54	56	44	46	45	50	30	47
	II%	47	33	49	37	42	33	20	26	47	37
	III%	19	7	-3	7	14	22	36	24	22	16

Figure

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