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*Supplement of*

## **A 150-year record of phytoplankton community succession controlled by hydroclimatic variability in a tropical lake**

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## 1 **1 Study area**

### 2 **1.1 Geology**

3 Lake Nong Thale Prong lies in a region characterized by karst topography of Permian  
4 limestone and/or dolomitic limestone, which forms part of the Ratburi Group and bounds the  
5 northern and southern directions of the lake (Raksasakulwong et al., 1989 Department of  
6 Mineral Resources of Thailand, 2007). Eastward mountain ranges consist of Jurassic-  
7 Cretaceous arkosic sandstone, claystone and siltstone (Department of Mineral Resources of  
8 Thailand, 2007). Undulating plains of Quaternary alluvial and colluvial sedimentary deposits  
9 generally surrounds the western part of NTP (Raksasakulwong et al., 1989; Department of  
10 Mineral Resources of Thailand, 2007). Vegetation is diverse, with the southern part covered  
11 by lowland tropical rainforest, dominated by Dipterocarpaceae and a significantly high  
12 diversity of Myrtaceae (Santisuk, 2006). The Nakhon Si Thammarat region also has extensive  
13 mechanized agricultural activities, consisting mainly of oil palm and natural rubber  
14 plantations.

### 15 **1.2 Thailand hydroclimate**

16 The study area is controlled by both the southwest and northeast monsoonal winds originating  
17 from the Indian Ocean and from Mongolia and China, respectively (Climatological Center,  
18 Thai Meteorological Department, 2011). The intertropical convergence zone (ITCZ)  
19 (Climatological Center, Thai Meteorological Department, 2011), El Niño southern oscillation  
20 (ENSO) (Singhrattna et al., 2005) and tropical cyclones (Climatological Center, Thai  
21 Meteorological Department, 2011), contribute substantially to annual precipitation. The mean  
22 annual temperature and rainfall averages  $\sim 27.3^{\circ}\text{C}$  and 2380 mm, respectively (Ministry of  
23 Communications, Thailand, 1977). Rainfall occurs almost all year round except for a short  
24 dry season of three months and  $< 50$  mm of rainfall in February (Ministry of Communications,  
25 Thailand, 1977)

## 26 **2 Sediment core dating**

27 The samples were tightly sealed and left standing for 2 to 3 weeks to achieve re-equilibration  
28 of decay products (daughter nuclei). The relative efficiency of the gamma detector system  
29 was determined by adding an externally calibrated standard (pitchblende, Stackebo, Sweden)  
30 to three of the already measured samples and analyzed again. The supported  $^{210}\text{Pb}$  was  
31 assumed to be in equilibrium with  $^{226}\text{Ra}$ , hence the unsupported  $^{210}\text{Pb}$  activity was calculated

1 by subtracting the activity of  $^{226}\text{Ra}$  from the activity of supported  $^{210}\text{Pb}$ . Based on  
2  $^{210}\text{Pb}_{\text{unsupported}}$  sediment,  $^{210}\text{Pb}$  chronology was established (see for example Cheevaporn and  
3 Mekkongpai, 1996, for a detailed description of this approach).

### 4 **3 $\delta\text{D}_{\text{wax}}$ of long chain *n*-alkanes biomarkers**

5 Long chain *n*-alkanes are robust and resistant to biodegradation after burial hence widely used  
6 as biomarkers for climate reconstructions (Castañeda and Schouten, 2011). They are  
7 ubiquitous and produced by a range of organisms, for example, *n*-C<sub>27</sub> to *n*-C<sub>35</sub> alkanes are  
8 constituents of epicuticular waxes of higher plants (Rieley et al., 1993; Eglinton and  
9 Hamilton, 1963, 1967); *n*-C<sub>23</sub> to *n*-C<sub>25</sub> alkanes are a dominant component of submerged  
10 aquatic macrophytes (Ficken et al., 2000; Baas et al., 2000); and *n*-C<sub>17</sub> to *n*-C<sub>21</sub> alkanes are  
11 primarily produced by aquatic algae (Robinson et al., 1984; Meyers and Benson, 1988).

12 The dominant carbon chain length distributions and isotopic compositions of *n*-alkanes vary  
13 extensively depending on the source organism, the environments of formation and organic  
14 matter diagenesis (Chikaraishi & Naraoka, 2005). This makes it possible to track back  
15 through time their sources and the environmental conditions prevailing at the time of  
16 deposition (Pancost & Boot, 2004). Several studies have revealed that the hydrogen isotopic  
17 composition (D/H ratio or  $\delta\text{D}$ ) of both terrestrial and aquatic biomarkers reflect that of their  
18 source water, although with an offset (Sachse et al., 2004), primarily due to biosynthetic  
19 fractionation effects (Sachse et al., 2012).

20 In the Thailand,  $\delta\text{D}$  of precipitation is primarily influenced by the amount effect and El Niño  
21 Southern Oscillation (ENSO) dynamics where El Niño leads to decreased rainfall whereas La  
22 Niña leads to increase rainfall. The  $\delta\text{D}_{\text{wax}}$  takes on the primary source water signal, but is in  
23 addition influenced by evaporation in soils (Smith and Freeman, 2006) and transpiration  
24 (Kahmen et al., 2013). Altogether,  $\delta\text{D}_{\text{wax}}$  values are thus influenced by rainfall amount –  
25 greatly connected to ENSO dynamics in the region under study – and evapotranspiration,  
26 which together cause an increase in  $\delta\text{D}_{\text{wax}}$  values under dryer conditions, whereas a decrease  
27 in  $\delta\text{D}_{\text{wax}}$  values corresponds to increased rainfall (e.g. Smittenberg et al., 2011; Konecky et al.,  
28 2012; Niedermeyer et al., 2014).

## 1 **4 Methods**

### 2 **4.1 Meteorological rainfall data (instrumental records)**

3 To compare the hydroclimatic conditions from our proxies to local observations, we use a  
4 time series of annual precipitation taken from the Global Precipitation Climatology Centre  
5 (GPCC Version 6.0, <http://www.esrl.noaa.gov/psd/data/gridded/data.gpcc.html>) (Schneider et  
6 al., 2011). The dataset has a horizontal resolution of 0.5° (~50 km) and the closest grid point  
7 to the proxy is used at 8.25° N and 99.25° W. As the proxy has a resolution of about 2-5  
8 years, a 3 year-running mean for precipitation is used for the period 1901-2010.

### 9 **4.2 Methodological considerations**

10 Several studies have used qPCR methods to quantify and screen microbial population  
11 dynamics and functional gene abundance in an ecosystem due to its sensitivity. Compared  
12 with conventional PCR, qPCR is able to detect very few copies of DNA and also differentiate  
13 target DNA molecule with high repeatability. However, its sensitivity has been challenged  
14 due to method biases including sample preservation, efficiency of DNA extraction (Alain et al  
15 2011, Luna et al 2006, Miller et al 1999, Webster et al 2003, Zhou et al 1996) and specificity  
16 of selected primers (Lloyd et al 2013, Smith and Osborn 2009, Teske and Sorensen 2007,  
17 Wintzingerode et al 1997). Additionally, this method cannot distinguish between the DNA  
18 from living and dead cells and also environmental DNA (eDNA).

### 19 **4.3 Comparison between $\delta D_{wax}$ , instrumental data and ESEM analysis**

20 A general coherent trend is observed between proxy data  $\delta D_{wax}$  and the instrumental data of  
21 the annual mean precipitation up until 1901, beyond which there are no recorded instrumental  
22 data. General increase in precipitation inferred from decreasing  $\delta D_{wax}$  values from ~1900-  
23 1960 relative to a general decreasing precipitation from ~1960 to present corresponds to  
24 relatively increase in annual mean precipitation from ~1900 -1960 relative to a general  
25 decrease in annual mean precipitation. The seeming coherence between  $\delta D_{wax}$  and the  
26 instrumental data is an indication of the ability of  $\delta D_{wax}$  proxy to track precipitation. This is  
27 further substantiated when compared to the images taken during the ESEM analysis. Increase  
28 and decrease in precipitation inferred from the  $\delta D_{wax}$  corresponded with increase and decrease  
29 in fluvial deposits, respectively, as observed from the image scans of the sediments. Increase

1 in precipitation also coincided with increase in diatom diversity and bloom as was observed  
 2 both in picture scan and also the abundance of HBIs concentration, a proxy for diatoms.

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8 Table S1. Geochemistry data showing Age, Depth,  $\delta^{13}\text{C}_{\text{org}}$ ,  $\text{C}_{\text{org}}$ ,  $\delta^{15}\text{N}$ , N, C/N, S,  $\text{O}_2$  and P

Age	Depth	$\delta^{13}\text{C}_{\text{org}}$ (‰)	% $\text{C}_{\text{org}}$	$\delta^{15}\text{N}$ (‰)	% N	C/N	S	$\text{O}_2$	P
2010	0,5	-26,55	34,13	0,44	3,80	8,98	5,20	45,93	0,77
1997	6,5	-26,56	36,68	0,64	3,81	9,62			
1988	10,5	-26,81	36,08	0,67	3,77	9,56	6,17	47,80	0,90
1982	13,5	-26,76	35,93	0,71	3,77	9,53	5,17	46,53	0,73
1974	17,5	-26,86	35,88	0,81	3,72	9,65	5,27	47,17	0,83
1957	25,5	-27,73	34,96	0,63	3,47	10,09	5,07	47,10	0,70
1948	29,5	-27,94	35,94	0,52	3,22	11,17	4,77	47,57	0,47
1935	35,5	-27,99	35,61	0,49	3,36	10,61	5,67	48,27	0,53
1920	42,5	-28,14	36,25	0,38	3,33	10,87			
1912	46,5	-28,24	37,00	0,34	3,15	11,75	5,10	48,60	0,73
1901	51,5	-29,35	37,37	0,23	3,50	10,69	6,10	48,20	0,50
1882	60,5	-29,84	38,82	0,08	3,31	11,71	5,47	47,53	0,47
1871	65,5	-33,03	39,74	-0,70	3,09	12,87	6,77	48,07	0,60
1861	70,5	-30,52	31,55	-0,51	2,33	13,55	4,10	48,73	0,37
1855	73,5	-31,28	31,17	-0,47	2,56	12,16			

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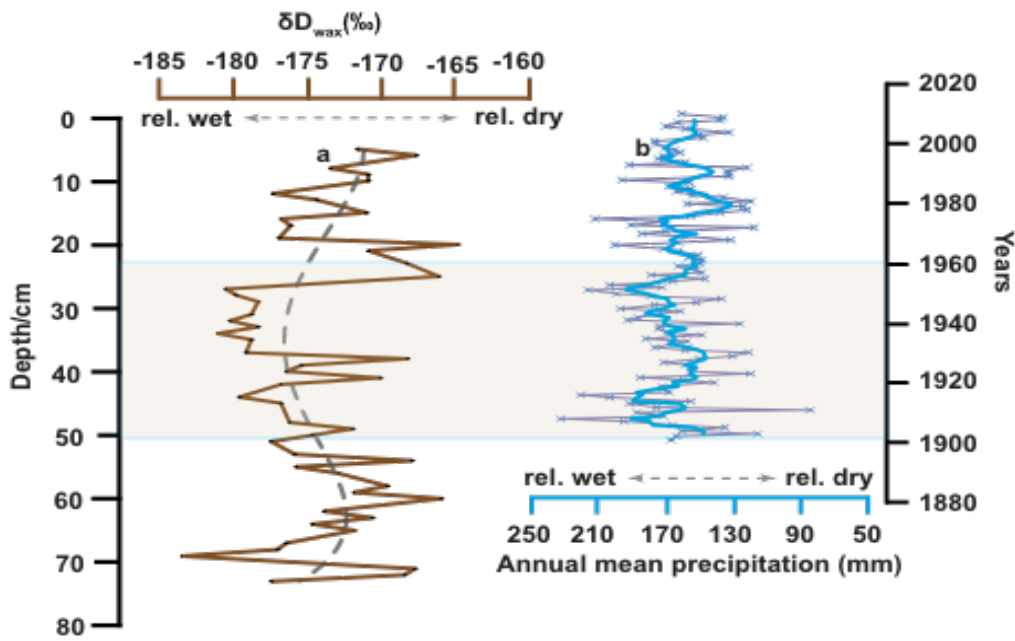
1 Table S2. Biomarker data ( $\mu\text{g/g}$  dry sample) and hydrogen isotopes of  $\text{C}_{27}\text{-C}_{31}$  *n*-alkanes (VSMOW  
2 ‰). n.d. = not detected;  $< 0.1 \mu\text{g/g}$  dry sample. Estimated standard error for the biomarker based on  
3 prior results is 5% and the average standard deviation for hydrogen isotopes is 4‰.

Age	Depth	$\text{C}_{17}$ <i>n</i> -alkanes	Total Botryococcenes	$\text{C}_{25}$ HBI	$\delta\text{D}$ of $\text{C}_{27}\text{-C}_{31}$ <i>n</i> -alkanes
2008	1,5				
2006	2,5	53,8	1,3	73,8	
2001	4,5	49,7	0,9	59,7	-172
1999	5,5	2,0	1,1	59,0	-168
1995	7,5	39,4	1,4	64,3	-174
1993	8,5	43,2	2,2	92,7	-171
1991	9,5	36,3	1,8	71,5	-171
1986	11,5	31,5	2,0	79,9	-178
1984	12,5	31,1	1,9	69,0	-175
1980	14,5	31,8	2,4	96,5	-171
1978	15,5	28,4	2,3	139,5	-177
1976	16,5	7,0	n.d	n.d	-176
1972	18,5	20,5	1,7	73,3	-177
1969	19,5	17,5	1,8	68,9	-165
1967	20,5	17,6	1,5	76,7	-171
1963	22,5	16,7	2,4	143,5	-168
1961	23,5	12,7	2,5	159,4	
1959	24,5	13,2	3,2	201,1	-166
1955	26,5	6,8	3,3	215,7	-181
1952	27,5	4,1	2,8	177,5	-180
1950	28,5	4,0	3,1	179,7	-179
1946	30,5	2,6	3,1	180,5	-179
1944	31,5	2,4	3,0	177,4	-180
1942	32,5	2,5	4,0	213,8	-178
1940	33,5	2,2	2,9	n.d	-181
1938	34,5	1,7	2,9	165,4	-179
1933	36,5	1,6	3,6	89,6	-179
1931	37,5	1,5	3,6	151,3	-168
1929	38,5	2,0	4,8	n.d	-176
1927	39,5	1,9	4,5	147,8	-177
1925	40,5	1,7	4,8	147,3	-170
1923	41,5	1,5	3,9	160,1	-177
1918	43,5	0,3	2,7	21,5	-180
1916	44,5	0,6	4,1	28,2	-177
1914	45,5	0,5	3,7	25,5	
1910	47,5	0,5	4,2	25,0	-176
1908	48,5	0,6	5,7	24,5	-172
1906	49,5	0,5	6,3	17,5	-175
1903	50,5	0,6	7,3	16,4	-178
1899	52,5	0,5	8,7	12,7	-176
1897	53,5	0,3	4,9	6,2	-168
1895	54,5	0,3	6,3	5,9	-176
1893	55,5	0,4	8,4	8,7	-173
1889	57,5	0,7	8,5	9,8	-170
1886	58,5	0,5	6,3	8,2	-172
1884	59,5	0,5	7,6	9,2	-166
1880	61,5	0,4	8,5	4,7	-174
1878	62,5	0,4	10,5	5,0	-171
1876	63,5	0,4	7,8	6,0	-175
1874	64,5	0,4	5,2	5,5	-172
1869	66,5	0,6	8,4	8,0	-177
1867	67,5	0,6	7,0	8,7	-177
1865	68,5	0,4	5,1	10,6	-184
1861	70,5	0,3	4,4	12,2	-168
1859	71,5	0,3	4,5	11,2	-169
1857	72,5	0,3	5,3	11,1	-178

1 Table S3. QPCR data showing Archaea, Bacteria, Cyanobacteria, Eukarya, Diatoms,  
 2 Botryococcus and *mcrA* genes abundance.

Age	Archaea		Bacteria		Cyanobacteria		Eukarya		Diatoms		Botryococcus		mcrA	
	abundance cells g-1	Standard error	abundance cells g-1	Standard error	abundance cells g-1	Standard error	absolute abundance cells g-1	Standard error	absolute abundance cells g-1	Standard error	absolute abundance cells g-1	Standard error	absolute abundance cells g-1	Standard error
2010	7,14E+09	7,56E+08	2,97E+11	3,22E+10	7,94E+10	1,64E+10	1,55E+10	3,86E+09	1,68E+08	2,69E+07	1,16E+11	6,39E+09	6,10E+08	3,91E+07
1997	6,18E+09	2,26E+08	2,35E+11	1,28E+10	5,23E+10	3,81E+09	8,96E+09	2,49E+09	9,01E+07	1,76E+07	9,14E+10	1,42E+10	3,39E+08	1,86E+07
1988	1,16E+10	1,00E+09	3,25E+11	3,53E+10	3,58E+10	2,07E+09	1,15E+10	1,71E+09	1,62E+08	1,73E+07	2,88E+10	2,94E+09	4,79E+08	1,85E+07
1982	6,18E+09	6,85E+08	2,03E+11	1,92E+10	1,05E+10	4,47E+08	3,90E+09	6,26E+08	4,22E+07	6,92E+06	7,03E+09	7,99E+08	1,40E+08	4,70E+07
1974	7,39E+09	1,30E+09	2,25E+11	1,07E+11	1,85E+10	4,46E+09	1,00E+10	1,00E+09	1,59E+08	1,99E+07	3,01E+10	4,85E+08	4,04E+08	8,33E+07
1957	4,30E+08	4,00E+07	7,67E+09	7,30E+08	2,95E+08	4,00E+06	2,49E+08	5,38E+07	5,11E+06	1,24E+06	2,98E+08	8,72E+07	1,22E+07	1,31E+06
1948	1,69E+10	3,29E+09	5,73E+11	1,48E+10	7,54E+09	6,24E+08	1,32E+10	9,16E+08	1,15E+08	2,25E+07	2,41E+09	2,69E+08	4,74E+08	1,52E+07
1935	6,72E+08	3,53E+07	1,80E+10	8,31E+08	2,21E+08	9,64E+06	1,68E+08	1,78E+07	2,27E+06	3,08E+04	1,40E+08	6,24E+07	9,73E+06	1,21E+06
1920	3,20E+07	2,27E+06	3,61E+08	1,60E+08	5,26E+06	1,81E+06	8,85E+06	9,86E+05	ND		1,78E+07	3,08E+07	5,25E+05	1,54E+05
1912	6,91E+09	2,29E+09	1,54E+11	2,95E+10	2,72E+09	1,18E+08	4,11E+09	3,24E+08	5,58E+07	5,18E+06	1,36E+09	6,93E+07	1,82E+08	7,43E+07
1901	4,51E+08	9,32E+07	8,10E+09	3,76E+08	2,08E+08	2,02E+07	1,20E+08	3,17E+07	8,21E+05	5,43E+04	6,96E+07	4,37E+07	4,62E+06	1,24E+06
1882	4,48E+09	3,37E+08	1,03E+11	1,38E+10	1,01E+09	1,51E+08	3,57E+09	7,96E+08	1,57E+07	3,67E+06	2,07E+09	3,21E+08	1,39E+08	1,89E+07
1871	2,34E+10	1,79E+09	2,86E+11	4,66E+09	3,84E+09	2,73E+08	6,57E+09	3,87E+09	4,96E+07	7,55E+06	6,77E+09	9,98E+08	5,26E+08	1,01E+08
1861	5,51E+09	5,52E+08	8,37E+10	1,98E+09	6,51E+08	4,74E+07	3,05E+09	2,26E+08	2,73E+07	3,08E+06	2,49E+10	3,35E+09	1,62E+08	1,26E+07
1855	1,13E+10	3,45E+08	2,33E+11	1,14E+10	7,41E+08	1,53E+08	1,12E+10	6,92E+08	5,18E+07	3,69E+06	1,08E+11	1,17E+10	3,09E+08	1,55E+07

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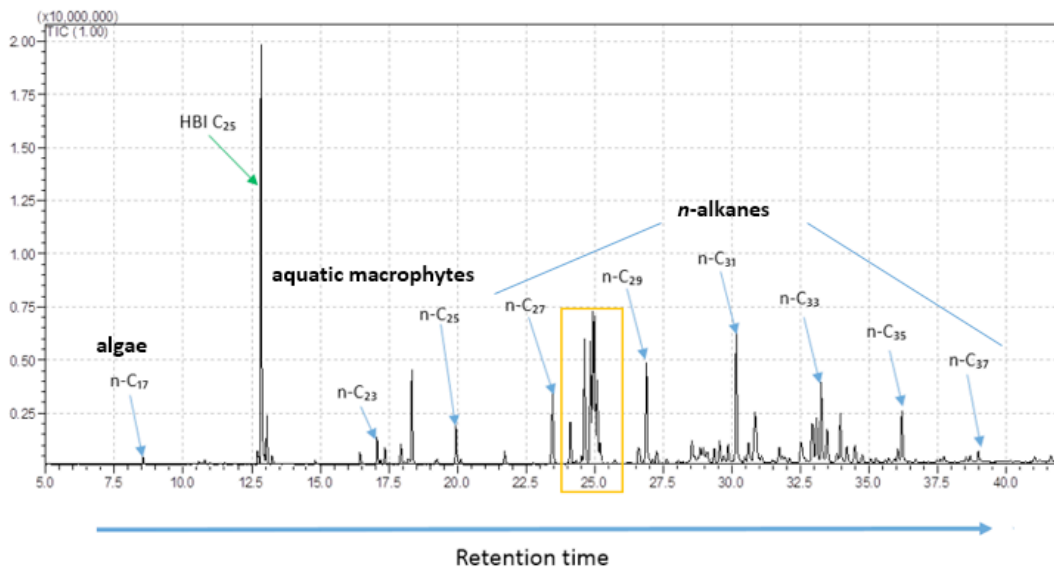
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2 Figure S1. A comparison between proxy data (a)  $\delta D_{wax}$  and instrumental data (b) Annual mean  
 3 precipitation. The dashed line represents the polynomial fit.

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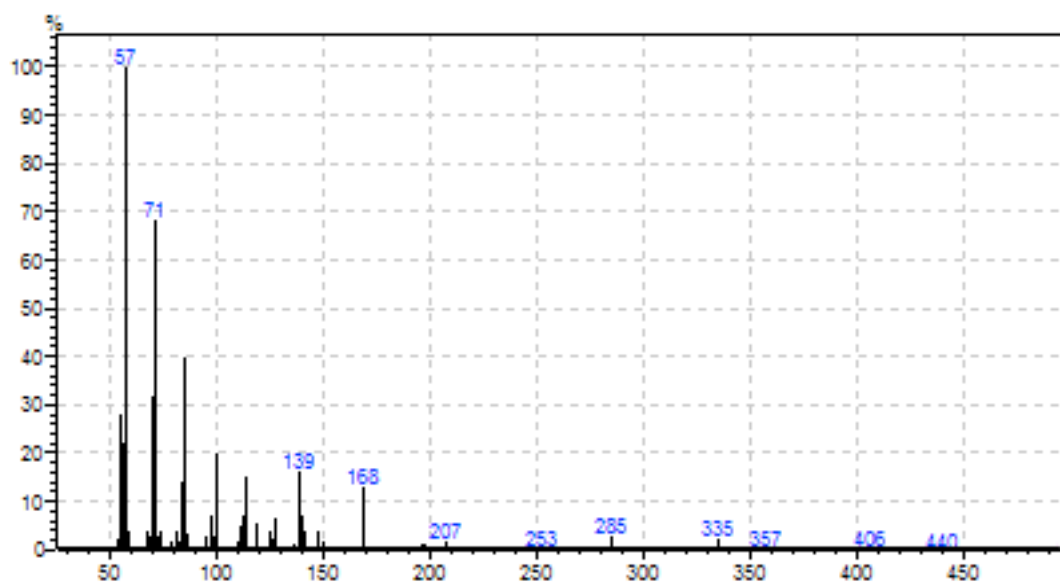


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8 Figure S2. A GC-MS chromatogram of Nong Thale Pron sample, depth 70.5 cm. X-axis=  
 9 retention time [min] and y-axis= abundance of compound. Chromatograms in yellow box  
 10 represent botryococenes (details below).



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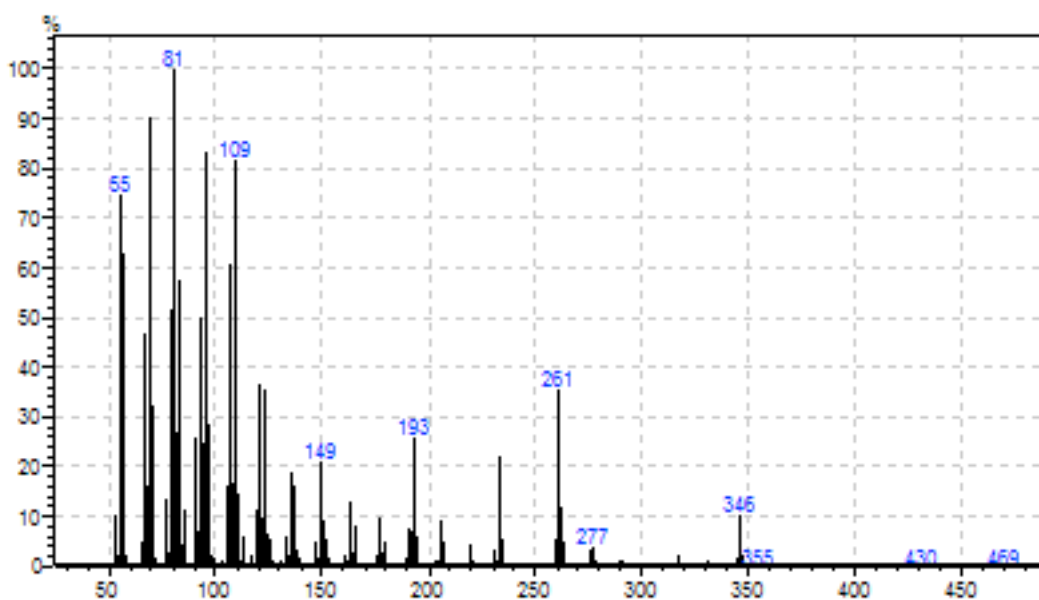
3 Figure S3. Spectrum showing the C<sub>17</sub> n-alkane, the x-axis= molecular mass while the y-axis= the ratio  
4 of intensity of abundance in the molecule.

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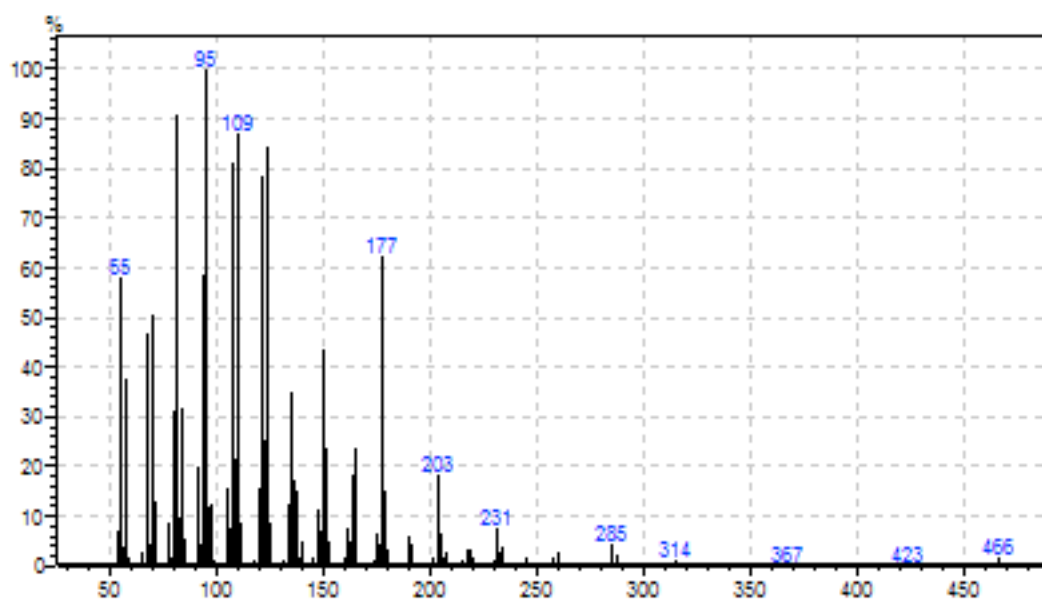


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10 Figure S4. Spectrum showing the C<sub>25</sub> Highly branched Isoprenoid (HBI). The x-axis= molecular mass  
11 while the y-axis= the ratio of intensity of abundance in the molecule.

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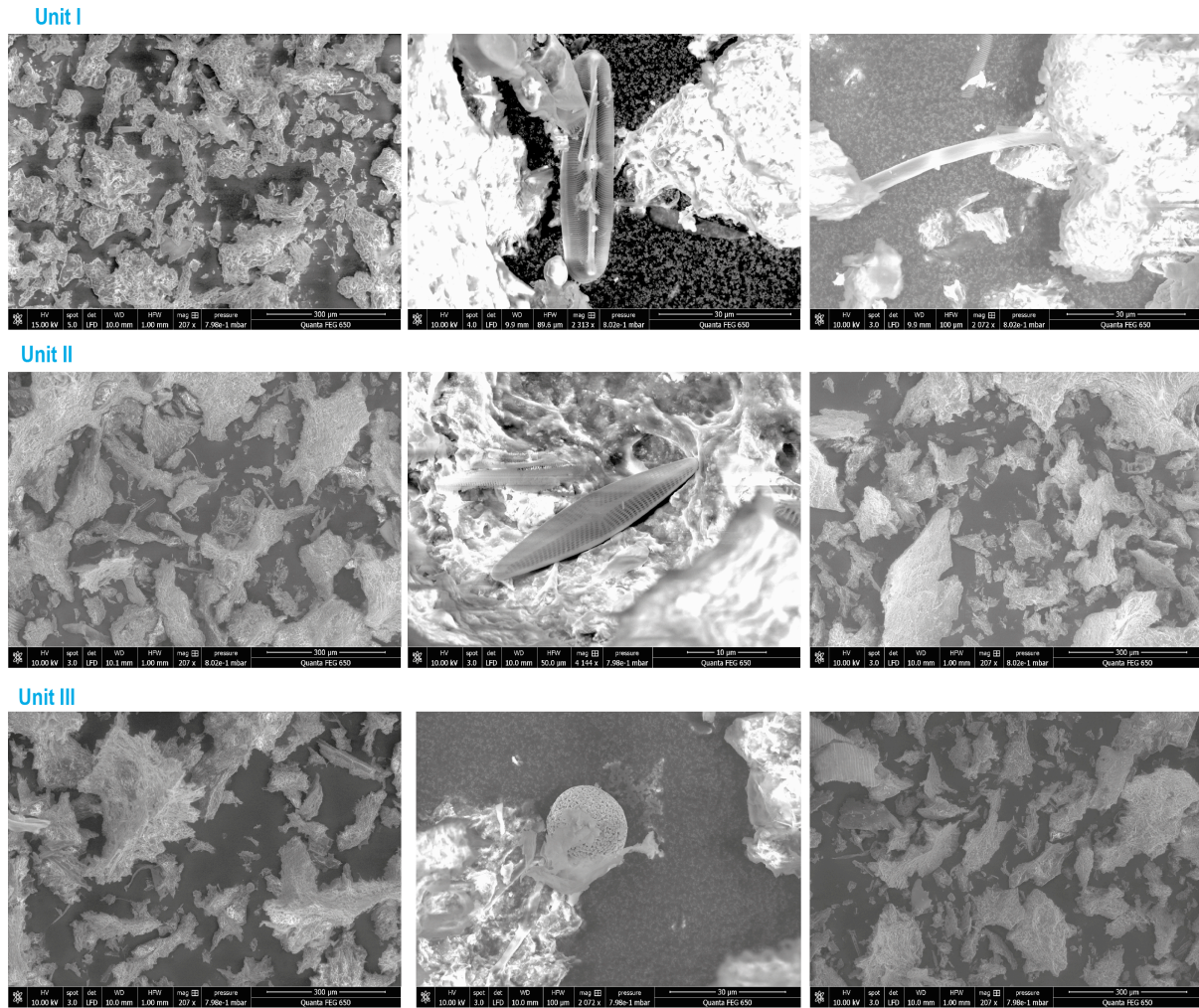
4 **Figure S5.** Spectrum showing the C34:5 monocyclic Botryococcene, with x-axis= molecular mass  
5 while the y-axis= the ratio of intensity of abundance in the molecule.

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2 **Figure S6.** Examples of electron scan images of the sediment samples showing different  
3 morphologies' or tests of diatoms

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