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Diatom-Based Paleoenvironmental Reconstruction of Lake Telmen for the Last 6230 Years

N. Soninkhishig*, M. B. Edlund and J. A. Peck*****

**Department of Botany, Faculty of Biology, National University of Mongolia, Ulaanbaatar 210646, Mongolia e-mail: Soninkhishig2000@yahoo.com*
***St. Croix Watershed Research Station, Science Museum of Minnesota, 16910 152nd St. N., Marine on St. Croix, Minnesota 55047, USA e-mail: mbedlund@smm.org*
****Office for Terrestrial Records of Environmental Change, Department of Geology, University of Akron, Akron, OH 44325-4101, USA e-mail: jpeck@uakron.edu*

Abstract

The preserved diatom flora in a 14C dated (0-6230 yBP), 343 cm long core sequence from Lake Telmen, Mongolia, was investigated to determine the nature of the lake-ecosystem and watershed response to Late Holocene climate change. Modern Lake Telmen is a slightly saline (presently 4 g L-1) closed-basin lake located along a N-S and E-W aridity ecotone in north-central Mongolia, making it sensitive to climate-driven changes in effective moisture balance. Diatoms were not preserved regularly in two areas of the Lake Telmen sediment record (5380-4150 yBP and 1050-425 yBP) possibly due to high carbonate preservation; however, diatom preservation between these areas was good to excellent. Diatom-based paleosalinity reconstruction using species-specific salinity optima from the Northern Great Plains of North America and community analysis suggests the following climate-lake response model during the Late Holocene. From 6230 to 5520 radiocarbon years ago, warm-dry climate resulted in a small salty (20 g L-1) lake in the Telmen basin that was dominated by high salinity indicator species (e.g. *Cyclotella caspia, Navicella pusilla, Brachysira aponina*). From 3860 to 1200 radiocarbon yBP, Lake Telmen recorded a period of a modulating climate that resulted in regular fluctuations in paleosalinity from 2 to 4 g L-1 in conjunction with lake level changes. Dominance in the diatom flora fluctuated between the freshwater planktonic form *Cyclotella bodanica* var. *affinis* and the salinity-tolerant benthic taxon *Anomoeoneis sphaerophora* f. *costata* during this period characterized by generally more humid climatic periods interspersed with dry-as-present conditions. The most modern samples (0-250 yBP) preserve floristic assemblages similar to those found between 3860 to 1200 radiocarbon yBP and indicate that as recently as 250 years ago Lake Telmen had lower salinity values than modern day.

Key words: Diatoms, saline lake, paleosalinity, paleoclimate reconstruction

Introduction

The assemblages of diatoms preserved in lake sediments can directly reflect the floristic composition and productivity of the lake diatom communities, and can indirectly reflect lake water quality, especially pH, alkalinity, nutrient status, and salinity (Battarbee, 1991). Among the fossils contained in lake sediment, diatoms are probably the most sensitive indicators of limnological change because of their widespread distribution, diversity, and rapid response to water chemistry change (Fritz *et al*., 1993). Variation in moisture balance results in lake level changes, concentration or dilution of ionic composition, and changes in groundwater inputs. Among the common ecological gradients in aquatic systems, diatom distribution is especially responsive to gradients of conductivity, salinity, and ionic composition (Cumming *et al*., 1995), thus responses to climate change are often faithfully recorded in closed basin systems.

Lake Telmen (in Khangai Province, Mongolia) has two characters especially suitable for paleoclimate study. First, hydrological closed lakes represent a sensitive balance between climate parameters such as evaporation, precipitation, and temperature. Small changes in these parameters can result in large sedimentary, biological, and geochemical changes in closed basins (Kelts, 1997;

Williams, 1991). Second, Lake Telmen is located near to the major ecosystem boundary between the Khangai Mountain and Valley of the Lakes depression, which make it a particularly sensitive recorder of climate (Peck *et al.*, 2002).

A qualitative lake level history of Lake Telmen has recently been reconstructed based on historical basin morphometry and multiproxy geological and biological sedimentary signals (Peck *et al.*, 2002). Two 14-C dated cores recovered from the central basin of Lake Telmen, recovering three main downcore units (Peck *et al.*, 2002) (Fig. 2). Multiproxy analysis associated each unit with three major climatic periods that have impacted north central Mongolia over the last 6230 years.

From 6230 to 5520 radiocarbon yBP (Unit C, depth 308-328 cm), Lake Telmen was at least 14 m shallower than the present, reflecting a substantial decrease in the effective moisture balance. This conclusion was supported by the very compact silty brown mud with gypsum in the core, the diatom assemblage with *C. caspia* as a dominant species which is indicative of saline conditions of about 20 g L-1 and the pollen assemblage contained abundant *Artemisia* and Chenopodiaceae relative to Gramineae, which is indicative of arid conditions.

Between 5520 and 3960 radiocarbon years (Unit B, depth 232-308 cm) Lake Telmen had risen slightly and was about 14 m shallower than present. Sedimentation abruptly changed from very compact silty brown mud with gypsum to gray-white sediment, which displays the highest values of wet bulk density (WBD), dry bulk density (DBD) and CaCO3, and the lowest average values of loss-on-ignition (LOI) organics. The pollen assemblage was very similar to that found in Unit C, indicating arid conditions and poor, unstable, dusty soils in the watershed.

Since 3960 radiocarbon years (Unit A, depth 0-232 cm), effective moisture balance increased. Lake Telmen was often deeper than the present day lake between 1300-2370 yBP. Wetter conditions were indicated by an increase in Gramineae relative to *Artemisia* and Chenopodiaceae and fluctuating hydrologic conditions by the diatom taxa preserved between 1600-2700 yBP. The steppe-forest pollen index revealed a more substantial increase in wetness above 100-120 cm and 40 cm depths.

In this paper, we present further detailed paleoecological analysis of the diatom record from a 14-C dated Lake Telmen core sequence covering the last 6230 years. Paleosalinity reconstructions for Lake Telmen are presented using species salinity optima models generated with weighted averaging regression and calibration (Birks *et al.*, 1990) from the ecologically similar region of the North American Great Plains (Fritz *et al.*, 1993). This study further represents the first synoptic survey of the diatom flora of Lake Telmen. Biogeography and taxonomy of the flora are noted in relation to application of North American paleosalinity models.

Study Area

Lake Telmen is located in Khangai Province of Mongolia (48°50'N, 97°20'E, 1789 m a.s.l.) in the North Khangai physic-geographical mountain region, and it is the biggest lake in this region. The lake is located between the Tarvagatai and Khangai Mountain ranges and receives fluvial input from rivers draining the Tarvagatai and Khangai Mountains mainly from Khooloin Gol and has no outflow (Tserensodnom, 1970; Fig. 1).

Lake Telmen has shore length of 93.4 km, maximum length of 26 km (E-W), mean width of 12 km (N-S), and maximum width of 16 km. Mean depth is 13 m and the maximum depth is 27 m within the central basin. Lake Telmen drains a watershed of 3940 km^3, has surface area of 194 km^2 including islands, and volume of 2.671 km^3. Modern Lake Telmen is classified by its $Na(Mg)SO_4(CO_3)$ ion dominance and has mineralization of 7.69 g L-1 and pH 9.2, (Tserensodnom, 2000).

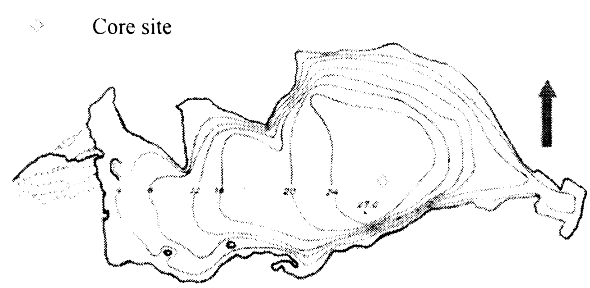

Fig. 1. Lake Telmen bathymetry map (from Tserensodnom, 1970) with core sample location.

Modern water balance in Lake Telmen can be broken down as annual precipitation falling on the lake surface of 190 mm y-1 (0.036 km3 y-1), incoming waters (surface and groundwater inputs) of 620 mm y-1 (0.120 km3 y-1), and losses from evaporation totaling 810 mm y-1, (0.156 km3 y-1). In summer, surface water temperature reaches 15°C with a thermocline (metalimnion) formed at 14 m depth overlying 4°C hypolimnetic waters. Summer Secchi disk readings are 3-5 m. By the end of hydrologic summer, the metalimnion is located directly at the bottom of the water column (Tserensodnom, 2000).

Materials and Methods

During summer 1999, two cores, TN99C1 (1.85 m) and TN99C4 (3.28 m) were recovered using a modified Kullenberg corer from Lake Telmen's central basin from water depth of 24.54 m. (Fig. 1). The two cores were correlated using several lithological parameters (wet bulk density, magnetic susceptibility) and determined to have recovered a total sediment length of 343 cm (Peck *et al.*, 2002). AMS radiocarbon dating was based on sediment humic acid from six subsamples taken at mean sediment depths of 38.5, 78.5, 138.5, 182, 239, and 336 cm (Peck *et al.*, 2002). Additional biological and geochemical analyses that cores C1 and C4 are discussed elsewhere (Peck *et al.*, 2002).

Diatom subsamples were taken mainly from 10 cm intervals along the entire core sequence. Sediment samples were oxidized in concentrated nitric acid to remove organic materials. Oxidation byproducts were removed by rinsing material six times with distilled water. The remaining material and diatoms were air-dried onto cover slips. Cover slips were mounted on microscope slides with Naphrax and studied with immersion objectives at 1250x magnification. A minimum of 600 recognizable valves was counted from each core section unless samples contained few or no diatom remains. In the case of few remains, an entire 22x22 mm cover slip was scanned at 1250x magnification. Counts were converted to percent abundance relative to the total number of valves.

To detect relationship between communities in the different depths and the paleoenvironment have used an average- linkage clustering (Jongman *et al.*, 1987).

Paleosalinity reconstruction applied weighted averaging calibration (Birks *et al.*, 1990) to downcore diatom relative abundance using diatom salinity optima taken from a dataset generated using weighted averaging regression of diatom assemblages and environmental variables collected from 39 lakes across the North American Northern Great Plains (Fritz *et al.*, 1993). The model's inverse deshrinking equation which is necessary for final calculation of downcore paleosalinity was not given in the original manuscript, thus our paleosalinity calculations represent best approximations (Birks *et al.*, 1990).

Results

1. Lithological units and diatom preservation.

The 343 cm long lacustrine core from Lake Telmen displays three distinct lithological units Peck *et al.*, 2002). In Figure 2, a relationship is shown between these units and diatom preservation. Unit C, the compact light brown silty sediment, corresponds to a period of good diatom preservation with abundant microfossils below 308 cm depth (5520-6230 yBP). Unit B (232-308 cm, 3960-5520 yBP) corresponds to a period of poor diatom preservation. In this unit we were not able to find any siliceous microfossils. Sedimentological study of Unit B showed that the WBD, DBD and CaCO3 display the largest values, whereas LOI organics display the lowest average values in this unit. Unit A (0-232 cm depth, last 3960 yBP) contains two periods of diatom preservation and fossils showed signs of dissolution. The lower preservation peak in Unit A (75-227 cm depth, 1204-3863 yBP) is separated from the uppermost preservation peak (5-15 cm depth, 91-257 yBP) by a period of poor diatom preservation.

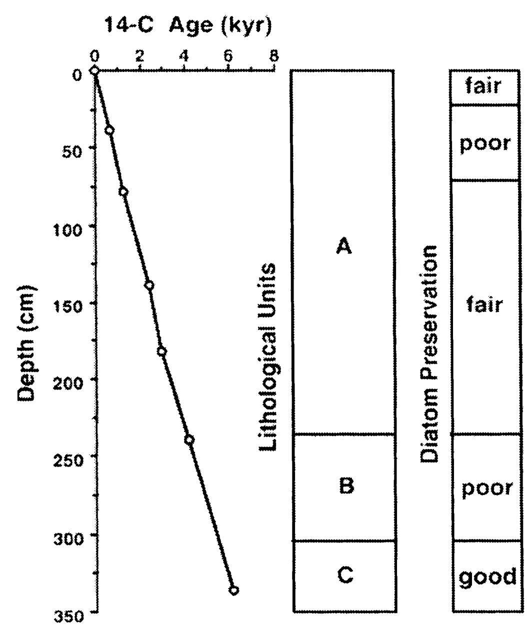

Fig. 2. Comparison of lithological zones and diatom preservations

The 343 cm long sediment core that was analyzed from Telmen Lake contains 65 diatom species (Tables 1 and 2) composed of five assemblage groups that were identified by cluster analysis (Fig. 5). Group 5 (Unit C) was dominated by *Cyclotella caspia* while all other groups (Unit A) were dominated by *Cyclotella bodanica* var. *affinis*. Each group was overwhelmingly dominated by one planktonic taxon. The occurrence of similar assemblage groups at other core depths is discussed.

2. Downcore distribution of specific taxa.

Downcore abundances of 32 diatom taxa that were present at >1 % relative abundance in at least one sample are presented in Figures 3 and 4. The downcore distribution, ecology, and biogeography of 19 taxa used in the cluster analysis (Fig. 5) will be presented in detail.

Achnanthes brevipes was distributed in the all depths of Unit C. Relative abundance increased upcore from 1.33 % 341.5 cm depth to 4.77 % at 311.5 cm depth. Depths with highest abundance of this taxon (311.5 and 321.5 cm) belong to the cluster analysis zone 5. *Achnanthes brevipes* is a cosmopolitan diatom distributed along the sea shore, streams, closed basin salty water bodies (Krammer & Lange-Bertalot, 1991b) and in Mongolia reported in a salty lake (Edlund *et al.*, 2001).

Achnanthidium minutissimum was rare and only single valves were reported in each of three samples in Unit A. Relative abundance reach a 28.57 % at 207.5 cm depth where we found very few microfossils. A sample with high abundance (7.14 %) of *A. minutissimum* at 95.5 cm depth is linked in cluster analysis zone 4 and also an influential contributor in the outlier at 207.5 cm. This is an ecologically indifferent cosmopolitan diatom occurring at pH 4.3-9.2 (Krammer & Lange-Bertalot, 1991b), salinities below 0.5 g L-1 (Vam Dam *et al.* 1994) and has been reported in Mongolia (Ulziikhutag & Tsetsegma, 1980).

Amphora libyca is one of the most common taxon in the upper core and recorded in the 11 samples in Unit A. Its high abundances at 15.5 (6.06 %) and 105.5 (2.96 %) cm depths help link sample depths in cluster analysis zone 1, 175.5 and 186.5

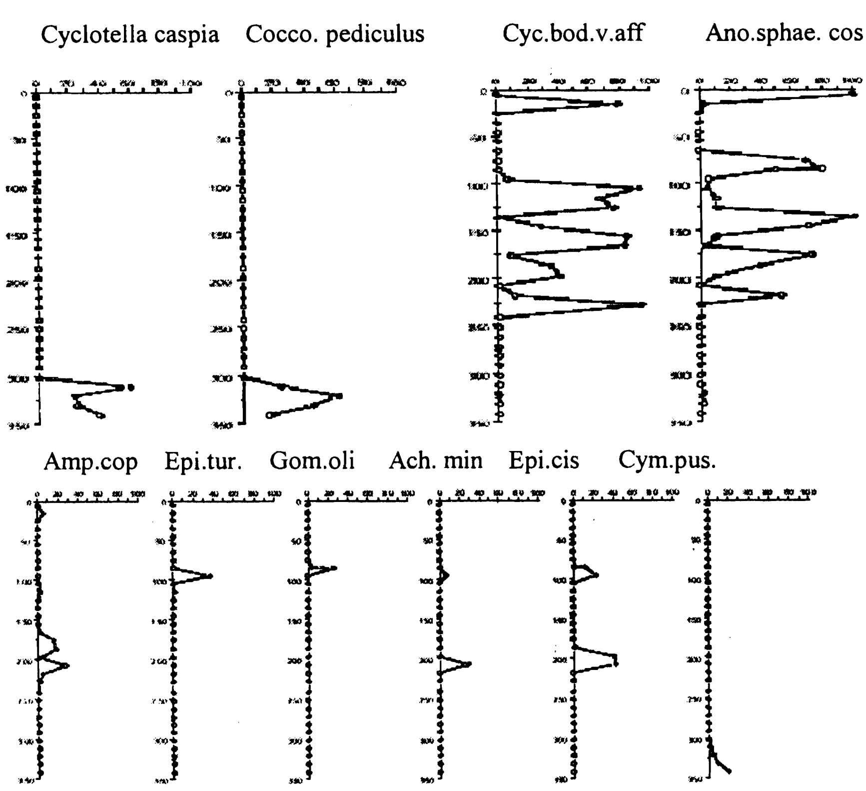

Fig. 3. Down core distribution of diatom taxa with >15% of relative abundance

cm are linked in cluster zone 3, and 207.5 cm as the outlier. This is a common species in waters with middle and high conductivity, in saline waterbodies (Krammer & Lange-Bertalot, 1997a), and in Mongolia (Ulziikhutag & Tsetsegma, 1980). It has *sphaerophora* f. *costata* were linked in cluster analysis zones 2 and 3. This taxon is widely distributed in waters with middle and high conductivity, especially brackish, coastal and closed basin salty waters both worldwide (Patrick &

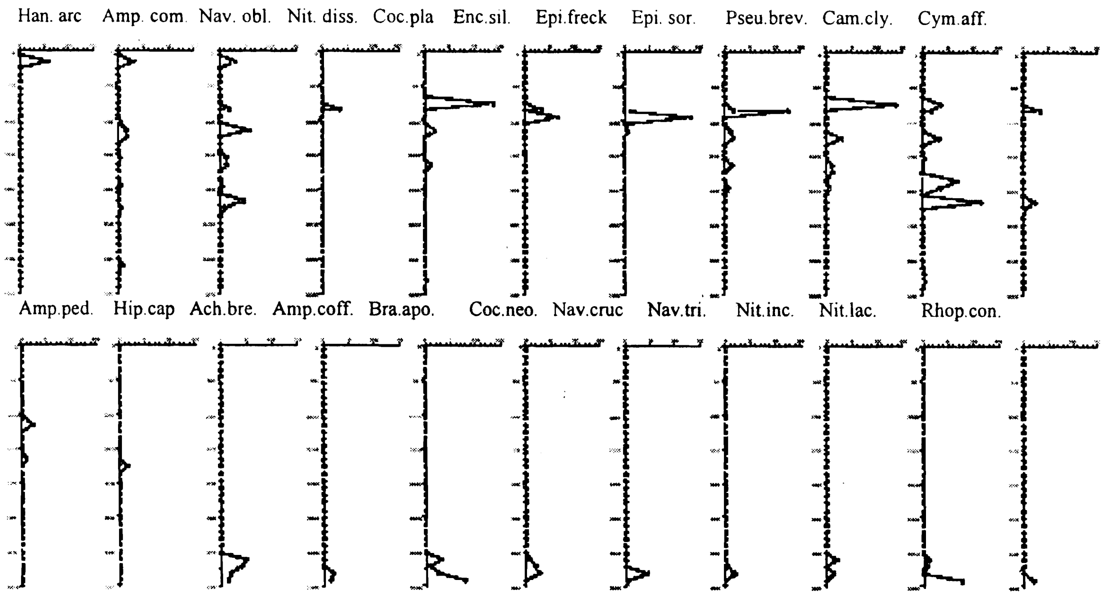

Fig. 4. Down core distribution of diatom taxa with >1% of relative abundance

a salinity optimum 2.95 g L-1 (Fritz *et al.*, 1993).

We found *Anomoeoneis sphaerophora* f. *costata* in all diatom-containing samples except 207-208 cm with relative abundances varying between 0.15 % and 100 %. It was especially abundant in upcore Unit A. Samples with high abundance of *A.*

Reimer 1966; Krammer & Lange-Bertalot, 1997a) and in Mongolia (Ulziikhutag & Tsetsegma, 1980). *Anomoeoneis sphaerophora* f. *costata* is extremely resistant to fluctuations in the osmotic potential of its environment (Round *et al.*, 1990)

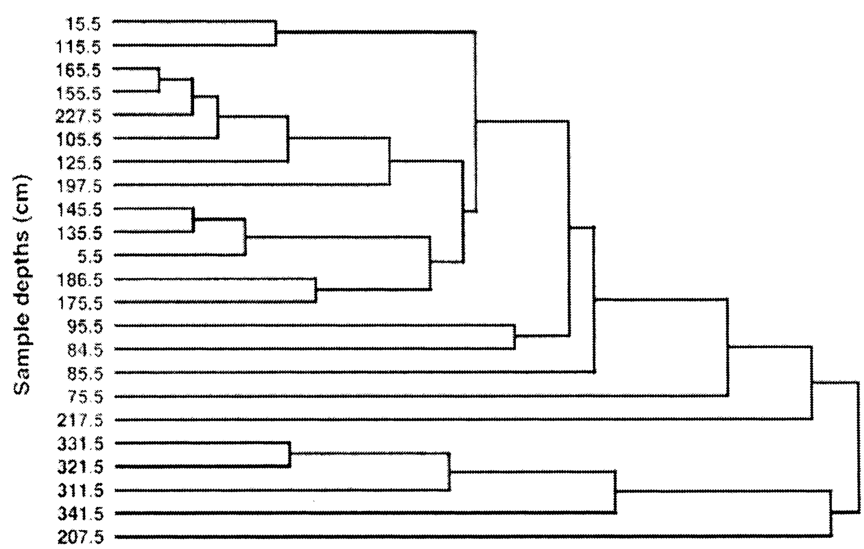

Fig. 5. Complete linkage cluster analysis of diatom-containing samples from Lake Telmen 1999 cores C1 and C4 (down core relative abundance of nineteen diatom taxa with two or more occurrences at >2% relative abundance were used)

Table 1. Species of the floral group-1 (showed relative abundance and optimum salinity from Fritz, 1993*)

№	Taxa	311-312 cm	321-322 cm	331-332 cm	341-342 cm	Sal.opt. gL-1
1.	*Achnanthes brevipes* C.Agardh	4.77	4	1.9	1.33	-*
2.	*Amphora coffeaeformis* (C.Agardh) Kütz.			1.76	1.33	8.46
3.	*Amphora commutata* Grunow in Van Heurck	0.77				-
4.	*Amphora holsatica* Hust.	0.615	0.15			-
5.	*Amphora montana* Krasske			0.54	0.8	-
6.	*Amphora veneta* Kütz.	0.31	0.6			7.32
7.	*Anomoeoneis sphaerophora f. costata* (Kützing) Schmid	0.31	1.33	0.95	0.13	-
8.	*Brachysira aponina* Kütz.	3.23	0.88	2.44	7.86	-
9.	*Campylodiscus clypeus* Ehrenb.		0.29	0.4		-
10.	*Cocconeis neothumensis* Krammer	0.77	2.07	2.7		-
11.	*Cocconeis pediculus* Ehrenb.	24.31	61.48	45.24	17.2	16.77
12.	*Cocconeis placentula* Ehrenb.			0.27		-
13.	*Ctenophora pulchella* (Ralfs) D.M.Williams & Round	0.77	0.29		0.26	10.32
14.	*Cyclotella caspia* Grunow	59.69	22.81	25.54	40.53	21.32
15.	*Cymbella pusilla* Grunow	1.23	4.29	8.15	19.06	8.54
16.	*Cymbella* with dots			0.135		-
17.	*Diploneis marginestriata* Hustedt		0.29			-
18.	*Fallacia pygmaea* (Kütz.) D.G.Mann in Round, Crawford & Mann		0.15			-
19.	*Hippodonta hungarica* (Grunow) Lange-Bert., Metzeltin &Witkowski			0.27		3.96
20.	*Luticola mutica* (Kütz.) D.G.Mann in Round, Crawford & Mann			0.135		-
21.	*Mastogloia braunii* Grunow (Figs. 32, 33)	0.31				-
22.	*Navicula crucicula var. cruciculoides* (Brockmann) Lange-Bert.		0.15	4.35	0.4	-
23.	*Navicula sp.*		0.29	0.54		-
24.	*Navicula trivialis* Lange-Bert.		0.29	1.9		-
25.	*Nitzschia frustulum* (Kütz.) Grunow				0.53	-
26.	*Nitzschia inconspicua* Grunow	1.85		1.35		16.45
27.	*Nitzschia lacuum* Lange-Bert.	1.08	0.6		7.73	-
28.	*Nitzschia obtusa* W.Sm.				0.8	11.11
29.	*Nitzschia solita* Hust.			0.81		-
30.	*Nitzschia subacicularis* Hust.			0.54		2.17
31.	*Rhopalodia constricta* (W.Smith) Krammer				2	-

* - some values are not available in Fritz, 1993

and has a salinity optimum of 3.76 g L-1 (Fritz *et al.*, 1993).

Brachysira aponina is one of the most abundant taxa throughout the depths of Unit C. Relative abundance was between 0.88 % at 321.5 cm depth and 7.86 % at 341.5 cm depth. *Brachysira aponina* is one of most common taxa in the cluster zone 5. This taxon is distributed in waters with high or hyperconductivity (Krammer & Lange-Bertalot, 1997a) and has been reported in Mongolia (Edlund *et al.*, 2001).

Caloneis westii is reported mostly from downcore samples of Unit A. The relative abundance increased downcore from 0.16 % at 115.5 cm to 11.63 % at 217.5 cm depth. The highest relative abundances were at 125.5 and 217.5 cm depths within cluster zones 2 and 4. *Caloneis westii* is a cosmopolitan diatom distributed in the sea, coastal waters and high conductivity inland waters (Krammer & Lange-Bertalot, 1997a). This taxon

Table 2. Species of the floral group-2 (showed relative abundance and optimum salinity from Fritz, 1993*)

№	Taxa	105-106cm	115-116cm	155-156cm	165-166cm	227-228cm	Sal.opt. gL-1
1.	*Achnanthidium minutissimum* (Kütz.) Czarn.		0.32				-*
2.	*Amphora commutata* Grunow in Van Heurck	0.325	1.44	0.16		0.3	-
3.	*Amphora libyca* (Kütz.) Schoeman & R.E.M.Archibald	0.81	2.72	0.99	2.35	1.63	-
4.	*Amphora ovalis* (Kütz.) Kütz.				0.156		4.2
5.	*Amphora pediculus* (Kütz.) Grunow	0.325	2.24		0.94		4.23
6.	*Anomoeoneis sphaerophora f. costata* (Kützing) Schmid	4.39	10.4	10.9	3.44	0.15	3.76
7.	*Caloneis limosa* (Kütz.) R.M.Patrick					0.15	-
8.	*Caloneis molaris* (Grunow) Krammer in Krammer & Lange-Bert.				0.31		-
9.	*Caloneis westii* (W.Smith) Hendey	0.16	0.32				-
10.	*Campylodiscus clypeus* Ehrenb.		0.32	0.32	0.156		4.75
11.	*Cocconeis placentula* Ehrenb.	0.16	2.08		1.25		-
12.	*Cyclotella bodanica var. affinis* (Grunow) Cleve-Euler var. affinis (Grunow) Cleve-Euler	92.84	67.68	84.46	83.09	93.78	1.8
13.	*Cymbella affinis* Kütz.					0.44	-
14.	*Encyonema silesiacum* (Bleisch ex Rabenh.) D.G.Mann in Round, Crawford & Mann			0.16			2.34
15.	*Epithemia adnata* (Kütz.) Bréb.		0.96		0.62		2.17
16.	*Epithemia cistula* (Ehrenb.) Ralfs				0.31		-
17.	*Epithemia freckei* Krammer		0.64				-
18.	*Epithemia sorex* Kütz.		1.12		1.41		-
19.	*Epithemia turgida var. granulata* (Ehrenb.) Brun		1.28				-
20.	*Fragilaria capucina* Desm.			0.16			-
21.	*Gomphonema olivaceum var.minutissimum* Hustedt						-
22.	*Hannaea arcus* (Ehrenb.) R.M.Patrick						1.78
23.	*Hippodonta capitata* (Ehrenb.) Lange-Bert., Metzeltin &Witkowski						1.28
24.	*Luticola mutica* (Kützing) D.G.Mann in Round, Crawford & Mann			0.16			-
25.	*Mastogloia braunii* Grunow					0.15	-
26.	*Navicula cincta* (Ehrenb.) Ralfs in A.Pritch.					0.3	9.3
27.	*Navicula humerosa* Bréb. ex W.Sm.					0.3	-
28.	*Navicula oblonga* (Kütz.) Kütz.	0.16	5.76	1.32	1.25	0.88	2.48
29.	*Navicula vandamii* Schoeman & Archibald						-
30.	*Nitzschia capitellata* Hustedt						-
31.	*Nitzschia dissipata* (Kütz.) Grunow						0.88
32.	*Nitzschia frustulum* (Kütz.) Grunow				0.156		2.17
33.	*Nitzschia pseudofonticola* Hustedt						-
34.	*Pseudostaurosira brevistriata* (Grunow) D.M.Williams & Round			0.16	1.25		1.72
35.	*Rhoicosphenia curvata* (Kütz.) Grunow				0.31		4.38
36.	*Rhopalodia gibba* (Ehrenb.) O.Müll.				0.45		3.57
37.	*Stauroneis anceps* Ehrenb.						-
38.	*Surirella brebbissonii* Krammer & Lange-Bert.		0.16			0.3	-
39.	*Surirella striatula* Turpin (Fig. 30)				0.156		7.03
40.	*Tabellaria*						-
41.	*Tryblionella*						-

* - some values are not available in Fritz, 1993

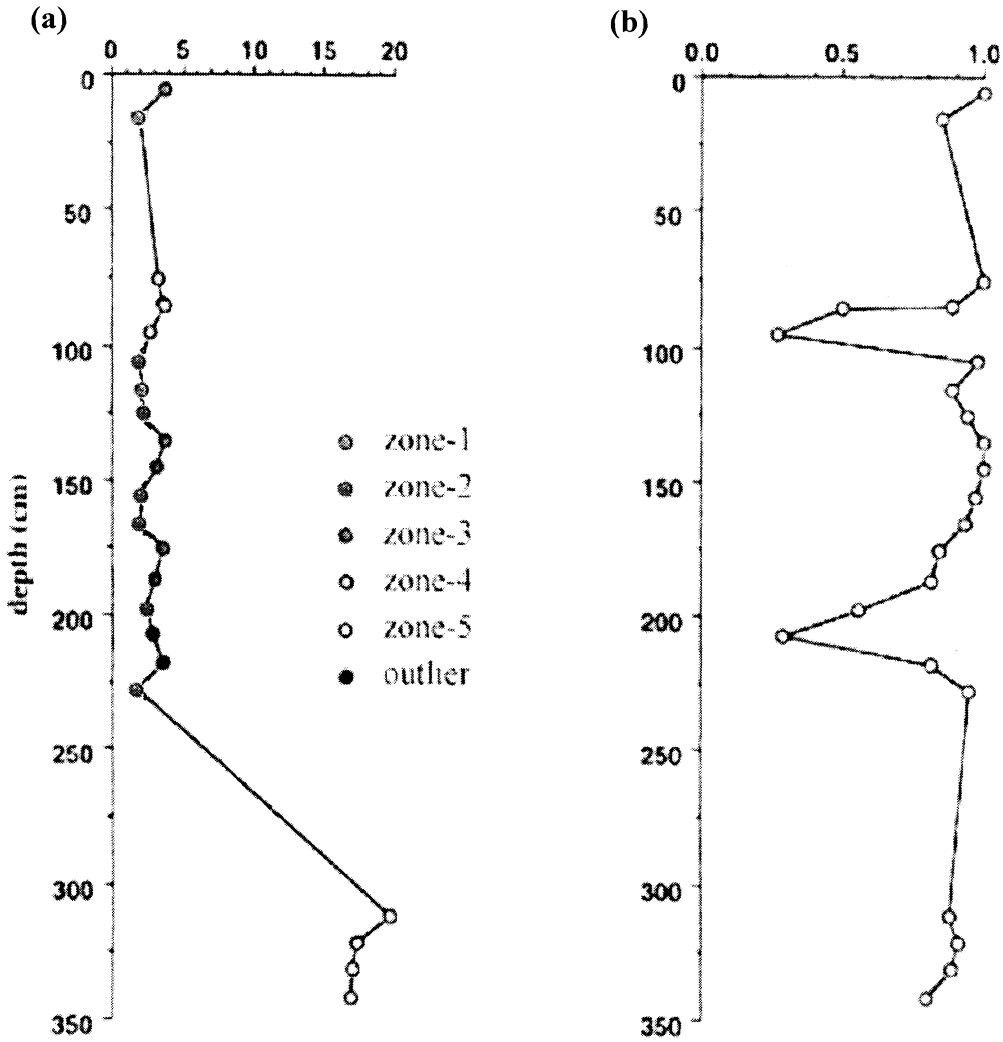

Fig 6. Diatom inferred salinity reconstruction (a) and percentage of microflora used in reconstruction (b).

is reported for the first time in the flora of Mongolia by this study.

Campylodiscus clypeus was reported in 11 samples. It is one of very few diatoms which are distributed in the both Units A and C. Relative abundance was between 0.16 % and 11.67 %. Highest abundance was at 75.5 and 217.5 cm depths, which belong to cluster zone 4, 12.5 and 197 cm depths within zone 2 and 186.5 cm depth within zone 3. *Campylodiscus clypeus* is a salt-water cosmopolitan diatom distributed in the coastal area of North and Baltic Sea and saltwater interior lakes and frequently occurs as a fossil (Krammer & Lange-Bertalot, 1997b) and in Mongolia (Ulziikhutag & Tsetsegma, 1980). Its optimum salinity is 4.75 g L-1 (Fritz et al., 1993).

Cocconeis neothumensis was reported from the first 3 depths in Unit C within cluster zone 5. Relative abundance increased downcore from 0.77 % to 2.7 %. *Cocconeis neothumensis* is probably widespread, especially in the core sediments (Krammer & Lange-Bertalot, 1991b) and in Mongolia (Soninkhishig & Edlund, 2001). It is exclusively occurring at pH>7, is an oligosaprobous, nitrogen-autotrophic taxa, and tolerates very small concentrations of organically bound nitrogen (Van Dam *et al.*, 1994).

Cocconeis pediculus is the second common taxon after *Cyclotella caspia* in all sample depths of Unit C or cluster zone 5. The maximum abundance is 61.48 % at the 321.5 cm depth. *Cocconeis pediculus* is a cosmopolitan, epiphytic diatom in the inland waterbodies with middle and high conductivity, and it is distributed in brackish and coastal waters (Krammer & Lange-Bertalot, 1991b) and in Mongolia (Ulziikhutag & Tsetsegma, 1980). Optimum salinity is 16.77 g L-1 (Fritz *et al.*, 1993).

Cocconeis placentula is found in 4 samples in Unit A and 1 sample in Unit C. Samples with high abundance of *Cocconeis placentula* were linked in cluster analysis zones 1 and 4. Maximum relative abundance was 13.79 % at 75.5 cm depth, a sample linked in cluster zone 4. This is a cosmopolitan, widely distributed diatom (Krammer & Lange-Bertalot, 1991) and has been reported in Mongolia (Ulziikhutag & Tsetsegma, 1980). Optimum salinity is 2.31 g L-1 (Fritz *et al.*, 1993).

Cyclotella bodanica var. *affinis* is the most abundant and only planktonic taxa throughout Unit A. It has been reported in 13 levels with six abundance peaks. Highest abundances are at 15.5, 105.5, 115.5, 125.5, 155.5, 165.5, 227.5 cm depths and they help define cluster zones 1 and 2. This taxon is distributed in fresh and slightly brackish water and also in fossil deposits. This is a first record in the flora of Mongolia. This species mainly occurs in pH around 7, salinity <0.5 g L-1 , and it is an oligosaprobic taxon (Van Dam *et al.*, 1994).

Cyclotella caspia is the dominant plankton diatom in the all depths of Unit C and the most common taxon in the cluster zone 5. The highest relative abundances are 59.69 % at 311.5 cm and 40.53 % at 341.5 cm depth. This diatom is widespread in brackish and marine waters and occurs in a wide range of salinity from 2-3 % to 15-20 %. Its highest abundances are usually found in the summer and autumn (Håkansson *et al.*, 1993) and it has been earlier reported in Mongolia (Edlund *et al.*, 2001).

Cymbella affinis was distributed in Unit A and from three depths. Maximum relative abundances were 3.5 % at 84.5 cm depth and 2.32 % at 217.5 cm depths. These samples belong to the cluster zone 4. *Cymbella affinis* is a cosmopolitan, epilithic and epiphytic diatom in standing and flowing waters (Krammer & Lange-Bertalot, 1997a) and has been reported earlier in Mongolia (Soninkhishig & Edlund, 2001). It mainly occurs at pH >7, salinity < 0.5 g L-1 and it is a β-mesosaprobous diatom (Van Dam *et al.*, 1994).

Navicella pusilla is one of the dominant benthic taxa in Unit C and its relative abundance increased downcore from 1.23 % (311.5 cm depth) to 19.06 % (341.5 cm depth). Highest abundances were at 321.5, 331.5 and 341.5 cm depths, which contribute to cluster zone 5. It is widely distributed and prefers high conductivity, brackish and salty inland waters. It is frequently found in lime-rich water (Krammer & Lange-Bertalot, 1997a) and has been reported in Mongolia (Soninkhishig & Edlund, 2001). Its salinity optimum is 8.54 g L-1 (Fritz *et al.*, 1993).

Encyonema silesiacum was recorded in three depths of Unit A. Maximum abundances are 3.5 % and 7.14 % at 84, 5 and 94.5 cm depths, which contribute to cluster zone 4. *Encyonema silesiacum* has a pH around 7 (Van Dam *et al.*, 1994). Salinity optimum is 2.34 g L-1 (Fritz *et al.*, 1993). This is a cosmopolitan, widely distributed diatom that prefers oligotrophic water with medium conductivity (Krammer & Lange-Bertalot, 1997a) and has been reported in Mongolia (Soninkhishig *et al.*, 2000).

Epithemia cistula was recorded at seven depths within unit A. Major peaks in relative abundances are at 85.5 cm (12.5 %) and 95.5 cm (25 %), which are linked within cluster zone 4, 197 cm (40.76 %) within zone 2 and its maximum abundance at 207 cm (42, 85 %), the outlier zone. This taxon has been reported from tropical Asia, USA, South Africa and South Europe. This is the first report of this species in the diatom flora of Mongolia.

Gomphonema olivaceum var. *minutissimum* was reported at 84 cm and 86 cm depths with 3.5 % and 25 % relative abundance. It contributes to cluster zone 4. *Gomphonema olivaceum* var. *minutissimum* is a cosmopolitan diatom distributed in inland waters, and also in the industrial waste water (Krammer & Lange-Bertalot, 1997a). This is a first record for the diatom flora of Mongolia. It occurs mainly at pH about 7, and salinity <0.1 g L-1 (Van Dam *et al.*, 1994).

Navicula oblonga was registered from nine depths in Unit A with six abundance peaks. Highest relative abundances were at 15.5 and 115.5 cm depths within cluster zone 1 and at 84.5 and 217.5 cm depths within cluster zone 4. Due to its thicker central area and general coarse structure it has been better preserved in most core depths. *Navicula oblonga* is a cosmopolitan epipelic diatom distributed in standing, alkaliphilious water with high conductivity and slightly brackish condition; it is a powerful oxygen diffuser, is sulfide hydrogen tolerant (Krammer & Lange-Bertalot, 1997a) and has been reported from Mongolia (Ulziikhutag & Tsetsegma, 1980). Its optimum salinity is 2.48 g L-1 (Fritz *et al.*, 1993).

Pseudostaurosira brevistriata was registered at six depths in Unit A with abundance peaks at 75.5 and 125.5 cm sample depths. These depths play an influential role in cluster zones 4 and 2. This is a cosmopolitan diatom that is widely distributed in inland waters and is often abundant as a fossil (Krammer & Lange-Bertalot, 1991a). It has been reported earlier from Mongolia (Ulziikhutag & Tsetsegma, 1980). Optimum salinity is 1.72 g L-1 (Fritz *et al.*, 1993). It is an oligosaprobic taxon mainly occurring at pH >7 (Van Dam *et al.*, 1994).

3. Community analysis.

Cluster analysis based on the downcore distribution of 19 taxa found with 2 occurrences at >2% relative abundance shows that the Lake Telmen diatom assemblage has fluctuated greatly in the last 6000 years (Fig. 5). Cluster analysis resolved five microfossil assemblage zones based on similarities of species makeup and relative abundance rather than identifying discrete depth-age periods (except Zone 5) in Lake Telmen's history. A summary of the samples grouped within each cluster analysis zone, and the dominant diatoms contributing to each zone, is presented below.

Cluster Zone 1 - 15.5, 115.5 cm

Zone 1 groups samples taken at 15.5 cm and 115.5 cm (Fig. 5). The diatom community of Zone 1 samples can be defined by abundance peaks of *Cyclotella bodanica* var. *affinis, Amphora libyca*, and *Navicula oblonga*.

Cluster Zone 2 - 165.5, 155.5, 227.5, 105.5, 125.5, 197.5 cm

Zone 2 groups 165.5, 155.5, 227.5, 105.5, 125.5 and 197.5 cm sample depths (Fig. 5). Zone 2 can be characterized by high abundance peaks of *Cyclotella bodanica* var. *affinis* (Fig. 3). Secondary taxa distributed in this zone include *Anomoeoneis sphaerophora* f. *costata, Amphora libyca*, and *Navicula oblonga*.

Cluster Zone 3 - 145.5, 135.5, 5.5, 186.5, 175.5 cm

Zone 3 clusters samples from 145.5, 135.5, 5.5, 186.5, 175.5 cm core depths. The most important taxon distributed in Zone 3 is *Anomoeoneis sphaerophora* f. *costata*; it was found in all Zone 3 samples at peaks of > 30% relative abundance. Other taxa distributed in Zone 3 samples include *Cyclotella bodanica* var. *affinis* and *Amphora libyca*.

Cluster Zone 4 - 95.5, 84.5, 85.5, 75.5 cm

Zone 4 group depths from 75.5 to 95.5 cm and 217.5 cm. Similar to Zone 3, Zone 4 can be characterized by two abundance peaks of *Anomoeoneis sphaerophora* f. *costata*. One peak extends from 75.5 to 95.5 cm and 217.5 cm represents a second abundance peak. Subdominant diatoms are *Gomphonema olivaceum* var. *minutum, Cocconeis placentula, Epithemia cistula, Pseudostaurosira brevistriata* and *Campylodiscus clypeus*. Sample 217.5 cm is loosely grouped in this zone; it is characterized by high abundance of *A. sphaerophora* f. *costata*. Zone 4 most closely resembles Zone 3 in the contributing taxa (Fig.4).

Cluster Zone 5 - 331.5, 321.5, 311.5, 341.5

Zone 5 clusters samples from the lowest part of the core or 311-341 cm depth (5580-6200 BP years), and had the highest order of differentiation in this analysis. The microflora was dominated by an assemblage with a downcore distribution restricted to these depths. *Cyclotella caspia* was the only plankton diatom in this zone, and the benthic taxa *Achnanthes brevipes, Brachysira aponina, Cocconeis pediculus, C. neothumensis* and *Navicella pusilla* were also restricted to these sample depths.

Cluster Outlier - 207.5 cm

Sample 207.5 cm was an outlier in our cluster analysis. It had a poorly preserved microflora containing only three taxa: *Amphora libyca, Epithema cistula* and *Achnanthidium minutissimum*. No other depth in the core had a similarly depauperate community.

4. Reconstructed salinity

The paleosalinity of Lake Telmen has been inferred based on the downcore distribution of 29 of the 32 dominant species. Salinity optima for Lake Telmen diatoms were drawn from Fritz et al (1993) (Fig. 6a). The Fritz *et al.* (1993) paleosalinity model was chosen because it reports salinity optima for 29 taxa from Lake Telmen sediment assemblages. Fritz *et al.* (1993) did not report the inverse deshrinking equation associated with their model, thus we were not able to deshrink our salinity reconstructions. Generally, this produces reconstructed salinity estimates that are too low at the higher salinities and too high at the lower salinity reconstructions (Birks *et al.* 1990).

Based on the diatom-reconstructed salinity (Fig. 6) the Lake Telmen was around 17- 20 g L-1 approximately 6000 years ago. This covers lithological Unit C or the lowest depths of the core (411-441 cm). Downcore distribution of the two most common taxa in this unit, *Cyclotella caspia* and *Cocconeis pediculus* (Fig. 3), show that lake salinity fluctuated slightly, during these earliest stages of the lake's history. Paleosalinity inferences of this unit were strongly controlled by downcore abundance of *Cyclotella caspia,* which is only plankton diatom in this unit, and the benthic taxa *Achnanthes brevipes, Brachysira aponina, Cocconeis pediculus, C. neothumensis* and *Navicella pusilla.* All these dominant taxa are either high salinity or salinity fluctuating indicators.

Lake salinity decreased to around 2 g L-1 by approximately 4000 yBP. Since that time, lake salinity has fluctuated between about 2 and 4 g L-1 until present day. Downcore distribution of the two most common taxa in this unit, *Cyclotella bodanica* var. *affinis* and *Anomoeoneis sphaerophora* f. *costata* (Fig. 3), shows that lake salinity was fluctuating. There are five low salinity (< 3 g L-1) and five high salinity (> 3 g L-1) peaks in this lithological Unit A. Low salinity peaks were strongly inferred from the downcore distribution of *Cyclotella bodanica* var. *affinis,* which is a freshwater planktonic diatom and slightly higher salinity peaks inferred from the downcore abundance of *Anomoeoneis sphaerophora f. costata* (Fig. 3), which is extremely resistant to fluctuations in the osmotic potential of its environment.

The percentage of the microflora used in the salinity reconstruction is very low at 85.5, 95.5, 197 and 207 cm depths due to the lack of published salinity optima of some dominant species such as *Amphora libyca, Caloneis westii* and *Gomphonema olivaceum* var. *minutissimum* (Fig. 6.b) that are common at these depths.

Discussion

Diatom records in the sediment core show a strong hydrological response to climate change over the last 6230 years in the Lake Telmen basin. In general, since 6230 yBP the lake level rose and salinity decreased until around 3960 yBP. Since that time the lake level and salinity (between 2 and 4 g L-1) have regularly fluctuated. We will discuss these changes based on the lithological units identified by Peck *et al.* (2002).

Lithological Unit C. Unit C covers the lowest core sediment (6230-5520 yBP). Previously studied paleoecological and geochemical indicators suggest that the Lake Telmen region was hyperarid and a small saline lake was present at that time. Lake Telmen was at least 14 m shallower and lake volume was about 25% compared to modern Lake Telmen (Peck *et al.*, 2002). The diatom microfossils in Unit C support this interpretation and indicate a similar inferred climate and hydrològic regime. The sediment assemblage contained a flora composed of 31 taxa, which was characterized by diatoms indicative of saline conditions or taxa that are tolerant of wide-ranging or fluctuating salinities (Table 1). Cluster analysis showed the diatom assemblages in this unit had the highest differentiation (Fig. 5). The plankton was dominated by *Cyclotella caspia* (cf. *C. choctawhatcheeana*), a taxon characteristic of inland saline systems throughout the world (Fig. 3). The salinity optimum of *C. caspia* is approximately 20 g L-1 salinity (Fritz *et al.* 1991, 1993). Reconstructed salinity of Lake Telmen fluctuates around 20 g L-1 (Fig. 6) during this period of time. Downcore distributions of the two most common taxa, *Cyclotella caspia* and *Cocconeis pediculus,* suggest that the lake level may have fluctuated somewhat during this period of time (Fig. 4).

The benthic flora preserved in Unit C is characterized by taxa that are also salinity indicators (*Achnanthes brevipes, Cymbella pusilla, Amphora coffeaeformis, Cocconeis pediculus, Brachysira aponina*) (Figs. 4 & 5). These taxa are found across a wide range of elevated salinities and can also be found in marine waters. Species with broad salinity tolerances amongst the saline water species (the gradient between lower and upper limit is from 12.96 to 36.81 g L-1; Fritz *et al.*, 1993) are *Amphora coffeaeformis, Amphora veneta, Cocconeis pediculus, Ctenophora pulchella, Cyclotella caspia, Navicella pusilla, Nitzschia inconspicua* and *Nitzschia obtusa.* Diatom preservation in this group is good compared to the rest of cores.

Lithological Unit B. Unit B covers core sediment (232-302 cm depth) deposited from 5520 yBP to 3960 yBP. Increased effective moisture but continued arid conditions were inferred for this period of time by the previous study (Peck *et al.*, 2002). Within this unit there are very large amplitude changes in each of the sedimentological parameters reflecting major, abrupt changes in sedimentation from black-brown organic rich sediment (unit A) to gray-white $CaCO_3$ rich sediment (Peck *et al.*, 2002). Unfortunately, poor diatom preservation characterizes this unit. In all probability, lack of preservation in Lake Telmen is a consequence of dissolution; modern limnological data on alkalinity (pH ca. 9.0) provides corroborating evidence. Diatom preservation is variable in different lake types, mainly related to increased dissolution at high salinity, high water depth, low diatom production coupled with high erosion rates, and high carbonates proportion (Fritz *et al.*, 1993). Preservation is extremely low at 238-301 cm. In these intervals microfossils were not preserved.

Preservation is extremely poor at the depths 25-65 cm and 228-311 cm. In these intervals diatoms were absent. Between 5-96 cm, 125-146 cm, 175-218 cm and 238-302 cm intervals we were not able to count at least 300 microfossils on single slide, thus it is difficult to hindcast paleosalinity based on the diatom assemblage alone. We must therefore rely on other paleoproxies during this time of period (Peck *et al.* 2002).

Lithological Unit A. After 3950 yBP there were generally more humid conditions near Lake Telmen with more humid than present conditions especially between 2370-1300 yBP as suggested by the palynologcial and sedimentological study by Peck *et al.* (2002). Diatom microfossil preservation and species composition also indicate more humid conditions in this period of time compared to the older units. The diatom flora changed dramatically compared to Unit C. Reconstructed salinity and community analysis show that a lake with similar size (probably even larger) to present was formed and that salinity decreased from 20 to 2 g L-1 at the 227.5 cm depth (approximately 3960 yBP ago). The Lake Telmen area had five periods with low salinity (around 2 g L-1) or more humid conditions than present day and 5 periods of relatively drier condition similar to the present day (4 g L-1) over the last approximately 4000 years (Fig. 6).

The low salinity peaks (less than 3 g L-1) recorded at 227.5 (after 3960 yBP at 232 cm), 197, 165.5, 155.5, 125.5, 115.5, 105.5 and 15.5 cm depths (Fig. 6) and most depths except 115.5 and 15 cm have relatively similar species composition as determined by cluster analysis (Fig. 5). The lake was probably bigger than the present lake during these periods of time. The low salinity period at the 125.5-105.5 cm depths covers a longer period of humid climate compared to the rest of the low salinity peaks; this may indicate the most humid condition of the lake area between 2370-1300 yBP as suggested by previous study (Peck *et al.*, 2002).

High salinity peaks (greater than or about 3 g L-1) were recorded at the 217.5, 207.5, 186.5, 175.5, 145.5, 135.5, 95.5, 85.5, 84.5, 75.5 and 5.5 cm depths (Fig. 6). Species composition of high salinity peaks are more diverse compared to the low salinity peaks. Low salinity peaks cover the cluster groups 1 and 2, which are more similar by their species composition.

Even though the lake has fluctuated in the last 4000 years there is some general feature in its diatom species composition. The plankton was dominated by *Cyclotella bodanica* var. *affinis*, the most abundant planktonic taxa throughout Unit A. It has been reported in 13 layers with six abundance peaks (Fig. 3). The maximum relative abundance is 93.78 % at 227-228 cm depth and 92.84 % at 105-106 cm depth.

The benthic flora in Unit A is characterized by taxa that are alkaline indicators such as *Anomoeoneis sphaerophora* f. *costata, Amphora libyca, Achnanthes minutissimum, Epithemia cistula, Amphora commutata, Navicula oblonga, Cocconeis placentula, Encyonema silesiacum, Epithemia sorex, Pseudostaurosira brevistriata* and *Campylodiscus clypeus* (Figs. 3 & 4). These taxa are mostly cosmopolitan, but are especially noted in middle and high conductivity brackish, coastal and closed basin salty waters.

Anomoeoneis sphaerophora f. *costata* has extreme resistance to fluctuations in the osmotic potential of its environment (Round *et al.*, 1990). We were able to find this taxon in all the samples with good diatom preservation except 207-208 cm depth. Relative abundance increased from 0.13 % at the lowest depth in Unit C to 100 % at some depths in Unit A. It has 6 abundance peaks in the Unit A at 5, 75, 115, 135, 175 and 217 cm depths, whereas the dominant plankton taxon *Cyclotella bodanica var. affinis* has lowest abundance at these depths (Fig. 3). This implies that the lake salinity and lake level has fluctuated regularly in the last approximately 4000 years. Lake Telmen was bigger and the lake environment was more humid than present in the 1758-2135, 2594-2721, 3248, 3863 yBP years. Between these more humid intervals, the lake was similar in size to the present one.

The present lake condition was similar to the condition 2380 and 2900 yBP years ago, considering the inferred water salinity (4 g L-1), and because the diatom species composition at 5 cm is also similar to these core depths.

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