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The importance of eolian input on lake–sediment geochemical composition in the dry proglacial landscape of western Greenland

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A B S T R A C T

In proglacial landscapes, such as western Greenland, eolian transport plays an important role for the influx of particulate material to lakes. On the basis of an analysis of a sediment profile and surface sediments from several lakes, we show that eolian activity has a strong influence on sediment deposition in time and space. Principal component analysis revealed that sediments that accumulated during periods with high eolian activity were enriched in zirconium—originating from coarse silt and sand fractions preferentially transported by wind—and depleted in rubidium. In addition, zirconium to rubidium ratios in the surface sediment of four additional lakes decreased with distance from the ice sheet. Finally, previously published data show that pH and alkalinity tend to be higher in lakes close to the front of the ice sheet, which we speculate is coupled to a larger supply of fresh eolian material. These findings demonstrate that lakes in proglacial landscapes may receive a substantial part of their sediment load through eolian deposition, and that this is especially true close to the glacial outwash plains along the ice margin.

INTRODUCTION

Lake sediment is a mixture of material from three sources: (1) material supplied directly from the atmosphere, (2) material formed in the lake, and (3) material transported to the lake from the drainage basin (Wetzel, 2001). Depending on, for example, lake morphology, size and shape of the drainage basin, and climate, the relative importance between these sources will differ from one lake to the other (Wetzel, 2001). In general though, the drainage basin is the main source for particulate mineral material and weathering products (Håkanson and Jansson, 1983). This close cou-

pling between lakes and their drainage basin has been used in many studies using sediment records as natural archives to study, for example, climate, landscape development, and land use (Wright, 1964; Engstrom and Wright, 1984; Koinig et al., 2003; Mourier et al., 2010; Anderson et al., 2012). However, under more arid conditions (i.e., where evapotranspiration exceeds precipitation) the runoff from the drainage basin will be small, and thus, erosion and particulate matter transport will be limited. If the dry conditions are combined with a considerable supply of wind-eroded material—for example, due to high winds and sparse vegetation cover—direct deposition might become

an important source of particulate material (Harrison et al., 2001; An et al., 2011).

One environment where eolian transport has the potential to be an important transport mechanism is in cold and arid regions close to an active ice sheet. An active ice sheet, as well as larger glaciers, produces large amounts of silt-sized mineral particles that can be transported in suspension by wind (Bullard and Austin, 2011). The area around Kangerlussuaq in western Greenland has such a cold and arid climate where eolian transport is an important mechanism for particulate matter transport (Dijkmans and Törnqvist, 1991). Both sand-dune profiles (Willemse et al., 2003) and lake sediment records (Eisner et al., 1995; Perren et al., 2012; Olsen et al., 2013) have shown that the extent of eolian transport has varied over time, largely in pace with climate and the movements of the front of the ice sheet. However, for two reasons there is a need for further studies of how eolian activity affects a lake and its sediment. First, previous sediment studies have mainly used loss-on-ignition (LOI; i.e., the ratio between organic and inorganic material) to assess the patterns in eolian activity. Because many other processes also affect the LOI content, it is a relatively crude proxy for eolian activity. This is especially true close to the present-day margin of the ice sheet where movements of the front of the ice sheet can drastically affect, for example, hydrological flow paths that control the transport of particulate mineral material (Briner et al., 2011; Kelley et al., 2012; Levy et al., 2012; Carrivick et al., 2013). Second, because the main objective of the previous studies has been to use the record of eolian activity to understand how the climate has changed in the area, these studies did not consider the potential effects of eolian material on the lake itself (Psenner, 1999).

The aim of the present study was to investigate the geochemical composition in the sediments of Two-Boat Lake (TBL), western Greenland, in order to determine if and how variations in eolian activity have influenced the geochemical composition of the sediment (TBL is also known as Lake SS903; Sobek et al., 2014). In addition to a down-core sediment profile from Two-Boat Lake, we used surface sediment samples from four additional lakes (Fig. 1) to assess how the potential influence of eolian material on the sediment geochemistry varies depending on distance from the ice sheet. Two-Boat Lake is currently the main focus of an extensive drainage basin-scale ecosystem study

(Clarhäll, 2011; Johansson et al., 2015a; Johansson et al., 2015b), and both the geochemical record in general, and the eolian record in particular, will be vital information to place the present-day conditions into a longer time perspective and when creating scenarios for future landscape development (Lindborg et al., 2013).

STUDY AREA

Regional Setting

The bedrock in the study area is dominated by gneisses (van Gool et al., 1996). The region has a continental climate (Low Arctic to subarctic) due to stable high-pressure cells over the ice sheet, and the predominant wind direction for the area is from east to southeast (Rott and Obleitner, 1992; van den Broeke et al., 1994; van den Broeke and Gallee, 1996). Mean annual temperature for the area is -5.1°C , ranging from -9.1 to -0.3°C (1977–2011; Cappelen, 2012), and mean annual precipitation (1977–2011) is 173 mm yr^{-1} , of which $\sim 40\%$ falls as snow (data corrected for wind and adhesion losses) (Johansson et al., 2015a, 2015b).

About 10,000 years ago the ice sheet covered western Greenland all the way to the present-day coastline about 120 km west of Kangerlussuaq (Fig. 1). About 6000 years ago the ice front had receded to its present position, and over the following 2000 years it receded even farther to the east. During the glacial minimum, it was likely located at least 10 km further inland as compared to its present position. From this minimum some 4000 years ago, the ice has readvanced (Funder, 1989; van Tatenhove et al., 1996).

The Kangerlussuaq area is highly influenced by eolian activity. This is most evident in the two river valleys, Sandflugtdalen and Ørkendalen, but the whole area is covered by a thick loess deposit, which has largely been stabilized by vegetation (Dijkmans and Törnqvist, 1991; Willemse et al., 2003). The eolian activity is considered to be source limited, and to be highest during the winter months when wind strengths generally are higher (Rott and Obleitner, 1992; Johansson et al., 2015a, 2015b); however, in winters snow might also decrease the availability of erodible material (Bullard and Austin, 2011).

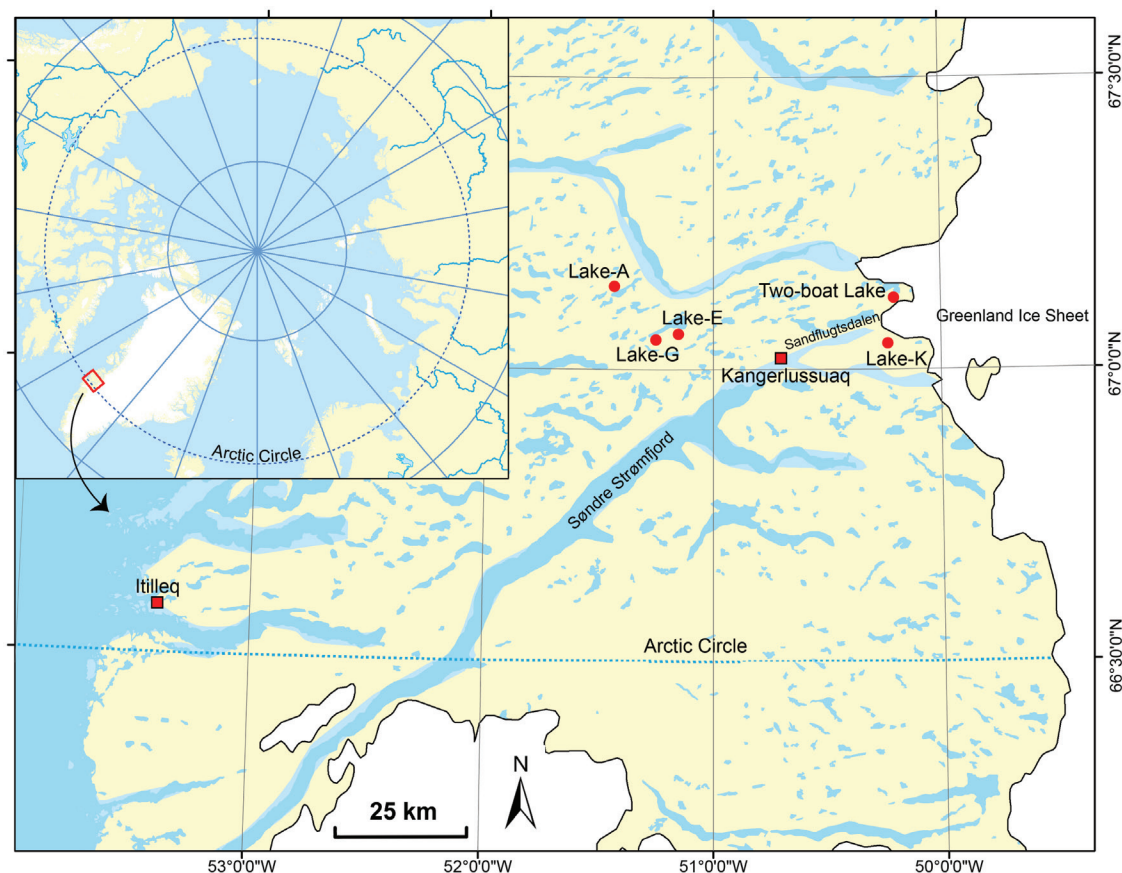


FIGURE 1. The Kangerlussuaq region with major settlements marked as red squares and the studied lakes as red circles. In the upper left corner is a pan-arctic map showing the location of the study area (red square)

Two-Boat Lake

Two-Boat Lake ($67^{\circ}7'44''\text{N}$, $50^{\circ}10'23''\text{W}$) is a dimictic lake located about 26 km east of Kangerlussuaq, at an altitude of about 335 m a.s.l., which places the lake about 1 km from the current front of the inland ice sheet (Fig. 1). It is 29.9 m deep, has a surface area of 37 ha, and has a lake-to-drainage basin ratio of about 1:4. Annual mean lake water pH, conductivity, and total organic carbon (TOC) concentrations are 8.1, $127 \mu\text{S cm}^{-1}$, and 8 mg L^{-1} , respectively (averages of 3 years of measurements in April, June, and August). The oxygen concentration in the bottom waters was 1.3, 1.8, and 3.6 mg L^{-1} in April 2011, 2013, and 2014, respectively, while in August the oxygen concentration was higher, 5.4, 5.9, and 9.2 mg L^{-1} for 2011, 2012, and 2013 (measured using an In-Situ Multi-parameter Troll 9500). Even if the area is dry, the water balance in Two-Boat Lake is positive. Hydrological modeling for the past 37 years shows that there is an out-

flow from the lake in about 70% of the years, that between-year variation in lake water level is 0.7 m, while within-year variation in lake water level is less than 0.25 cm (Johansson et al., 2015b). The predominant wind direction is from the southeast, and the strongest winds occur during winter (Johansson et al., 2015a).

The deeper Quaternary deposits around Two-Boat Lake consist of till and glaciofluvial material, which are largely overlain by younger, 30–40 cm thick, deposits of eolian silt-fine sand (Table 1; Fig. 2; Willemse et al., 2003). The eolian deposits are partly eroded by the wind, exposing patches of the underlying till or bedrock. There are limited signs of erosion due to running water, and overland flow is restricted to the snowmelt period. Some low-lying areas have wetter soil conditions and the eolian deposits can here be classified as peaty silt due to an enrichment of organic material. Permanently frozen conditions (permafrost) prevail in the area, and thus, chemical and physical soil processes are

TABLE 1

Absolute and relative surface distribution of Quaternary deposits in the catchment of Two-Boat Lake.

	Area	
	(ha)	(%)
Quaternary deposit		
Exposed bedrock	12.2	7.3
Colluvial material	0.9	0.5
Glaciofluvial deposits	2.2	1.3
Peaty silt	5.3	3.2
Eolian silt–fine sand	109.9	65.6
Till	37	22.1

mostly limited to the uppermost active layer. Furthermore, soil development is limited due to the dry conditions and the young landscape age, and there are only limited indications of solifluction on some north-facing slopes.

METHODS

Sample Collection

The sediment profile of Two-Boat Lake was retrieved from the deepest part of the lake in spring 2011 using an HTH-gravity corer (Renberg and Hansson, 2008) for the uppermost 40 cm and a piston corer (Chambers and Cameron, 2001) for deeper sediment layers (Fig. 2). The two cores were taken with an approximate 30 cm overlap and were later aligned using the loss-on-ignition (550 °C) profiles (Heiri et al., 2001). The gravity core was subsectioned into 0.5 cm slices in the

field, while the piston core was transported to the laboratory, opened, and subsectioned into 1 cm slices. Known sample volumes were freeze-dried and weighted to determine bulk density. In August 2011, a second gravity core was retrieved from the same location as the initial core; this core was subsectioned in 1 cm slices and used for lead-210 dating (^{210}Pb).

In addition to the long sediment profile from Two-Boat Lake, we have analyzed surface sediments from four additional lakes: Lake A (67°9'58"N, 51°26'53"W), Lake E (67°3'43"N, 51°7'41"W), Lake G (67°3'25"N, 51°12'58"W), and Lake K (67°2'42"N, 50°9'58"W; Fig. 1; Table 2). Sampling of the additional lakes was done in 2000 using an HTH-gravity corer, and the sediments of Lakes A, E, and G have been used in several previously published studies concerning organic and metal pollutants (Bindler et al., 2001; Malmquist et al., 2003; Lindeberg et al., 2006). In the present study, we have only analyzed the bulk geochemical composition of the top 1–2 cm of the sediment from these lakes. All samples, both from Two-Boat Lake and the additional lakes, were freeze-dried and powdered using a Retsch Swing-mill (30 Hz, 2 min) prior to analysis. In the upper part of the record, the sample resolution for all analyzed sediment variables varied between 1 and 2.5 cm. In the lower part of the record (i.e., below 24 cm sediment depth), the sample resolution was 2 cm.

In the summer of 2012, we also collected a soil sample from Sandflugtdalen and an eolian deposit at Two-Boat Lake. These samples were dried and sieved to obtain the 0–35, 35–63, and

TABLE 2

Location, altitude, water depth, lake area, catchment area to lake area ratio (LA:CA), and distance to the front of the ice sheet for all five study lakes.

Lake	Coordinates (WGS 84)		Altitude (m)	Depth (m)	Lake area (ha)	LA:CA	Distance to ice front (km)
	(Lat.)	(Long.)					
TBL	67°7'44"N	50°10'23"W	335	29.9	37	1:4	1
Lake-K	67°2'42"N	50°9'58"W	455	15	15	1:11	2
Lake-E	67°3'43"N	51°7'41"W	198	20	13	1:8	37
Lake-G	67°3'25"N	51°12'58"W	338	15	7	1:20	40
Lake-A	67°9'58"N	51°26'53"W	400	7.5	82	1:186	48

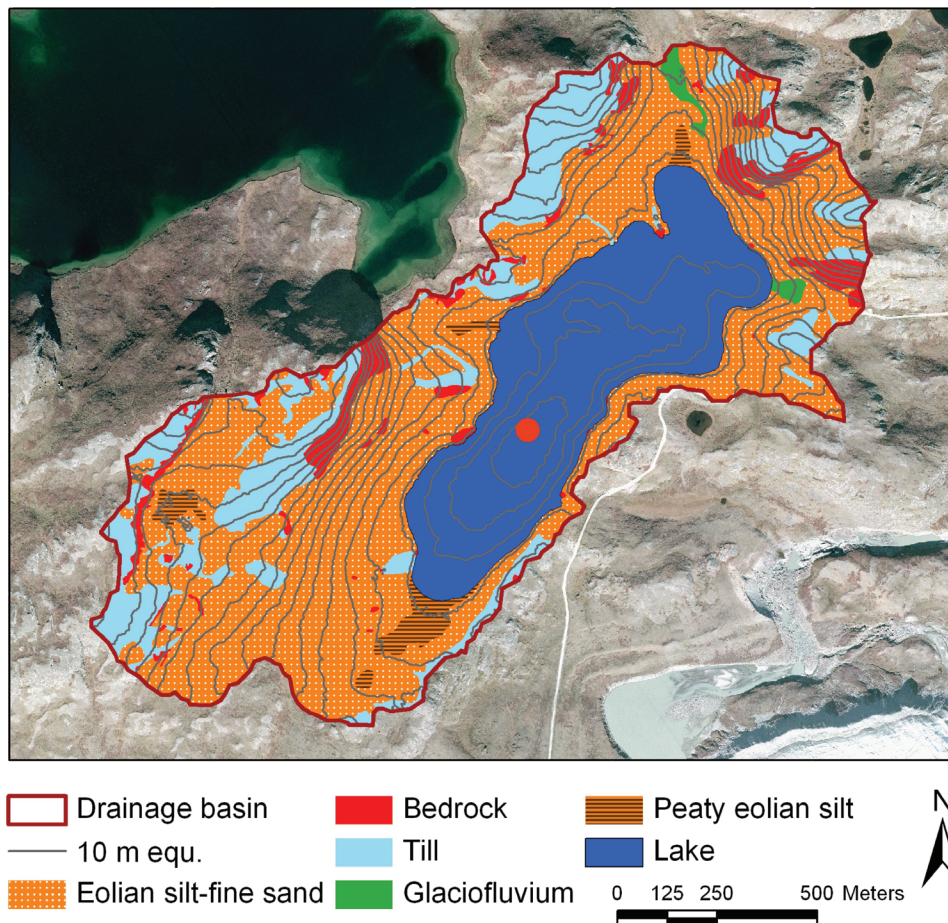


FIGURE 2. The catchment area of Two-Boat Lake (TBL) showing Quaternary deposits and topography/bathymetry. The red circle marks the coring location in the lake's deep basin.

63–125 μm fractions. The subsamples were then pulverized using a Retsch Swing mill (30 Hz, 2 min) and analyzed using WD-XRF (see below).

Chronology of the Two-Boat Lake Sediment Core

The activity of ^{210}Pb , radium-226 (^{226}Ra), and cesium-137 (^{137}Cs) was measured using gamma spectrometry at Risø National Laboratory for Sustainable Energy, Danish Technical University. Total ^{210}Pb and ^{226}Ra were used to calculate unsupported ^{210}Pb inventories for each sediment section, which in turn were used for age-depth modeling using a constant rate of supply model (CRS; Appleby, 2008).

Macrofossils suitable for AMS ^{14}C dating were separated from the bulk sediment by wet sieving. Plant remains were pretreated with 1M HCl at 80 $^{\circ}\text{C}$ for 1 hour, 1M NaOH at 80 $^{\circ}\text{C}$ for at least 3 hours, and lastly 1M HCl at 20 $^{\circ}\text{C}$ overnight. The samples were combusted to CO_2 in sealed evacu-

ated quartz tubes containing CuO. For radiocarbon dating, the CO_2 was converted to graphite with the H_2 reduction method (Vogel et al., 1984), and radiocarbon was measured at the ^{14}C CHRONO Centre, Queen's University Belfast. All ages were reported as conventional ^{14}C dates in ^{14}C yr B.P. (Stuiver and Polach, 1977). The ^{210}Pb and ^{14}C dates were combined to a single age-depth model, and calibrated ages were obtained using the P_sequence in OxCal version 4.1 (Bronk Ramsey, 2008) using the calibration curve IntCal09 (Reimer et al., 2009). Calibrated ages are quoted as cal yr B.P. (i.e., calibrated years before A.D. 1950).

Total Concentration and Isotopic Composition of Carbon and Nitrogen

Total concentrations and isotopic composition of carbon (C) and nitrogen (N) were determined simultaneously using an elemental analyzer (Flash EA 2000, Thermo Fisher Scientific) coupled with an isotope-ratio mass spectrometer (Delta V,

Thermo Fisher Scientific). In order to remove any carbonates from the samples, they were fumigated with concentrated HCl prior to analysis (Harris et al., 2001). The data are corrected for drift and sample-size effects. $\delta^{13}\text{C}$ is expressed in relation to Vienna PeeDee Belemnite (VPDB) and $\delta^{15}\text{N}$ is expressed relative to atmospheric nitrogen (Meyers and Ishiwatari, 2003). Analytical performance was assessed using internal standards that are regularly checked against certified reference materials; the standard deviation of all internal standards ($n = 42$) were $\pm 0.38\%$ for C, $\pm 0.21\%$ for $\delta^{13}\text{C}$, $\pm 0.03\%$ for N, and $\pm 0.13\%$ for $\delta^{15}\text{N}$.

Geochemical Composition

A Bruker Tiger S8, WD-XRF analyzer was used to determine the elemental concentrations of 20 major and trace elements: sodium (Na), magnesium (Mg), aluminum (Al), silicon (Si), phosphorous (P), sulfur (S), potassium (K), calcium (Ca), vanadium (V), titanium (Ti), manganese (Mn), iron (Fe), nickel (Ni), copper (Cu), zinc (Zn), bromine (Br), rubidium (Rb), strontium (Sr), zirconium (Zr), and barium (Ba). About 0.5 g of powdered sediment material was analyzed and evaluated using a calibration method specifically designed for lake sediments (Rydberg, 2014). Lower limits of detection (LLD) range from a few ppm (parts per million) for trace elements to a few tens of ppm for major elements. Accuracy was assessed using 10 different certified reference materials ($n = 5$), and was within $\pm 10\%$ (or a few ppm) for all elements except S, which had an accuracy of about 20%. Precision, based on replicate measurements of Two-Boat Lake samples ($n = 30$) was always better than 5% (or ± 1 ppm for elements present in low concentrations).

Statistical Analysis

Instead of interpreting every sediment variable individually, we used principal component analysis (PCA) to assess changes in the geochemical composition down through the sediment profile. The advantage of this approach, as compared to interpreting individual elements, is that the sediment is viewed as one unit where the covariation between different sediment variables is used to describe the main patterns in a few principal components (PCs; Rydberg and Martinez Cortizas, 2014). Based

on the patterns that are identified by the PCA, it is then possible to discuss these PCs in terms of drainage basin and lake processes based on previous knowledge about the geochemical behavior of different elements or groups of elements. For the full down-core geochemical data set for Two-Boat Lake please refer to the appendix.

The PCA was based on the following variables, C, $\delta^{13}\text{C}$, N, Na, Mg, Al, Si, P, S, K, Ca, Ti, V, Mn, Fe, Ni, Cu, Zn, Br, Rb, Sr, Zr, and Ba. $\delta^{15}\text{N}$ was initially included in the PCA, but because of a communality (i.e., sum of all squared loadings) below 0.6 it was excluded in the final PCA. The samples of stratigraphic unit II (see further below) were also excluded from the PCA because they have a very different geochemical composition as compared to the other sections of the sediment record; PC-scores were passively assigned to these samples. Prior to the analysis, all values were converted to z-scores (average = 0, variance = 1). All PCs with eigenvalues > 1 were extracted using a Varimax rotated solution (Kaiser, 1958), which reduces the number of components used to explain each variable. Factor loading coefficients (loadings) were calculated as regression coefficients, which is analogous to r in Pearson correlations. For all PCs, variables with squared factor loadings less than 0.15 were considered to be nonrelated to that particular PC. The sediment accumulation rate (A.R.), bulk density (B.D.), Fe:S, Fe:Mn, and C:N ratios were not included in the PCA but were entered as passive variables in the loading plots according to their respective correlation to the extracted PCs. All statistical analyses were made using the IBM SPSS software package PASW 20 (<http://www.spss.com>).

RESULTS

Chronology of the Two-Boat Lake Sediment Profile

Unsupported ^{210}Pb was only present in the uppermost 5 cm of the core, and it displayed an exponential decline with depth (Fig. 3, part a). The ^{210}Pb CRS-model was found to be in agreement with the ^{137}Cs -peak, which was found in the sample between 1 and 2 cm sediment depth (i.e., representing approximately 1995–1969; Fig. 3, part a). The age of the four macrofossils were estimated to be 438 ± 49 , 990 ± 41 , 1258 ± 39 , and 3093 ± 87 cal yr B.P. for 19, 29.5,

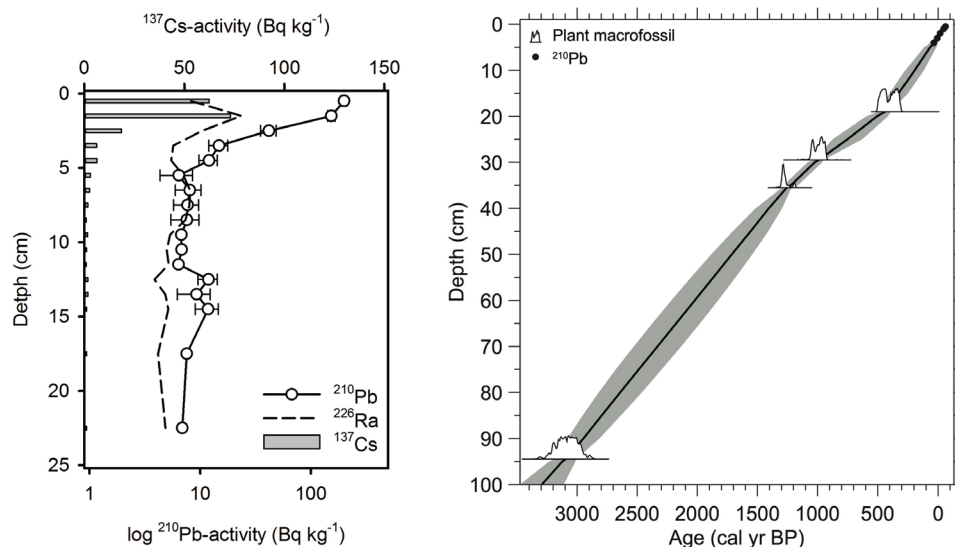


FIGURE 3 (left) Down-core profiles of ^{210}Pb , ^{226}Ra , and ^{137}Cs activities for the short sediment core collected from Two-Boat Lake in 2011. Open circles with error bars linked with a solid line represent total ^{210}Pb activity, while the dashed line represents ^{226}Ra , which is used as a measure of supported ^{210}Pb activity. The gray bars represent the ^{137}Cs activity. (right) Combined, ^{210}Pb , and ^{14}C age-depth model for Two-Boat Lake. The gray shaded area represents the uncertainty of the model, and small probability plots for each ^{14}C date depict the dating errors

35.5, and 94.5 cm, respectively (Table 3). By combining the ^{14}C and ^{210}Pb dates into a single age-depth model—which yielded an agreement index (A_{model}) of 93.0%—the deeper layers of the sediment core from Two-Boat Lake were dated to about 3100 cal. yr B.P. (Fig. 3, part b). It is worth noting though that while the upper section (32–0 cm) of the sediment record is fairly well constrained with three ^{14}C dates and the ^{210}Pb chronology, the lower section (96–33 cm) relies on a single dating point at 91–90 cm sediment depth.

Sediment Geochemistry in Two-Boat Lake

The ~3200-year-long sediment sequence from Two-Boat Lake could be visually divided into two

main stratigraphic units (Fig. 4). The deeper unit—that is, unit I, 96–40 cm sediment depth or ~3170–1420 cal. yr B.P.—consisted of light, gray-brown material, while the upper unit—that is, unit III, 36–0 cm sediment depth or from ~1300 cal. yr B.P. to present—consisted of a much darker, red-brown material. The two units were separated by a ~4 cm section of grayish material that was overlain by a thin, distinct, clay layer designated as unit II. Based on smaller differences in appearance, units I and III were further divided into two subunits each. Units Ia is darker than unit Ib, while unit IIIa is lighter than unit IIIb (both unit Ia and Ib are lighter in color than units IIIa and IIIb). Black lamina is present in both units Ia and IIIb, but absent from Units Ib and IIIa. These visual differences between the

TABLE 3

Laboratory ID, type of sample, sediment depth, $\delta^{13}\text{C}_{\text{AMS}}$, ^{14}C -Age estimates, and calibrated ages for the four macrofossils found in the long sediment core from Two-Boat Lake.

Lab ID	Material	Depth (cm)	$\delta^{13}\text{C}_{\text{AMS}}$ (‰, $\pm 1\%$)	^{14}C Age (yrs B.P.)	Calibrated age (cal. yrs B.P.)
UBA-19655	Various terrestrial	19	–28	355 ± 37	438 ± 49
UBA-19653	Various terrestrial	29.5	–26	1075 ± 41	990 ± 41
UBA-19367	Twigs, leaves	35.5	–26	1345 ± 31	1258 ± 39
UBA-19649	Terrestrial leaves	94.5	–29	2924 ± 54	3093 ± 87

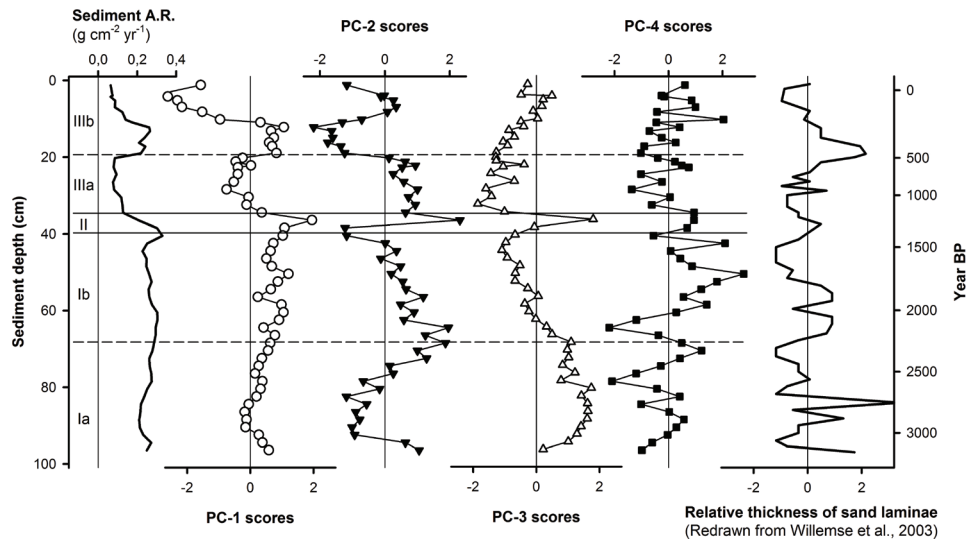


FIGURE 4. Down-core sediment profiles from Two-Boat Lake plotted against depth (left-hand scale) and age (right-hand scale). Horizontal solid lines separate the three stratigraphic sediment units, whereas the thin dashed lines separate subunits. From left to right: bulk density; PC-1, representing shifts between the organic and inorganic fractions of the sediment (higher scores equals less organic matter); PC-2, representing shifts between coarser and finer grain sizes (higher scores = finer grain sizes); PC-3, representing shifts in oxygen availability; PC-4, representing more or less V and Ni. The plot to the far right represents the temporal variations in sand lamina thickness in Sandflugtdalen (Fig. 1), which can be used as a proxy for eolian activity (redrawn from Willemse et al., 2003)

stratigraphic units were also reflected in sediment accumulation rates (Fig. 4). For unit I the average sediment accumulation rate was $0.26 \text{ g cm}^{-2} \text{ yr}^{-1}$. On average, unit III had a lower sediment accumulation rate, $0.13 \text{ g cm}^{-2} \text{ yr}^{-1}$, but for the period between 500 and 250 cal. yr B.P., the sediment accumulation rate was comparable to that of unit I.

The PCA extracted four PCs that together explained $\sim 88\%$ of the variation in the data set (for complete geochemical data for all analyzed sediment variables, please see the appendix). The first PC (PC-1) explained $\sim 43\%$ of the variance and Al, Si, Na, Ca, Ba, K, Sr, Ti, Rb, Mg, and Zr had positive loadings, while C, N, Br, and Zn loaded on the negative side of PC-1 (Fig. 5, part a). The sediment accumulation rate (passive variable) also had a positive loading. There was a decrease in PC-1 scores between unit I and unit III, and the uppermost 10 cm of the sediment record had the lowest PC-1 scores (Fig. 4). For the second PC (PC-2)—which explained $\sim 18\%$ of the total variance—Cu, Rb, Mg, Zn, Ni, and K had positive loadings, while Zr had a negative loading (Fig. 5, part a). Here the down-core trend showed that sediments below 80 cm and between 10 and 20 cm had more negative loadings—that is, were enriched in Zr—as compared to

other sediment sections (Fig. 4). On the third PC (PC-3)—which explained $\sim 15\%$ of the variance—S, $\delta^{13}\text{C}$, Ti, and Sr had positive loadings while C:N ratio (passive) and P had negative loadings (Fig. 5, part b). The main down-core trend was that unit Ia had higher scores (i.e., more S and lower C:N ratios), while unit Ib and IIIa had low PC-3 scores and unit IIIb average scores (Fig. 4). The fourth PC (PC-4) explained $\sim 11\%$ of the total variance, and the elements with the highest loadings were V, Ni, and Zn, which all had positive loadings (Fig. 5, part b). The down-core trend was characterized by a large degree of short-term variability, but sediment samples between 30 and 60 cm had a tendency to have slightly higher scores (Fig. 4).

Geochemical Composition of Surface Sediments and Soil Samples

In addition to the investigation of the sediments of Two-Boat Lake, we also compared the elemental ratios between Zr:Rb, Zr:K, and Zr:Ti in surface sediments of the four additional lakes. The rationale for using those ratios was that both Rb and K plotted orthogonally to Zr on PC-2, and that Zr is known to be enriched in the coarse silt fraction

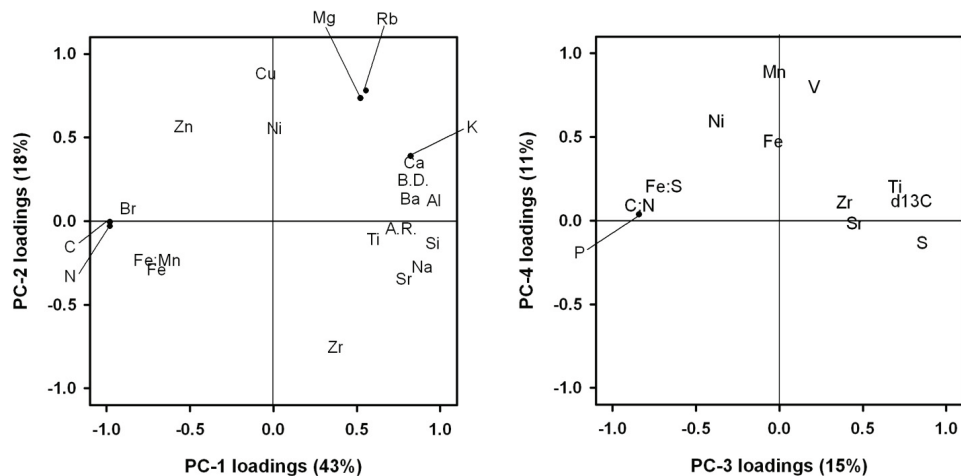


FIGURE 5. Loadings plots showing the importance of the different sediment variables for the four extracted PCs. The left panel shows PC-1 vs. PC-2, whereas the right panel shows PC-3 vs. PC-4. PC-1 represents shifts between the organic and inorganic fractions of the sediment, and higher scores mean less organic material. PC-2 represents shifts between coarser and finer grain sizes, with higher scores indicating a finer grain size. PC-3 represents shifts in oxygen availability, and higher scores are interpreted as less oxygen available in the bottom waters; PC-4 represents more or less V and Ni.

as compared to Rb, K, and Ti. In other words, the Zr to Rb, K, and Ti ratios can be used as a coarse proxy for grain size (Taboada et al., 2006). This comparison showed that the surface sediments of Two-Boat Lake and Lake K had higher Zr:Rb, Zr:K, and Zr:Ti ratios, and hence were more enriched in Zr, as compared to Lake A, Lake E, and Lake G, which are located farther from the ice front and from the source areas of eolian material (Table 4). Similar to the surface sediment samples, the Zr:Ti and Zr:Rb ratios were calculated for the three size fractions of each of the two soil samples, and the Zr concentration, as well as the Zr:Rb and Zr:Ti ratios, were higher in the 35–63 mm fraction for both samples (Table 5).

DISCUSSION AND CONCLUSIONS

The down-core fluctuations in the geochemical record from Two-Boat Lake reveal significant temporal variations in sediment accumulation, which with the aid of the principal components analysis can be discussed in terms of the main processes affecting sedimentation, and how these processes relate to the surrounding landscape.

Positive PC-1 scores indicate high concentrations of elements associated with silicate minerals (Deer et al., 1992), while negative scores indicate

high concentrations of elements associated with organic material (Fig. 5, part a). Hence, PC-1 depicts differences in the relative amount of minerogenic versus organic material. However, even if the negative PC-1 scores showed that the concentration of C—and other elements related to organic material—were higher in unit III as compared to unit I, the higher sediment accumulation rate in unit I actually translates to a higher accumulation of organic material in unit I as compared to unit III (0.68, 0.61, 0.37, and 0.45 g C m⁻² yr⁻¹ for units Ia, Ib, IIIa, and IIIb, respectively; Fig. 4). Hence, the driving factor behind the change to more organic sediments at ~1300 cal. yr B.P. was a decrease in the input of minerogenic material to the sediment rather than an increase in the input of organic material. It is important to recognize that the accumulation rates for unit I are uncertain and assume a linear sedimentation rate between 3093 and 1258 cal. yr B.P. It is therefore possible that the sedimentation rate have varied also within this stratigraphic unit; however, the low variability in sediment composition throughout the entire unit I suggests that there were no major changes in the sedimentation processes during this time period.

Several processes might lead to a reduced accumulation of mineral material in a lake sediment: decreased eolian input, decreased soil erosion, altered lake-water level affecting, for example, sediment fo-

TABLE 4

Zirconium (Zr) concentrations and Zr to Rb, Ti, and K ratios for the surface sediments (0–2 cm) of all five lakes used in this study. A higher Zr:Rb, Zr:K, and Zr:Ti ratio implies a greater influence of eolian material.

Lake	Distance to ice front	Zr (ppm)	Zr:Rb	Zr:K	Zr:Ti
TBL	1	301	12.0	302	0.11
Lake-K	2	222	7.9	248	0.11
Lake-E	37	121	6.7	73	0.09
Lake-G	40	47	6.3	136	0.07
Lake-A	48	155	7.4	195	0.08

cusing, or the disappearance of an inflowing stream. For Two-Boat Lake a decreased eolian activity is less likely, because none of the records of regional eolian activity shows any long-lasting decrease that fits the temporal trend in Two-Boat Lake (Eisner et al., 1995; Willemse et al., 2003). Soil erosion is primarily controlled by runoff and vegetation cover—where the latter stabilizes the soil (Håkanson and Jansson, 1983; Koinig et al., 2003)—and neither of these are realistic in explaining the decreased accumulation of mineral material in Two-Boat Lake. First, there is no indication of decreased precipitation at ~1300 cal. yr B.P. in the precipitation reconstructions that exist for the area (McGowan et al., 2003). Second, the macrofossil record from Lake SS16 (located ~26 km southeast of Two-Boat Lake) suggests a reduction rather than an increase in vegetation cover from around 1500 to 1800 cal. yr B.P. (Heggen et al., 2010). It is possible that a change in the lake-water level can have affected the sedimentation patterns in the lake basin, thus resulting in decreased accumulation of mineral material in the center basin of Two-Boat Lake (Håkanson and Jansson, 1983). Because Two-Boat Lake is a head-water lake without any permanent surface inflow,

the lake-water level is largely controlled by the balance between precipitation and evaporation. Currently, the lake-water level is approximately 20 cm below the threshold of the outflow, and no surface-water runoff from the lake has been observed since 2009. It is possible that Two-Boat Lake could have experienced significant lake-water level fluctuations in the past. However, there are no indications from other records that there was any major change in the water balance at ~1300 cal. yr B.P., which also makes changes in lake-water level a less likely explanation for the altered sediment accumulation rate in Two-Boat Lake (McGowan et al., 2003).

This leaves the possibility that Two-Boat Lake previously had a surface inflow, which linked it to a larger drainage basin. Although it is impossible to determine if this had been the case for Two-Boat Lake from the present data, it is not unlikely that the hydrological flow paths have changed over time. The lake is situated less than 1 km from an active inland ice sheet that has rearranged the landscape as it has changed its position with time, for example, through catastrophic drainage of ice-dammed lakes (Tweed and Russell, 1999; Levy et al., 2012; Carrivick et al., 2013). That the change in

TABLE 5

Zirconium (Zr) concentrations and Zr to Rb and Ti ratios for the two size fractionated soils samples used to verify that silt-sized mineral particles are enriched in Zr, which can be seen as a higher Zr:Rb and Zr:Ti ratio.

Sample	Size fraction (μm)	Zr (ppm)	Zr:Rb	Zr:Ti
Sandflugtdalen	0–35	277	8.9	0.09
	35–63	507	18.1	0.12
	63–125	254	8.8	0.10
Eolian deposit at Two-Boat Lake	0–35	265	8.0	0.09
	35–63	289	8.8	0.10
	63–125	177	5.5	0.07

sediment accumulation is linked to an event, rather than a gradual change, is supported by the distinct, purely minerogenic, clay layer that separates unit I from unit III. One possible explanation for this clay layer is an input of glacial meltwater from the inland ice sheet (which contains high amounts of fine-grained mineral material). However, to determine the specific mechanism behind the formation of this layer would require further analysis of, for example, the sediments of other lakes in the region to determine the flow path from the ice sheet to Two-Boat Lake. Regretfully, it is also impossible to precisely determine the duration of this event due to the lack of macrofossils in the sediment immediately below unit II.

The second PC separates Rb and K, which are enriched in fine silt and clay, from Zr, which is enriched in the coarse silt and fine sand fractions (Deer et al., 1992; Koinig et al., 2003; Taboada et al., 2006; Table 5). This indicates that PC-2 represents relative changes in the grain size of the mineral particles. A smaller grain size, that is, positive scores, would also result in a larger surface area of the sediment particles, and hence, larger adsorption capacities for trace elements such as Cu, Ni, Zn, and P to be adsorbed to the mineral particles (Stone and Droppo, 1996). The periods with lower than average PC-2 scores—that is, around 3000 cal. yr B.P. and 500–250 cal. yr B.P.—correspond well with known periods with higher eolian activity in the Kangerlussuaq area (Fig. 4; Eisner et al., 1995; O'Brien et al., 1995; Willemse et al., 2003; Perren et al., 2012). A higher eolian activity suggests a larger transport of silt-sized mineral particles, which are enriched in Zr and depleted in Rb, Cu, Ni, and Zn (Koinig et al., 2003; Taboada et al., 2006). An enrichment in the coarse silt fraction is also supported by the soil samples from Sandflugtdalen (i.e., the most likely primary source area for eolian material in this area) and an eolian deposit found at Two-Boat Lake, where both Zr:Rb and Zr:Ti ratios were higher in the 35–63 μm silt-sized fraction. This higher input of silt-sized mineral particles could come about either as a result of higher wind speeds or—more likely—a larger availability for this type of material, for instance, because of a lake being closer to the primary source areas for silt-size mineral particles—in this case, the glacial outwash plains of Sandflugtdalen (Bullard and Austin, 2011).

Positive PC-3 scores indicate higher concentrations of S and a lower C:N ratio, while negative scores indicate higher P concentrations and higher C:N ratios. The most likely interpretation is that PC-3 represents the redox conditions in the bottom waters, where less oxygen in the bottom waters would favor the incorporation of S as sulfides in the sediment (Holmer and Storkholm, 2001; Leng et al., 2012). For P, the opposite behavior would be expected, with oxic conditions favoring incorporation of P bound to iron hydroxides and oxyhydroxides, and anoxic or hypoxic conditions resulting in dissolution of iron hydroxides and a release of P to the water column (Davison, 1993; Hupfer and Lewandowski, 2008). This interpretation would also fit with the down-core variation in PC-3 scores where positive scores are mainly associated with unit Ia, but also to some extent with unit IIIb (Fig. 4). Both these stratigraphic units have a darker color and a higher frequency of black laminae as compared to unit Ib and IIIa, which indicate a higher presence of sulfide minerals and limited bioturbation, which is consistent with anoxic conditions (Shchukarev et al., 2008). In unit Ia there is also remnants of pigments from bacteria living under anoxic or hypoxic conditions (unpublished data). High PC-3 scores are also associated with lower C:N ratios, which often is interpreted as a sign of higher algal production (Meyers, 2003). This would also fit with the interpretation that PC-3 indicates more hypoxic conditions, because a higher autochthonous production would likely lead to a higher oxygen demand, and lower oxygen concentrations, due to more organic matter degradation in bottom waters (Wetzel, 2001). Even if the present-day bottom waters of Two-Boat Lake (Lake SS903) are reported to be oxic by Sobek et al. (2014), in situ oxygen profiles measured within the GRASP-project show that the bottom waters often have low oxygen saturation during summer—5.4, 5.9, and 9.2 mg L^{-1} in August of 2011, 2012, and 2013, respectively—and hypoxic conditions during late winter—1.3, 1.8, and 3.6 mg L^{-1} in April of 2011, 2013, and 2014, respectively.

The fourth PC explains the lowest amount of total variance (11%), and it is also the one displaying the most erratic temporal trend (Fig. 4). From the available data, it is not possible to discuss the cause behind the variations in V, Ni, and Zn. One

possible explanation could be that there is a slight variation in the mineral composition in the minerogenic material that enters the lake, but it can also be linked to analytical uncertainty.

The Effect of Distance to the Ice Front

The surface sediments of Two-Boat Lake and Lake K, located within 1–2 km from the front of the ice sheet, have higher Zr:Rb, Zr:K, and Zr:Ti ratios as compared to the surface sediments of Lake A, Lake E, and Lake G, which are located 37–48 km from the front of the ice sheet (Table 4). This strengthens the interpretation from the down-core Two-Boat Lake record that an enrichment in Zr is caused by an increased eolian activity, because Two-Boat Lake and Lake K are located closer to the source areas for eolian material as compared to Lakes A, E, and G (Fig. 1). For example, in Two-Boat Lake the PC-2 scores (i.e., coarse- vs. fine-grained material) indicate a lower eolian activity between 2200–600 cal. yr B.P. followed by a period with a higher input of silt-sized minerogenic material from around 500 cal. yr B.P. This could be a sign of a less windy climate for the period between 2200 and 600 cal. yr B.P., and that the wind strengths increased from around 500 cal. yr B.P. (Willemse et al., 2003). However, lower input of silt could also be interpreted as being a result of the ice front being further inland during the period 2200–600 cal. yr B.P. (Willemse et al., 2003), and that the eolian input of silt-sized minerogenic particles to Two-Boat Lake increased again when the ice front returned to its current location. Hence, caution is needed when using proxies for eolian activity—or any other geochemical proxy—to derive information about the climate, because eolian activity is not strictly a climatic signal. It is also important to recognize that the local geology and sedimenting environment of individual lakes have an influence on the Zr:Rb, Zr:K, and Zr:Ti ratios in the sediment, and it is therefore necessary to not rely on a single proxy. This can, for example, be seen in Lake K, where there is no difference in Zr:Rb ratio as compared to Lakes A, E, and G, but where the Zr:K and Zr:Ti ratios are considerably higher.

Possible Implications of a High Eolian Input to Lake Ecosystems

Even if the most pronounced effects of eolian transport are seen in the area close to the source

areas in front of the ice sheet, lakes farther away from the ice sheet also will receive eolian input (Dijkmans and Törnqvist, 1991; Bullard and Austin, 2011). From the many wind-erosion scars that are present in the landscape, it is also evident that some redistribution of previously deposited material occurs (Dijkmans and Törnqvist, 1991). Together with many other studies, and the fact that a significant part of the top soils in the Kangerlussuaq area consist of eolian loess, this study shows that eolian activity is an important transport mechanism for mineral material to lakes in this proglacial environment (Eisner et al., 1995; Anderson et al., 2012; Olsen et al., 2012; Perren et al., 2012). This implies two things. First, it highlights that the catchment area of a lake extends beyond the boundaries of the drainage basin, and that in dry landscapes with large supply of silt-sized mineral particles (e.g., proglacial landscapes), this input can contribute significantly to the mass balance of the lake. Second, because a part of the material supplied through eolian transport comes from the glacial outwash plains—which consists of fresh, largely unweathered mineral grains rich in base cations (White et al., 1999; Milner et al., 2007; Klaminder et al., 2011)—this input could have implications for the lake–water chemistry and potentially also the autochthonous productivity (Psenner, 1999). This hypothesis is supported by the data from two previous studies conducted in the area around Kangerlussuaq.

First, Perren et al. (2012) showed that there is a long-term trend of slow acidification due to soil development observed in several lakes in the Kangerlussuaq area. However, for the two lakes closest to the ice front, Lake SS32 and Lake SS16, pH is increasing during the most recent 500 years, that is, the period with increased eolian input of presumably fresh minerogenic material in Two-Boat Lake. This increase could be caused by other factors such as increased autochthonous production due to a warmer climate or increased N-deposition (Hobbs et al., 2010); however, the timing of the increase well predates the 20th century increases in temperature and N-deposition, and coincides with the increase in eolian activity starting about 500 cal. yr B.P. (Eisner et al., 1995; Willemse et al., 2003). Second, Anderson et al. (2001) and Ryves et al. (2002) report that lakes close to the ice front tend to have higher pH and alkalinity as compared to lakes closer to the coast. The main factor for these patterns

is likely—as discussed in both studies—a combination of a higher evaporation rates and younger, less weathered and more minerogenic soils in the inland areas as compared to soils closer to the coast. However, studies on lake development from Glacier Bay, Alaska, have shown that the effect of fresh catchment soils declines already after 500–1000 years (Engstrom et al., 2000), and in the Kangerlussuaq region even the lakes closest to the ice front, like Two-Boat Lake, are in excess of 3000 years. This indicates that there is an additional factor that contributes to the observed spatial pattern in pH and alkalinity. We therefore suggest that the influx of eolian material could contribute to sustained elevated pH and alkalinity in the lakes closer to the front of the ice sheet (Psenner, 1999). However, to determine more precisely how eolian inputs influence lake-water chemistry would require a study-design including a monitoring program.

CONCLUSIONS

The most pronounced variations in the down-core sediment record from Two-Boat Lake were changes in the ratio between organic and mineral material. These variations can partly be attributed to variations in the eolian input of particulate material to Two-Boat Lake, which result in variations in the composition of the minerogenic fraction. Some of the eolian material originates from soil erosion within the lake's catchment, but the main source is likely the glacier outwash plains located close to the lake. Furthermore, our study suggests that eolian input is higher close in lakes to the inland ice sheet, mainly due to a greater availability of material that can readily be transported by wind. We also speculate that this input of eolian material has an effect on lake-water chemistry because the fresh, un-weathered material can result in a higher pH and alkalinity as compared to lakes not receiving less or no inputs of eolian material. Together this implies that eolian transport needs to be considered, for example, when calculating mass balances for lake-catchment ecosystems in dry proglacial landscapes.

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APPENDIX

TABLE A1

The full geochemical data set from Two-Boat Lake.

Sediment depth (cm)	Age (cal. yrs B.P.)	C (‰)	δ ¹³ C (‰ vs. VPDB)	N (‰)	δ ¹⁵ N (‰ vs. Air)	C:N	Na (‰)	Mg (‰)	Al (‰)	Si (‰)	P (ppm)	S (‰)	K (‰)	Ca (‰)	Ti (ppm)	V (ppm)	Mn (ppm)	Fe (‰)	Ni (ppm)	Cu (ppm)	Zn (ppm)	Br (ppm)	Rb (ppm)	Sr (ppm)	Zr (ppm)	Ba (ppm)
1.25	40	5.89	-27.82	0.60	1.62	9.796	2.392	0.803	5.527	27.111	1029	0.489	0.997	2.681	2865	92	759	6.102	75	68	59	50.4	25	310	301	515
4	31	8.23	-27.83	0.77	1.47	10.660	2.075	0.746	5.016	24.499	1285	0.745	0.919	2.429	2434	87	774	5.983	83	82	81	57.7	25	284	252	508
4.25	40	7.24	-26.68	0.68	1.76	10.582	2.227	0.788	5.391	24.59	1009	0.7	0.99	2.554	2540	94	730	6.39	76	75	64	69.2	26	291	278	531
5.25	72	7.00	-26.59	0.68	1.87	10.326	2.244	0.814	5.491	24.873	1014	0.536	1.031	2.673	2602	93	781	6.066	93	80	76	63.5	27	295	258	524
7	118	7.22	-26.76	0.69	2.08	10.438	2.319	0.856	5.639	25.663	993	0.514	1.025	2.67	2585	95	779	5.888	92	84	79	62.7	28	297	271	513
8.25	150	5.96	-27.18	0.56	1.73	10.620	2.401	0.835	5.808	26.68	931	0.614	1.064	2.694	2595	88	723	5.391	93	86	74	41.3	27	310	295	548
10.25	202	4.55	-26.93	0.43	1.91	10.566	2.529	0.827	5.86	27.265	985	0.684	1.094	2.79	2675	99	800	6.517	90	83	65	39.7	27	321	308	581
11	221	2.75	-27.14	0.26	1.83	10.627	2.812	0.822	6.303	30.213	820	0.28	1.167	2.825	2794	87	732	5.039	70	59	53	21.2	28	343	312	620
12.25	254	1.75	-26.82	0.16	1.65	11.035	2.983	0.791	6.496	31.456	816	0.25	1.207	2.893	2956	88	744	5.288	69	52	51	13	28	362	371	637
13.25	280	1.68	-26.76	0.15	1.35	11.443	2.848	0.755	6.377	30.689	928	0.24	1.201	2.835	2646	87	729	4.924	68	49	46	11.3	28	354	297	595
15	326	2.13	-27.16	0.19	1.29	11.213	2.845	0.823	6.393	30.68	958	0.151	1.199	2.848	2809	89	731	5.017	66	55	51	14.8	29	344	347	647
16.25	361	2.66	-27.47	0.23	1.46	11.484	2.801	0.815	6.307	30.835	1117	0.2	1.169	2.859	2862	85	761	5.296	73	68	55	18.6	27	344	345	631
17.25	389	2.12	-27.41	0.19	1.34	11.230	2.787	0.804	6.366	30.76	1095	0.223	1.232	2.895	2815	83	717	5.195	64	62	55	14.8	29	351	328	646
19	438	2.34	-27.44	0.21	1.46	11.352	2.882	0.878	6.585	30.594	1138	0.13	1.181	2.908	2700	84	709	4.591	75	61	49	16.2	27	356	301	639
20.25	518	4.07	-27.57	0.35	1.45	11.658	2.532	0.996	6.181	29.228	1387	0.147	1.137	2.87	2629	88	749	4.966	74	83	62	25.4	31	311	270	553
21.25	567	4.31	-27.32	0.36	1.21	11.905	2.394	0.917	5.96	28.825	1583	0.252	1.131	2.796	2564	94	764	5.039	104	94	61	25.9	31	307	249	606
22.25	616	3.82	-26.96	0.34	1.31	11.333	2.581	1.12	6.35	29.289	1271	0.18	1.189	2.917	2953	94	753	5.014	90	87	66	24.2	33	326	248	575
22.75	641	4.86	-27.13	0.40	1.43	12.231	2.465	1.015	6.057	28.508	1451	0.182	1.124	2.834	2670	91	785	5.24	104	100	60	26.5	32	306	273	582
24.5	726	3.74	-27.30	0.32	1.44	11.783	2.344	0.896	5.924	28.683	1541	0.194	1.151	2.808	2539	85	748	4.709	84	85	56	21.7	31	305	259	586
26.5	830	4.54	-26.82	0.40	1.21	11.307	2.489	0.955	5.97	29.358	1206	0.356	1.145	2.824	2624	88	746	5.09	99	94	63	25.3	32	301	275	568
28.5	936	4.90	-27.59	0.42	1.59	11.678	2.304	0.882	5.881	28.397	1794	0.24	1.127	2.772	2524	85	731	4.606	95	105	61	27.6	32	297	242	591
30.5	1043	3.98	-27.99	0.35	1.61	11.476	2.486	1.069	6.131	29.06	1441	0.141	1.187	2.887	2652	89	761	4.893	102	96	61	22.3	34	300	284	590
32.5	1123	3.39	-28.41	0.29	1.67	11.623	2.422	0.976	6.071	28.983	1706	0.202	1.183	2.919	2556	92	734	4.589	94	99	62	22.3	32	304	245	591
34.5	1203	3.05	-27.33	0.28	1.70	11.001	2.704	1.111	6.377	29.732	1316	0.267	1.183	2.975	2734	94	770	5.088	104	93	62	17.1	33	316	271	587
36.5	1290	0.66	-26.28	0.06	2.06	10.991	3.044	1.596	7.48	29.975	957	0.2	1.347	3.143	3770	105	717	4.819	62	57	73	5	39	413	183	755
38.5	1356	1.02	-25.73	0.09	1.85	11.007	2.88	1.073	6.59	30.709	898	0.224	1.147	3.041	3123	90	754	4.742	65	47	51	9.7	29	347	322	545
40.5	1421	1.09	-26.21	0.10	1.85	11.401	2.871	0.978	6.51	31.176	1035	0.178	1.135	3.001	2923	85	728	4.402	63	53	50	10.6	27	360	284	586
42.5	1482	2.47	-26.30	0.22	1.94	11.407	2.753	1.131	6.513	29.735	1378	0.102	1.148	3.095	2856	95	797	5.163	108	85	61	19.2	30	330	290	577
44.5	1543	2.60	-26.68	0.26	1.77	11.353	2.666	1.089	6.473	29.659	1545	0.116	1.172	3.114	2770	87	754	4.721	82	87	62	19.3	31	338	275	637
46.5	1605	2.27	-26.65	0.20	1.91	11.262	2.684	1.08	6.444	29.317	1221	0.083	1.14	3.048	2826	88	766	4.917	77	76	61	16.3	30	329	276	577
48.5	1666	2.51	-26.58	0.23	1.66	11.039	2.707	1.073	6.473	29.712	1201	0.157	1.197	3.087	2849	94	763	4.736	92	91	64	17.5	32	339	287	630
50.5	1728	2.17	-26.38	0.20	1.76	10.844	2.865	1.14	6.707	30.305	1133	0.189	1.221	3.182	2956	97	803	5.072	138	78	62	16.3	32	343	296	621
52.5	1790	2.13	-26.34	0.19	2.23	11.519	2.733	1.088	6.597	29.522	1439	0.135	1.212	3.06	2859	98	790	4.954	106	92	64	17.2	32	339	282	659
54.5	1851	2.79	-26.26	0.25	2.19	11.184	2.805	1.004	6.573	29.767	1295	0.138	1.209	2.999	2906	97	760	4.905	98	116	67	22.7	31	341	303	672
56.5	1913	2.70	-26.28	0.24	1.95	11.221	2.555	1.018	6.315	28.674	1279	0.4	1.246	2.987	2832	96	758	4.841	91	106	69	21.2	33	332	282	669
58.5	1975	1.76	-26.07	0.16	2.21	10.803	2.847	1.099	6.632	30.262	1088	0.269	1.277	3.03	2834	94	772	4.926	119	83	63	14.9	33	333	298	640
60.5	2037	1.64	-26.19	0.14	2.55	11.380	2.806	1.008	6.622	31.126	1269	0.177	1.366	3.069	2914	94	746	4.771	85	95	64	17.5	35	341	279	664
62.5	2099	1.42	-25.72	0.13	2.44	10.867	2.82	1.01	6.653	30.92	1010	0.118	1.318	2.903	2818	87	709	4.423	73	84	58	13.9	34	336	287	677

TABLE A1
(Continued)

Sediment depth (cm)	Age (cal. yrs B.P.)	$\delta^{13}\text{C}$ (‰ vs. VPDB)	N (‰)	$\delta^{15}\text{N}$ (‰ vs. Air)	C:N	Na (‰)	Mg (‰)	Al (‰)	Si (‰)	P (ppm)	S (‰)	K (‰)	Ca (‰)	Ti (ppm)	V (ppm)	Mn (ppm)	Fe (‰)	Ni (ppm)	Cu (ppm)	Zn (ppm)	Br (ppm)	Rb (ppm)	Sr (ppm)	Zr (ppm)	Ba (ppm)
64.5	2161	-26.15	0.21	2.02	10.466	2.614	1.015	6.46	30.166	992	0.184	1.329	2.871	2825	87	679	3.912	74	122	65	17.5	36	335	264	686
66.5	2223	-26.24	0.20	1.95	9.992	2.811	1.096	6.647	30.32	850	0.528	1.379	2.972	2954	88	731	4.845	98	89	61	13.6	37	333	277	664
68.5	2285	-26.31	0.22	1.87	10.242	2.706	1.167	6.552	29.762	896	0.776	1.384	3.022	3005	99	745	4.911	95	103	62	15.2	38	337	276	669
70.5	2347	-26.28	0.26	1.83	10.348	2.802	1.164	6.603	29.615	831	0.71	1.277	3.007	3045	99	762	5.118	89	102	63	16	34	345	298	630
72.5	2409	-26.46	0.29	1.84	8.887	2.623	1.063	6.452	29.024	937	0.864	1.353	3.102	3014	98	741	4.888	83	100	63	16.3	34	349	282	622
74.5	2472	-26.63	0.25	2.37	10.118	2.731	1.009	6.405	29.322	797	1.104	1.228	2.888	2839	91	735	5.004	81	82	54	15.3	31	346	305	667
76.5	2533	-26.90	0.27	2.36	9.085	2.686	0.975	6.358	29.078	826	1.608	1.307	2.929	2886	87	715	4.914	76	68	51	15.1	32	346	301	666
78.5	2595	-26.28	0.22	2.06	9.879	2.812	0.924	6.474	29.574	747	1.134	1.251	2.833	2813	78	706	4.684	57	51	48	12.2	31	345	320	676
80.5	2657	-25.46	0.24	1.16	9.795	2.666	0.875	6.275	29.766	767	1.375	1.308	2.923	2985	90	754	4.8	67	59	51	15.5	32	355	314	708
82.5	2718	-25.14	0.33	0.72	9.177	2.735	0.854	6.206	29.651	692	0.953	1.181	2.804	3064	89	773	4.991	73	60	47	16.7	29	347	357	661
84.5	2780	-25.78	0.34	0.28	10.357	2.656	0.863	6.163	29.905	719	1.192	1.204	2.826	3083	90	720	4.56	54	60	48	16.4	29	354	314	636
86.5	2841	-25.02	0.35	0.33	9.411	2.706	0.85	6.159	29.323	676	1.037	1.128	2.749	3068	92	756	4.716	63	61	49	17.3	28	347	322	602
88.5	2902	-25.52	0.39	-0.06	9.781	2.785	0.868	6.263	29.537	638	1.127	1.142	2.766	3069	93	774	4.861	71	76	51	20	28	351	327	619
90.5	2964	-25.48	0.37	0.26	9.646	2.747	0.849	6.242	29.225	628	0.987	1.136	2.722	2998	92	769	4.889	66	66	49	17.7	28	348	327	612
92.5	3030	-25.42	0.31	0.70	9.686	2.801	0.89	6.341	30.098	698	1.011	1.197	2.822	3027	88	756	4.813	71	61	49	16.3	29	352	335	642
94.5	3097	-26.25	0.24	1.97	10.052	2.786	1.083	6.539	29.522	792	0.962	1.266	2.924	2943	89	728	4.875	74	82	57	15	33	344	285	656
96.5	3175	-25.88	0.17	2.38	10.465	2.833	1.055	6.667	30.578	1010	0.311	1.312	2.935	2842	87	712	4.308	87	88	59	50.9	35	337	279	650