



Watershed-scale reconstruction of middle and late Holocene paleoenvironmental changes on Melville Peninsula, Nunavut, Canada

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ABSTRACT

Arctic regions have heightened sensitivity to climatic changes, however regional scale differences exist in the magnitude and timing of biotic responses. Melville Peninsula in the east-central Canadian Arctic is a transitional area with respect to modern climate, with a continental climate to the west, and more maritime influences to the east. This, and the presence of Thule archaeological sites, make the Peninsula an area of high importance for paleoclimate reconstructions. Lake sediment cores from two adjacent ultra-oligotrophic and very dilute lakes (SP02 and SP04) from interior Melville Peninsula (68°33'N and 83°17'W, 220 m a.s.l.) were analyzed for diatom assemblages (microscopic algae) to track paleoclimatic changes. High magnetic susceptibility, coarse-grained sediments, low organic matter, and lack of diatoms in sediments older than 6000 years BP confirm earlier suggestions of a persistent ice cap on the Peninsula. Peak diatom concentration and biogenic silica, and maximum values for sediment organic matter, between 4400 and 2900 years BP may indicate the Holocene Thermal Maximum (HTM). The timing of the HTM is similar to that of the Baffin region to the east. Decreases in these proxies, as well as small shifts in diatom assemblages following 2900 years BP indicate the advancement of Neoglacial cooling. The changes of the pre-industrial portion of the last millennium were of smaller magnitude than those of the HTM, but subtle changes in diatom assemblages after 750 years BP may be indicative of the Little Ice Age, the timing of which agrees well with that of Boothia Peninsula to the west. The Anthropocene is well marked in these records, with increases in diatom species richness from a pre-industrial maximum of 28–51 diatom species in the modern assemblage at Lake SP02. Planktonic diatoms appear in the 20th century, signalling profound ecological changes associated with longer ice-free seasons.

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1. Introduction

Arctic surface temperatures have warmed at a greater magnitude than the rest of the Northern Hemisphere during the past century, with average warming of 0.09 °C/decade (McBean et al., 2005). The rapid climatic change is attributed primarily to anthropogenic greenhouse gas emissions, and to the heightened sensitivity of Arctic ecosystems due to positive land-surface albedo feedbacks (Overpeck et al., 1997). Recent studies of Arctic climatic changes during the 20th century document a variety of biophysical changes, such as decreased sea-ice extent, increased pollen concentration in lake sediments, and changes in the algal communities of freshwater bodies (e.g. Douglas et al., 1994; Zabenskie and Gajewski, 2007; Comiso et al., 2008). The study of climatic changes during the middle and late Holocene can be used to place recent and future changes into the context of natural climatic variability. To determine timing, rates and

magnitude of previous changes, and to improve climate and ecosystem models, particularly at the regional scale, more paleoclimatic data are required from climatically sensitive locations.

1.1. Diatoms as biological proxies

Due to their generally good preservation in sediments and their ubiquity in freshwater environments, diatoms (single-celled algae in the class Bacillariophyceae) have become a common proxy for past environmental variability, especially in the Arctic (Stoermer and Smol, 1999). Diatom production and community composition is influenced by various climatic factors. Temperature, for example, is positively associated with the rate of diatom photosynthesis, short-term nutrient uptake, nitrogen metabolism, and cell growth, but these effects vary from species to species (e.g., Raven and Geider, 1988; Berges et al., 2002). For arctic lakes, temperature determines the duration of ice cover, which is a more proximate control on diatom communities (Smol, 1983). In addition to affecting diatom community composition, the length of the ice-free

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season affects algal production, since higher light penetration due to shorter periods of ice cover increases the rate of photosynthesis; increased ice cover also tends to limit habitat availability, particularly for planktonic diatoms (Smol, 1988). Temperature also indirectly influences diatom assemblages through controls on water chemistry, notably pH (Pienitz et al., 1995).

Modern studies indicate that pH is one of the most significant variables controlling diatom species distribution, allowing for diatoms to be very effective direct indicators of pH change in lakes (Joynt and Wolfe, 2001; Bigler and Hall, 2002; Jones and Birks, 2004). Previous paleoclimate studies have utilized diatom assemblages to quantitatively reconstruct past lake water pH in alpine (Psenner and Schmidt, 1992; Larsen et al., 2006), arctic (Wolfe, 2002; Antoniadou et al., 2005), and subarctic (Weckström et al., 1997) lakes. Particularly for dilute, low pH lakes in ice-dominated regimes, longer periods of ice cover will result in decreased CO₂ evasion, decreased photosynthesis and a decrease in lake water pH (Wright and Schindler, 1995; Wolfe, 2002; Larsen et al., 2006).

To estimate values of past lake water pH, a transfer function is used (Birks, 1995; Tropea et al., 2007; Chen et al., 2008). To produce successful diatom-based transfer functions, both accurate measures of species–environment relations, and reasonable similarities between fossil and modern assemblages, are required. For the Arctic, quantitative data on optima and tolerances with respect to pH and other limnological conditions for diatom taxa have become increasingly available (e.g., Joynt and Wolfe, 2001; Bouchard et al., 2004; Lim et al., 2007). More research is required however to determine the degree of similarity required between fossil and modern assemblages to produce robust reconstructions. The Arctic is vast and highly heterogeneous in terms of local climate, geology and water chemistry. Therefore, there is also ongoing debate about the appropriate geographic and physiographic scope for the modern samples applied to fossil reconstructions using transfer functions (e.g., Hubener et al., 2008).

The Fragilarioids are a family of benthic and tychoplanktonic diatoms that dominate many Arctic lakes (Douglas et al., 1994; Lim et al., 2001; Finkelstein and Gajewski, 2008). This group includes the genera, *Fragilaria* Lyngbye, *Pseudostaurosira* (Grunow) Williams and Round, *Staurosira* (Ehrenberg) Williams and Round, and *Staurosirella* Williams and Round. The various Fragilarioid genera possess similar ecological affinities and have been associated with circum-neutral to alkaline water and habitats with low light penetration, short ice-free seasons, and low nutrient and silica concentrations (Douglas et al., 1994; Michel et al., 2006; Lim et al., 2007; Keatley et al., 2008).

Recent modern studies of these taxa and related environmental variables suggest that Fragilarioid taxa differ subtly from each other in terms of optima and tolerances with respect to water temperature, summer air temperature, and various water chemistry parameters, including pH and conductivity (Joynt and Wolfe, 2001; Bouchard et al., 2004; Schmidt et al., 2004; Karst-Riddoch et al., 2009). Differing responses to Holocene climatic changes are also noted between Fragilarioid species in fossil records (Wolfe, 2003; Antoniadou et al., 2005; Finkelstein and Gajewski, 2008). Thus, while autecological differences between Fragilarioid taxa are poorly understood and paleolimnological inferences cannot easily be made from this group, shifts in the species composition of Fragilarioid assemblages can indicate that limnological change of some kind has taken place. Used in conjunction with other proxies, the Fragilarioids can thus be used to infer paleoenvironmental changes despite the complexity of this group.

1.2. Arctic paleoclimates

Early post-glacial Arctic climates were characterized by a Holocene Thermal Maximum (HTM) which was spatially variable across the

Canadian Arctic in terms of timing of initiation and termination. Kaufman et al. (2004) indicate that the HTM occurred approximately 2000–3000 years later in the eastern Canadian Arctic than in the western Canadian Arctic, owing primarily to the persistence of the Laurentide Ice Sheet over Hudson Bay, but also land–ocean–ice feedbacks, latitudinal gradients in insolation, and local topography. Following the HTM, the polar regions experienced Neoglacial cooling during the past approximately 3000 years, attributed mainly to progressively decreasing summer insolation (Berger and Loutre, 1991).

Within the context of this supra-millennial-scale cooling for the late Holocene, century-scale climate fluctuations in the Northern Hemisphere resulted in relatively warm temperatures from 900 to 1100 AD (the Medieval Warm Period, MWP), and relatively cool temperatures between 1450 and 1850 AD (the Little Ice Age, LIA) (Mann et al., 2008). The sub-millennial-scale climatic changes, superimposed on the long-term cooling, documented in the hemispheric syntheses are also evident in meta-analyses of paleoclimate records from the Arctic (e.g. Kaufman et al., 2009) and site-specific studies (e.g. Rolland et al., 2009). Owing to the interaction between site-specific factors (e.g. topography, proximity to coast), and global and regional forcings, the timing, the rate and the magnitude of climatic changes of the past millennium were spatially variable across the Arctic. Differing climate controlling factors between regions of the Canadian Arctic result in spatially significant variations in modern climate (Maxwell, 1980) and, by extension, in paleoclimate.

Dissimilarities in modern- and paleo-climate between Boothia Peninsula and Baffin Island (Maxwell, 1980; Kaufman et al., 2004; Finkelstein et al., 2009) confirm the importance of the Melville Peninsula as a region of transitional climate between the more continental climate of Boothia Peninsula, and the more maritime-influenced climate of the Baffin region (Fig. 1). The paleoclimate of Melville Peninsula may more closely resemble the paleoclimates of one region over the other, possibly depending on the extent of multi-year sea-ice cover in the Foxe Basin, which contributes to the degree of maritime influence on Melville Peninsula (Finkelstein et al., 2009). Hence the Peninsula may provide sensitive paleoclimate data and may provide new insights into shifts in the key influences on local climate over time, as a function of changes in sea-ice or other boundary conditions.

The importance of paleoenvironmental records from this area is increased by the presence of Thule archaeological sites on Melville Peninsula. The Thule are the ancestors of the modern Inuit and traversed the Canadian Arctic from Alaska to Greenland during the past millennium (McGhee, 2000). One hypothesized impetus for the migration was the relatively mild climate around 1000 AD, and less severe sea-ice conditions, resulting in increased eastward access to the bowhead whale, the Thule's primary prey. The other possibility is that the migration was motivated by cultural factors (McGhee, 2000; Schledermann and McCullough, 2003). However it is difficult to evaluate the two ideas without increased study of paleoclimate records produced at higher resolution and with stronger chronologies for key areas of Thule activities.

1.3. Research objectives

The primary objective of this study is to quantify paleoenvironmental change on the Melville Peninsula during the middle and late Holocene. Specifically, the study will 1) determine if the paleoclimate changes on the Melville Peninsula are more similar in timing and magnitude to those of the areas to the east, or to the west, thus providing new insight into spatio-temporal variability in Holocene paleoclimates for the Canadian Arctic, and the possibility of shifts in key climate influences across a zone of transition in modern climates, 2) produce two records from adjacent lakes

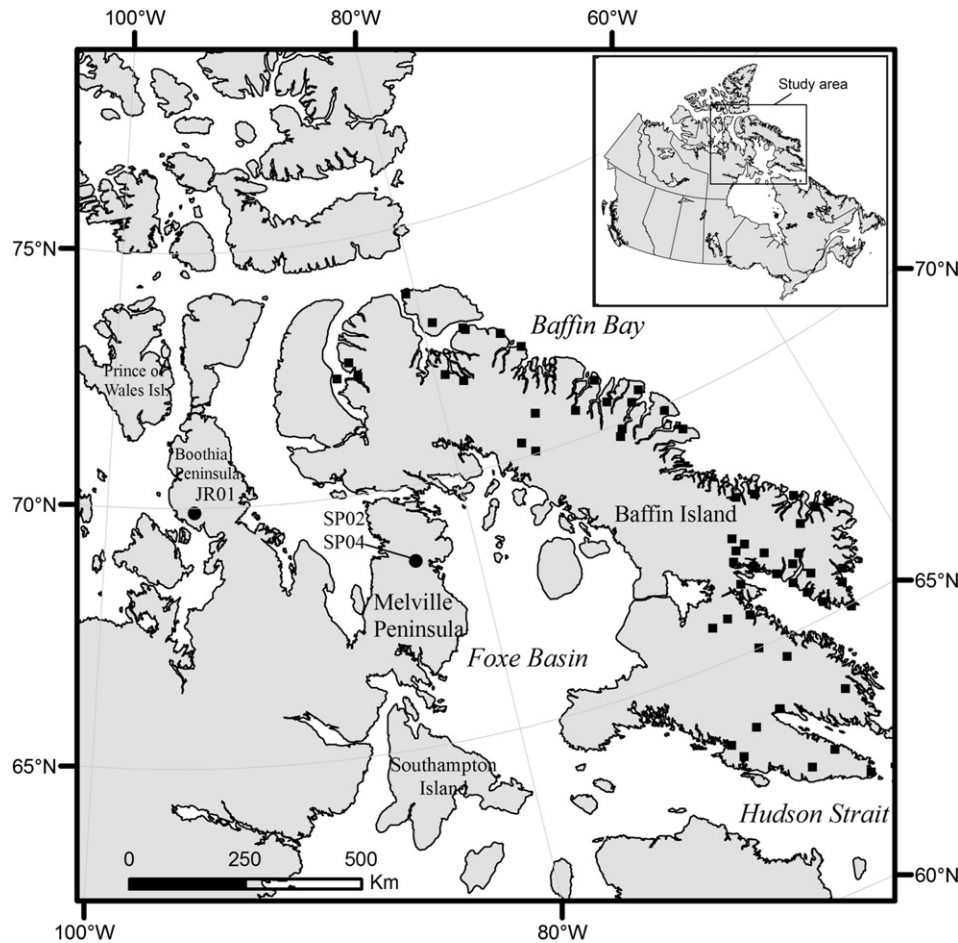


Fig. 1. Map of the Canadian Arctic showing the study lakes SP02 and SP04 in the vicinity of Sarcpa Lake on Melville Peninsula, Nunavut, and locations of other sites mentioned in the text.

contributing to an understanding of watershed-scale variability in paleoecological records, and 3) compare the utility of fossil diatom assemblage changes vs. transfer functions derived from modern species–environment relations in determining the timing and magnitude of environmental changes at two adjacent sites on Melville Peninsula.

2. Regional setting

Two study lakes were chosen for paleolimnological analyses in the vicinity of Sarcpa Lake (68°33'N and 83°17'W, 220 m above sea level (a.s.l.)) on Melville Peninsula, Nunavut, Canada (Fig. 1). The area around Sarcpa Lake is underlain by Precambrian basement rocks of the Canadian Shield, primarily granitoid gneiss. The terrain is characterized by granitic outcrops, and some glacial drift; analysis of till samples in the study region show carbonate content ranging from 0 to 25% by mass (Dredge, 1995). There was negligible glacial drift observed in the immediate vicinity of the study lakes. Retreat of the Foxe Ice Dome, which dominated Melville Peninsula, did not take place until the middle Holocene. Using ice-contact marine deposits, washing limits and radiocarbon dates, Dredge (2001) infers that deglaciation occurred along the southern coast of the peninsula at about 6900 years BP, and along the northern coast around 6500 years BP (Dredge, 1995, 2001).

The landscape is riddled with small lakes and ponds within ridges and valleys; local relief ranges from 30 to 60 m a.s.l. Two small lakes have been given unofficial names for scientific study,

SP02 and SP04 (Fig. 1; Table 1). No bathymetric data are available for the lakes and depths were determined at point measurements at core locations. The lakes are ultra-oligotrophic and very dilute. Vegetation in the Sarcpa Lake region consists of a graminoid prostrate dwarf-shrub and forb tundra (CAVM Team, 2003). As is typical for the Canadian Shield in the Arctic, vegetation cover is not continuous; barren areas are characterized by exposed bedrock with some lichen cover.

The SP sample sites are located within the Northern Arctic ecological zone of Canada, with vegetation, solar radiation regime, and landforms distinct from other Arctic ecological zones (Natural Resources Canada, 1999). The Northern Arctic is a non-mountainous region characterized by extreme radiation deficit in the winter and surpluses in the summer. Average (1970–2000) yearly mean daily temperature in the closest community (Hall Beach) is -14.1°C , with average temperatures below -20°C from November to April. Hall Beach receives an average of 216 mm total annual precipitation, of which 102 mm fall as rain between July and August, and 114 mm as snow between September and June (Environment Canada, 2000).

3. Materials and methods

3.1. Field methods

Sediment cores were collected under ice cover from Lakes SP02 and SP04 in June 2008, using a Livingstone piston corer and casing.

Table 1

Morphological characteristics and water chemistry of lake sites on Melville Peninsula, Nunavut, used for modern diatom species–environment modelling, and paleolimnological reconstructions. Sites were sampled in June, 2008.

Site Code	Latitude (°N)	Longitude (°W)	Surface area (ha)	Maximum Depth (m)	Conductivity (μS/cm)	pH	Silica (mg/L)	Total Kjeldhal Nitrogen (Unfiltered) (mg/L)	Total Phosphorus (Unfiltered) (mg/L)
SP02	68.55	83.29	3.0	16	41.3 ± 0.8	6.89 ± 0.01	0.07	0.07	<0.005
SP04	68.55	83.27	2.5	8	39.3 ± 0.8	6.90 ± 0.01	0.12	0.15	<0.005

We captured the intact sediment–water interface using a clear plastic tube fitted with a piston. The uppermost non-consolidated sediments were extruded in 0.5 cm increments at the field camp. The remaining section was extruded as single units into PVC split tubes lined with aluminum foil and plastic wrap. Each core was packaged and shipped by air freight to the laboratory at the University of Toronto. Surface samples from these two cores were used to expand modern calibration data for quantitative reconstructions.

Specific conductivity and pH for Lakes SP02 and SP04 were measured in situ. Water samples were collected for more extensive laboratory analysis. Water sample preparation was conducted in the field, within 24 h of collection. Unfiltered samples were submitted for measurement of total phosphorus (TP), total Kjeldhal nitrogen (TKN), alkalinity, major ions, and metals. Sub-samples were filtered using cellulose acetate filter paper, and the filtrate was submitted for filtered TP/TKN analysis. All analyses were conducted by the City of Ottawa Public Works Laboratory.

3.2. Laboratory methods

The chronology was established for the SP02-H4 and SP04-H3 cores using the activity of ^{210}Pb (measurements done by Flett Research, Winnipeg, Canada) and accelerator mass spectrometry (AMS) radiocarbon dating. Radiocarbon ages were determined at Beta Analytic (Miami, USA) on micro-samples hand-picked on a stereomicroscope after sieving sediment samples through a 90-μm screen (Table 2). Calibration of conventional radiocarbon ages to calendar years was performed using the INTCAL04 database and the software CALIB v5.0.1 (Stuiver et al., 1993). All ages given (expressed as years BP) refer to calibrated, calendar years before AD 1950.

Magnetic susceptibility (MS) was measured at 1-cm increments along the length of each sediment core using a Bartington magnetic susceptibility meter and MS2E sensor; MS of the uppermost sediments extruded in the field was not measured. Loss-on-ignition was used to estimate the percent organic matter by mass of dried sediment samples. Standard methods were used, with ignition of dried samples of known mass and volume at 550 °C for 4 h (Heiri et al., 2001).

For diatom analysis, sub-samples of 0.5 cm³ were taken at 1-cm increments between 0 and 30 cm depth, and at 4-cm increments between 30 and 62 cm for core SP02. Core SP04 was sub-sampled at 1-cm increments from 0 to 5 cm depth, 2-cm increments from 5 to 39 cm depth, and at 4-cm increments from 39 to 59 cm depth. Sediment samples were treated with 10% HCl, followed by 15 mL of a 50:50 molar ratio mixture of H₂SO₄ and HNO₃. Samples were heated in a water bath for 2 h and then neutralized by repeated distilled water washes. Slurries were then diluted appropriately for microscopy, and mounted using Naphrax®.

An average of 1300 diatom valves were enumerated per sample (range = 679–2564), with the exception of the oldest sample from Lake SP02, in which only 170 valves were enumerated due to low diatom concentration. Diatom valves were identified and counted along randomly selected transects under 1000× magnification on a Zeiss Axio Imager A1 microscope equipped with differential interference contrast (DIC) optics. One to six transects were counted on each slide. Diatom species were identified using Cumming et al.

(1995), Fallu et al. (2000), Krammer and Lange-Bertalot (2004, 2007), Lavoie et al. (2008), and Antoniadou et al. (2008). The Fragilarioids were distinguished as in Finkelstein and Gajewski (2008).

Diatom concentration was calculated in valves/g dry sediment by pipetting a known volume of slurry of known concentration (in grams of sediment ml⁻¹) onto coverslips, and then measuring (in mm²) the area of the coverslip over which diatoms were actually enumerated, giving a value for number of valves in a given amount of sediment. Species richness was calculated using a species rarefaction index with the program Analytic Rarefaction 1.3 (<http://www.uga.edu/strata/software/>). Species rarefaction was applied because the number of valves counted varied from sample to sample, and rarefaction standardizes the diatom taxonomic richness to a common sum (Birks and Line, 1992). To further support our measurements of diatom concentration, we also determined weight percentages of biogenic silica (BSi) at 1-cm intervals in core SP02. BSi determinations were done using wet-alkali digestion (DeMaster, 1981). Concentrations of BSi were measured spectrophotometrically using the reduced molybdosilic acid reaction after digestion of finely-ground sediment samples for 2, 3, 4 and 5 h in 1% Na₂CO₃ in a heating-shaking water bath at 85 °C.

3.3. Data analysis

The initial raw counts of diatom valves from each interval were converted to percent abundance of each species. To de-emphasize a few extremely common taxa, abundances were square root transformed. Principle Components Analysis (PCA) and cluster analysis based on unweighted pair-group average clustering was conducted using statistical programming software, R v2.8.1. A transfer function for pH was applied to the fossil diatom assemblages from Lakes SP02 and SP04 using a combined calibration set of modern diatom assemblages from 61 lakes on Baffin Island (Joynt and Wolfe, 2001) and the surficial assemblages from the two lakes sampled here on Melville Peninsula (Table 1). The dataset of Joynt and Wolfe (2001) was selected because the lakes in that study are similarly dilute and slightly acidic, owing to surrounding crystalline bedrock of the same Precambrian formation.

Canonical correspondence analysis, as performed by Joynt and Wolfe (2001), indicates pH as a primary environmental control over diatom distributions. Joynt and Wolfe (2001) thus developed a diatom-based inference model for pH using weighted-averaging (WA) regression and calibration. The reconstructions of lake water pH for Lakes SP02 and SP04 were conducted using the program C2 v1.5.1 (Juggins, 2005). A weighted-averaging partial least squares (WA-PLS) regression was applied to each dataset based on bootstrapping cross validation (Birks, 1995), excluding those taxa with maximum abundance <0.5% to avoid overestimating the effect of rare taxa.

4. Results

4.1. Sediment cores and chronology

The sediment core from Lake SP02 was collected through 11.5 m of water (including ice of ~2 m in thickness), and measured 106 cm

Table 2
Radiocarbon dates and calibrated ages from Lake SP02 and SP04 sediment cores.

Core	Depth (cm)	Lab code	Conventional radiocarbon age (Yr BP)	2-sigma calibrated age range (Cal yr BP)	Median calibrated age (Cal yr BP)	$\delta^{13}\text{C}$ (‰)	Material dated ^a
SP02	18.5–21.5	BETA-258119	1890 ± 40	1720–1920	1830	N/A	Organics
SP02	35.5–38.5	BETA-252730	3850 ± 50	4100–4420	4270	N/A	Organics
SP02	55.5–58.5	BETA-252731	7970 ± 50	8630–9010	8840 ^b	–31	Organics
SP02	57	BETA-252732	4940 ± 40	5600–5740	5660	–27.3	Wood fragment (small stem)
SP02	77	BETA-252733	5820 ± 40	6500–6730	6630	–28.9	Plant remains
SP02	77	BETA-252734	5650 ± 50	6310–6540	6430	–26.8	Plant and wood remains
SP04	21.5–24.5	BETA-260581	1300 ± 40	1170–1300	1240	N/A	Organics
SP04	33–38	BETA-264485	1530 ± 40	1340–1520	1420	N/A	Organics
SP04	57.5–61.5	BETA-260582	1620 ± 40	1410–1600	1500 ^b	N/A	Organics

^a “Organics” includes both plant remains and chitinous remains (mainly chironomid head capsules) hand-picked on a stereomicroscope.

^b Sample not incorporated into age-depth modelling.

in length. A linear interpolation was applied between four AMS radiocarbon dates and the lowermost ^{210}Pb date for age-depth modelling (Table 2; Fig. 2). A constant rate of supply model was chosen for the ^{210}Pb chronology for both cores, as it assumes a variable sedimentation rate; ^{210}Pb activity declines exponentially from each other; another pair of replicates at about 57 cm depth produced one anomalously old date of 8840 years BP (Table 2). This date was rejected because geological evidence indicates that deglaciation occurred on this part of Melville Peninsula around 6650 years BP (Dredge, 1995); the material dated was likely re-deposited from elsewhere during high energy outwash events associated with deglaciation. The resulting age model produces an average rate of sediment accumulation since about 6000 years BP of 0.12 mm/yr for Lake SP02, comparable to other small arctic lakes at similar latitudes (Brothers et al., 2008; Peros and Gajewski, 2009). The rate of accumulation for the most recent sediments, dated by ^{210}Pb , was higher, at 0.28 mm/yr, and the rate of sediment accumulation in the middle section of the core (the past 3000 years), was slower than the average for the core, at 0.09 mm/yr (Fig. 2).

The sediment core from Lake SP04 was collected through 8 m of water and measured 62 cm. Activity of ^{210}Pb decreases exponentially to background levels of supported ^{210}Pb by 10 cm depth, producing a recent sediment accumulation rate of 0.88 mm/yr for the top 10 cm of the core. Three radiocarbon dates were produced from the core (Table 2). Taking just the uppermost radiocarbon date

(depth 23 cm) produces a rate of sediment accumulation of 0.11 mm/yr for the section between it and the lowermost ^{210}Pb -dated depth (10 cm), comparable to the late Holocene rate of sediment accumulation for Lake SP02, providing a rationale for retaining the date from the depth of 23 cm in the age model (Fig. 3).

The two-sigma ranges for the two other radiocarbon dates (depths 35.5 and 59 cm) overlap (Table 2). Sustained decreases in magnetic susceptibility, and trends in diatom assemblages such as sustained increases in the taxon *Fragilaria microstriata* (Fig. 5) through this section, suggest that these sediments do not represent a slump or evidence for a rapid mass wasting event. The sediments in this section consist of fine-grained gyttja, with no evidence for sharp changes in grain size, organic matter content, mineralogy or diatom assemblages. Changes in all or some of those variables would be expected if this section was a product of a rapid mass wasting event. Therefore, we chose to retain one of the two overlapping radiocarbon dates.

The rate of sediment accumulation between the date at the depth of 35.5 cm and date at the depth of 23 cm (which we have accepted) is 0.72 mm/yr, comparable to reported rates for other lakes of similar size at similar latitude (Brothers et al., 2008). This rate is higher than observed in Lake SP02, but the recent rate of sediment accumulation (in the ^{210}Pb -dated section of the core) is similarly higher for Lake SP04 relative to SP02. The rate of sediment accumulation between the date at the depth of 59 cm and the date at the depth of 23 cm (which we have accepted) is 1.38 mm/yr. This

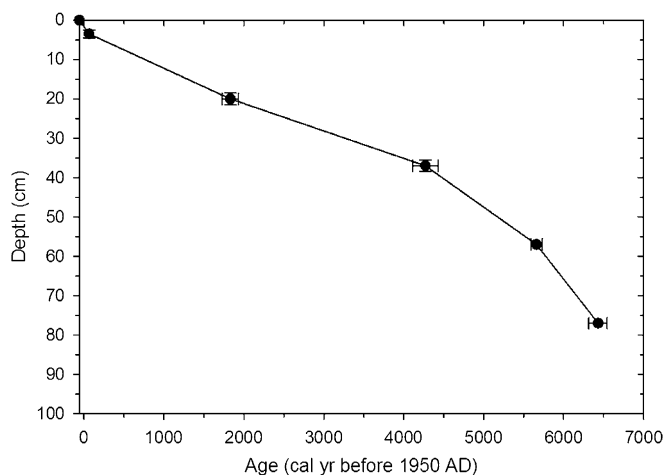


Fig. 2. Age-depth curve for Lake SP02 based on ^{210}Pb dates from the uppermost 3.5 cm and four AMS radiocarbon dates (Table 2).

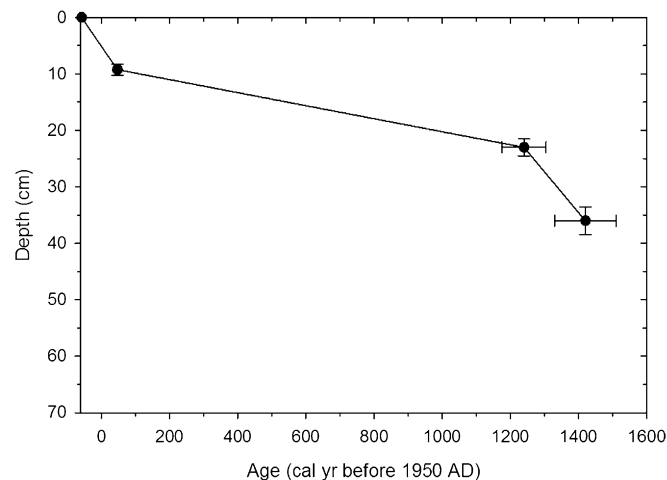


Fig. 3. Age-depth curve for Lake SP04 based on ^{210}Pb dates from the uppermost 10 cm and two AMS radiocarbon dates (Table 2).

rate of sediment accumulation exceeds the recent rate, and is an order of magnitude higher than reports of rates of sediment accumulation for small arctic lakes (e.g., Peros and Gajewski, 2009). Therefore, we developed an age model using the radiocarbon dates obtained at depths 23 cm and 35.5 cm only. We conclude that the date at 59 cm is anomalously young, and may have resulted from bioturbation or contamination during coring. We acknowledge the uncertainties in the chronology for core SP04 for sediments older than 1240 years BP, therefore the biostratigraphic data are plotted as a function of depth (Fig. 5).

4.2. Magnetic susceptibility (MS) and loss-on-ignition (LOI)

MS in the early record for SP02 is high, with maximum values recorded at 83.5 cm depth, and all measurements below 6180 years BP greater than 100 SI units. MS values decline through time with a minimum recorded 1670 years BP (Fig. 4b). LOI₅₅₀ for core SP02 is low in the early portion of the record, coincident with high MS. LOI₅₅₀ reaches maximum values of 9–11% between 2980 and 4440 years BP, then declines to low values (3%) around 750 years BP.

MS values from SP04 are low compared to the lower sections of SP02, but are comparable to values recorded during the past 4000 years in SP02. MS values are fairly constant through the SP04 record, with a subtle decrease in the more recent sediments (Fig. 5b). LOI₅₅₀ also shows little trend for the section of core SP04 spanning 16.5–61 cm depth, but increases above 16.5 cm depth (480 years BP). Values for LOI₅₅₀ are 3–4 times higher than those recorded for SP02.

4.3. Lake SP02 diatom assemblages

Diatoms are well preserved throughout the uppermost 62 cm of the core; no diatoms are recorded below 62 cm depth (5880 years BP). Diatom concentration varies by two orders of magnitude, ranging from 5.08×10^7 valves/g at 5880 years BP to a maximum of 6.01×10^9 valves/g in the most recent sample (Fig. 4b). A total of 108 diatom taxa from 35 genera were identified from 39 samples in core SP02. The average species richness for each sample in core SP02 is 23 taxa, after controlling for number of individuals counted using rarefaction.

Of the 108 species identified in the record, only 10 species were present at >5% relative abundance in any one sample, all of which were benthic Fragilarioids. The two dominating taxa were *Staur-osirella pinnata* and *Staurosira construens* var. *venter*. The diatom stratigraphy from SP02 was divided into 4 zones using cluster analysis (data not shown) and PCA axis scores (Fig. 4).

4.3.1. Zone 1: 5880–5170 years BP (62–50 cm)

Diatoms first appear in Zone 1 but at relatively low concentration (Fig. 4b); biogenic silica is also low in this zone. When diatoms colonized Lake SP02–5880 years BP, only six species are present: *Gyrosigma obtusatum*, *Nitzschia amphibia*, *S. pinnata*, *S. pinnata* (long form), *S. pinnata* var. *intercedens*, and *S. construens* var. *venter*. By 5170 years BP, however, species richness increases to 18 taxa (Fig. 4b). Initially, *S. pinnata* represents 60% of the assemblages. The ratio of *S. pinnata*:*S. construens* var. *venter* remains relatively high, and the combined abundance of *S. pinnata* and *S. construens* var. *venter* is >70% (Fig. 4a).

4.3.2. Zone 2: 4890–2845 years BP (46–27 cm)

Between 4330 and 2990 years BP, diatom concentrations are at the highest consistent values recorded in the record and biogenic silica reaches its pre-Anthropocene maximum (Fig. 4b). The abundance of all Fragilarioids declines modestly, and the ratio of *S. pinnata*:*S. construens* var. *venter* falls relative to Zone 1 (Fig. 4b).

Diatom species richness is relatively low in Zone 2 as several species disappear from the record, including *Amphora thumensis* and *Gyrosigma obtusatum*. Zone 2, however, is also marked by the appearance of non-Fragilarioid epiphytes and benthic taxa such as *Achnanthes*, *Caloneis* and *Cocconeis* spp.

4.3.3. Zone 3: 2700–330 years BP (26–6 cm)

Diatom concentrations and biogenic silica decline in Zone 3, while species richness increases (Fig. 4b). Some epiphytic and benthic taxa decline or disappear in Zone 3 (e.g., *Cocconeis neodiminuta* and *C. pediculus*), while new species appear for the first time, including *Cymbella angustata*, *C. neocistula*, and *Pinnularia balfouriana*. *G. obtusatum* reappears, and *Fragilaria brevistriata*, *F. microstriata* and *Pseudostaurosira pseudoconstruens* increase, indicating diversification of the diatom community (Fig. 4a). Following 950 years BP, there is a small decrease in the ratio of *S. pinnata* to *S. construens* var. *venter*, and an increase in the abundance of *P. pseudoconstruens*, as reconstructed pH increases slightly. After 750 years BP, *S. pinnata* begins to increase again, while *P. pseudoconstruens* decreases. Minima in LOI₅₅₀ and diatom valve concentrations are also recorded around 750 years BP (Fig. 4b).

4.3.4. Zone 4a: 225–36 years BP (5–3 cm)

Zone 4a is characterized by increasing diatom concentrations and species richness (Fig. 4b). The combined abundance of all Fragilarioids decreases substantially for the first time in the record to ~90%. The ratio of *S. pinnata*:*S. construens* var. *venter* declines and remains below 1.0 for the remainder of the record. Epiphytic taxa such as *Kolbesia suchlantii* increase in abundance early in Zone 4a, while several species appear, including *Encyonema fogedii*, *Navicula agrestis*, and *N. schmassmannii* (Fig. 4b). Towards the end of Zone 4a, *F. brevistriata* and *F. microstriata* increase while *S. construens* var. *venter* (long form) declines (Fig. 4a).

4.3.5. Zone 4b: –15–58 years BP/1965–2008 AD (2–0 cm)

The most recent period is characterized by profound ecological changes, including maximum recorded species richness, diatom concentration and biogenic silica (Fig. 4b). The combined abundance of Fragilarioids continues to drop after 1965 AD, declining to a recorded minimum of 84% in the uppermost sample. *P. pseudoconstruens* increases to maximum abundance in the uppermost sample (Fig. 4a). Six species from the planktonic genus *Cyclotella* appear in Zone 4b, beginning with the appearance of *Cyclotella pseudostelligera* at low abundances around 1965 AD. Epiphytic and benthic genera also diversify, including *Achnanthes*, *Cymbella* and associated genera, as well as *Navicula* and *Nitzschia* (Fig. 4b).

4.4. Lake SP04 diatom assemblages

A total of 94 diatom taxa from 35 genera are identified from SP04. The average rarefacted species richness for core SP04 is 20 species (Fig. 5b). Both diatom concentration and diversity were lower in SP04 than in SP02, likely in part due to the more rapid rate of sediment accumulation in parts of the SP04 core, but also explained by the smaller size of the lake. Of the 94 species identified in SP04, only 8 species are present at >5% maximum relative abundance in any one sample, all of which are benthic Fragilarioids. *S. construens* var. *venter* dominates the record (Fig. 5a); *S. pinnata* was more abundant in SP02. The diatom record obtained from SP04 was divided into 3 zones, delineated based upon cluster analysis (data not shown) and PCA axis scores (Fig. 5b).

4.4.1. Zone 1: 59–25 cm

If the rate of sediment accumulation between the two dates at depths 23 and 59 cm is taken, this zone represents the time period

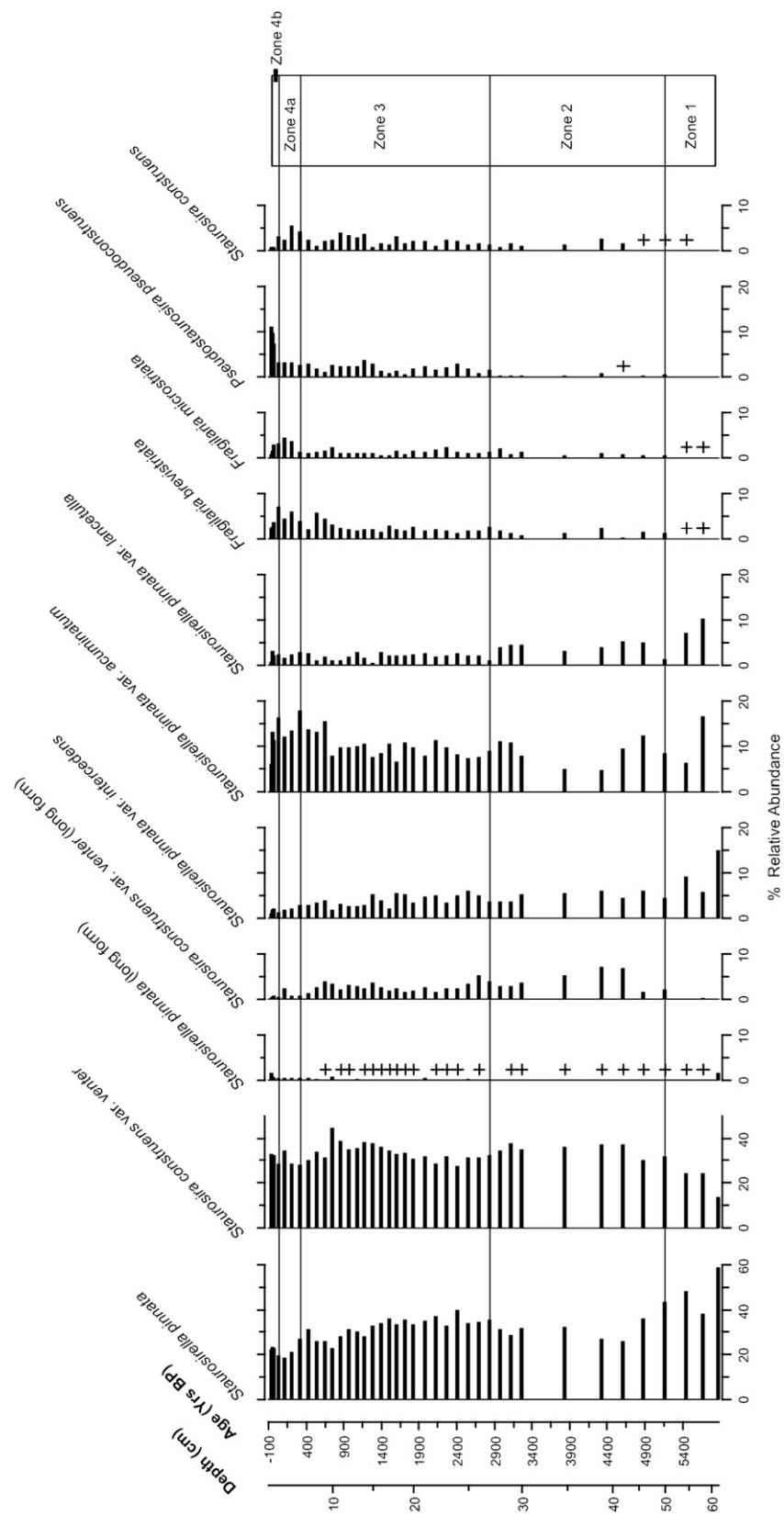


Fig. 4. a. Relative abundance of all Fragilarioid diatom species found in SP02 plotted against time (age model follows Fig. 2) and delineated into zones. '+' symbol indicates relative abundance <0.5%. b. Diatom biostratigraphies, pH reconstruction, and magnetic susceptibility for the SP02 record plotted against time and delineated into zones. Magnetic susceptibility is plotted on a log scale.

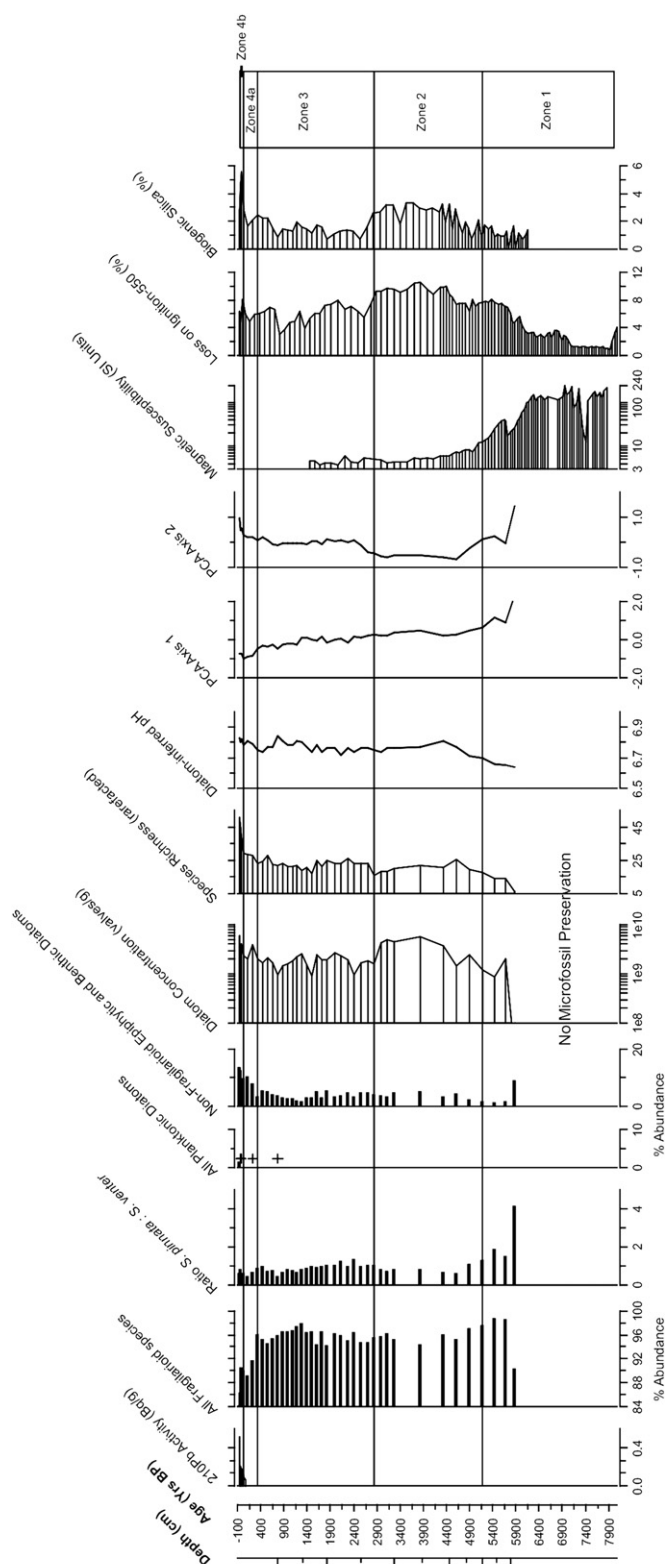


Fig. 4. (continued).

spanning 1240–1500 years BP. Diatom concentration and species richness are both low (Fig. 5b). The abundance of Fragilarioids is high, ~99%. In terms of non-Fragilarioid epiphytes, low abundances of *Achnanthes* spp. and *C. neodiminuta* occur between 59 and

25 cm, while *A. thumensis* is present at low abundances from 59 to 35 cm, after which it disappears from the record (Fig. 5b).

4.4.2. Zone 2: 1240–44 years BP (23–9 cm)

The rate of sediment accumulation slows in this zone, and diatom concentration in valves/g increases by one order of magnitude in Zone 2 relative to Zone 1; species richness changes little in Zone 2. The combined abundance of all Fragilarioids declines through Zone 2, reaching 93% by 44 years BP, which is slightly higher than the 90% abundance of Fragilarioids in the more diverse Lake SP02 at 36 years BP (Fig. 4a). Epiphytic species, such as *Cymbella amphicephala* and *C. incerta*, as well as benthic *Cyclotella antiqua*, appear in the assemblage 44 years BP, while *Navicula* diversifies towards the end of Zone 2, with the appearance of *Navicula viridula* and *N. vulpina* (Fig. 5b).

4.4.3. Zone 3: 10–58 years BP/1940–2008 AD (7–0 cm)

Although a sustained increase in diatom concentration in recent decades is not observed, several samples since 1940 AD display the highest concentrations recorded from SP04. Species richness increases in this zone, reaching a maximum of 37 species in the most recent sample, which is similar to the observed recent increase in SP02 (Fig. 5b). Zone 3 is marked by the substantial decline in the abundance of Fragilarioids to the recorded minimum of 91% in the uppermost sample, similar to the recent decline recorded in SP02. *P. pseudoconstruens* also displays similar trends as in SP02, reaching maximum abundance in the most recent sediments. *F. brevistriata* increases in this zone to the maximum recorded abundance in the record (Fig. 5a). Several species of planktonic *Cyclotella* appear in SP04 beginning around 1970 AD, including *Cyclotella bodanica*, *C. comensis*, *C. meneghiniana*, and *C. pseudostelligera*. However the abundance of any one taxon is low, as is the case in SP02. Further diversification of species in SP04 includes the appearance of *Achnanthes*, *Cymbella* and *Navicula* spp. beginning 1970 AD; planktonic Fragilarioid species such as *Fragilaria cyclopum* and *F. tenera*, and epiphytic *Denticula* spp., appear in the assemblage around 1990 AD, and although rare, increase to present day (Fig. 5b).

4.5. Diatom-inferred pH reconstruction

Modern surface sediment diatom assemblages from 61 sites from Baffin Island (Joynt and Wolfe, 2001) and core-top samples from the two sites analyzed on Melville Peninsula were used to quantitatively reconstruct pH changes for the middle and late Holocene from the fossil diatom sequences from Lakes SP02 and SP04. The combined dataset of modern diatom assemblages contains 190 species from 42 genera. Detrended correspondence analysis (DCA) of the 63 sites resulted in a gradient length of 6.77 standard deviations, suggesting unimodal response of diatom taxa to underlying environmental gradients, and the appropriateness of ordination methods such as correspondence analysis (Birks, 1995). The ordination indicates a separation of modern vs. fossil sites along axis 1 (Fig. 6).

Our analysis confirms the findings of Joynt and Wolfe (2001) that diatom assemblages are a reasonable predictor of pH (r^2 for expanded dataset = 0.57; see Joynt and Wolfe (2001) for details). However, the root mean squared error of prediction (RMSEP) calculated by the model, 0.39 pH units, encompasses the range of reconstructed diatom-inferred pH for both Lakes SP02 and SP04. Diatom-inferred reconstructed pH for SP02 varies by 0.19 pH units since the mid-Holocene (Fig. 4b). The lowest diatom-inferred pH of 6.64 occurs 5880 years BP, while the highest diatom-inferred pH of 6.83 occurs both 760 years BP and in the uppermost sample. Similarly, diatom-inferred pH at SP04 does not vary greatly throughout the record (0.16 pH units). Minimum diatom-inferred

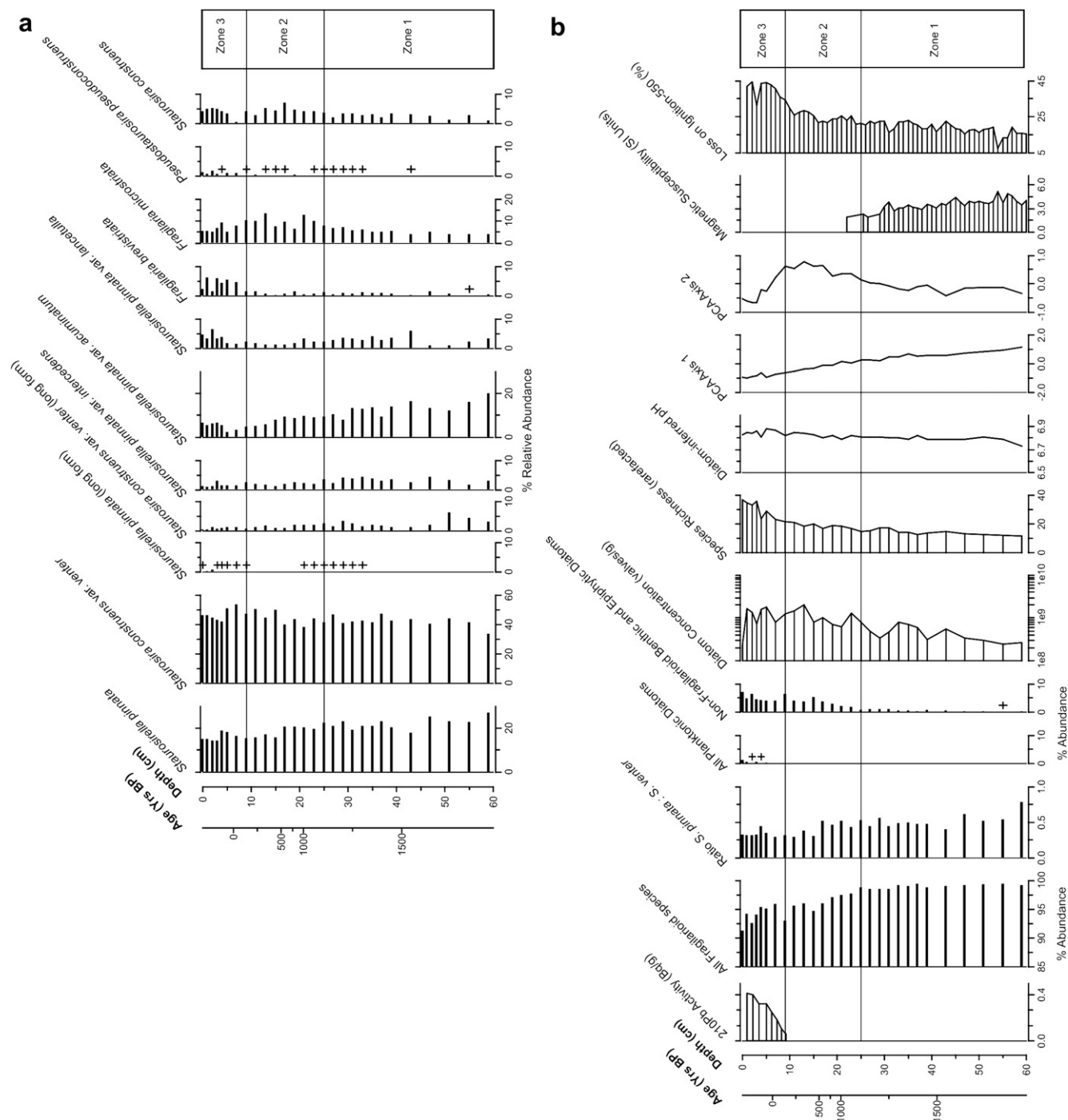


Fig. 5. a. Relative abundance of all Fragilarioid diatom species found in SP04 plotted against time (age model follows Fig. 3) and delineated into zones. '+' symbol indicates relative abundance <0.5%. b. Diatom biostratigraphies, pH reconstruction, and magnetic susceptibility for the SP04 record plotted against time and delineated into zones.

pH of 6.72 is recorded ~1500 years BP, and maximum diatom-inferred pH of 6.88 occurs ~20 years BP (1970 AD), with small fluctuations in the record (Fig. 5b).

5. Discussion

5.1. The early post-glacial and Holocene Thermal Maximum on Melville Peninsula

The multi-proxy record obtained from Lake SP02 confirms the chronology for glacial retreat for the interior Melville Peninsula

suggested by Dredge (1995). Prior to 6000 years BP, the sediments of Lake SP02 indicate a high energy glacial outwash environment, shown by high magnetic susceptibility values and coarser-grained, highly inorganic sediments (Fig. 4b). Diatoms are absent, likely due to the extreme disturbances related to deglaciation. When diatoms first appear in Lake SP02 ~5880 years BP, a cold climate is inferred through low diatom concentrations and the small number of taxa present. The cold local climate is most likely associated with the retreating Foxe Ice Dome (Dredge, 1995).

The diatom records from Lakes SP02 and SP04 are dominated by Fragilarioid species, particularly *S. construens* and *S. pinnata*. Modern

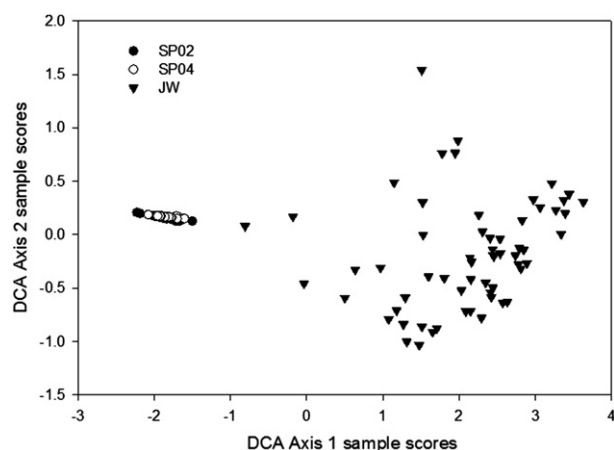


Fig. 6. Detrended Correspondence Analysis (DCA) of surface and fossil diatom assemblages from SP02 and SP04, and the modern diatom assemblages from calibration set lakes from Baffin Island (Joynt and Wolfe, 2001).

biogeographic studies indicate that these taxa are very similar, but not indistinguishable, in terms of autecology (Joynt and Wolfe, 2001; Bouchard et al., 2004; Schmidt et al., 2004; Karst-Riddoch et al., 2009). Paleolimnological studies show that in some cases, the abundances of different Fragilarioid taxa do not co-vary during the Holocene, further suggesting that taxa within the Fragilarioid group respond somewhat differently to environmental changes (e.g., Cremer et al., 2001; LeBlanc et al., 2004). Since existing modern autecological data do not clearly indicate specific variables that unambiguously differentiate the taxa, it is likely that multiple environmental gradients need to be considered to explain the distribution of the taxa. Thus, quantitative inferences on past environmental changes can be challenging using this group. But since the modern biogeographic data indicate that the taxa are somewhat different with respect to environmental optima, even subtle shifts in the relative abundance of different Fragilarioid taxa can be used to infer the timing of environmental changes, particularly in records from polar regions with few other taxa or proxies available (Cremer et al., 2001; Wolfe, 2003; Finkelstein and Gajewski, 2008).

Between 4400 and 2900 years BP, peak LOI_{550} values, enhanced algal productivity as indicated by consistently high diatom valve concentrations and biogenic silica, higher abundances of epiphytic diatoms, diatom assemblages changes including decreases in the ratio of *S. pinnata*:*S. construens* var. *venter*, and a subtle increase in diatom-inferred pH at Lake SP02 suggest a warmer climate and a probable Holocene Thermal Maximum (HTM) on Melville Peninsula. The transition to a warmer climate is due to the final retreat of the Foxe Ice Dome and higher summer insolation in the mid-Holocene relative to present-day forcings (Berger and Loutre, 1991). A small increase in the abundance of epiphytic diatoms suggests more aquatic vegetation during this time, possibly coincident with climate warming and a lengthening of the ice-free season, which would allow an increase in the availability of habitat for littoral plants (Lim et al., 2008). Therefore 4400–2900 years BP is most likely a period of relatively warm temperatures, compared to the periods that precede and follow it.

This evidence for the HTM on Melville Peninsula helps to refine the spatial and temporal mapping for maximum Holocene warmth in the North American Arctic proposed by Kaufman et al. (2004). The timing of the HTM indicated in the record from Lake SP02 is similar to that recorded for the HTM on southern Baffin Island, northwestern Baffin Island, and Labrador (Mode and Jacobs, 1987; Kaufman et al., 2004; Kerwin et al., 2004), suggesting that mid-Holocene climatic changes on Melville Peninsula were more similar

to those of the more maritime-influenced climate regions of the eastern Arctic, than to the western Arctic.

After 2900 years BP (end of Zone 2 in the SP02 record; Fig. 4), diatom concentrations and LOI_{550} values decline, and the ratio of *S. pinnata*:*S. construens* var. *venter* increases. The rate of sediment accumulation declines in core SP02 (Fig. 2), suggesting longer seasons of ice cover. The transitions in these proxies indicate a cooler climate, with decreased productivity, and likely represent the advancement of Neoglacial cooling (Bradley, 1990; Kaufman et al., 2004) due to the decrease in summer insolation. Species richness increases in Lake SP02 at the beginning of the Neoglacial (Fig. 4); peaks in diatom diversity have been noted elsewhere at times of environmental change as ranges of tolerances overlap for more taxa (e.g., Wolfe, 2003).

5.2. The last 2000 years on Melville Peninsula

Higher resolution data from Lakes SP02 and SP04 for the late Holocene permit discussion of paleoclimate for the past ~2000 years, a time period of recent interest due to the need for data to calibrate and validate climate models at the sub-millennial time-scale (Kaufman et al., 2009). The longer SP02 record shows that the whole of the past 2000 years should be considered in the context of the long-term cooling of the Neoglacial. There are some small changes in the biostratigraphy which could be indicative of warming coincident with the Medieval Warm Period, including a small increase in the abundance of the taxon *P. pseudoconstruens*, noted elsewhere to track warmer air and water temperatures (Joynt and Wolfe, 2001; Bouchard et al., 2004; Finkelstein and Gajewski, 2008), following 970 years BP.

This warming that may have occurred on Melville Peninsula during the MWP however appears to have been considerably less pronounced than what has been reconstructed in records from the more maritime-influenced Baffin Island (e.g., Moore et al., 2001). The MWP has been identified in lake sediment records from sites west of Baffin Island, including in chironomid assemblages from Southampton Island (Rolland et al., 2009), and pollen and diatom records at site JR01 from Boothia Peninsula (LeBlanc et al., 2004; Zabenskie and Gajewski, 2007), however the magnitudes of the reconstructed changes at those two sites are relatively small. The synthesis of Kaufman et al. (2009) also indicates only very subtle shifts in Arctic ecosystems during the time of the MWP.

The Little Ice Age on Melville Peninsula is suggested by minima in LOI_{550} and diatom concentration in core SP02 around 750 years BP. Increases in *S. pinnata* var. *acuminatum* at this time further suggest some limnological change at this time. The timing of this cooling at Lake SP02 coincides with the beginning of the LIA in other regions of the Canadian Arctic, including the neighbouring Boothia Peninsula (LeBlanc et al., 2004; Zabenskie and Gajewski, 2007), whereas records from Baffin Island do not indicate the initiation of the LIA until two centuries later, around 550 years BP (Hughen et al., 2000; Grunet et al., 2001; Moore et al., 2001). In the record from Lake SP04, cooler LIA climates with longer seasons of lake ice cover are suggested by a decrease in sediment accumulation rate during the past millennium (Fig. 3), although there were no notable shifts in diatom community composition at this time (Fig. 5). Thus, biotic evidence from the Lakes SP02 and SP04 indicates that the climate changes of the mid-Holocene were of larger magnitude than those experienced during the pre-industrial portion of the last millennium.

Whereas the timing of the HTM at Lakes SP02 and SP04 was closer to that of the Baffin region, the timing of the more subtle climatic changes of the last millennium is more similar to that of the central Arctic. It is possible that the Melville Peninsula experienced more maritime influences during the mid-Holocene because

of the decreased size of the Peninsula at that time due to inundated shorelines as a result of isostatic depression (Dredge, 1995). Less sea-ice cover in the Foxe Basin during the HTM would also have increased the maritime influence on Melville Peninsula (e.g., Dyke and Morris, 1990). Dredge (1995) reports relict erosional features on former shorelines along the eastern edge of the Melville Peninsula, interpreted as indicative of enhanced coastal erosion under more open (less sea-ice) conditions in the mid-Holocene. Thus, our analysis shows the importance of Melville Peninsula as a region of transitional climate, and confirms the importance of regional boundary conditions, such as sea-ice cover, in causing shifts in the controlling factors for local climate regimes.

The subtle ecological changes recorded at our study sites on Melville Peninsula during the MWP and LIA emphasize the importance of non-climatic factors in the interpretation of the Thule archaeological record (e.g., McGhee, 1994). Widespread evidence for technological specialization allowed the Thule to continuously occupy Melville Peninsula and adjacent regions through the climate fluctuations of the past millennium (see Finkelstein et al., 2009), which even during the MWP was cool relative to both earlier time periods and today.

5.3. The Anthropocene

Diatoms in lake sediments have been used to document unprecedented changes in Arctic aquatic ecosystems associated with the onset of the Anthropocene (Smol and Douglas, 2007). The records from Lakes SP02 and SP04 provide further evidence for substantial recent changes in these ecosystems. Several small planktonic *Cyclotella* spp. appear around 1965 AD in SP02 and around 1970 AD in SP04, and display increases in richness and abundance in more recent sediments. Increases in planktonic diatoms indicate reduced ice cover and stronger stratification due to warming climates (e.g., Rühland et al., 2003). The warm-tolerant taxon *P. pseudoconstruens* also doubles in relative abundance at the onset of the Anthropocene (Zone 4b of core SP02 and Zone 3 of core SP04; Figs. 4a and 5a), further indicating climate warming. After 1965 AD, species richness increases by 85% relative to pre-Anthropocene maxima in the SP02 record and by 76% in the SP04 record. Most of the increase in species richness is due to increases in non-Fragilarioid taxa. Similar declines in Fragilarioid abundance have been observed on Banks Island and Ellesmere Island in the recent record (Douglas et al., 1994; Lim et al., 2008). Increases in non-Fragilarioid taxa are attributed to increasing temperatures and corresponding decreases in ice cover, providing new microhabitats for additional diatom taxa.

Diatom production has also increased in the Anthropocene at both sites. Based on the increases in diatom concentration and biogenic silica reported here during the Holocene Thermal Maximum, it is likely that diatom production will begin to increase more substantially in these lakes with continued warming. Increases in species richness that are unprecedented for the Holocene and enhanced biological productivity confirm ecological regime shifts reported elsewhere for Arctic lakes (Smol et al., 2005).

5.4. Watershed-scale reconstructions

The analysis of two records from adjacent lakes in the same watershed allows for comparisons of watershed-scale variability in ecological responses to environmental change. Both lakes show profound recent changes, with increase in diatom species richness and production, as well as changes in assemblage composition. Although the planktonic genus *Cyclotella* appears at approximately the same time in SP02 and SP04 (1970 AD), SP04 shows greater recent diversification of *Cyclotella*. More *Cyclotella* species, as well

as the appearance of planktonic *Fragilaria cyclopus* and *F. tenera* in the uppermost sediments of Lake SP04, indicate an important increase in the relative abundance of planktonic vs non-planktonic benthic diatoms. While Lake SP02 shows a large recent increase in species richness, this increase has taken place across both planktonic and non-planktonic genera. The more significant increase in planktonic taxa in Lake SP04 may be attributed to the smaller surface area and depth of the lake, which result in lower thermal inertia compared to a larger water body (Antoniades et al., 2005). Our study thus confirms the sensitivity of small lakes to environmental change, and the comparison of two adjacent lakes confirms that lake size influences the response to climate change.

5.5. Quantitative reconstructions

Despite the lack of substantial change in reconstructed pH in the SP02 and SP04 records compared to previous Arctic reconstructions (e.g. Larsen et al., 2006), ordinations indicate shifts in diatom community composition during the mid- and late-Holocene which can be linked to paleoclimatic change (Figs. 4 and 5). Similarly, Jones and Birks (2004) found in paleolimnological records from Svalbard that diatom-inferred pH also remains fairly constant during the Holocene despite changes in diatom community composition. Our dataset shows relatively poor analogs between the fossil and modern samples used for calibration (Fig. 6), which reduces the quality of the reconstructions. No modern sample is dominated by Fragilarioids to the same extent as the fossil samples, suggesting the possibility that anthropogenic impacts on Arctic lakes have already resulted in no-analog situations. A second issue relates to taxonomic resolution within the Fragilarioids. This group dominates fossil assemblages from many small lakes in the Arctic and is composed of many species and sub-species; there are relatively few data however available on their optima and tolerances with respect to environmental variables. Thus, due to poor modern analogs and a lack of data on the autecological differences between particular Fragilarioid species and sub-species common to the Arctic, transfer functions cannot always provide a complete representation of paleoenvironmental change for Arctic lakes.

6. Conclusions

The analysis of two paleolimnological records from adjacent lakes in the same watershed in the interior Melville Peninsula improves upon previous syntheses of Arctic paleoclimates. The sediment core records confirm the retreat of remnant ice on Melville Peninsula by 6000 years BP, previously estimated only through a small number of radiocarbon dates on shells, and multiple proxies were used to infer maximum Holocene temperatures for Melville Peninsula between 4400 and 2900 years BP. Ecological changes during the pre-industrial late Holocene (since 2000 years BP) were of smaller magnitude than those of the middle Holocene. The timing of paleoclimatic changes in the middle Holocene was closer to that of the more maritime-influenced eastern Arctic and Baffin Region, whereas the timing of late Holocene changes appears to be more similar to the adjacent Boothia Peninsula to the west, characterized by more multi-year sea-ice and a more continental climate. Thus, these records provide some evidence for a shift in the forcing factors that control local climate, perhaps due to changes in the extent and duration of sea-ice cover in the Foxe Basin.

The Anthropocene began in the 20th century at both sites, and is resulting in unprecedented increases in diatom species richness and novel diatom communities. Comparing recent changes under warming climates to those of the Holocene Thermal Maximum suggests that algal production will continue to increase significantly. The present spike in biodiversity may be temporary until

stronger competitors under the new climate regime begin to dominate more productive assemblages. The analysis of two adjacent lakes shows that lake size can influence the response to warming as the smaller lake shows more rapid and ecologically significant recent shifts in diatom community composition.

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