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Rapid Communication

Multiproxy evidence of an early Holocene (8.2 kyr) climate oscillation in central Nova Scotia, Canada

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ABSTRACT: An early Holocene lake sediment record from central Nova Scotia contains a minerogenic oscillation that is closely correlative with the 8.2 kyr event (ca. 8200 cal. yr BP), an event that has not been reported elsewhere in Atlantic Canada. A variety of biological and sedimentological indicators have been examined to characterise autochthonous and allochthonous changes that occurred during this time. The minerogenic upper oscillation (UO, ca. 8400 cal. yr BP) is marked by an increase in the chrysophyte:diatom ratio. Following the oscillation, the diatom community reflects a shift to more productive, less acidic conditions. The pollen record shows no major response to this short-lived event. Lithostratigraphic analyses indicates that the UO is characterised by an increase in clastic content, magnetic susceptibility and mean sediment grain size, all indicators of changing environmental conditions, most likely the result of regional cooling. The Taylor Lake record adds to a growing body of evidence for a widespread, hemispheric climate oscillation at 8.2 kyr. Copyright © 2002 John Wiley & Sons, Ltd.

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KEYWORDS: 8.2 kyr event; climate change; Nova Scotia; palaeolimnology.

Introduction

The 8.2 kyr event (8400–8000 calendar years ago; Bond *et al*, 1997; Barber *et al.*, 1999) is the most notable negative change in δ^{18}O in the Greenland ice-cores during the Holocene. A number of proxy records of this cooling event have been documented, particularly in Greenland, the North Atlantic and western Europe (Alley *et al.*, 1997; Klitgaard-Kristensen *et al.*; 1998, von Grafenstein *et al.*, 1998; McDermott *et al.*, 2001; Tinner and Lotter, 2001). Yu and Eicher (1998) report an 8.2 kyr equivalent decrease in δ^{18}O in cores from marl lakes in central Canada. Kurek *et al.* (2002) report a 4 °C temperature decline through the 8.2 kyr event. Other reported 8.2 kyr correlative events are in West Asia and North Africa (Gasse and Van Campo, 1994) and the tropical Atlantic region (Hughen *et al.*, 1996). A number of authors have proposed that an increase in freshwater influx into the North Atlantic associated with the final stages of deglaciation of the Laurentide ice sheet is the most likely forcing mechanism capable of inducing rapid cooling; however, this process is not well understood or documented (Barber *et al.*, 1999).

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In this paper we present a multiproxy record from a small, headwater lake in the Antigonish Highlands of central Nova Scotia (Fig. 1) that contains sedimentological and palaeoecological evidence of an Early Holocene climate oscillation. Models for Late-glacial and early Holocene environmental change in Nova Scotia are complex. During the final stages of deglaciation remnant ice-caps were thought to have developed in highland areas (Stea and Mott, 1989; King, 1993, 1996; Miller, 1996). Younger Dryas (YD) equivalent regional cooling probably resulted in rejuvenation of local ice-caps; the formation of glacial lakes and buried organic deposits (a result of landscape instability associated with regional cooling) is well documented (Mott and Stea, 1993). Previous palaeolimnological research tracking YD cooling shows that siliceous diatom microfossils can be used to infer the extent of ice cover on lakes (Rawlence, 1988; Rawlence and Senior, 1988) and other studies have described how diatom:chrysophyte ratios can be used to infer climate shifts (Douglas and Smol, 1995; Smol, 1983, 1988). Other records in Nova Scotia and Newfoundland suggest a prolonged period of post-YD early Holocene cooling (Anderson and Lewis, 1992; Anderson and Macpherson, 1994; Grant, 1994; MacDonald and Spooner, 2001). Our investigation of sediments from Taylor Lake was aimed at resolving early Holocene climate conditions in central Nova Scotia, a region from which few studies exist. This site was of particular interest as buried organic deposits nearby suggest YD ice advance and nearby lakes record the YD as a minerogenic oscillation (Stea and Mott, 1998). In addition, the lake's rapid response to air temperature change (a consequence primarily of high surface area to volume ratio) coupled with its exposed location suggest that the site is sensitive to climate oscillations. We present physical (magnetic susceptibility, grain size, grey scale), chemical (loss on ignition, LOI) and biological (pollen, siliceous diatoms, chrysophyte cysts, sponge spicules and testate amoebae plates) proxy data to infer changing environmental conditions at this site.

Approach

Study site

Taylor Lake is a small (surface area = 12 ha), shallow (6 m) lake with acidic (pH 6.1) waters of low conductivity. It was formed in a glaciated depression at an elevation of 190 m a.s.l. (Fig. 1). The regional bedrock is Carboniferous sandstone, which is covered by a thin veneer of compact clay lodgement till. The lake is presently monomictic and oligotrophic with no inflow and minimal outflow. It receives its input from precipitation within its watershed. The present day climate is east-coast northern temperate (Ritchie, 1987). Runoff is low owing to subdued (1°) lakeside slopes and a small (120 ha) watershed. Acadian forest covers the region and is typified by red spruce (*Picea rubens*), sugar maple (*Acer saccharum*), eastern hemlock (*Tsuga canadensis*), birch (*Betula spp.*) and beech (*Fagus grandifolia*) (Ritchie, 1987). Lake bathymetry is relatively simple and consists of a central basin with a maximum depth of 6 m. Anoxic conditions exist in the basin-deeps. Given these conditions, biological productivity would be particularly sensitive to changes in water temperature (air temperature) and ice-cover duration and their associated effects.

Methods

Coring sites on Taylor Lake were chosen after detailed surveying with sub-bottom profiling sonar (Fig. 1). Three lake

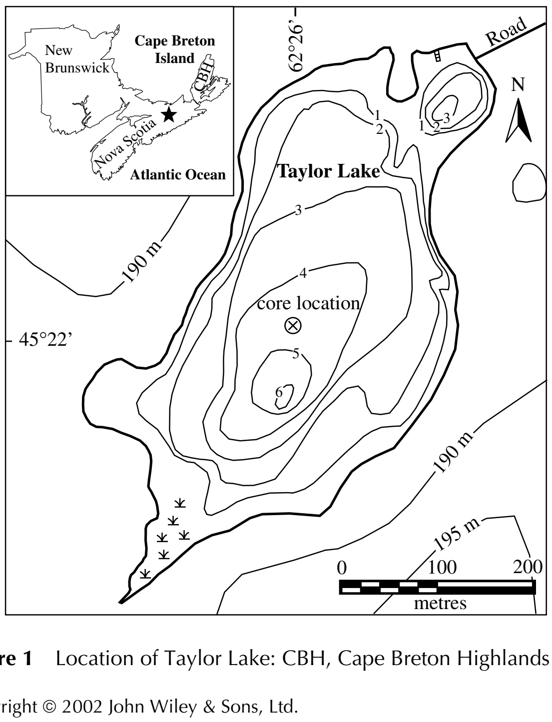

Figure 1 Location of Taylor Lake: CBH, Cape Breton Highlands

sediment cores (ca. 200 cm in length) were collected using a portable percussion coring system (Reasoner, 1993) and all cores show a consistent lacustrine stratigraphy. In this paper only the lower section of core TAY3-97 is described in detail. All cores penetrated at least 15 cm of basal diamicton considered to be regional till. Cores were frozen and split along length to facilitate description and sampling; all samples were taken from the middle of the core where sediment disturbance is minimal. The chronology of the cores is based on five accelerator mass spectrometry (AMS) ^{14}C dates (Table 1). The AMS ^{14}C measurements were carried out at Isotrace Laboratories, The University of Toronto and NSF-Arizona AMS Facility, The University of Arizona and converted to calendar years using the CALIB 4.2 program (HTML version; Stuiver and Reimer, 1998; see Table 1). All dates were performed on terrestrial samples and one sample produced a minimum age limit owing to its low weight. Inorganic grain-size distribution was determined using a Fritsch Laser Particle Sizer Analysette 22-E and by thin-section image analysis techniques (Francus, 1998). Average and maximum grain size of the sand-sized fraction (0.05–2.0 mm) were computed. Loss on ignition (LOI) analysis (Dean, 1974) was carried out at 1 cm intervals; duplicate samples were run at selected intervals and analytical error of LOI measurements averaged 1.1%. Magnetic susceptibility was measured using a KT-9 Kappameter unit in continuous scan mode at 2 cm intervals. Grey-scale values were obtained from X-rays and are an indication of the relative density of the lake sediment. Pollen analysis was conducted on 1 cm^3 sediment subsamples obtained from the centre of the core following the procedure of Faegri and Iverson (1975). Palynomorphs were identified under 400× magnification using pollen reference slides and various reference texts (McAndrews *et al.*, 1973; Faegri and Iverson, 1975; Bassett *et al.*, 1978). Siliceous microfossils including diatom valves, sponge spicules, chrysophyte cysts and protozoan plates were extracted from the sediments using standard techniques for microfossils and examined at 400× and 1000× magnification (Lim *et al.*, 2001). Diatoms were identified using mainly Kramer and Lange-Bertalot (1985–91), Camburn and Charles (2000), Siver and Kling (1997) and Patrick and Reimer (1966, 1975). Sponge spicules were identified according to Ricciardi and Reiswig (1993). Chrysophyte cysts were enumerated and protozoan plates were identified using Douglas and Smol (1987). Pollen grains were identified using reference slides and a variety of reference texts (McAndrews *et al.*, 1973; Bassett *et al.*, 1978; Traverse, 1988; Moore *et al.*, 1991).

Results and interpretation

Six distinct sedimentary units were recognised (Fig. 2). The basal diamicton (unit 1; 202–185 cm) is coarse grained, brown and overlain by a clay-rich diamicton (unit 2; 185–180 cm) that contains rare angular pebble- to cobble-sized clasts. The clay diamicton is overlain by sandy gyttja (unit 3; 180–172 cm); the contact between these two units is gradual. A date of 11 608 cal. yr BP was obtained on twig fragments within this unit at 178 cm. A sandy layer (Lower Oscillation, LO; 171–170 cm), which has a low organic content, is in abrupt contact with the sandy gyttja below and with a highly organic gyttja above (unit 4; 170–159 cm). A date of 11 300 cal. yr BP was obtained immediately above this contact (168 cm, twig fragment). A silty layer (Upper Oscillation, UO; 158–159 cm) was visually distinguished on the basis of subtle colour differences with the surrounding gyttja. The UO is bracketed by AMS ^{14}C dates of 8525 cal. yr BP (160 cm, seed)

Table 1 Radiocarbon dates and calibrated ages for Taylor Lake core. Calibration done using CALIB 4.3 (Stuiver and Reimer, 1998)

Depth (cm)	Age (^{14}C yr BP)	Calendar date (yr BP)	Calendar range (2σ) (yr BP)	Laboratory Number[a]	Material
152	5709 ± 59	6490	6660–6323	AA-41877	Twig fragment
157	>7620	8405	8411–8387	TO-7203	Bark fragments
160	7760 ± 140	8525	9005–8222	TO-7204	Seed
168	9967 ± 68	11 300	11 917–11 203	AA-41876	Alder twig
178	10 090 ± 120	11 608	12 332–11 226	TO-7202	Twig fragments

[a] TO = Isotrace Laboratories, Toronto, ON. AA = Arizona AMS Facility, Tucson, AZ.

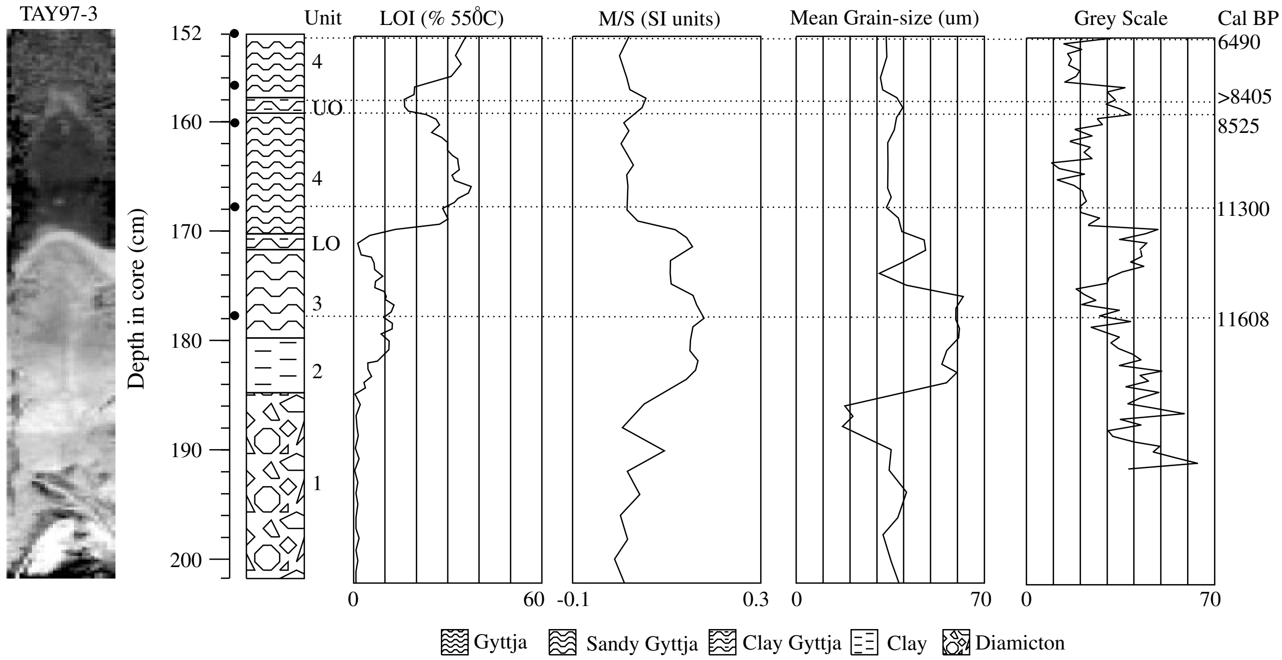

Figure 2 Details of stratigraphy, loss-on-ignition, magnetic susceptibility, mean grain-size, and grey-scale analyses of core TAY3-97. Six distinct units were recognised, observed primarily on the basis of grain size, texture and volume of the clastic component. The convex appearance of the strata in the photograph is the result of frictional distortion at the side of the core barrel. Note the abrupt initiation and termination to the LO (Lower Oscillation) and the difference in the gyttja that brackets this unit. The UO (Upper Oscillation) also displays an abrupt initiation, the termination is obscured somewhat by oxidation of the overlying gyttja. Unit 3 and the LO are YD correlative. The UO is correlated with the 8.2 kyr event. Dates are calibrated years BP

and > 8405 cal. yr BP (157 cm, terrestrial plant fragments). The greater-than (minimum) date is unconventional and a result of the low amount of datable carbon in the sample. However, this date, given its stratigraphical position can be used to constrain the timing of the UO (R.P. Beukens, Isotrace Laboratories personal communication, 2001). Gyttja, indistinguishable from unit 4, continues from the top of the UO to the top of the core. A date of 6490 cal. yr BP was obtained from a twig fragment at depth of 152 cm in this unit (Fig. 2).

Unit 2 contained the finest grained sediment in the core and is similar to sediment observed in lake sediment cores by Stea and Mott (1989) and Spooner (1998). These fine sediments are interpreted to be periglacial silts and clays deposited during the initial stages of lake basin development following deglaciation. Unit 3 is a sandy gyttja and contains the coarsest sediment within the core interval described; magnetic susceptibility is uniformly high. This unit contained abundant sedge (Cyperaceae) and birch (*Betula spp.;* Fig. 3); the palynomorph assemblage is consistent with a shrub-tundra environment. Unit 3 is terminated abruptly by the LO, a primarily inorganic unit composed of fine to medium sand. The coarse, dense sediment and elevated magnetic susceptibility evident in units 3 and the LO are an indication of vigorous minerogenic sediment transfer, most likely a consequence of a combination of landscape denudation, shoreline instability and inflow focusing as a result of ice and snow melt. The short time interval over which unit 3 and the LO were deposited is likely a consequence of high sedimentation rates. Decreased productivity owing to increased lake ice-cover also may have contributed to the decrease in organic material observed in this interval (Stea and Mott, 1998). Pollen concentrations in units 3 and the LO were reduced; no diatoms, sponge spicules, or other siliceous microfossils were present, with the exception of one level (177 cm) in which a few sponge spicules were observed. Rawlence (1988) attributed a lack of diatoms in Splan Lake, New Brunswick during the Younger Dryas interval to high sedimentation rates and reduced light penetration. The observed absence of siliceous microfossils also may be the result of poor preservation, as there is evidence of dissolution throughout the core. Given the dates obtained within unit 3 and directly above the LO it is likely that these units were deposited during Younger Dryas cooling. The LO may represent the termination of that event. Stea and Mott (1998), King (1996)

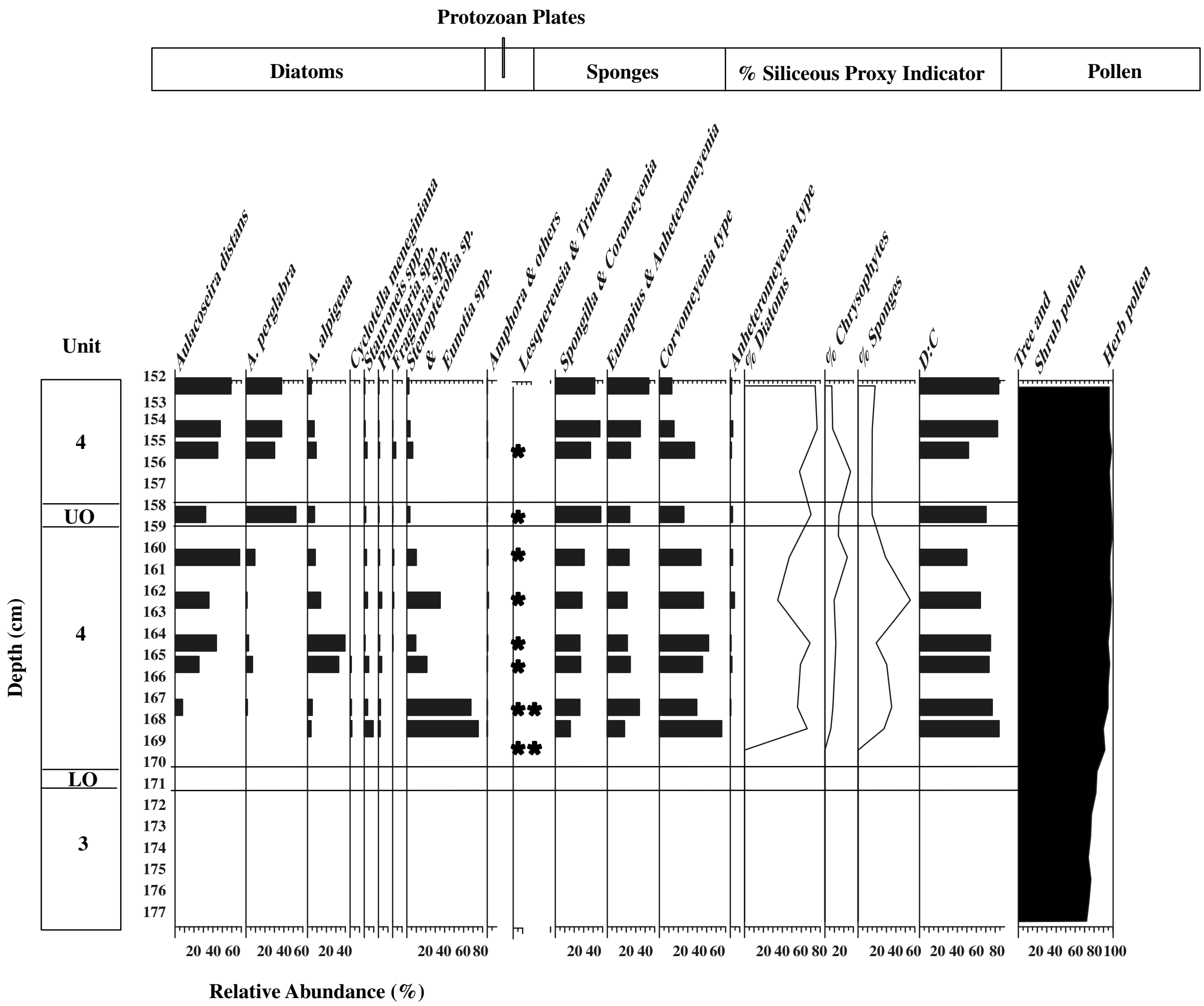

Figure 3 Late Glacial to early Holocene diatom, sponge spicule, chrysophyte, protozoan plates and pollen stratigraphy for Taylor Lake. Protozoan plates are marked as presence/absence (∗ = present). Dates are calibrated years BP

and Grant (1994) have all indicated that Younger Dryas glacial ice or aufeis was possible within the region during this time.

Algal gyttja (unit 4) is in abrupt contact with both the LO and UO. Microfossil and sedimentological data indicate the rapid increase of productivity within the lake basin and watershed. Representatives of all of the siliceous proxy indicators appear in this unit (Fig. 3). The diatoms appearing immediately above the LO are characteristic of an acidic, oligotrophic environment. *Eunotia* and *Stenopterobia* species dominate with a minor presence of *Pinnularia* spp., *Stauroneis* spp. and *Cyclotella meneghiniana*. *Stenopterobia* is common in acidic, oligohalobous conditions and *Eunotia* species are commonly found living attached to acidic mosses such as *Sphagnum*. The presence of these *Sphagnum*-dominated, bog-like habitats is confirmed by the co-appearance of protozoan plates belonging to the genera *Trinema* and *Lesquereusia*, which are typically found in these habitats. Although *Aulacoseira* spp. were initially present in low concentrations following the LO, their abundance increased and *A. distans* (Her.) Simonson becomes the dominant diatom taxon. At the UO, *A. perglabra* (Oestr.) Haworth becomes co-dominant. The presence of these *Aulacoseira* species indicates a fair degree of turbulence in order to keep these heavy planktonic taxa in the water column. This diatom assemblage progressed from an acidic and benthic dominated community to one that was increasingly planktonic. It indicates that ice-free open water conditions were prevalent during this time. The pollen record indicates a decrease in herbs and shrubs and increases in spruce (*Picea sp.*), balsam fir (*Abies balsamea*) and birch (*Betula spp.*), an assemblage consistent with local warming and drying (Mott, 1985). All palaeoecological data indicate the rapid establishment of a stable and productive landscape.

The upper sediment oscillation (UO, lower contact 8525 cal. yr BP, upper contact >8405 cal. yr BP; 158–159 cm, Fig. 2) marks a short-lived event that might be climatically induced: both physical and biological indicators show a marked response. However, it is difficult to identify unequivocally the environmental forcing responsible for this shift. Although the lithostratigraphical proxies display similar trends for both the LO and UO, trends for the latter are more subtle. Magnetic susceptibility increases slightly in this interval and image analysis of the bounding gyttja and the UO indicate that the UO is slightly sandier and mean grain size has increased slightly. The decrease in LOI and the slight increase in mean grain size can be attributed to increased clastic sediment influx during this time. As with the LO, these lithostratigraphical changes are consistent with a destabilised environment, commonly associated with regional cooling (Spooner, 1998).

The biological response at this level is subtle yet it is clear that there has been an important shift in environmental conditions. However, only a cautious interpretation can be offered at this stage, as the autecology of some of these bioindicators is loosely constrained. The presence of heavy planktonic *Aulacoseira* diatom species indicates that some circulating open water must have been present in order to keep these planktonic diatoms suspended in the water column. A similar diatom response was noted by Rawlence and Senior (1988) with respect to cooling trends that did not cause complete perennial ice cover. *Aulacoseira distans* decreases in abundance at this level from approximately 70% to 30% and *A. perglabra* increases from approximately 10% to 50%. A published calibration of diatoms from nearby soft-water lakes in northeastern USA suggests that this could be reflective of a very slight nutrient increase; however, the difference in the abundance weighted mean (AWM) for total phosphorus (a limiting algal nutrient) for both diatoms is extremely slight (*A. distans* AWM $= 4.62$ mg L^{-1} and for *A. perglabra* AWM $= 5.08$ mg L^{-1}) and not significant (Camburn and Charles, 2000). A second bioindicator, chrysophyte cysts, responded to the changing environment during the UO by decreasing in relative abundance. In Arctic regions, Smol (1983) interpreted a decrease in chrysophyte cyst abundance as a response to cooling and greater ice cover. However, at temperate latitudes, chrysophytes have been observed to be less competitive than diatoms in higher nutrient environments and hence the diatom:chrysophyte ratio (D:C) can be used to interpret the palaeonutrient status of a lake (Smol, 1985). Applying this relationship, Smol (1985) observed that at temperate latitudes the D:C ratio increased following deglaciation and interpreted these as periods of higher nutrient concentrations resulting from the terrestrial–aquatic interactions driven by warmer climates. In our study, the D:C ratio increased markedly during the UO but the interpretation of the D:C ratio remains difficult. Although the D:C ratio points towards an increase in nutrients, this increase is not substantiated by the known autecology of the *Aulacoseira* species that responded at the UO nor from the lithological data. No significant change in nutrient availability can be inferred and the decrease in LOI and corresponding increase in magnetic susceptibility and mean grain size point to cooler climates. In addition, the decrease in chrysophyte abundance also suggests cooler climates. It is conceivable that during a cooler event at Taylor Lake, environmental conditions would have been windier resulting in the turning over of the lake and blowing of terrestrial nutrients into the lake. This would have served to increase, albeit slightly, the nutrient availability in the lake (greater recycling from bottom waters and input from the landscape) as well as increasing the turbulence to maintain the planktonic diatoms in the water column.

Other siliceous microfossil groups (protozoan plates and sponges) did not record any interpretable change at the UO; however, their known autecology is consistent with the site as all of these species are typical of acidic to circumneutral, cold waters.

Above the OU, the algal gyttja (unit 4) continues to the top of the core. Conditions are indicated by low minerogenic content (higher LOI values) and a diatom and sponge assemblage consistent with less acidic, more nutrient-rich conditions. Acidic taxa such as *Eunotia* continue to decrease in abundance and the diatom assemblage shows a marked increase in the abundance of *A. perglabra*, which becomes co-dominant with *A. distans*. *Aulacoseira perglabra* is a diatom species characteristic of waters with higher pH, acid neutralising capacity and higher total phosphorus values than *A. distans* (Camburn and Charles, 2000).

Discussion

The importance of the Taylor Lake record lies in its resolution of a lithostratigraphical and biological oscillation (UO, about 8400 cal. yr BP), which is closely correlative to a cooling event (8.2 kyr event) not well resolved in North America (Yu and Eicher, 1998). A sudden increase in freshwater flux associated with Hudson Bay deglaciation and decreased thermohaline circulation in the North Atlantic have been proposed as possible triggers for 8.2 kyr cooling in northwestern Europe, Greenland and Iceland (Andrews *et al.*, 1995; Alley *et al.*, 1997; Klitgaard-Kristensen *et al.*, 1998; von Grafenstein *et al.*, 1998; Barber *et al.*, 1999). The timing of the 8.2 kyr equivalent climate oscillation at Taylor Lake is similar to that observed by McDermott *et al.* (2001; 8380 cal. yr BP) and about 200 yr older than other records from western Europe and the North Sea (Klitgaard-Kristensen *et al.*, 1998; von Grafenstein *et al.*, 1998; Tinner and Lotter, 2001). The record is consistent with the age proposed for a freshwater pulse associated with Hudson Bay deglaciation, considered to be the most probable forcing mechanism for the event (ca. 8550 cal. yr BP; von Grafenstein *et al.*, 1998).

The lithostratigraphical characteristics of the UO are consistent with the LO and with other records in which Younger Dryas equivalent oscillations have been recognised (Spooner, 1998; Stea and Mott, 1998). Of particular interest, then, is the equivocal nature of the biological response to this event. A strong palynological response at Taylor Lake to a short-lived early Holocene climate event may be precluded as the vegetation assemblage at the site was not at a sensitive ecotone at the time of climate change (Levesque *et al.*, 1993; Mott, 1994; Jetté and Mott, 1995). In addition, only one biostratigraphical sample in the UO could be obtained, precluding at the outset the possibility of a definitive interpretation of the allochthonous biological response to the event. Although siliceous microfossils responded during the UO, interpretation of this response must be treated with caution. Decreased abundance of chrysophytes suggests a cooler, more nutrient poor environment, however the D:C ratio suggests a slight increase in nutrients. Future work is necessary to refine the interpretation of the D:C ratio. The biogenic response to air temperature (and consequently water temperature) change may be highly site specific, a function of a wide variety of controls including latitude, depth, surface area, water chemistry, local climate effect and hydrogeology.

Also of interest is the apparent lack of corroborating evidence for this event in other palaeolimnological records from eastern North America (Railton, 1973; Mott, 1985, 1994; Rawlence, 1988; Cwynar and Levesque, 1995; Jetté and Mott, 1995; Mayle and Cwynar 1995). In previous studies the stratigraphical sampling resolution used over this time interval may not have been high enough to reveal such a subtle sedimentological or biological response. In addition, although studies by Mott (1985), Cwynar and Levesque (1995) and Mayle and Cwynar (1995) in Nova Scotia and New Brunswick show considerable consistency in the patterns of Late-glacial LOI curves, work by others has indicated that the intrabasin and interbasin character of minerogenic oscillations, regardless of their thickness, can be highly variable, a topic that requires more study (Donner, 1995; Spooner, 1998; T.D. Henze, University of Maine personal communication, 1998). Sampling method also may determine whether a thin oscillation is recognised. By splitting a frozen core lengthwise and allowing the core to oxidise, subtle changes in the character of the sediment can be recognised and those horizons can be targeted for sampling. In addition a certain degree of frictional distortion at the edge of the sample is characteristic of all sediment coring systems. If the core is sampled by extrusion and slicing (common for most gravity and piston coring systems) the resultant composite sample may obscure subtle stratigraphical trends.

Summary

Significant changes in the physical characteristics of UO sediments are readily apparent. The UO is a short-lived event, as supported by the radiometric dates. In addition, the rapidly reproducing organisms, such as the diatoms and chrysophytes, showed the most responsiveness of any of the biological proxies to this event, whereas terrestrial vegetation, characterised by longer reproduction rates, showed no marked response. Future studies in this area will determine the geographical extent of this oscillation and, as more data are collected, a better understanding of its environmental significance will be possible.

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