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Holocene Climate and Environmental Changes in Western Subarctic Québec as Inferred from the Sedimentology and the Geomorphology of a Lake Watershed

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Abstract

This study presents a paleoenvironmental and paleoclimatic reconstruction of western subarctic Québec based on the watershed geomorphology of Lake Kaapumticumac (including terraces, stratigraphy, and peatlands) as well as lake sediments, with reference to stratigraphy, grain size, and organic matter content. The integration of data from diverse sources provides valuable information about the regression of the Tyrrell Sea, lake isolation, and lake level fluctuations. Marine processes dominated prior to ca. 6960 cal yr BP, while the marine-lacustrine transition lasted about 500 years (ca. 6960–6400 cal yr BP). In comparison to other study sites in the Whapmagoostui-Kuujjuarapik area, the earlier isolation of Lake Kaapumticumac is consistent with its higher elevation and its greater distance from Hudson Bay. After 6400 cal yr BP, lake evolution was primarily influenced by the climate. Two major climatic periods were recorded: first, the Hypsithermal (ca. 6400–3500 cal yr BP), during which warm conditions caused partial terrestrialization of Lake Kaapumticumac; and second, the post-Hypsithermal or Neoglacial (ca. 3500 cal yr BP to ca. 200 cal yr BP), which triggered the rise in lake levels and caused levees to form in several places around the lake.

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Introduction

Lake basins located in recently deglaciated coastal environments provide important clues about postglacial relative sea levels (e.g. Pienitz et al., 1991; Corner et al., 1999; Smith et al., 2005). In fact, the marine-lacustrine transition (as indicated by the "isolation contact") in sediment cores from lake basins can be documented using lithostratigraphic and biostratigraphic indicators. These indicators track changes between marine and lacustrine sediments in basins that have been isolated or transgressed by sea level fluctuations. In coastal regions characterized by relative sea levels that fell due to post-glacial isostatic rebound, many forms were observed including ancient coastal terraces, cliffs, and perched deltas (e.g. Allard and Tremblay, 1983; Lavoie et al., 2002; Bhiry et al., 2011; Lemieux et al., 2011). The eastern coast of Hudson Bay is a region that is significantly affected by rapid forced regression. The rate of emergence was quite high at the outset (on the order of 9–10 m per century) (Lavoie et al., 2012) but decreased significantly thereafter (settling at approximately 1 m per century as of about 2800 cal yr BP) (Ricard and Bégin, 1999; Cayer, 2002; Miousse et al., 2003). In the regions along the Hudson Bay coastline, isostatic uplift continues to be among the most rapid in the world at a rate of up to 13 mm per year (1.3 m per century) (Lavoie et al., 2012).

Lake Kachishayoot, located 8 km north of Whapmagoostui-Kuujjuarapik on the southeastern coast of Hudson Bay near the study lake (Lake Kaapumticumac), was examined in two complementary studies that focused on its isolation from the sea due to glacial isostatic rebound during the Holocene and its subsequent development as a freshwater coastal basin. The first study focused on diatom assemblages from a core recovered from Lake Kachishayoot (Saulnier-Talbot and Pienitz, 2001). Three successive stages of the lake basin evolution were identified: a marine stage that ended around 4500 cal yr BP, a stage of gradual isolation of the lake basin from the postglacial marine waters, and finally the modern lacustrine stage from 1600 cal yr BP to the present. The second study carried out on the same lake (Miousse et al., 2003) combined sedimentological, macrofossil, and pollen data. Two periods of major lake level fluctuations occurred after its isolation some time during the Late Holocene: first, a rise in water level occurring after 3620 cal yr BP and then a decrease that started a short time before 2250 cal yr BP.

This study concentrated on lake sediments, coastal terraces, and sedimentary units that are exposed in sections in the vicinity of the study lake in order to address questions related to lake isolation in addition to climatic and environmental changes. The results of this study will provide a greater understanding of newly deglaciated coastal environments such as Hudson Bay, which are characterized by differential glacio-isostatic adjustment. In particular, the data could be used to support or refine postglacial rebound modeling (Dyke et al., 2003; Peltier, 2007).

Following isolation from the sea, lakes are highly affected by climate, particularly with regard to the morphology of the lake and water level fluctuations. The influence of climate on the hydrological budgets of lakes is primarily due to atmospheric circulation patterns, precipitation, insolation, evaporation, and temperature changes (Harrison and Metcalfe, 1985). Given such factors, lake evolution may be inferred from organic and mineral sediments as well as from the shape of the lake.

The main purpose of this study was to investigate how land emergence and climate change contributed to the isolation and evolution of the study lake. Marine regression, lake isolation (as related to the continental uplift process), and climate variation were examined through a geomorphological assessment of the lake's watershed area (including terraces, levees, and stratigraphic sections) and through sediment core analyses (including grain size). This type of study will be of great value in environments where bioindicators are absent or scarce.

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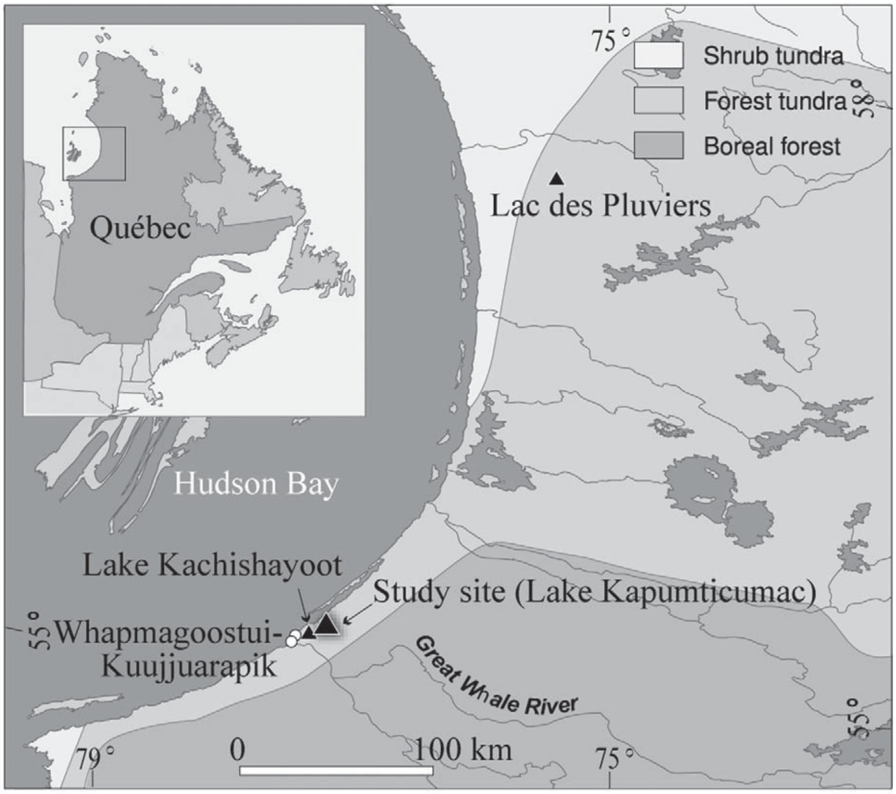

FIGURE 1. Location of the study site and other sites mentioned in the text.

STUDY SITE

Lake Kaapumticumac is located on the southeastern coast of Hudson Bay approximately 8 km north of Whapmagoostui-Kuujjuarapik (55°20′N; 77°40′W) (Fig. 1). The region is located on the Precambrian formation of the Canadian Shield and consists primarily of granite and gneiss outcrops (Biron, 1972). After the retreat of the Laurentide Ice Sheet at approximately 8000 yr BP (Dyke and Prest, 1987), the postglacial Tyrrell Sea submerged the region at around 7625 ± 120 yr BP (8400 cal yr BP) (Hillaire-Marcel, 1976). Surficial deposits include tills, fluvioglacial sediments, marine clays, and littoral sand. The sediments are mainly located in depressed and lower zones and are generally absent on the rolling hills.

The region lies in the discontinuous permafrost zone (Allard and Séguin, 1987a, 1987b) and is characterized by a prevailing subarctic climate. The mean annual temperature is –4.4 °C and monthly mean temperatures range from –23.4 °C in January (coldest month) to 11.4 °C in August (warmest month) (Environment Canada, 2010). Annual precipitation is approximately 650 mm, of which 40% falls as snow. During the past 20 years, this region has been much warmer than expected (Bhiry et al., 2011). The region in which the lake is situated is part of the forest-tundra zone, where lichen-moss, shrub tundra vegetation, and forested patches are mainly located on wind-protected zones. *Picea mariana*, *P. glauca*, and *Larix laricina* are the main species surrounding the site.

Lake Kaapumticumac is the deepest and largest lake in the lake system (Fig. 2, part A), which is located in a large structural depression. Three major peatlands (i.e., the northwestern, central, and southwestern peatlands) divide the lake system into different basins. A fourth peatland is located at the northeastern end of the main basin (Fig. 2, part A). The surface area of the peatlands varies between 5000 and 40,000 m^2 while the depth is between 50 and 150 cm. The lake surface is approximately 115 m above sea level and its maximum depth is 3 m. Three low-energy streams flow into the lake and one outlet drains it westward toward Hudson Bay.

METHODS

Prior to our visit to the study site, a 1:15,840 aerial photograph set was analyzed using a Wild ST4 stereoscope equipped with 3× lenses. This allowed us to identify the main geomorphological features of the study site and several terraces. The geomorphological study was conducted on the site using a theodolite to identify, record, and measure the altitude of the ancient marine terraces.

Two sections located in the western and eastern parts of the lake were excavated to document the initial isolation and early history of the lake. Facies identification was based on texture, color, size, and type of sedimentary structures. For the lithostratigraphic study, we used the International Stratigraphic Guide (Hedberg, 1976) and the "North American Stratigraphic Code" (NACSN, 1983). Samples were collected from each section for grain-size analysis. Plant remains were sampled in the eastern section and were dated by the conventional radiocarbon method at the Centre d'études nordiques (CEN) Laboratory at Laval University in Québec City. The four peatlands (Fig. 2, part A) were cored to retrieve the peat-mineral interface using a Russian peat corer. A 1-cm-thick sample was taken from the deepest zone of each peatland and submitted for dating.

A sediment core was recovered using a 5-cm-diameter gravity corer from the deepest part of the lake (as determined by manual

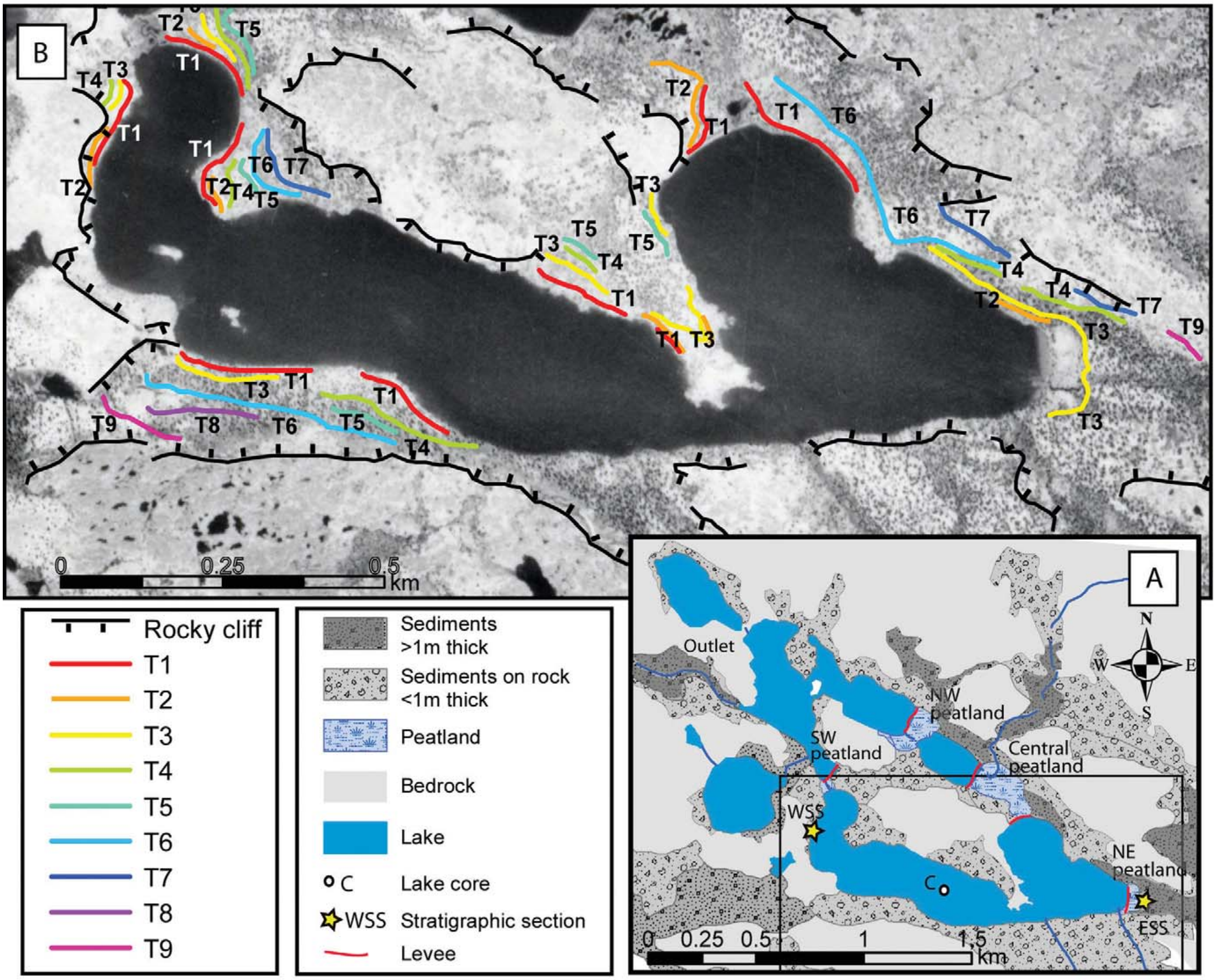

FIGURE 2. **(a) Mapping of surficial deposits and the locations of the sampled core and sections (WSS: western stratigraphic section; ESS: eastern stratigraphic section); (b) locations of 9 preserved marine terraces (T9–T1) identified on lake Kaapumticumac.**

TABLE 1

Radiocarbon and calibrated ages from the lake core, the eastern stratigraphic section, and the basal peat of peatlands.

	Laboratory number	Age (^{14}C yr BP)	Two-sigma range (cal yr BP)	Calibrated age (cal yr BP)	Material dated
Lake core (depth)					
15 cm	UL-2072	1390 ± 90	1166–1426	1295	Charcoal
40 cm	To-8908	4440 ± 120	4821–5332	5080	Plant macrofossil
78 cm	To-8909	6080 ± 120	6675–7247	6960	Plant macrofossil
Stratigraphic section					
Unit 2a Eastern	UL-2247	6240 ± 100	7922–8223	7120	Plant macrofossil
Basal peat					
Central peatland	UL-2231	3350 ± 70	3441–3728	3580	Peat
Southwestern peatland	UL-2230	3950 ± 100	4140–4651	4390	Peat
Northwestern peatland	UL-2246	4040 ± 90	4294–4826	4560	Peat
Northeastern peatland	UL-2288	5690 ± 120	6278–6749	6510	Peat

sounding) (Fig. 2, part A). The collected core (93 cm long) was subdivided into 1-cm-thick samples. Very little dating material was present, as only one charcoal sample and two plant remains were recovered at depths of 15, 40, and 78 cm, respectively, in the core. The charcoal was submitted to CEN's ^{14}C Laboratory for conventional dating, whereas the plant remains were sent to the University of Toronto's Isotrace Laboratory for accelerator mass spectrometry dating. Radiocarbon dates were calibrated with the CALIB 6.0 program (Stuiver et al., 1998). Both calibrated and non-calibrated dates were integrated in Table 1 for comparison with previous studies.

Grain-size analysis and loss-on-ignition (LOI) testing were performed at 2-cm intervals. Grain-size analysis was conducted on minerals (after LOI) using a SediGraph (<63 µm) and a settling tube (63-1000 µm). Data were acquired using Particle Sizing System 3.1 (PSS) software and were integrated into one general grain-size distribution. Statistical parameters were calculated using the moment method (McManus, 1988), which takes into account Mean size (Ms), Sorting (Sc), and Skewness (Sk). Particle diameters were reported as Phi values to allow direct application of conventional statistics even on non-Gaussian distribution (Pierce and Graus, 1981). LOI was performed at 440 °C for 2 h to avoid distortions due to dewatering structural effects on clay minerals (Ball, 1964; Nelson and Sommer, 1996; Smith, 2003).

Results and Interpretation

LAKE WATERSHED GEOMORPHOLOGY AND PEAT ACCUMULATION

Terraces and Watershed Sediments

Surficial deposits, terraces, stratigraphic sections, and peat accumulation zones were investigated to document the evolution of the site. Figure 2 shows that in the southwestern and southern parts of the lake watershed area, sediments (including pebble, gravel, and sand) are abundant and thicker (>1 m) in depressions and valleys or overlying the bedrock. In the northwest (toward Hudson Bay), barren rock is widespread and sediment deposits are less thick and less frequent. These findings suggest that ancient hydrodynamic conditions were energetic on the northwestern side of the lake. This interpretation is supported by the NW–SE orientation and by the morphology of the lake watershed area, which is oval in shape and opens westward to the sea (Hudson Bay).

In total, there are nine discontinuously preserved marine terraces (T9–T1) that are composed of fine sediments (silt to medium sand). Their altitude varies between 9.25 m and 1 m above the current lake level (Table 2; Fig. 2, part B). The higher and older terraces are located on the southwestern and south sides of the lake watershed area, while the lowest and most recent terraces are located along the sheltered sides of the lake and in the downstream zone (which is the release point of the lake system) (Fig. 2, part B).

Stratigraphic Sections

Two sections located 1 km apart provided valuable data about the evolution of the site prior to the marine retreat and lake isolation. The western section is 150 cm thick and was extracted from Terrace T2. The section is composed of two distinct stratigraphic units (Fig. 3). Unit 2 forms the base (43 cm thick) and is composed of alternating thin coarse and fine silt layers (rhythmites) that contain several dropstones. Unit 3 is 95 cm thick and is composed of three sandy subunits that were differentiated based on sediment color and grain size (Subunits 3a, 3b, and 3c). In addition, an erosion contact was identified between Unit 2 and Unit 3. The composition of the subunits is as follows: Subunit 3a contains reddish sandy silt within which a 2-cm-thick silt bed was observed; Subunit 3b consists of coarsening upward brownish sand; and Subunit 3c is composed of coarse sand. This section is overlain by organic horizons (12 cm thick). The grain-size parameters are indicative of

TABLE 2

Terrace levels, their altitudes and inferred ages, characteristics of their surficial sediments, and interpreted environments.

Level	Altitude relative to the lake (m)	Ages cal yr BP*	Recurrence	Sediment characteristics	Hydrodynamics	Environment
1	1	—	11	Fine to medium, homogeneous, or rhythmites	Very low energy	Lake-sea transition
2	1.5	6740	9	Fine to coarse, homogeneous, or rhythmites	Low energy	Bay
3	2.25	6900	10	Fine to coarse, homogeneous, or rhythmites	Low energy	Bay
4	3.5	7060	8	Fine to very coarse, homogeneous	High energy becoming low energy	Bay
5	4.25	7220	6	Fine to gravels, homogeneous	High energy becoming low energy	Bay
6	5.5	7400	5	Fine to gravels, homogeneous	High energy becoming low energy	Beach
7	7.25	7750	3	Medium to coarse, sorted	High energy	Beach
8	8	7930	2	Fine to medium, sorted	High energy	Beach
9	9.25	8120	2	Fine to coarse, sorted, erosion contact	High energy	Beach

*Ages inferred by emergence rates (Allard and Tremblay, 1983; Lavoie et al., 2012).

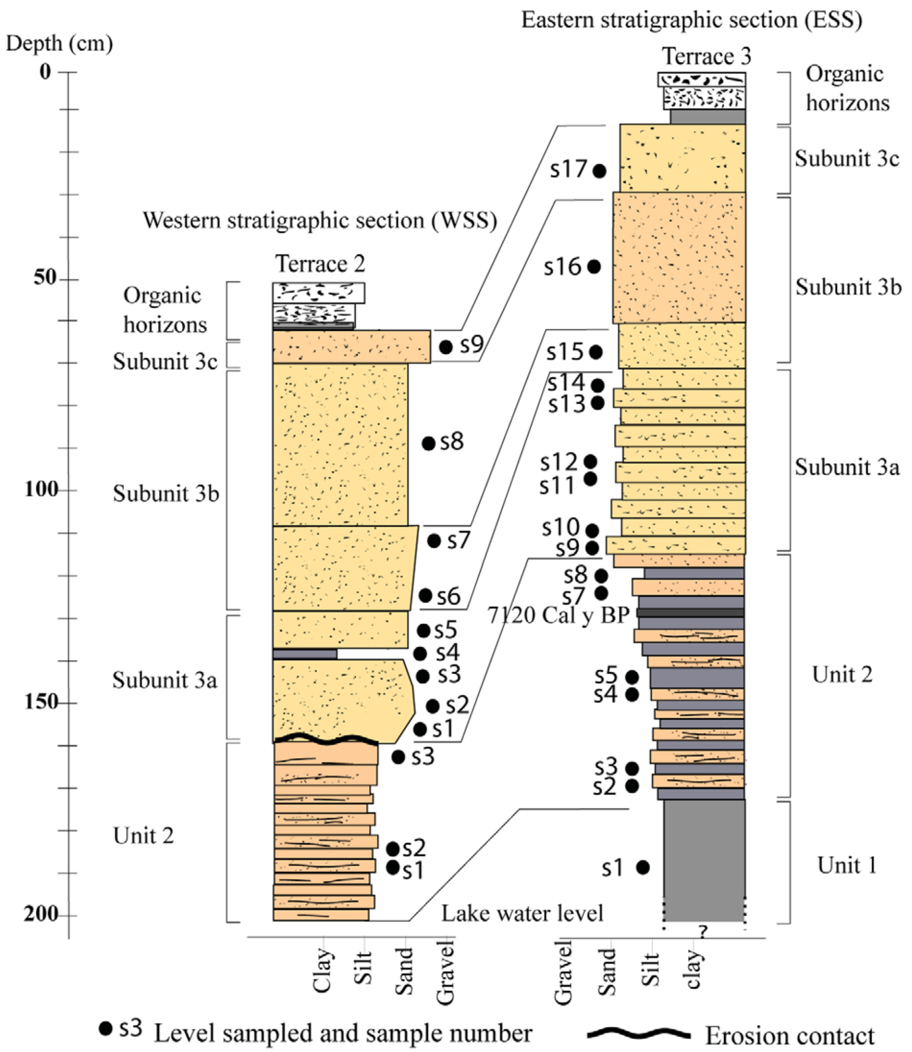

FIGURE 3. Stratigraphy of eastern section and western section.

two different sedimentological environments (Fig. 4): (1) a relatively poorly sorted, low-energy environment (Unit 2), and (2) a more efficiently sorted, higher-energy environment (Unit 3). The former may be related to a glaciomarine offshore environment, and the latter may be related to a littoral environment.

The eastern stratigraphic section is 207 cm thick and is composed of three distinct stratigraphic units (Fig. 3). Unit 1 (30 cm thick) is at the base and is mainly composed of massive grayish clay with a few dropstones. There is a gradual transition between Units 1 and 2. Unit 2 is 58 cm thick and consists of a gray and reddish silt layer of rhythmites (medium and fine) with a coarsening upward grain size. A layer of organic material containing plant macrofossils was found at the summit of the unit and was radiocarbon dated at 7120 cal yr BP. Unit 3, which is 100 cm thick, was divided into 3 distinct subunits based on the sediment color and texture. Subunit 3a is 42 cm thick and is formed by reddish and yellowish sand rhythmites. Subunit 3b is 42 cm thick and is composed of a medium reddish sand layer, while Subunit 3c is only 16 cm thick and consists of a yellowish medium sand layer. This section is covered by organic horizons (19 cm thick). The grain-size parameters (Fig. 4) are indicative of three different depositional environments: (1) very low-energy hydrodynamic conditions (Unit 1); (2) a marked increase in hydrodynamic energy and variable conditions prior to ca. 7120 cal y BP (Unit 2); followed by (3) steadier and higher-energy hydrodynamic conditions (Unit 3).

In conclusion, Unit 2 in each section appears to indicate that there were more energetic hydrodynamic conditions in effect at that time as compared to Unit 1, which indicates a low-energy setting typically associated with deep seawater. The rhythmites in Unit 2 may be associated with foreshore conditions such as tides and alongshore currents (i.e., the seashore of the Tyrrell Sea). Unit 3 represents a quick transition to the progressive isolation of the lake from marine influences.

Peatlands

The northeastern peatland is located on Terrace 1 at a height of 116 m (Fig. 2, part B). Radiocarbon dating of the basal peat showed that it was the first to be established in the area at approximately 6510 cal yr BP (Table 1). The northwestern, southwestern, and central peatlands were established at about 4560, 4390, and 3580 cal yr BP, respectively. Natural sandy levees were observed on both sides of the central peatland, on the border of the northeastern peatland (Fig. 2, part A), and on the western side of the southwestern peatland.

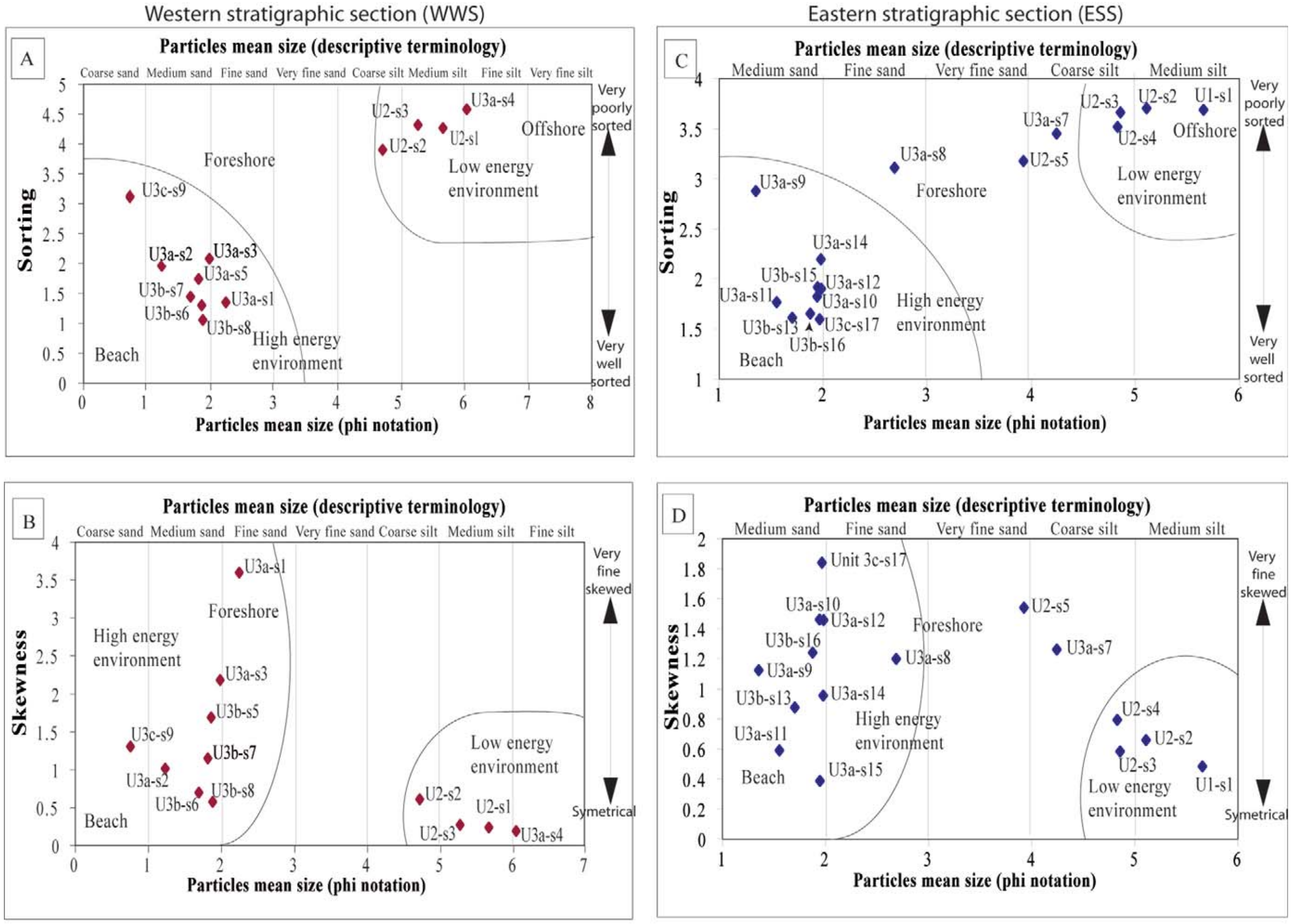

FIGURE 4. Bivariate plots of mean size vs. sorting and mean size vs. skewness for (A–B) western section and (C–D) eastern section.

LAKE STRATIGRAPHY AND SEDIMENTOLOGY

Four stratigraphic units were identified based on the sedimentology analyses carried out on the lake sediment core (Fig. 5).

Unit 1 (93–77 cm) is composed of cohesive, gray, silty clay with a relatively low organic content that gradually increases toward the top (from 3 to 10%) (Fig. 5). The grain size of the mineral fraction ranged between medium-sized silt and clay. The grain-size parameters (Ms, Sc, and Sk) were represented on bivariate plots (Fig. 6) and indicate a low-energy sedimentary environment. The highly dispersive pattern position of Unit 1 samples is mainly the result of dropstones and gravels that were transported by ice. These sediments are characterized by low sorting and asymmetrical coarsely skewed distribution. Plant remains consist mainly of *Potamogeton* sp. seeds that were recovered at a depth of 78 cm and were dated to 6960 cal yr BP (Table 1).

Unit 2 (77–63 cm) consists of dark green gyttja characterized by increasing organic matter content from 10 to 25% toward the top of the unit. Silt and clay fractions represent about 99% of the bulk sediment at the base of the unit. This proportion decreases slightly to 94% toward the top, likely due to the influx of fine sand into the lake (Fig. 5). Grain-size parameters suggest a sedimentary environment regulated by low-energy hydrodynamic conditions (Fig. 6). The relatively better sorting of sediment combined with the symmetrical distribution pattern suggest less variable sedimentary transport processes and inputs to the basin relative to Unit 1. The sedimentological properties and steady increase of organic matter content throughout the unit are indicative of relatively stable hydrodynamic conditions. Taken together, the data suggest a progressive isolation of the lake from marine waters, which made it less susceptible to the effects of waves and currents.

Unit 3 (63–35 cm) consists of green gyttja characterized by a high organic matter content (30 to 35%). The mineral fraction is composed of clay and silt (95%) with a mean particle size of approximately 8 (4 μm). Despite a significant difference in terms of color and organic content, the grain-size parameters suggest a low-energy environment (Fig. 6) that is comparable with Unit 2, although the percentage of organic matter is significantly higher. Plant remains (spruce needles, moss leaves, etc.) found at a depth of 40 cm were dated to 5080 cal yr BP (Table 1 and Figure 5).

Unit 4 (35–0 cm) is composed of brownish-green gyttja with a high organic matter content (between 30 and 35%). However, two levels (32 and 2 cm) show a sharp decrease in values, with organic content dropping to around 24% (Fig. 5). Charcoal fragments extracted at a depth of 15 cm were dated to 1295 cal yr BP. The mineral fraction is characterized by coarsening upward silty clay. The grain-size parameters are also indicative of a low-energy environment and suggest that there were more stable hydrodynam-

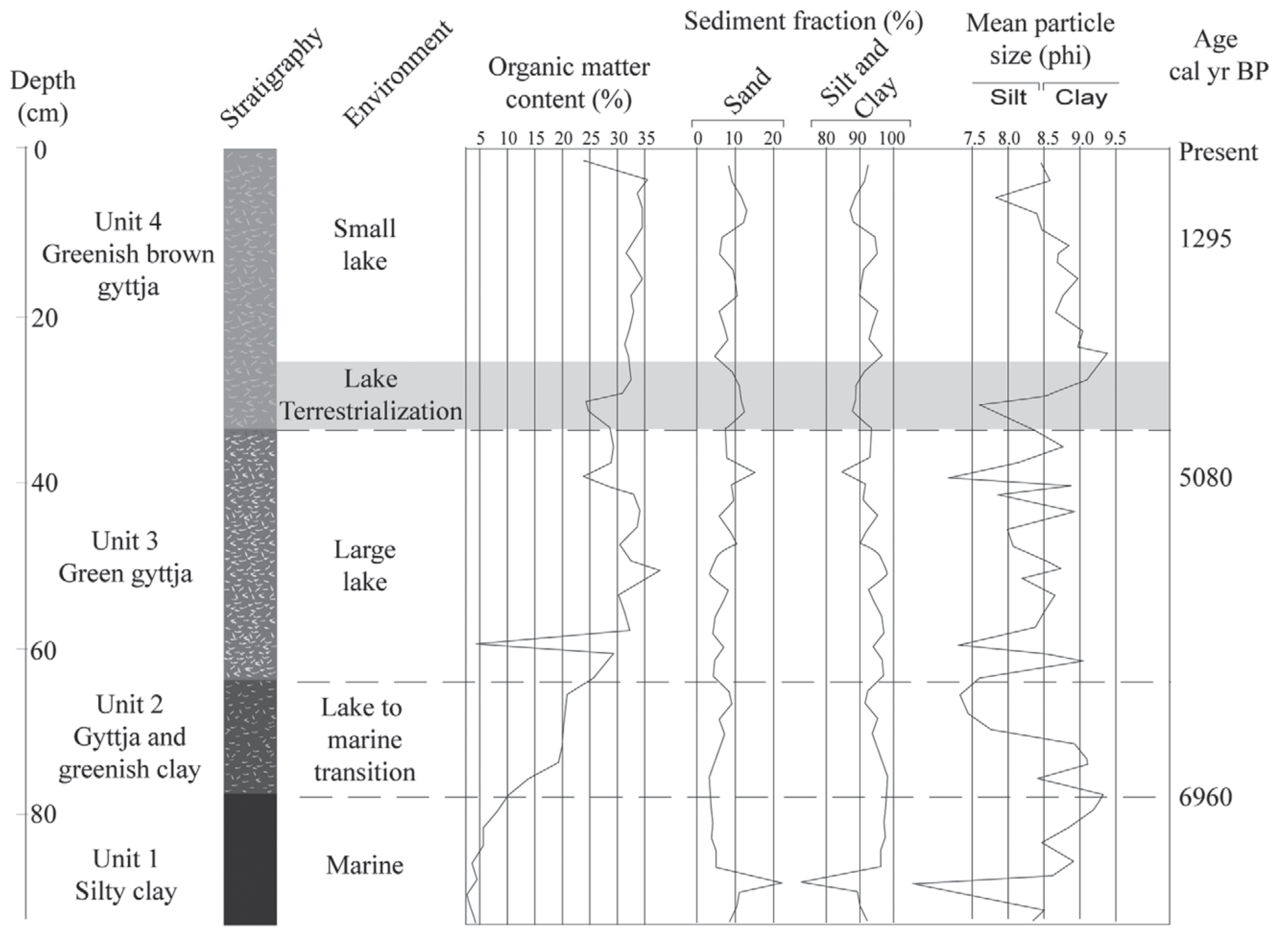

FIGURE 5. Stratigraphy of the lacustrine core, grain size, and loss-on-ignition (LOI).

ic conditions in Unit 4 than those suggested by the parameters of Units 1 and 2. The greater clustering of Unit 4 points on the bivariate plots (relative to the points of the first three units) supports this interpretation (Fig. 6). Stable conditions are also indicated by the fact that sediments are less sorted and therefore less affected by hydrodynamic properties (such as currents and waves), although they are more coarsely skewed due to ice rafting.

Discussion

MARINE PHASE: PRIOR TO 6960 CAL YR BP

The data suggest that watershed terraces, lake sediments (Unit 1), and the lower part of the eastern stratigraphic section were inherited from the marine phase. The date of 7120 cal yr BP obtained on plant macrofossils found at the summit of Unit 2 (coastal sediment) is consistent with the date of 8400 cal yr BP (7625 ± 120 yr BP), which was the date obtained for the *Macoma calcarea* samples that were collected from deep marine clays in the same region (Hillaire-Marcel, 1976). Radiocarbon ages obtained on the stratigraphic sections (Unit 2) and lake sediments (Unit 1) were correlated and compared to the level of Terrace 5, the emergence of which was dated based on extrapolations from the reported emergence rate (Allard and Tremblay, 1983; Lavoie et al., 2012) (Table 2) (Fig. 7). The position and sediment facies of the terraces suggest the occurrence of a confined energetic marine environment ca. 7000 cal yr BP (Fig. 7). This would likely have been a long bay or a sea arm characterized by quiet but variable hydrodynamic conditions (such as tide and currents). This period ended ca. 7000 cal yr BP with land emersion and the onset of lake isolation from marine influences. The very low organic matter content in the bottom sediment of Unit 1 prior to this date is likely related to the marine environment. This assumption is supported by the paleoecological investigation of Lake Kachishayoot, where the gray silty clay contained marine diatoms (poly-mesohalobian species) (Saulnier-Talbot and Pienitz, 2001) and foraminifera shells (Miousse et al., 2003) (Fig. 1).

MARINE TO LACUSTRINE TRANSITION PHASE AFTER 6960 CAL YR BP

The marine to lacustrine transitional phase corresponding to Unit 2 was found in both the eastern and western sections. The sediment facies are indicative of variable and more energetic conditions. The rhythmicity observed in both sections suggests that the site continued to be affected by tidal processes. The progressive establishment of vegetation cover in the watershed area and the progressive isolation of the lake may explain the increase in organic matter content in the lake sediment (in Unit 2).

The marine to lacustrine phase occurred between 6960 and ca. 6400 cal yr BP (extrapolated age). By comparison, Lake Ka-

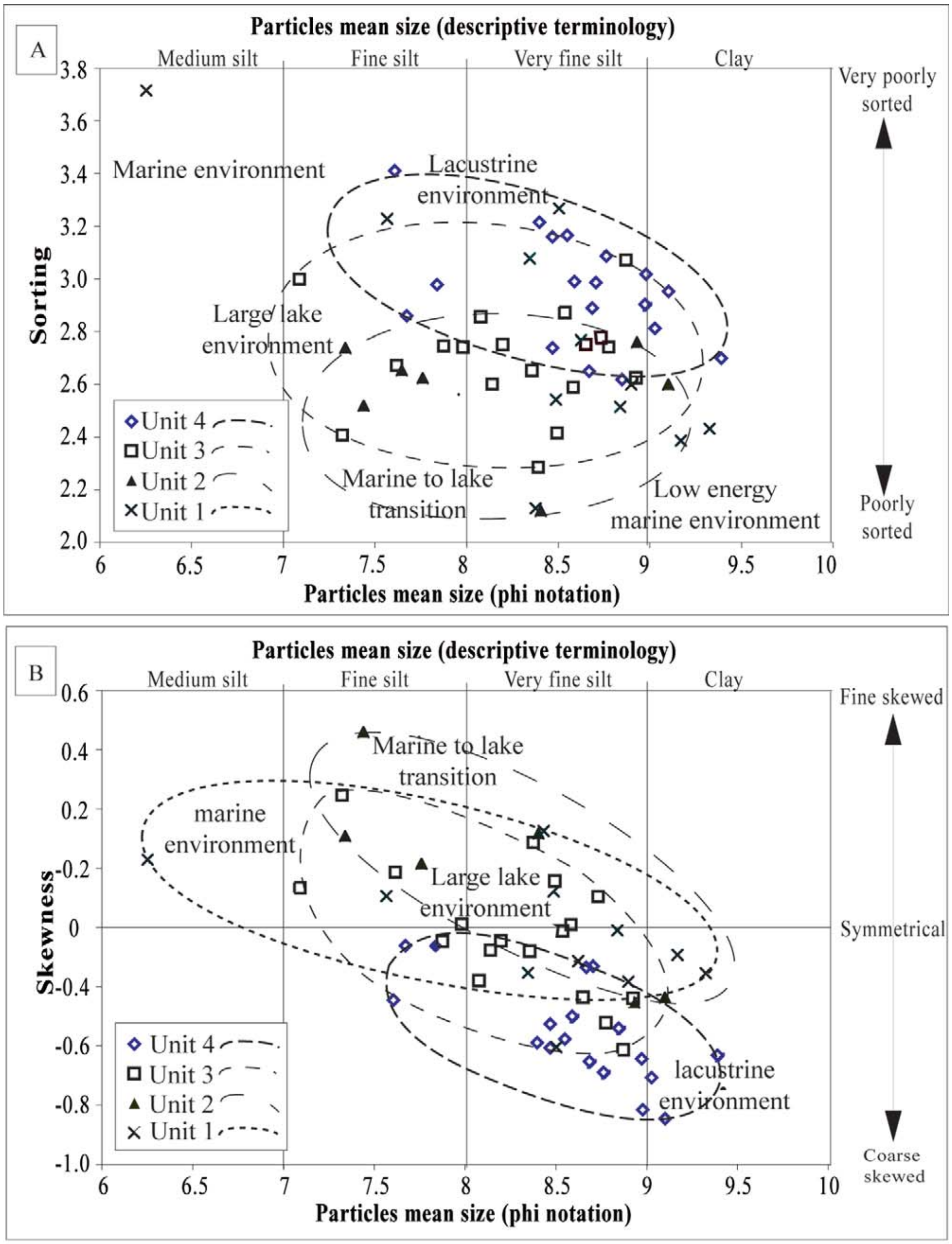

FIGURE 6. Bivariate plots, mean size vs. sorting and mean size vs. skewness for lacustrine sediments.

chishayoot was cut off from the sea at about 4700 cal yr BP according to the fossil diatom analysis of Saulnier-Talbot and Pienitz (2001), although sediment and macrofossil analyses indicate that it was isolated at about 5400 cal yr BP (Miousse et al., 2003). Nevertheless, the earlier isolation of Lake Kaapumticumac is consistent with its higher elevation and its greater distance from Hudson Bay. In fact, the study lake is about 115 m above sea level and 5 km east of the Hudson Bay coastline, while Lake Kachishayoot lies at an altitude of 100 m and is 3.2 km east of the coastline.

LACUSTRINE PHASE

The continental isostatic uplift process permanently isolated the lake from the sea and triggered peat formation in the north-eastern part of the lake basin ca. 6510 cal yr BP (Table 1). Two major lacustrine periods were identified. The first period is evident in Unit 3 and in the base of Unit 4 (lake sediment core). It is characterized by stable organic matter content and constant mean grain size. This period lasted from ca. 6400 to ca. 3500 cal yr BP, which corresponds to the Hypsithermal. Such warm conditions were favorable to a low lake level, which provoked the terrestrialization of shallow areas between 4560 and 4390 cal yr BP (in the northwestern and southwestern peatlands, respectively) and around 3580 cal yr BP within the lake basin (in the central peatland). In addition to the isostatic uplift, peat formation and accumulation contributed to the fragmentation of the large lake into several smaller ones (Fig. 2, part A). Lake Kachishayoot also recorded a low lake level prior to 3200 cal yr BP (Miousse et al., 2003). Lac des Pluviers, which is located at the limit of the forest-tundra (Fig. 1), recorded a low

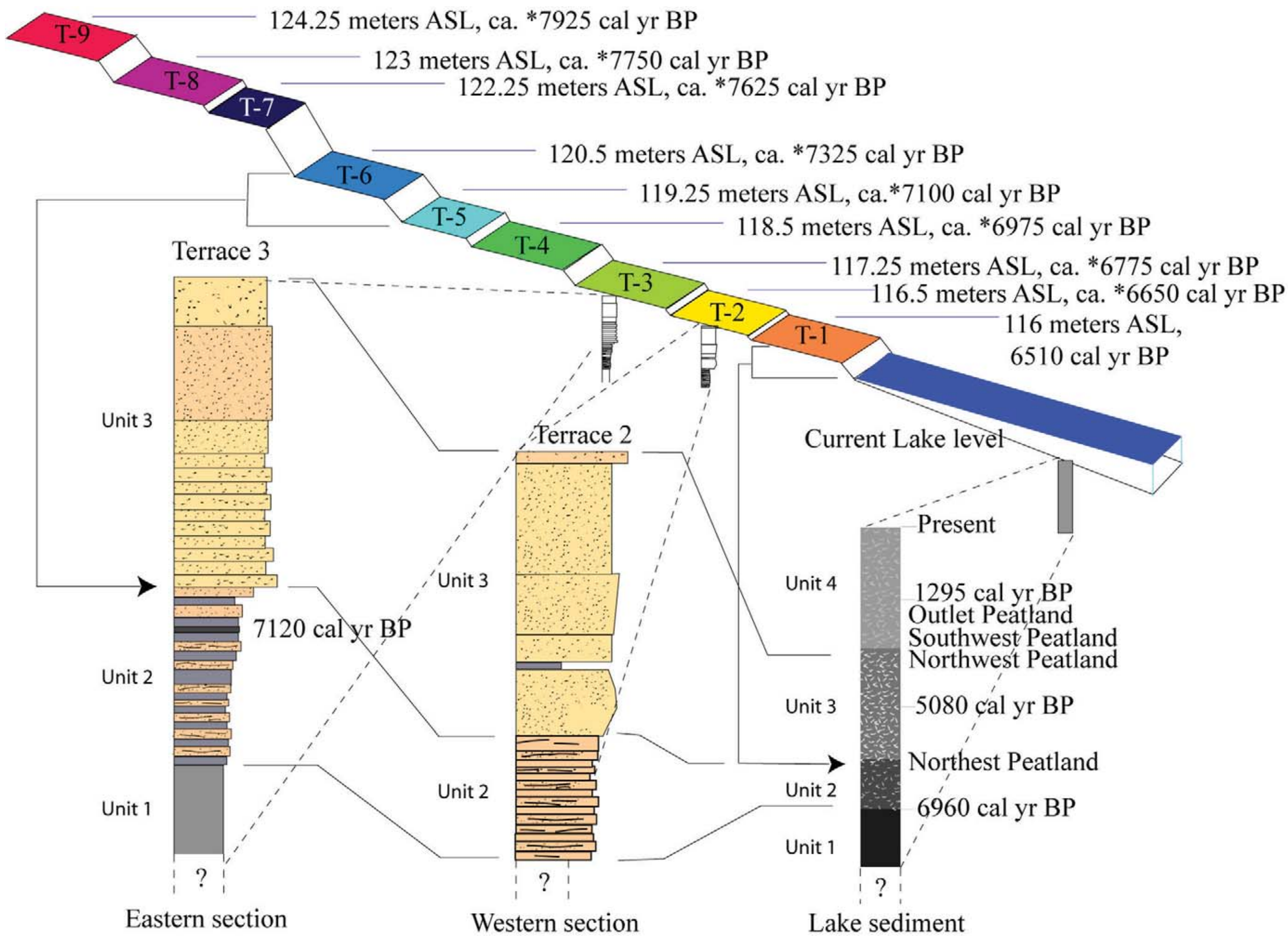

FIGURE 7. Correlation between bottom sediments, stratigraphic sections, and terraces. *Ages inferred by emergence rates (Allard and Tremblay, 1983; Lavoie et al., 2012).

lake level between 5300 and 4600 cal yr BP (Payette and Filion, 1993). Allard and Séguin (1987a) also documented this warm period in relation to the permafrost degradation near the tree line on the eastern coast of Hudson Bay between 4000 and 2500 cal yr BP. Synchronous warming was also recorded in lake sediment elsewhere in the northern hemisphere, e.g. in southern Greenland (Kaplan et al., 2002).

The second period is the post-Hypsithermal (Filion, 1984) or Neoglacial (Kaplan et al., 2002) period. This cool and wet period started in northern Québec and Labrador at about 3500 cal yr BP and continued throughout the Late Holocene. The change in climate triggered a rise in water levels in Lake Kachishayoot that in turn caused an erosional process associated with wave action. This erosion caused mineral deposition between 3200 and 2240 cal yr BP (Miousse et al., 2003). The rise in the Lac des Pluviers water level was also observed after ca. 3500 cal yr BP (Payette and Filion, 1993). A similar rise was noted in Lac des Affleurements-Noah (located 3 km east of the study site) at about 2760 and 2025 cal yr BP (Laframboise, 2011). Ombrotrophication of peatland 6 km south of Lake Kaapumticumac was also linked to these cold conditions (Bhiry and Robert, 2006). Such conditions favored permafrost aggradation in subarctic Québec between 2500 and 2000 cal yr BP (Allard and Séguin, 1987a) in addition to alluvial fan activities in the Guillaume-Delisle area (200 km north of this site) (Lafortune et al., 2006). Despite the fact that it was difficult to pinpoint this event by examining lake sediments at the study site, natural lacustrine banks were observed in some areas around the lake. These banks would have formed when lake levels were high as a result of the wet conditions of the Neoglacial period. In fact, they were dated to around 2240 cal yr BP (Lizotte, 2002).

Conclusion

The Tyrrell Sea regression from the eastern coast of Hudson Bay and the associated continental isostatic uplift were the initial factors that influenced the formation and evolution of the study lake. Climate and environmental factors contributed to its subsequent evolution.

The study of Lake Kaapumticumac, which lies 8 km east of Hudson Bay in subarctic Québec, revealed three successive phases of development: (1) A marine environment phase associated with the base of the lake sediment core and the higher terraces (9.25–5.5 m above current lake level). This phase was mainly controlled by marine processes (such as alongshore currents). (2) A transitional phase, associated with the lower terraces (4.5–1 m above current lake level), that was mainly related to marine and environmental processes (such as tidal currents and waves). (3) Finally, a lacustrine phase exclusively associated with the impact of climate changes on the lake watershed. Two main climate periods were identified: first, the warm period of the Hypsithermal, which caused lake terrestrialization followed by lake fragmentation and lacustrine and facies changes (i.e., changes in color and organic content); second, the colder Neoglacial period, which created cool-wet conditions that triggered the rise in lake levels as well as the formation of natural banks on riparian peatlands.

This study is distinct from others that have been conducted in the Whapmagoostui-Kuujjuarapik region because of its focus on a higher-altitude lake. Accordingly, it yields greater insight into isostatic uplift in the region. However, since all of the sites that have been studied in this region have either been on islands or very close to the coast (<5 km), it is necessary to conduct further studies at inland sites. Such studies will help to advance our understanding of postglacial rebound in the region.

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