INTRODUCTION

The sedimentary deposits in Canandaigua Lake, one of 11 Finger Lakes of western-central New York, preserve a relatively high-resolution hydrologic record, including the frequency and relative magnitude of runoff events, and by inference, storm events, over the past 14 ka. Specifically, fluxes of coarse-grained, terrestrial-derived sediment, including sand and charcoal, into the lake can be expected during extreme, repeated storm events during wetter intervals. During drier periods, fire events would likely increase, resulting in greater charcoal flux to the lake. The abundance of charcoal may also reflect anthropogenic influence related to early settlement in the region. The primary objective of this study is to document changes in mean grain size; relative proportions of sand, silt, and clay; and charcoal abundance to infer how regional precipitation patterns changed in response to changes in atmospheric circulation. In particular, 13 major precipitation events were identified.

SITE DESCRIPTION

The westernmost of the larger Finger Lakes (Fig. 1), Canandaigua Lake is 25 km long and 2.4 km wide at its maximum, and has a maximum water depth of 84 m (Mullins et al., 1996). The lake basin is longitudinally symmetrical, steep-sided, and flat-floored (Mullins et al., 1996). Approximately 66 streams drain the steeply sloped hillsides, which expose soil, glacial deposits and Devonian limestone, siltstone, sandstone, and shale.

METHODS

Site Selection and Core Collection

Analysis of high-resolution seismic reflection profiles collected in June 2005 helped to determine the best site to recover a high-resolution, continuous record of environmental and climate change. The 4.71 m-long core was collected (42°44.63’ N, 77°19.69’W) from the middle of the lake at 73 m water depth.

Magnetic Susceptibility

Bulk magnetic susceptibility measurements (MS) were made using a Bartington MS-2 meter and coil to determine the volume of magnetic grains and sediment composition throughout the
core. MS was measured at a 1-cm interval prior to splitting the core.

**Initial Core Description, Subsampling and Loss-on-Ignition**

The core was split, digitally photographed, described, and sampled at a 2-cm interval. Subsamples were freeze-dried to determine the water content (wt.%). Loss-on-ignition was used to determine the relative weight percent organic (500°C) matter (%TOM) and carbonate (1000°C) content (%TC) (Dean, 1974) and is discussed by Darden (2006, this volume).

**Grain Size Analysis**

Prior to grain size analysis, samples were treated to remove the organic matter and carbonate components (Jackson, 1969). Samples were analyzed for their particle size distribution between 0.04-2000 µm using a Coulter LS 230 laser particle size analyzer. The mean, sorting, and skewness of each sample were calculated using the method of moments (Boggs, 2001).

**Charcoal Abundance and Shell Taphonomy**

Samples were subsampled every 10-cm for charcoal and shell taphonomic analysis. Charcoal abundance was determined after gently wet sieving 1 cm³ of mud through 125 and 250 µm sieves to reconstruct local fire frequency. Samples were analyzed using an Olympus SZ-60 stereoScope. Grains that were black, angular, and split under the pressure of a dissecting needle were counted as charcoal (Whitlock and Larsen, 2001). Ostracode shell taphonomic conditions were noted to infer depositional energies.

**Chronologic Control**

Two plant macrofossil samples were collected from 118 cm and 248 cm depth for radiocarbon dating by accelerator mass spectrometry by Beta Analytical Inc. Assuming a zero time frame for the top of the core and 13,900 years for the bottom of the core (Mullins et al., 1996), and using these two radiocarbon ages, linear sedimentation rates were calculated to identify the timing of 13 significant depositional events (Fig. 2).

**RESULTS**

**Core Description**

The uppermost portion of the core (0-300 cm) is composed of very weakly laminated dark olive gray (5Y 3/2) and black (5Y 2.5/2) mud (Fig. 3). Distinct laminae occur near the base of the core (300-471 cm). Vivianite blobs are associated with organic matter at 258-395 cm whereas iron oxides nodules occur at 375-471 cm. Ostracode shells are scattered throughout the core.

**Magnetic Susceptibility**

MS values range from 5-52 x 10⁻⁶ SI units (average: 30 x 10⁻⁶ SI units) (Fig. 3). Fluctuations in MS are greatest in the middle of the core (100-288 cm). MS values are low from 400 to 470 cm, coincident with low %TC (Darden, 2006). MS exceeded 40 x 10⁻⁶ SI units at 20, 38, 40, 194, 220, 244, and 282 cm. High
MS values often correlate with higher % sand concentrations.

**Grain Size Analysis**

The mean grain size of the entire core is 4.6 µm (fine silt) (Fig. 3). The most variation in mean grain size occurs near the top of the core where laminae are diffuse. The % clay and silt are inversely related except when there are peaks in the % sand. While silt is the most prevalent grain size, the % clay is higher than silt at 20, 26, 38-60, 66, 82, 190, 230, and 250 cm. Low MS and sand concentrations are evident from 400-470 cm. There are also distinct laminations and a higher %TC in this section. Sand peaks >1%, average to high MS, and >15 charcoal grains occur at 36, 92, 110, 228, 282, and 362 cm. Although the mean grain size and % sand differs among Seneca, Keuka, and Canandaigua Lakes, we identified ~13 sand peaks throughout the Holocene in each lake (Crocker (2006), Lyons (2006), Petrick (2006), this volume).

**Charcoal Abundance and Shell Taphonomy**

Combined total charcoal counts for both size fractions, 125-250 µm and >250 µm, are always <40 grains/sample. There is more charcoal in the bottom half of the core. Peaks in charcoal abundance are coincident with higher % sand and are occasionally concurrent with high MS values. Changes in charcoal abundance determined for Keuka Lake reveal similar trends as Canandaigua although Keuka’s concentrations are ~10x greater (Lyons (2006), this volume).

Ostracode shells, whole and fragmented, were found throughout the core. However, few shells were present between 100-200 cm where carbonate values are 3%. Where ostracodes were observed, most were either fragmented or only one valve remained.

![Figure 3](image)

*Figure 3. A sediment core was extracted from Canandaigua Lake, NY to examine numerous sedimentological parameters, magnetic susceptibility, mean grain size, relative grain size distribution, % sand, charcoal abundance, and ostracode shell taphonomy. Proposed storm events are highlighted in yellow.*
Chronology

A radiocarbon date of 3210 +/- 40 B.P. from a depth of 248 cm indicates a deposition rate of 0.08 cm/year, consistent with previous studies. Wellner and Dwyer (1996) calculated rates from 0.027-0.244 cm/yr. The radiocarbon-based model indicates 13 precipitation events occurred at 0, 362, 466, 1191, 1424, 2071, 2511, 2718, 2951, 4840, 5894, 7716, and 8675 years B.P (Fig. 2).

DISCUSSION

Storm Events

Thirteen terrestrial-rich layers are interpreted to represent individual erosional events in the watershed that delivered terrigenous material to the lake. I propose that two possible events in the watershed could be responsible for the delivery of terrestrial sediment to the lake: removal of vegetation by fire or large storm events. Charcoal grains >250 µm reflect localized fire events while grains between 125 and 250µm reveal widespread fire events as the smaller grains can more easily be entrained by wind (Whitlock and Larsen, 2001). Because charcoal values of both size fractions are <50 particles/cm³, charcoal concentrations cannot be correlated to local fire events (Whitlock and Larsen, 2001). Therefore, I propose that large storm events triggered terrestrial influx of sediment into the lake.

This interpretation is supported by MS and grain size data. High MS values (40-52 x 10^{-6} SI units) and mean grain size suggest a greater influx of water and terrestrial material to the lake during mid-to-late Holocene storm events at 0, 362, 466, 1191, 1424, 2071, 2511, 2718, 2951, 4840, 5894, 7716, and 8675 years B.P. The prevalence of sand suggests high energy depositional conditions. A strong precipitation event could induce turbidity flows, entraining large grains into the water column, forming zones of coarser-grained material. The abundance of sand in the top half of the core suggests wetter conditions. In addition, the sand peaks (>1%), average-to-high MS values, and >15 charcoal grains at 36, 92, 110, 228, 282, 362 cm reflect periods of increased precipitation as larger grains are able to be entrained in runoff or turbidity flows. Lastly, observations of ~13 sand peaks in this core and those collected from Keuka and Seneca Lakes (Fig. 1) reveal that the storm events were most likely regional (Crocker, 2006; Lyons, 2006; Petrick, 2006).

Warm and dry or cool and dry?

Changes in lamination character and MS values may reflect changes in paleo-temperatures. Specifically, distinct laminations are observed at 300-470 cm, which indicate less bioturbation or agitation of sediment, and likely anoxic bottom water conditions. Warmer temperatures promote prolonged stratification and less mixing of the water column, and can induce anoxic conditions. Under these conditions, weaker bottom currents allow for the formation of well-laminated sediment. In addition, low MS values, %TC >30%, charcoal peaks, and the scarcity of sand from 400-470 cm indicate fewer storm events and a warmer climate. In addition, the increased frequency of charcoal in the bottom half of the core suggests more fires, likely from a drier environment. Wellner and Dwyer (1996)’s palynological study also suggests the climate was warmer and drier at the start of the Holocene, ~10,000 years B.P.

The core recorded other dry periods. The higher % clay, lack of sand, and low MS values at 20, 38-60, 82, 190, 230, 250 cm indicate drier periods as larger grains are not entrained in the water column. Low %TC (<10%) is observed at 20, 82, 100-200, and 230 cm, suggesting a cooler, drier climate.

Charcoal

Recent studies of sediment cores from Seneca
and Keuka Lakes reveal similar trends in charcoal concentrations, which suggest a regional source of fires. The peak at ~40 cm was observed in larger magnitude in Seneca and Keuka Lakes, and can most likely be attributed to anthropogenic deforestation between 3 and 4 ka (Personal communication Gary Solar, 3/20/2006).

CONCLUSIONS

Wellner and Dwyer (1996) documented a colder, wetter climate at 11,300–10,200 B.P., and a warmer, drier climate during the beginning of the Holocene (~10,000 B.P.), which continued to warm until 2,100 B.P. when the area returned to a cooler, wetter climate, similar to current conditions. Our data reinforces this hypothesis. Well-laminated sediment with low MS values, high %TC, higher charcoal abundances, and low % sand are interpreted to reflect warmer, drier conditions at the bottom of the core. The prevalence of sand and lower %TC in the top half of the core suggests a cooler, wetter climate. Fluctuations in precipitation and 13 associated storm events are inferred from peaks in mean grain size and MS, especially at the middle and upper portions of the core. Like the sand intervals, trends in charcoal abundance correlate to nearby lakes and reveal regional fire and storm events.

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