GOING WITH THE FLOW: EVIDENCE FOR CHANGES IN CIRCULATION IN SENECA LAKE, NY DURING THE HOLOCENE

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INTRODUCTION

Seneca Lake, one of 11 Finger Lakes located in central-western New York, records environmental changes that occurred since the last deglaciation (Fig. 1). This paper evaluates two hypotheses proposed by Halfman and Herrick (1998) to explain the formation of erosional surfaces observed at ~20 m water depth in northern Seneca Lake: 1) a 20 m drop in lake level and subsequent erosion along a shoreline that occurred at the end of the Hypsithermal or 2) an increase in active water circulation (stronger currents) at the transition from the Hypsithermal to the Neoglacial. A combination of loss-on-ignition (LOI) measurements, mineralogical analysis, grain size analysis by laser diffraction, magnetic susceptibility (MS) and magnetic anisotropy (AMS) of one core were used to reconstruct changes in paleocirculation patterns throughout the Holocene.

SITE DESCRIPTION

The Finger Lakes occupy elongate basins that formed as a result of erosion of pre-existing stream valleys by ice and subglacial meltwater at ~14 ka (Mullins et al., 1996). Seneca Lake is the largest (by volume) and deepest (maximum depth of 186 m) of the Finger Lakes (Mullins et al., 1996). The U-shaped lake floor has steep, bedrock walls and a relatively flat basin floor.

METHODS

A core was collected from northern Seneca Lake (N 42°49.578’, W 76°57.372’, 47.1 m) (Fig. 1). After measuring the MS of the core, it was split, photographed, described, and sampled at a 2-cm interval. Samples were weighed and freeze-dried to determine the weight percent water content. Samples were then analyzed for weight

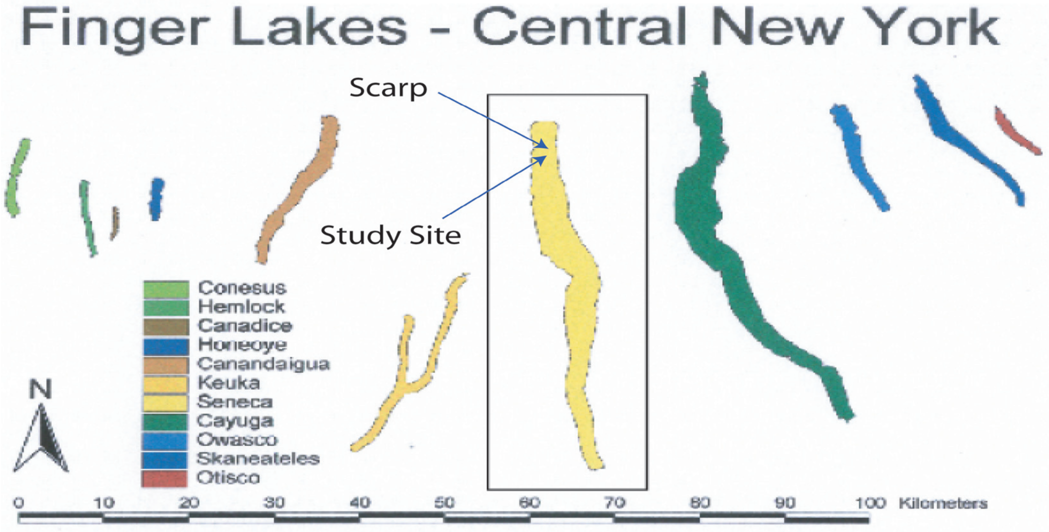

Figure 1. Location of Seneca Lake, one of 11 Finger Lakes. An arrow indicates the location of the core site. The core site is just south of a significant scarp at 20 m water depth.

percent total organic matter (%TOM) and carbonate content (%TC) by LOI at 550°C and 1000°C, respectively (Dean, 1974). Because the timing of the rise and fall of %TC in Seneca Lake is well-constrained, we used the %TC to infer the age of this core (Anderson et al., 1997; Ellis et al. 2004). Grain size was measured on organic- and carbonate-free sediment subsamples by laser diffraction using a Coulter LS 230 (Jackson, 1969). Mean grain size, sorting, and skewness were calculated using the method of moments (Boggs, 2001).

The mineralogy was determined using X-ray diffraction (XRD). Samples were crushed using an agate mortar and pestle, sieved, and micronized in isopropyl alcohol for 7 minutes. Ground samples were side-loaded into an aluminum sample holder to retain random orientation. Samples were characterized using a Rigaku Multiflex XRD equipped with CuKα radiation. Samples were scanned from 5° to 65° 2θ using a step size of 0.02° 2θ and a 1 second count time. Mineral relative abundances were calculated (± 10%) using the areas of selected peaks and mineral intensity factors from Hoffman (1976) and Bayliss (1986).

In order to measure the AMS of the core, orientated 2x2x2 cm subsamples were analyzed using a spinner KLY-4S KappaBridge. AMS quantifies the induced combined magnetic contributions of the ferromagnetic (i.e. magnetite), paramagnetic (i.e. clays), and diamagnetic (i.e. opal) grains, and may reflect grain orientation. Results of AMS analyses show the bulk orientation of all magnetic grains in a sample (magnetic fabric) and are represented in three-dimensional space by an ellipsoid. The parameter, P', mathematically represents the degree of anisotropy of the resulting ellipsoid and is defined as:

$$P' = \exp\{2[\eta 1-\eta_m)^2 + (\eta_2-\eta_m)^2 + (\eta_3-\eta_m)^2]\}^{1/2}$$

where $\eta_1 = \ln k_1$, $\eta_2 = k_2$, $\eta_3 = k_3$, $\eta_m = (\eta_1\eta_2\eta_3)^{1/3}$, and $k_1 > k_2 > k_3$ are the principle susceptibilities (SI units) (Joseph et al. 1999). Greater P' values reflect a more developed anisotropy of the magnetization ellipsoid. The T parameter defines the shape of the magnetization ellipsoid and is defined as:

$$T = (2\eta_2-\eta_1-\eta_3)/(\eta_1-\eta_3).$$

If T is between 0 and 1, then the ellipsoid is oblate (disc-shaped), whereas if T is between –1 and 0, the ellipsoid is prolate (cigar-shaped). If T =0, the ellipsoid is neutral (between oblate and prolate) (Joseph et al. 1999).

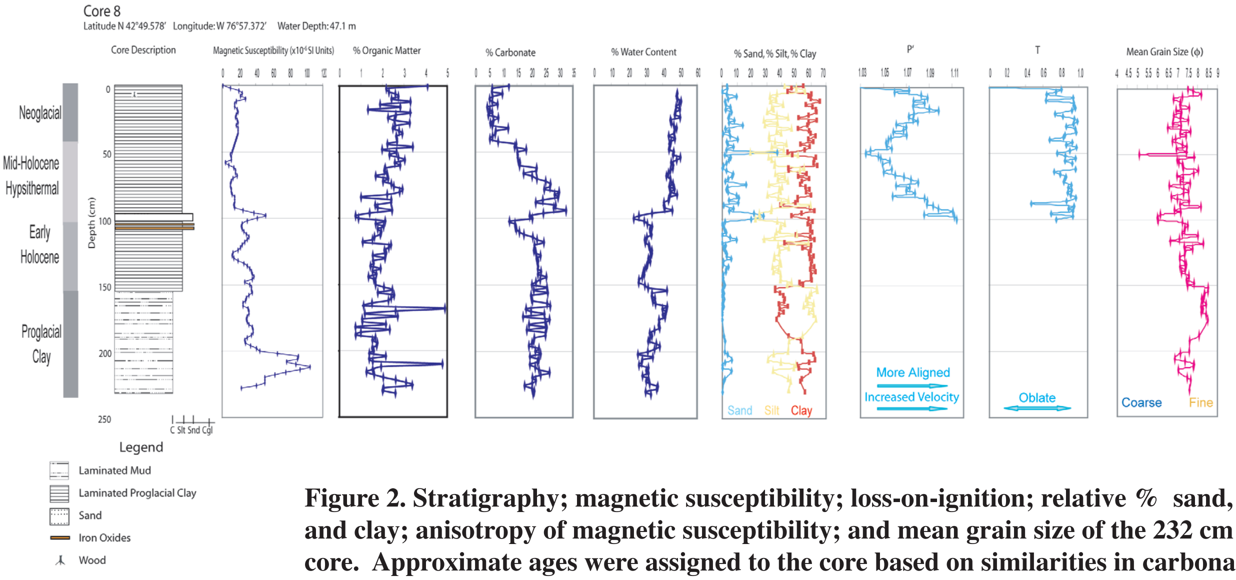

Figure 2. Stratigraphy; magnetic susceptibility; loss-on-ignition; relative % sand, silt, and clay; anisotropy of magnetic susceptibility; and mean grain size of the 232 cm long core. Approximate ages were assigned to the core based on similarities in carbonate abundance in Holocene laminated mud compared to that of previous studies by Anderson et al. (1997) and Ellis et al. (2004)

RESULTS

Proglacial Clay

The proglacial clay is dark reddish grey (2.5 Y4/1) and occurs between 152 and 232 cm. The average water content decreases upcore from 25 to 43% (Fig. 2). The average %TOM is 2%, with two peaks of ~5% at 168 and 210 cm. The average %TC (calcite by XRD) is 22%, but fluctuates between 17 and 26%. Calcite content ranges between 25% to 45% and quartz from 42-55%. Quartz and calcite have an inverse relationship (Fig. 2 and 4). MS ranges from 20-105 x 10^{-6} SI units. Mean grain size is 7.9 □ (very fine silt). The average % sand is 1.8. The average % silt is 47.2% (range: 35-62%). The % clay is 51.5% (range: 30-64%).

Laminated Holocene Mud

The proglacial clay is overlain by 152 cm olive gray (5Y 3/2) and black (N1) laminated silty clay (Fig. 2 and 3). Laminations are diffuse between 100-152 cm. Iron oxide nodule horizons occur at 109 and 116 cm. Although no organized shell beds are observed, there are scattered ostracodes between 106 and 142 cm. Weight percent water content generally increases upcore with a distinct increase at ~100 cm. The %TC ranges from 4-28%, with an average of 18.8% (Fig. 3). Through the Holocene section, %TC decreases briefly at ~100 cm and again between 50 and 0 cm. The %TOM is low, steadily increases upcore, and ranges from 0.7-4.8% (average: 2.1%). MS values range from 0-105 x 10^{-6} SI units with a distinct jump at ~100 cm. P' values range from 1.02 to 1.11 SI units. P' values decrease from 1.08 to 1.03 between 0 and 50 cm and gradually rise from 1.03 to 1.15 between 50 and 100 cm. T values are between 0.5 and 1, indicating an oblate shape of the magnetization ellipsoid.

Figure 3. Example of the well-defined laminae characteristic of Holocene mud in Seneca Lake from between 70-80 cm depth in the core.

The mean grain size is 7.2 □ (very fine silt). The average % sand is 5 (range: 0-37%). Average % silt is 56 (range: 18-59%). The average % clay is 38 (range: 39-65%). Percent silt and clay are inversely related. Percent sand has 3 peaks: at 30 cm (13%), at 50 cm (37 %), and at 98 cm (27%) (Fig. 2).

The mud contains a mixture of quartz, calcite, feldspars, micas, and clay minerals (Fig. 4). Quartz is most abundant and has an inverse relationship with calcite. Calcite content is greatest (20-54%) between 50 and 100 cm. Superimposed on this general rising and falling trend of %TC are at least three negative anomalies where calcite abundance decreases up to 35%. The clay mineral content is lowest at 100 cm, and gradually increases upcore.

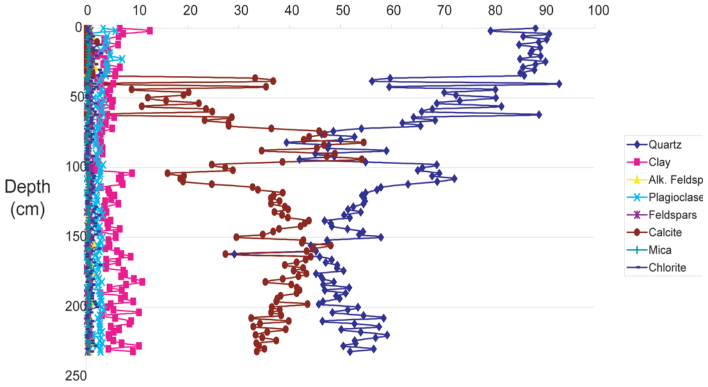

Figure 4. Diagram shows the mineralogical trends. Overall, quartz is the most abundant mineral. Quartz and calcite have an inverse relationship. Calcite is greatest between 50-100 cm. The clay mineral content is greatest near the bottom of the core and low at 100 cm but increases upcore. Alkali feldspar, plagioclase, mica (biotite and muscovite), and chlorite show minor variations in abundance with depth.

DISCUSSION

Changes in Environmental Conditions: Current Velocity

Physical, geochemical, and magnetic data record three changes in environmental conditions in the lake, at the beginning of the Hypsithermal (~9 ka), transition to the Neoglacial, and mid-to-late Neoglacial (<~4 ka) (Fig. 2). Previous studies show that depositional processes can be determined by combining grain size and magnetic fabric analyses (Joseph et al., 1999). Simplistically, stronger currents can transport larger grains that are more likely to become aligned. Thus, samples with relatively large median grain size and strong magnetic fabric indicate a relatively strong depositional environment (i.e., turbidites, wave erosion). Grains deposited by random settling (pelagic deposition) show little grain alignment. Thus, grain size and magnetic fabric provide clues into the depositional environment and circulation strength.

The mean grain size is greatest at during the Early to mid-Holocene and during the Neoglacial. The highest P’ values are approximately coincident with the coarsest mean grain size at ~9 ka (100 cm), which likely reflects an increase in depositional energy. The concurrent low P’ values and coarse grain size at 50 cm may indicate a diminished current influence even though mean grain size is larger. The larger grain size may reflect a change in provenance, a period of increased discharge, or more likely, transport distance. The mean grain size and relative proportions of sand, silt and clay remain constant during the Neoglacial, except near the top of the core. Between 50 and 0 cm, P’ values gradually rise and fall. This trend indicates an increase followed by a decrease in current velocity. P’ is highest when MS is relatively low, indicating high P’ values do not result from changes in magnetic mineralogy (Fig. 4). In fact, P’ values are highest when calcite is abundant.

Formation of the Scarp

Two hypotheses are proposed to explain the origin of the erosional surfaces in Seneca Lake: 1) subaerial erosion during a significant lowstand (~20 m) at the end of the mid-Holocene and 2) erosion occurred as a result of changes in lake current strength during the transition from the warm Hyspithermal to the cool Neoglacial (Halfman and Herrick, 1998; Mullins and Halfman, 2001). The concurrent increase in mean grain size, % sand, and decrease in P’ at the transition between the Hyspithermal and Neoglacial points to a possible decrease in lake level. This increase in mean grain size is observed basinwide and may result from a decrease in the distance the grains traveled as lake level dropped. However, active currents during the Neoglacial could play a role in the formation of the scarp. The decrease in %TC during the Neoglacial likely reflects cooler temperatures.

The combination of relatively finer grain sizes and low P' values during the early Neoglacial suggests there were weaker currents and/or extensive reworking by organisms, eliminating any preferred depositional alignment of grains by lake currents. The increase in P' but relatively constant mean grain size during the mid-Neoglacial could reflect an increase in depositional energy.

CONCLUSIONS

1. Peaks in mean grain size, % sand, and P' occurred at ~14 ka. This may reflect a pulse of sediment input into the basin and strong lake currents.
2. An increase in mean grain size occurred basinwide between 8 and 6 ka. This event could reflect either a major lake lowstand or an increase in the strength of waves and currents in the lake. If the increase in mean grain size reflects a major lowstand, the timing of this event is similar to major lowstands documented in nearby lakes (7.9 -7.0 ka).
3. During the Neoglacial, a gradual increase and decrease in P' reflect changes in current strength.

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