SEISMIC STRATIGRAPHY AND DEPOSITIONAL ARCHITECTURE OF HOLOCENE SEDIMENT IN KEUKA LAKE, NY

ROBERT F. ASPINWALL
Hobart and William Smith Colleges
Sponsor: Tara Curtin

INTRODUCTION

Keuka Lake, one of 11 Finger Lakes in western NY, preserves a detailed record of Holocene environmental and climate change. A combination of high-resolution seismic reflection profiles and sedimentological analyses of dredge samples and two piston cores were used to describe the youngest seismostratigraphic unit and provide insight into the sedimentation processes responsible for the observed subsurface stratigraphy.

SITE DESCRIPTION

Keuka Lake occupies an elongate (32 km), narrow (1.2 km) basin that has an area of 47 km^2. The morphology of Keuka Lake is especially interesting and unique. Not only is it the only Finger Lake that is in the shape of a Y, it is the only one with a relatively constant water depth, 40-50 m along its NW arm and 30-40 m along its NE arm.

The Finger Lakes originated as a series of N-S oriented river valleys that were subsequently deepened by glacial ice and sub-glacial meltwater (Mullins and Hinchey, 1989; Mullins et al., 1996). Between ~14,500 years BP and present, six seismostratigraphic packages of sub-and post-glacial sediments were deposited (Mullins et al., 1996). The oldest package, Sequence I, comprises thick, coarse-grained deposits of water-lain sands and gravel mapped as kame moraines (Muller and Cadwell, 1986). Sequences II and III represent the outpouring of fine-grained outwash from subglacial meltwater. As the ice sheet continued its northward retreat, a series of large proglacial lakes formed adjacent to the southern edge of the Laurentide Ice Sheet (LIS). Sequence IV represents rhythmites that were deposited in proglacial lakes as a result of the inflow of fine-grained sediments (rock flour) from meltwater from the LIS. As a consequence of the continued retreat of ice from the region, lake levels continued to drop. Ultimately, the drainage direction reversed to its current pattern, south to north. This reversal is responsible for the deposition of Sequence V (massive gray to brown clay). Sequence VI represents modern deposition of fine-grained, organic-rich sediment that enter the basins from localized watersheds.

METHODS AND MATERIALS

Collection and Analysis of Seismic Reflection Profiles

Approximately 145 km of high-resolution seismic reflection profiles were collected using an EdgeTech sub-bottom profiling system that uses CHIRP technology with a sweep frequency of 2-12 kHz, yielding a vertical resolution of 0.2 m. Fifty-six E-W transects and 2 N-S transects were made (Fig. 1a). The acquisition fish was towed at a speed of 4 knots at a depth of 1 m. A non-differential GPS shipboard satellite navigation system was employed to record latitude and longitude coordinates. Depths were determined assuming a velocity of sound of 1500 m/s.

Isopach maps were created by cataloging locations of data points in Excel and measuring depths to sediment water interface, Mid-Holocene, and Late Holocene facies boundaries. Sediment thicknesses were then calculated using Excel and exported into ARCVIEW and contoured to create isopach maps.

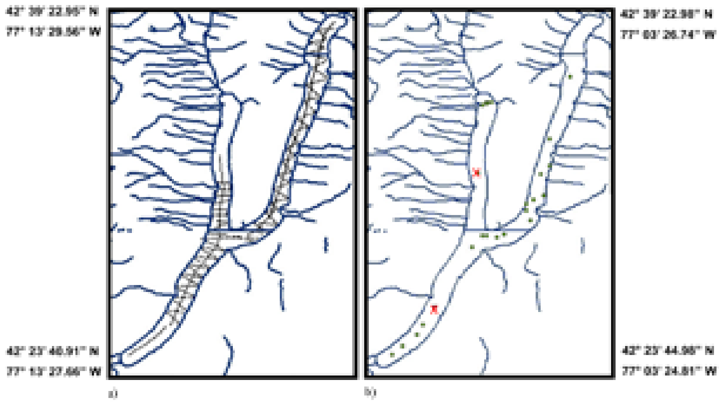

Figure 1a. Location of E-W and N-S seismic reflection tracklines. b. Location of dredge samples are indicated by green dots and core sites are identified by red Xs.

Sediment Sampling and Analysis

Twenty-four dredge samples and 2 piston cores were collected in order to ground-truth seismostratigraphic facies and provide a fairly complete stratigraphic and sedimentologic description of sediment in the basin (Fig. 1b). Dredge samples were described in terms of color, texture, composition, sedimentary structures, and macrofossil remains. Dredge samples were also sampled for sequential loss-on-ignition analysis (LOI). Samples were first freeze-dried and then analyzed for weight percent water content. The weight percent organic matter (%TOM) and carbonate (%TC) were determined at 550°C and 1000°C respectively (Dean, 1974). Samples were also analyzed for their bulk mineralogical composition using X-ray diffraction as well as grain size distribution using a Coulter LS 230 laser particle size analyzer. Piston cores were collected and analyzed by Petrick (2006) and Lyons (2006).

Chronology

Radiocarbon ages were obtained from aquatic and terrestrial organic matter preserved in the two sediment cores (Petrick, 2006; Lyons, 2006; *this volume*). These dates are reported as radiocarbon years before A.D. An age-depth model for both cores was developed using linear interpolation between radiocarbon data points.

RESULTS

Three seismic facies are recognized. These facies, from oldest to youngest, are proglacial mud (Sequence IV), early to mid-Holocene (Sequence VIA) and late Holocene (Sequence VIB). Like Mullins and Halfman (2001), we divided Sequence VI into two separate subunits on the basis of their acoustic characteristics and because these units are mappable throughout the basin. Because the X-Star profiler is able to best image the Holocene mud, we will focus on describing Sequences VIA and VIB.

Early Holocene Mud (Sequence VIA)

Sequence VIA onlaps onto sequence IV or older deposits or is conformable. Sequence VIA is characterized by laterally continuous, parallel to subparallel, low amplitude reflectors. In addition, there are multiple dark reflectors that are thickest near the basin edges and pinch out with increasing water depth and distance from the basin margin (Fig. 2a). These reflectors occur at similar stratigraphic levels in the subsurface. Sequence VIA occurs throughout the lake except along steep slopes and the southern region of NE arm (Fig. 3). The unit is thinnest along basin margins and at the confluence. There, sequence VIA pinches out against the erosional surface that truncates sequence IV. The thickest early Holocene package (7.6 m) is coincident with maximum water depth, just south of confluence. Thick deposits are also associated with major deltas. Based on analysis of core samples, we interpret this subunit to be composed of alternating

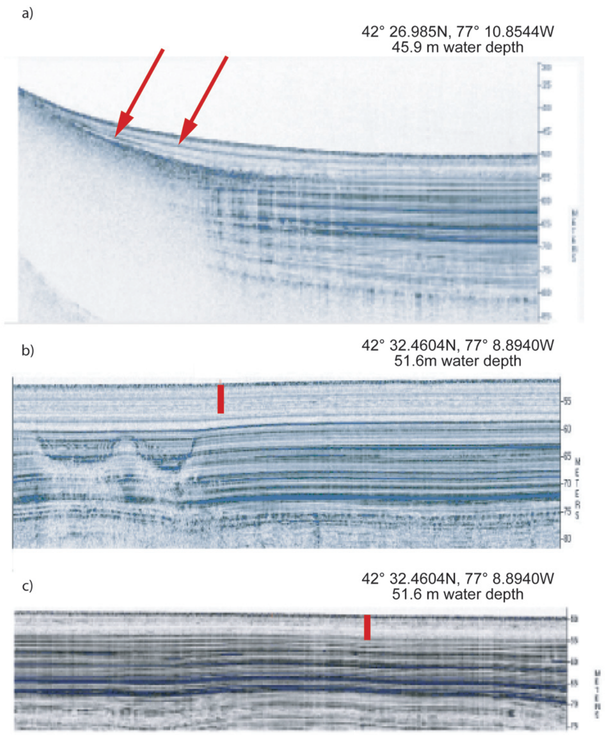

Figure 2 a. Note the two prominent, thick, dark reflectors that become more diffuse basinward. These reflectors are interpreted to be deltaic deposits. b. The location of Core 1, collected from the northwestern arm of the lake, is indicated by the vertical red bar. Note that Holocene reflectors are more pronounced near the bottom of the seismic reflection profile. c. The vertical red bar indicates the location of Core 2, collected from the southern region of the lake. As with Core 1, the reflectors in the basal two-thirds of the seismic reflection profile are more prominent than those observed in the upper one-third of the profile.

olive-gray and black laminae that are organic-rich (2-8%) and carbonate-poor (2.5-12.8%). The subunit is weakly to well-laminated. The median grain size is medium to coarse silt (9-46 μm). Spikes in magnetic susceptibility generally correlate with increases in sand content. This unit was deposited between 13.9 and 6 ka.

Late Holocene Mud (Sequence VIB)

Sequence VIB is conformable to sequence VIA. Based on radiocarbon ages, this subunit was deposited between ~6 ka and present. Sequence VIB is composed of very low amplitude reflections that can be traced across the basin (Fig. 2b, c). Sequence VIB is thinner than Sequence VIA (Fig. 3b). Like Sequence VIA, Sequence VIB is found throughout lake except along steep slopes along edges of basin. Unlike the Sequence VIA, the thickest deposits (4.7 m) are located in the NW arm and are not coincident with maximum water depth. The second thickest deposits (4 m) occur in deepest part of lake just SW of the confluence.

We interpret this subunit, on the basis of dredge samples and cores recovered, to be mottled to weakly laminated olive-gray and black mud. The subunit ranges in thickness from 0 to 4.7 m, and is organic-rich (2.4-8.5%) and carbonate-poor (2.6-8.6%). The mean grain size ranges from medium to very coarse silt (9.4-23.06 μm) and is finer-grained than sequence VIA. Variations in magnetic susceptibility correlate to

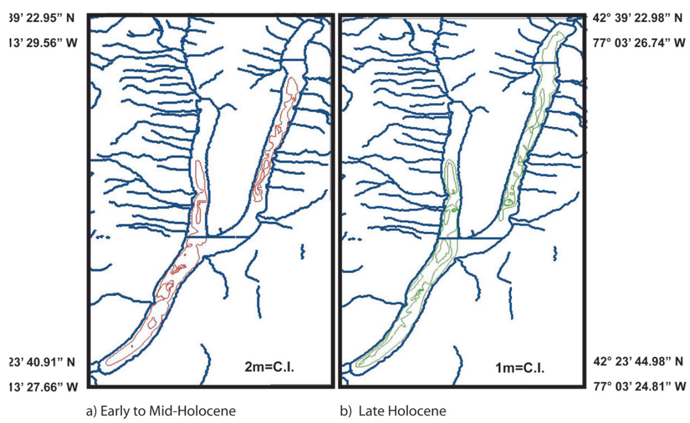

Figure 3 a. Isopach map of the Early to Middle Holocene sediment package. b. Isopach map of Late Holocene sediment package.

changes in % sand. Analysis of dredge samples shows three significant trends: grain size decreases with increasing water depth, grain size is at a maximum at the confluence, and calcite abundance is greatest near the confluence.

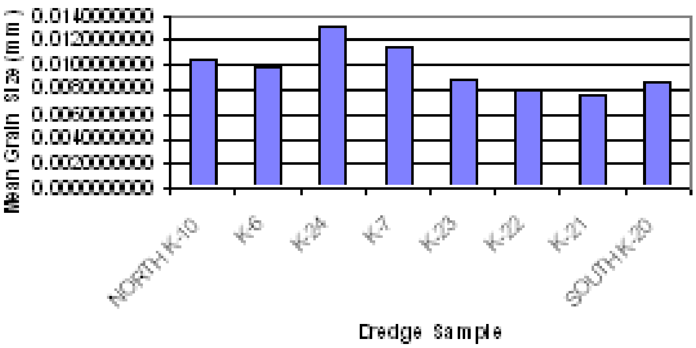

Figure 4. N-S transect of the mean grain size of dredge samples collected from the NW and southern forks of Keuka Lake. The maximum mean grain size occurs at site 24, which is located along the confluence of the NW and NE branches.

INTERPRETATIONS

The main controls on depositional architecture in lakes include lake level change, sediment supply, subsidence, sediment compaction, and flexural isostasy (Scholz, 2001). Although lake levels in Keuka Lake rose and fell dramatically during deglaciation, the lake likely has had relatively stable water levels during the Holocene. Today, lake level is predominantly controlled by hydrology and sediment supply. We will consider these two factors in our discussion of the origin of internal reflections in sequences VIA and VIB.

Early to Mid-Holocene Deposits (~14 to ~6 ka)

Multiple (5-7), parallel dark reflectors are observed throughout the basin. These reflectors may be due to overall coarser grain sizes, higher carbonate abundances, and well-defined laminations observed in sediment cores. The cores preserve olive-gray and black couplets that are usually <1 cm thick and composed of fine to medium silt. As sequence VIA is thickest in the middle of the lake, we infer that surface waves and currents focused sediment deposition into deep water.

Several prominent, dark reflectors observed throughout the lake originate in shallow water and pinch out offshore. We interpret these reflectors to correspond to thin (cms thick), moderately well-sorted, coarse-grained sandy silt beds observed in the cores. Based on comparison with dredge samples, we infer that these laminae become finer-grained with increasing water depth and distance from shore. These reflectors have comparable geometries at similar stratigraphic levels in the subsurface. These deposits do not exhibit toplapping strata and corresponding downlap associated with progradational lowstand deltas. These reflectors are interpreted as deltas advancing into the lake and may signify an increase in sediment supply as a result of higher effective precipitation.

Similar to observations made in the Great Lakes, these laminae may indicate suboxic to anoxic conditions, at least within the sediments and possibly at the sediment-water interface, existed during the early to mid-Holocene (Odegaard et al., 2003). Because the laminae are observed in cores, we interpret the accumulation and preservation of laminae to result from basin-wide phenomena. We propose that lake levels were higher during this interval as inferred from development of significant deltaic deposits. Quiet lake conditions may have allowed for accumulation and preservation of laminae.

Late Holocene Deposits (~6 to 0 ka)

A significant environmental change occurred at the boundary between sequence VIA and VIB based on comparison of their acoustic characteristics. Late Holocene sediment is more acoustically transparent than early to mid-Holocene mud, which is consistent with its massive character. Stronger bottom current activity, wave action, and resuspension may be responsible for the massive appearance of sediment in the cores. Therefore, we hypothesize that bottom currents became stronger by the end of the Hypsithermal at

~6 ka. Alternatively, the transition between sequence VIA and VIB could be indicative of a lakewide erosional event as proposed for Owasco (Mullins and Halfman, 2001) and Seneca Lakes (Halfman and Herrick, 1998). However, the lack of erosional surfaces and lowstand progradational deltaic deposits points to the stronger bottom current hypothesis.

CONCLUSIONS

1. The major source of Holocene sediment into the lake is rivers.
2. Sediment is likely focused into the deep water via resuspension and redeposition by waves and currents.
3. Occurrence of deltaic deposits throughout the lake during the early to mid-Holocene suggests more weathering and erosion occurred in the watershed as well as discharge into Keuka Lake.
4. During the early to mid-Holocene, better defined laminations may be indicative of relatively calm conditions within the water column.
5. During the Late Holocene, poorly defined laminations suggest an increase in activity of currents or burrowing that destroyed laminae.

REFERENCES CITED

Dean, W.E., 1974, Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss on ignition: Comparison to other methods, Journal of Sedimentary Petrology, v. 44, p.242-248.

Halfman, J.D. and Herrick, D.T., 1998, Mass movement and reworking of late glacial and postglacial sediments in northern Seneca Lake, New York, Northeastern Geology and Environmental Sciences, v. 20, p. 227-241.

Mullins, H.T. and Halfman J.D., 2001, High Resolution seismic reflection evidence for middle Holocene environmental change, Owasco Lake, New York, Quaternary Research, Quaternary Research, v. 55, p. 322-331.

Mullins, H.T. and Hinchey E.J., 1989, Erosion and infill of New York Finger Lakes, Implications for Laurentide ice sheet deglaciation, Geology, v. 17, p 622-625.

Mullins, H.T. Hinchey, Edward J., 1996, Seismic stratigraphy of the Finger Lakes: A continental record of Heinrich Event H-1 and Laurentide Ice Sheet Instability, Geological Society of America Special Paper No. 311 p. 1-36.

Muller, E.H., and Cadwell, D.H., 1986, Surficial geologic map of New York-Finger Lakes Sheet: Albany, New York State Museum, Geologic Survey Map and Chart Series No. 40, scale 1:250,000, 1 sheet.

Odegaard, C., Rea, D.K., and Moore, T.C., Jr., 2003, Stratigraphy of the mid-Holocene black bands in Lakes Michigan and Huron: Evidence for possible basin-wide anoxia. Journal of Paleolimnology, v. 29, p. 221-234.

Scholz, C.A., 2001, Applications of Seismic Sequence Stratigraphy in Lacustrine Basins *in* W.M. Last and J.P. Smol (eds.), Tracking Environmental Changes in Lake Sediments: Physical and Chemical Techniques, Kluwer Academic Publishers, Dordrecht, The Netherlands. pp. 7-22.