PROCEEDINGS OF THE TWENTY-SIXTH ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

April 2013
Pomona College, Claremont, CA

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SEDIMENTOLOGICAL EVIDENCE OF A PERSISTENT GROUNDWATER-DOMINATED SYSTEM IN DUCK LAKE, WI OVER THE PAST 8000 YEARS

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INTRODUCTION

Widespread flooding occurred in June 2008 across southern Wisconsin as the result of extreme precipitation events in the preceding months (Fitzpatrick et al., 2008). Several lakes in the area northwest of the town of Milton, WI (e.g., Clear Lake, Grass Lake, and Duck Lake) experienced groundwater flooding as much as one year after the peak surface water flooding. In Clear Lake, stage rose in excess of 2 meters, which represents a degree of flooding that has not been recorded in the historical records. A recent report by the Intergovernmental Panel on Climate Change has linked the occurrence of extreme weather events to anthropogenically induced climate change (IPCC, 2012); however, it is not clear if the recent groundwater-driven flooding of lakes in the vicinity of Clear Lake was an anomalous event or if such flooding was periodic throughout the Holocene. Here we present sedimentological data from a ^{14}C-dated lacustrine sediment core from Duck Lake, WI. These data show evidence of a steady, consistent depositional regime.

GEOLOGIC SETTING

Duck Lake is an approximately 50,700-m^2, groundwater-fed kettle lake in Rock County, Wisconsin, (42°47'45"N, 88°59'04"W; el. 246 m). It is adjacent to and hydrologically connected with Clear Lake. As a result, both lakes experienced similar groundwater flooding in June of 2008. In the immediate vicinity of Duck Lake, the surficial geology is dominated by glacial till and outwash deposits, which are the result of two separate phases of the Wisconsin Glaciation (80,000 to 10,000 years BP). Materials within the moraines consist of unsorted and unstratified clay, silt, sand, gravel, and boulders. The glacial sediments are deposited on a thick section of Cambrian and Ordovician sedimentary rocks composed of sandstone and dolomite, with some shale layers (Gaffield et al., 2002). At present, Duck Lake and neighboring Clear Lake appear to be seepage-dominated lakes that are influenced primarily by local flow systems and have limited interaction with regional hydrologic systems.

METHODS

A total of 6.07 meters of lacustrine sediment was recovered from Duck Lake (Core DL12-02) using a Livingstone square-rod piston corer with a 5-cm stainless steel barrel. The core was collected from a two-canoe coring rig from near the center of the lake in approximately 2m of water. The core was then extruded in 1-m segments, split, and described while wet (Fig. 1). Sediment samples were collected at 10-cm intervals for organic matter, carbonate, and lithic content analyses via Loss on Ignition (LOI) at 550°C and 1000°C. Organic material was collected from four discrete points in the Duck Lake core, two in the Grass Lake core and one in the Clear Lake core. These were sent for ^{14}C dating at the University of Arizona Accelerator Mass Spectrometry (AMS) laboratory. Biogenic silica was isolated from the core sediments through chemical treatments with H_2O_2, HCl, and HNO_3 to remove organic and carbonate material, respectively. Further isolation involved physical separation techniques such as wet sieving at 100µm and 50µm, differential settling, and heavy liquid separation with sodium polytungstate ($Na_6[H_2W_{12}O_{40}]$ or $3Na_2WO_4\,9WO_3\,H_2O$) to remove silt, clay, and other lithic fragments.

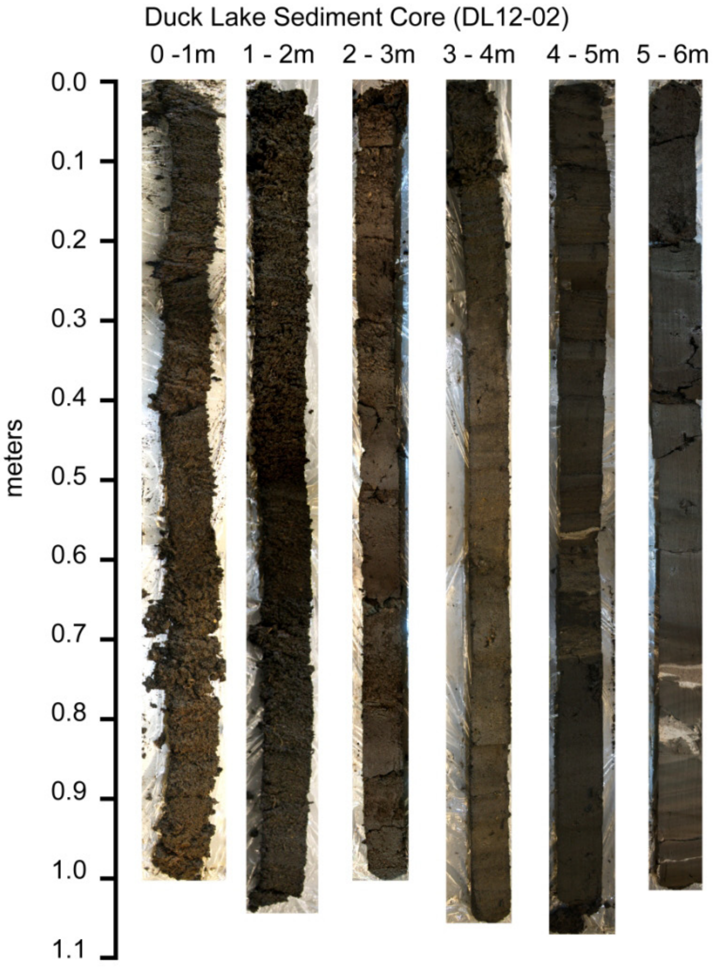

Figure 1. Split sections of the DL12-02 core. The core was collected in six approximately 1-m drives with core recovery varying between 0.98 and 1.08m. High organic content near the top of the core generally decreases with depth. Clay/silt content is highest in the bottom approximately 2m of the core with distinct light-gray layers of loess.

RESULTS

Core Description

The DL12-02 core consists of primarily dark brown to black, organic-rich, fibrous, and peaty sediments for approximately the top 3 meters. Between 3m and 4m from the top of core, there is a diffuse transition from peaty to predominantly silty sediments. From about 4 m depth to the bottom of the core at approximately 6 m, dark brown to dark gray silt is prevalent with four distinct, light-gray layers outlined by sharp contacts.

^{14}C Dates

Samples were taken from the Duck Lake, Grass Lake, and Clear Lake cores for ^{14}C dating at the University of Arizona Accelerator Mass Spectrometry (AMS) laboratory. Each sample represents a 2-cm section of core sediment, identified by the depth at the top of each sample (Table 1). A sample was taken from the absolute bottom 2cm of each core in order to find the maximum age of any sediment collected. All samples were deeper than 4m. Four samples from the bottom 2m of the Duck Lake core, two samples from the Grass Lake core and one sample from the Clear Lake core were analyzed. ^{14}C dates reported by the AMS laboratory were calibrated using the University of Oxford's OxCal v.4.2 program (Oxford, 2013). Possible sources of error in these measurements include small sample sizes from the Grass Lake core and the fact that some sediment samples were <50%-by-weight organic material. Depth of sediment recovered was ultimately limited by the ability of the Livingstone corer to penetrate past a certain density of material.

Sample ID	Depth (cm)	δ^{13}C	Age BP	Error (Years)	Calibrated Age BP (Years)	Calibrated Error (Years)
DL12-02-415.2	415	-17.5	7131	±50	5989	±130
DL12-02-459.5	459	-22.3	7977	±52	6875	±248
DL12-02-572.9	572	-25	8486	±54	7536	±87
DL12-02-600	600	-23.8	8575	±70	7625	±182
GL12-03-466.5	466	-15.3	9610	±130	8964	±460
GL12-03-730	730	-29.2	10560	±60	10565	±154
CL12-11-490	490	-25.7	11642	±64	11556	±260

Table 1. 14C Dates for Duck Lake, Clear Lake, and Grass Lake

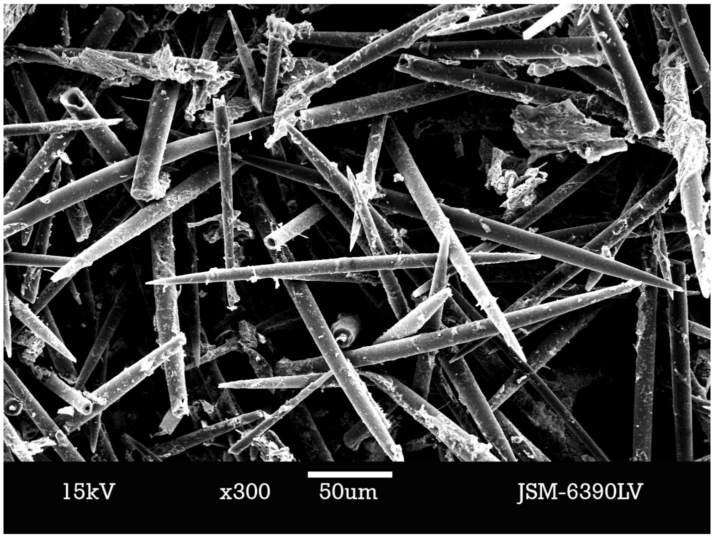

Figure 2. SEM image of DL12-02 sample, from 3.89m, prepared for oxygen isotope analysis. The siliceous material is composed almost entirely of freshwater sponge spicules. Note: 300X magnification

Biogenic Silica

Unfortunately, the Duck Lake sediments are nearly devoid of diatom frustules. However, there were significant amounts of another form of biogenic silica. Scanning electron microscope (SEM) images of the prepared samples revealed significant quantities of freshwater sponge spicules (Fig. 2). Although there was still too little biogenic silica for oxygen isotope analyses, the prevalence of sponge spicules is an interesting phenomenon that will be discussed in more detail below.

Sediment Composition

LOI analysis over the length of the DL12-02 core yielded substantial data regarding variations in the composition of the sediment (Fig. 3). There is an approximately 50% reduction in organic content from the top of core to the bottom and high variability in organic content in the 5m-to-6m section of the core. Carbonate content is low for the first 2m of the core, with a substantial increase at around 3m. Identifiable gray layers in the lowest 1m of the core have carbonate contents in the 35–50% range. Overall, the amount of non-combustible material shows a fairly steady down-core increase.

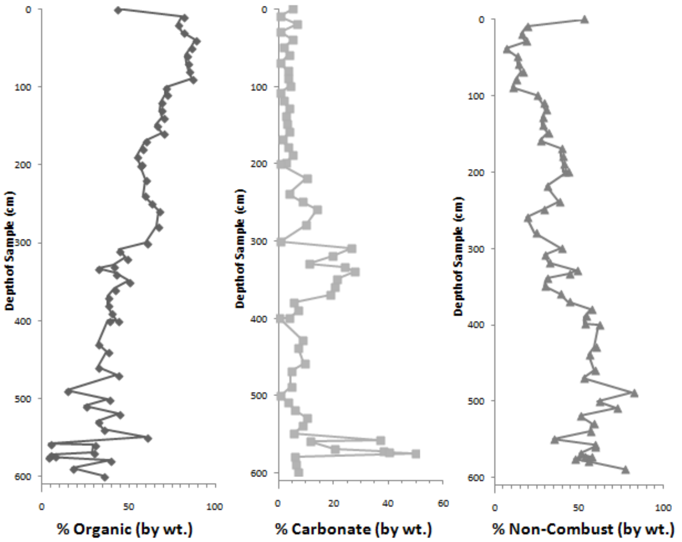

Figure 3. Percent composition of sediments by weight relative to their depths. Organics (diamonds) decrease consistently until the last 1.5m of core. Carbonate (squares) fluctuates, particularly between the clay sediment and the loess layers. Non-combustibles (triangles) generally increase down core.

DISCUSSION

Currently, Duck Lake is dominated by extensive growth of the green algea *Chara fragilis* (Mattox and Stewart, 1984). Despite the prevalence of *C. fragilis*, there is little or no authigenic carbonate or carbonate macrofossils in the DL12-02 core. The sediment in the upper layers of the DL12-02 core is organic-rich, peaty material composed of macroscopic plant fragments, *C. fragilis*, and terrestrial material within a dark, loose matrix of sapropel. The composition of the macroscopic material suggests that there is a significant flux of terrestrial organic material (i.e. woody plant material, seeds, roots, and leaves from herbaceous plants) to the lake from the surrounding woods and marshy shoreline. The gradual down-core transition from dominantly peaty, macroscopic material to dominantly silty sapropel is likely due to a combination of decomposition of original material over time and a lake basin that was originally several meters deeper than at present. It is unclear what is responsible for the higher proportion of carbonate between 3.09m and 3.69m. The large amount of non-combustible material at the top of the core is likely the result of sand runoff from a campground adjacent to the lake.

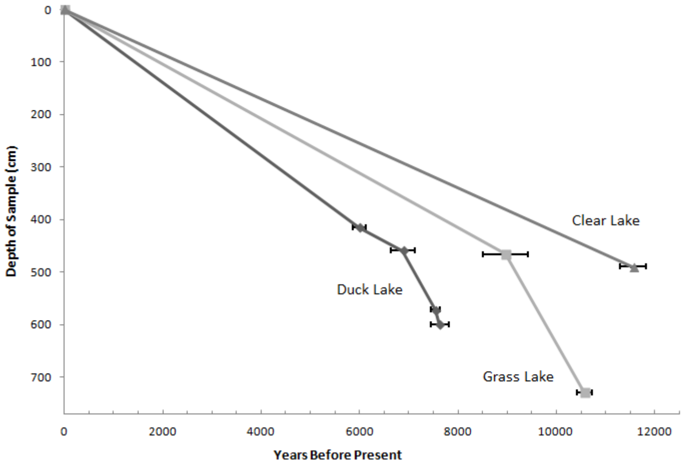

Figure 4. ^{14}C dates from Duck Lake relative to their depths display a nearly linear relationship between age and depth.

A graph of the ^{14}C data (Fig. 4) shows the distribution of dates measured with interpolated sedimentation rates. Organic material from the base of Duck Lake dates to 7625 years BP; Grass Lake and Clear Lake date to 10,565 years BP and 11,556 years BP, respectively. These dates are congruous with the end of the Wisconsin Glaciation (roughly 10,000 years BP); therefore, it is highly likely that the lakes were formed post-glacially in kettle moraines. The bottom sediments of Duck Lake were impenetrable with the Livingstone coring device. Given the geologic history of the region and the related hydrogeology of the three lakes, it is likely that all three lakes share a similar basal age/formation history.

The light gray layers found in the 4-5m and 5-6m segments of the core are most likely loess deposits. ^{14}C dates of this core indicate that these deposits are post-glacial. The deepest 3 layers date to around 7,600 years BP, but they could be reworked, glacial-derived aeolian deposits. It is possible that these layers correspond to periods of drought, which would result in fluxes of aeolian clay, sand, and silt deposits. This might point to a more barren terrestrial environment in the early lake history.

Freshwater sponges make structural components called spicules by precipitating biogenic silica (SiO_2) from silicic acid ($Si(OH)_4$) in the lake. The Duck Lake sediments have an abnormally high prevalence of sponge spicules, while diatom frustules are almost nonexistent, which is not common in temperate freshwater lakes. This phenomenon is most likely the result of low concentrations of dissolved silica within the lake water, resulting in greater competition for silica among siliceous organisms (Frost, 2001). A dearth of dissolved silica in the lake water could also explain the apparent dissolution pitting on the surface of the spicules (Fig. 5) and near-complete dissolution of diatom frustules, which have a more intricate morphology than the spicules. Studies have suggested that relative concentrations of sponge spicules, along with variations in their width can be used to asses silica concentrations in their habitat (Frost, 2001). Because Duck Lake is a seepage-dominated lake today, it is possible that as the groundwater interacts with the glacial sediments, dissolved silica precipitates as silica cements. The result is that the groundwater, and consequently the lake water, is significantly under-saturated with respect to silica. SEM examination of sediment at several intervals throughout the core indicates that sponge spicules have been the dominant form of biogenic silica throughout the entire sedimentation history of Duck Lake. It is therefore likely that the low silica in Duck Lake is due to its seepage-dominated hydrology and that this regime has been persistent throughout the past 7ka. However, further examination of the spicule widths and silica $\delta^{13}O$ values are needed to quantify changes in the amount of dissolved silica and/or the seepage flux through time.

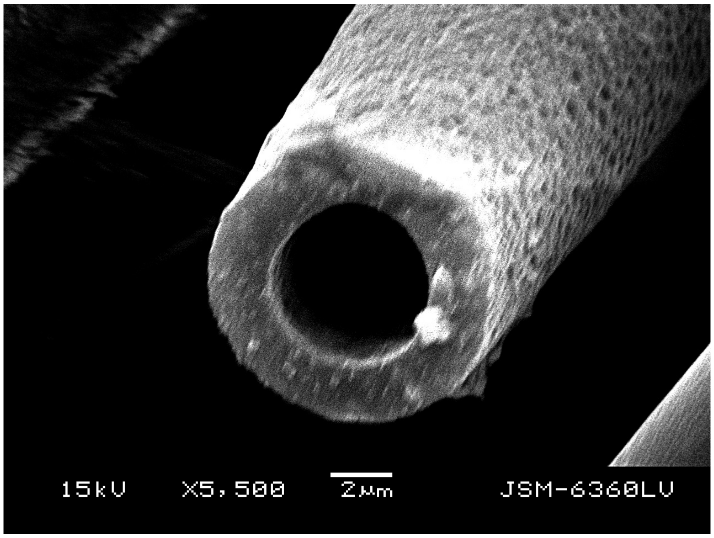

Figure 5. SEM image of sponge spicule shaft. The outer surface shows extensive dissolution pitting. Note: 5,500X magnification.

CONCLUSIONS

The relative homogeneity of Duck Lake sediments over a time period extending back to the early Holocene gives no indication of major changes in hydrology of the lake. ^{14}C dates of sediments from Duck Lake and neighboring lakes indicate that the lakes most likely originated as kettle lakes in glacial moraine deposits, further supporting the hypothesis of hydrologic continuity throughout the Holocene. The overall consistency of the material comprising the core suggests that the depositional environment within Duck Lake has remained relatively constant, with the only significant change being the decreasing depth of the lakes due to infilling of the lakes with sediments. The gradual down-core change from peaty material to clay is a result of predictable decay of organic matter over time and changes in the relative proportions of organic matter and inorganic matter that reached the center of the lake as it filled and became shallower. The increase in organic matter in the sediments in recent times could also reflect a change in the terrestrial environment from savannah to deciduous forest and/or land-use practices.

Duck Lake is a seepage lake; therefore, one would expect silica to be a limiting agent. There is evidence for this dynamic in the form of pitting and other signs of dissolution on the surfaces of the sponge spicules. In a low-silica environment, biogenic silica such as diatom frustules and sponge spicules deposited on the lake bottom, but not yet buried, would be highly susceptible to dissolution. The result is nearly complete dissolution of the diatom frustules and the pitting observed in the sponge spicules. However, it is unlikely that much dissolution has occurred subsequent to deep burial.

The prevalence of freshwater sponge spicules in the Duck Lake sediment record merits further research. Spicules can be used as proxies for changes in silica concentrations, clarity of lake water, and temperature (Frost, 2001). Although beyond the scope of this study, variations in the diameters, species, and degree of dissolution as well as oxygen isotope measurements of spicule silica over the length of a sediment core have the potential to quantify hydrologic and paleoclimate variability throughout the Holocene.

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