ASSESSING HOLOCENE STORM FREQUENCY THROUGH THE INORGANIC SEDIMENT RECORD IN LAKES, NORTHEASTERN USA

A Proposal Presented

By

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To

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The following members of the Thesis Committee have read and approved this document before it was circulated to the faculty:

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Date Accepted: ____________________

Abstract

In several locations around the world, the distribution of terrestrially-derived inorganic deposits in lacustrine sediment has been used to infer the timing, frequency, and relative magnitude of large storm events that erode sediment from basin hillslopes. For example, in northern Vermont a well-dated Holocene sedimentation chronology has been established from inorganic deposits in the postglacial sediment of Ritterbush Pond, and was used to infer periods of increased local storminess since deglaciation. Through my research, I will determine whether similar records exist in the sediment of other lakes in the northeastern United States. I will retrieve and analyze sediment cores from 5 to 10 postglacial lakes in Vermont, Massachusetts, and eastern New York, to assess the distribution of terrestrially-derived sediment layers within each lake basin. I will characterize each core with several techniques, including magnetic susceptibility, x-radiography, visual logging, and elemental analysis (nitrogen and organic carbon). I will use radiocarbon to date each core and establish a sedimentation chronology for each lake. Finally, I will compare these chronologies to existing records of hillslope erosion to determine whether temporal coherence exists between periods of increased erosion across the northeastern United States. From these primary observations, I may be able to infer periods of increased storminess, trends in Holocene weather patterns, and understand better natural climate variability.

Introduction

Lakes capture and store considerable information about temporal changes in their surrounding environments, from the lake's origin to the present. This continuous record of environmental change is preserved in the lacustrine sediments. These deposits derive from both the decay of aquatic organisms within the lake, and transport of terrestrial material to the lake via streams and mass movements (Meyers and Ishiwatari, 1995). Decay of aquatic organisms creates gyttja, a dark-colored, fine-grained sediment that is rich in organic carbon; this material comprises most lacustrine sediment. Episodic terrestrial sediment input deposits distinct layers of light-colored, inorganic material. These inorganic sediment layers most likely are deposited as the result of intense erosion—perhaps even mass movements—in the uplands surrounding the lake (Eden and Page, 1998; Brown, 1999). This erosion has been attributed to rainfall of much greater than average intensity and/or duration. Therefore, the distribution of terrestrial sediment layers in lacustrine sediments has the potential to reveal the timing, frequency, and possibly the relative magnitude of large storms within the drainage basin.

Background

Human activities have recently increased the atmospheric concentrations of carbon dioxide and other gases that have the potential to affect global climate (Mahlman, 1997). Consequently, the subject of human-induced climate change has received considerable attention in scientific and political circles in recent years. In order to place in perspective anthropogenic influences on global climate change, natural climate variability must first be understood (Stocker and Mysak, 1992). Several different natural archives of past regional and global climate variability have been discovered and investigated; these include oxygen isotopes in ice sheet cores (Mayewski, et al., 1993) and in biogenic silica (Rietti-Shati et al., 1998), pollen (Lin, 1996; Jackson and Whitehead, 1991), changes in sedimentation rates on alluvial fans (Church, 1997; Zehfuss, 1996; Bierman et al., 1997), and changes in the frequency, thickness, and grain size of inorganic deposits in lake sediments (Campbell, 1998; Digerfeldt, 1986; Eden and Page, 1998).

Inorganic deposits in lacustrine sediments have recently received increased attention as a proxy for climate variability (Moscariello et al., 1998; Cooper and O'Sullivan, 1998; Lamy et al., 1998). In each of these studies, changes in the character of inorganic deposits were used to interpret changes in local sedimentation rates and for comparison with regional and global climate records. Inorganic deposits have been used to determine storm frequency in Vermont (Brown, 1999), New Zealand (Eden and Page, 1998), British Columbia (Campbell, 1998), and Ecuador (Rodbell et al., 1999), and the frequency of monsoons in the South China Sea (Huang et al., 1997). These records of storm frequency have been attributed to forcing by regional and global climate patterns, such as El Niño/Southern Oscillation (ENSO) variability or other changes in atmospheric or oceanic circulation.

Significance of Research

In the northeastern United States, relatively few climate reconstructions have been made; those that exist are based on tree-ring widths (Conkey, 1986) or, more commonly, pollen stratigraphies (Lin, 1996; Jackson and Whitehead, 1991; Spear et al., 1994). Brown (1999) investigated the sediment record in Ritterbush Pond (in northern Vermont) and identified three intervals of increased inorganic sedimentation during the Holocene (Figure 1). These intervals were inferred to represent periods of greater storm frequency.

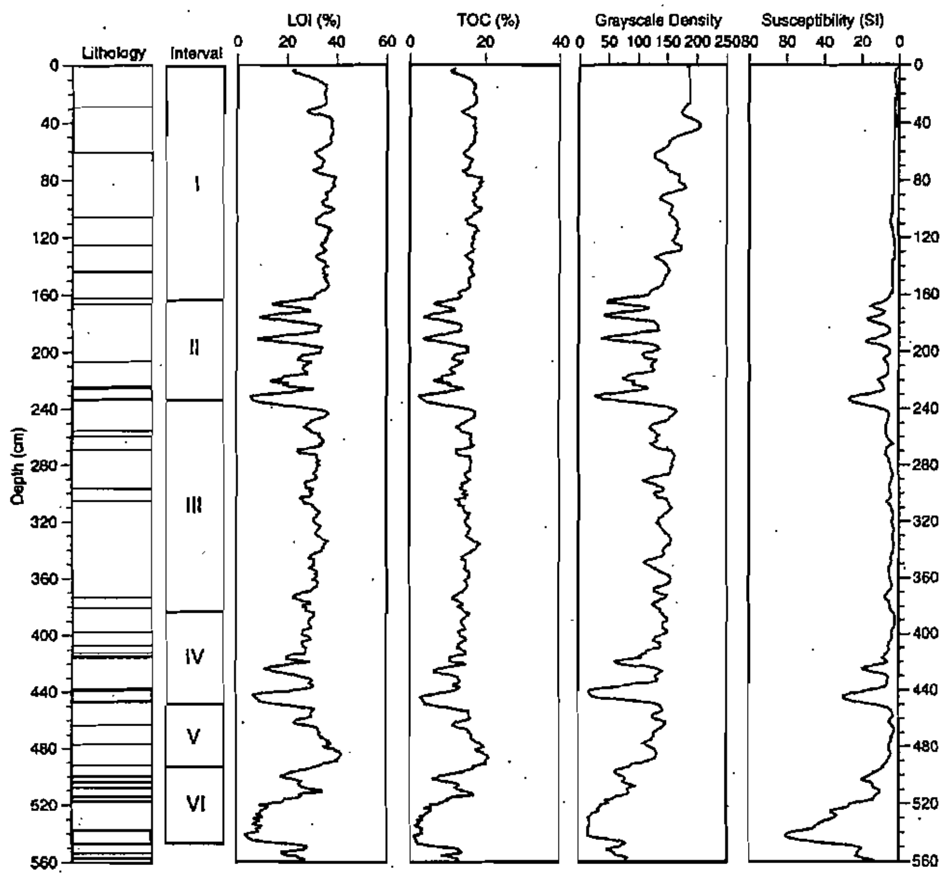

Figure 1. Comparison of whole-core data sets for Ritterbush Pond. All shifts to the left indicate the location of inorganic layers. Even Roman numerals correspond to periods of increased deposition of terrestrial material, and by inference, increased storminess. Lithology was determined from visual logging. The basal age of the core from which these data sets were derived is 8450 ^{14}C yr BP. From Brown (1999).

Although Brown (1999) and several other studies have used the sedimentation records from individual lakes or localized marine regions to infer temporal changes in storm frequency (Rodbell et al., 1999; Eden and Page, 1998; Campbell, 1998; Cooper and O'Sullivan, 1998; Moscariello et al., 1998; Lamy et al., 1998; Meyers et al., 1993), none have investigated sediment cores from locations distributed across a broad region. Consequently, these studies do not resolve the spatial scale at which erosive events have operated in the past. By determining the sedimentation histories of several lakes in Vermont, Massachusetts, and eastern New York, I will assess the temporal and spatial distribution of conditions capable of triggering hillslope erosion in the northeastern United States during the Holocene. From these primary observations, I may be able to infer periods of increased storm frequency in this region, and I will attempt to determine the climatic causes of these storm frequencies. In this manner, I aim to expand our understanding of Holocene climate in the northeastern United States.

Research Plan

As most lakes' sediments lack discreet layers of inorganic sediment, the candidate lakes for this study must be hydrologically sensitive—they are chosen based on characteristics that maximize the potential for periodically generating and preserving pulses of terrestrial sediment. Ritterbush Pond in northern Vermont (Brown, 1999) and Lake Tutira in New Zealand (Eden and Page, 1998) serve as models for candidate lakes in this project. Previous research has determined that to a great degree, the potential for upland erosion and sediment preservation is controlled by the character of the uplands surrounding the basin, the presence of streams entering the lake, and the depth of water in the basin. Important characteristics include:

- erodible sediment must be available and in great supply;
- steep hillslopes at the lake margins maximize the potential for erosion and slope failure;
- streams entering the lake concentrate the effects of rainfall-induced erosion;
- steep perimeter bathymetry that grades to depocenters ensures that all terrestrial sediment reaching the lake will be focused to a central location (Blais and Kalff, 1995).

When the last condition is met, deciphering the record of terrestrial sedimentation is considerably easier as one core will represent the sediment across the entire lake basin (Brown, 1999). Therefore, steep, bowl-shaped basins with ample sediment supply, streams entering the lake from several sides, and deep water are ideal candidates for this project. The lakes I have selected to date represent the best approximations of basins with such desired physical characteristics in Vermont. Next year, I will sample additional lakes in Massachusetts and New York to assess most effectively regional sedimentation variability (Figure 2 and Table 1).

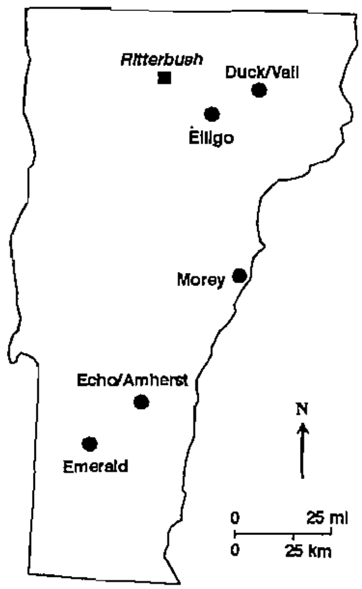

Figure 2. Map of Vermont showing locations of lakes for sampling during Winter 1999. Ritterbush Pond, top left, was studied by Brown (1999) and is included here for comparison. See Table 1 for physical characteristics of these lakes.

Lake	Town	Elev. (m)	Sfc. Area (km^2)	Depth (m)	Basin Area (km^2)	Basin Relief (m)	#Cores • Date
Amherst	Plymouth	326	0.33	27	49.4	675	by 3/30/99
Duck	Sutton	520	0.03	14	0.7	290	by 3/30/99
Echo	Plymouth	323	0.42	28	68.1	678	1 • 01/30/99
Elligo	Greensboro	269	0.70	30	13.1	259	1 • 02/05/99
Emerald	Dorset	217	0.13	13	14.7	713	1 • 01/23/99
Morey	Fairlee	127	2.22	13	20.7	414	2 • 02/19/99
Vail	Sutton	455	0.06	14	2.0	354	by 3/30/99
Ritterbush	*Eden*	*317*	*0.05*	*14*	*2.2*	*293*	by 3/30/99

Table 1. Selected physical characteristics of candidate lakes in Vermont (sampled in winter 1999). Additional lakes will be chosen for sampling in winter 2000. Ritterbush Pond, at bottom, was studied by Brown (1999) and is included here for comparison. See Figure 2 for locations.

Using a modified percussion coring device designed by Reasoner (1993), I have already retrieved cores from several Vermont lakes in the winter of 1999 (Table 1). When successfully retrieved, each core is nearly 6 m in length, and may represent up to 12,000 years of lacustrine deposition. After retrieval, I cut the cores into 1.5 m sections, cap the sections, and place each section in refrigerated storage until they are analyzed in the laboratory.

After I have constructed dated sedimentation chronologies for each lake basin, I will determine whether intervals of increased terrestrial sedimentation correlate between cores from different lakes. Such a correlation would be a strong indication of periods of increased regional rainfall duration, intensity, or frequency during these intervals. Using instrumentation records, literature review, and communication with regional climatologists, I will gain an understanding of the climatic causes of major regional storms in historical records. From these known climatic circumstances that produced major historical storms, I will attempt to infer the climatic conditions that caused large storms during the Holocene.

Analytical Techniques

Magnetic Susceptibility

Before I open each core, I use a Bartington Magnetic Susceptibility Meter (MS2) to identify changes in sediment lithology where differences in magnetic mineral content exist (Dearing, 1986). Since minerogenic (inorganic) sediment has a higher susceptibility than gyttja, I use peaks in susceptibility to locate layers of inorganic sediment within each core. The rapidity of this analysis allows me to gain a general idea of the contents of a core immediately after its retrieval. Therefore, I am able to re-assess continually the importance of various parameters in deciding coring locations.

X-Radiography

Prior to opening the cores, each segment will be X-radiographed at the University of Vermont Radiation Safety Lab. On X-radiographs, high density represents gyttja; low density represents inorganic sediment. This method yields high-resolution black-and-white images of core stratigraphy, including small features and sedimentary structures not visible to the naked eye (Van Weering and Van Iperen, 1984). From these X-radiographs, I will create X-ray density profiles using various scanning and photo-editing software packages, including Adobe PhotoShop and NIH Image.

Visual Logging

I will split each core segment lengthwise and immediately photograph the core to record the colors accurately before the sediment begins to oxidize. I will then log each segment in detail, noting color, lithology, and grain size, and other features of interest such as macrofossils.

Elemental Analysis (Nitrogen and Organic Carbon)

Samples taken from each core at 1-cm intervals will be combusted in a CE Instruments NC 2500 Elemental Analyzer to produce gases that are analyzed to determine the percent N and organic C within the sample. The total organic carbon (TOC) and total nitrogen (N) of a sample indicates sediment type (the carbon content of gyttja is markedly higher than that of inorganic sediment), and the ratio of carbon to nitrogen (C/N) suggests the source for the organic material in the sediment. Because vascular (terrestrial) plants have a higher cellulose content than nonvascular (most aquatic) plants, C/N ratios of organic matter derived from terrestrial plants are typically more than 10 higher than C/N ratios of organic matter derived from aquatic plants (Meyers and Ishiwatari, 1995). Large increases in C/N ratios in lake sediments are interpreted as episodes of increased sedimentation of terrestrial material (Krishnamurthy, 1986; Meyers et al., 1993).

Radiocarbon Dating

Several samples containing organic carbon from each core will be dated at the Center for Accelerator Mass Spectrometry at Lawrence Livermore National Laboratory. Macrofossils (rather than gyttja) will be used preferentially for these dating purposes, as dates derived from gyttja are commonly offset from macrofossil dates due to the lake reservoir effect or the settling of macrofossils into unconsolidated deposits at the sediment-water interface (Bierman et al., 1997). I will preferentially choose macrofossils from within the thickest inorganic layers, as the macrofossils are presumed to be deposited contemporaneously with the inorganic sediment. If macrofossils do not exist within the major inorganic layers, I will bracket the age of the layer by dating macrofossils stratigraphically above and below the layer. From these radiocarbon dates (typically 5 to 6 dates per core), I will construct age models for each core following the technique of Brown (1999). In this manner, I will assign ages to the entire core, including any layers not dated directly by radiocarbon. These radiocarbon dates and the ages modeled from them will form the basis for attempting to correlate the sedimentation records from each lake.

Expected Outcomes

Although several possible outcomes exist for this research, I believe they may be grouped into three categories:

1. Inorganic layers will be randomly distributed throughout each core, or dated intervals of increased inorganic sedimentation will not correlate between cores from different lakes. Either scenario would suggest that conditions capable of triggering hillslope erosion were localized in this region during the Holocene.
2. Only a small number of inorganic layers will exhibit temporal coherence between cores from different lakes. This scenario would suggest that only regional-scale erosive events (such as hurricanes) affect several drainage basins synchronously.
3. All dated intervals of increased inorganic sedimentation will correlate between cores from different lakes in the region. It may be inferred from this scenario that large regions were affected by the increased erosive force of either large individual events or multiple smaller events in the region. In either case, the favorable regional conditions for event generation may represent changes in atmospheric or oceanic circulation that drive climate variability.

Preliminary Results

To date, I have analyzed the core from Echo Lake (collected by the 1999 Geohydrology class), which contains several layers of inorganic sediment. The initial results of my analyses revealed two major inorganic sedimentation events, at 360 ± 30 and >1150 ± 50 ^{14}C years before present (yr BP), and a marked increase in inorganic sedimentation in the top 1.5 m of the core (< 360 ^{14}C yr BP) (Figure 3).

The shorter length of the Echo Lake core, and the smaller amount of time it represents (compared with the Ritterbush cores) make initial comparisons between the two chronologies somewhat difficult. None of the Echo Lake sedimentation events correspond to intervals of increased sedimentation in Ritterbush Pond (Brown, 1999). However, the modeled ages of two thin (2 mm) laminae in the Ritterbush sediment approximately correlate with the ages of the two major inorganic layers in the Echo Lake core. These Ritterbush laminae, with modeled ages 391 ± 100 and 1310 ± 100 ^{14}C yr BP, could potentially represent sedimentation induced by the same regional events that deposited the inorganic layers in Echo Lake at 360 ± 30 and >1150 ± 50 ^{14}C yr BP. Additional radiocarbon dates and a thorough age model for the Echo Lake core are needed to justify correlation of these sedimentation events. Deeper cores from Echo Lake, to be retrieved before the end of the 1999 winter season, may reveal additional sedimentation patterns similar to those in the Ritterbush cores.

Funding

Funding for this project comes from NSF Career Grant #EAR-9702643: "Holocene Geologic Records of Episodic Sedimentation—Characterizing the Timing and Distribution of Hillslope Erosion and Extreme Hydrologic Events". If needed, I will apply for grants to cover the cost of additional radiocarbon analyses, and for travel to meetings.

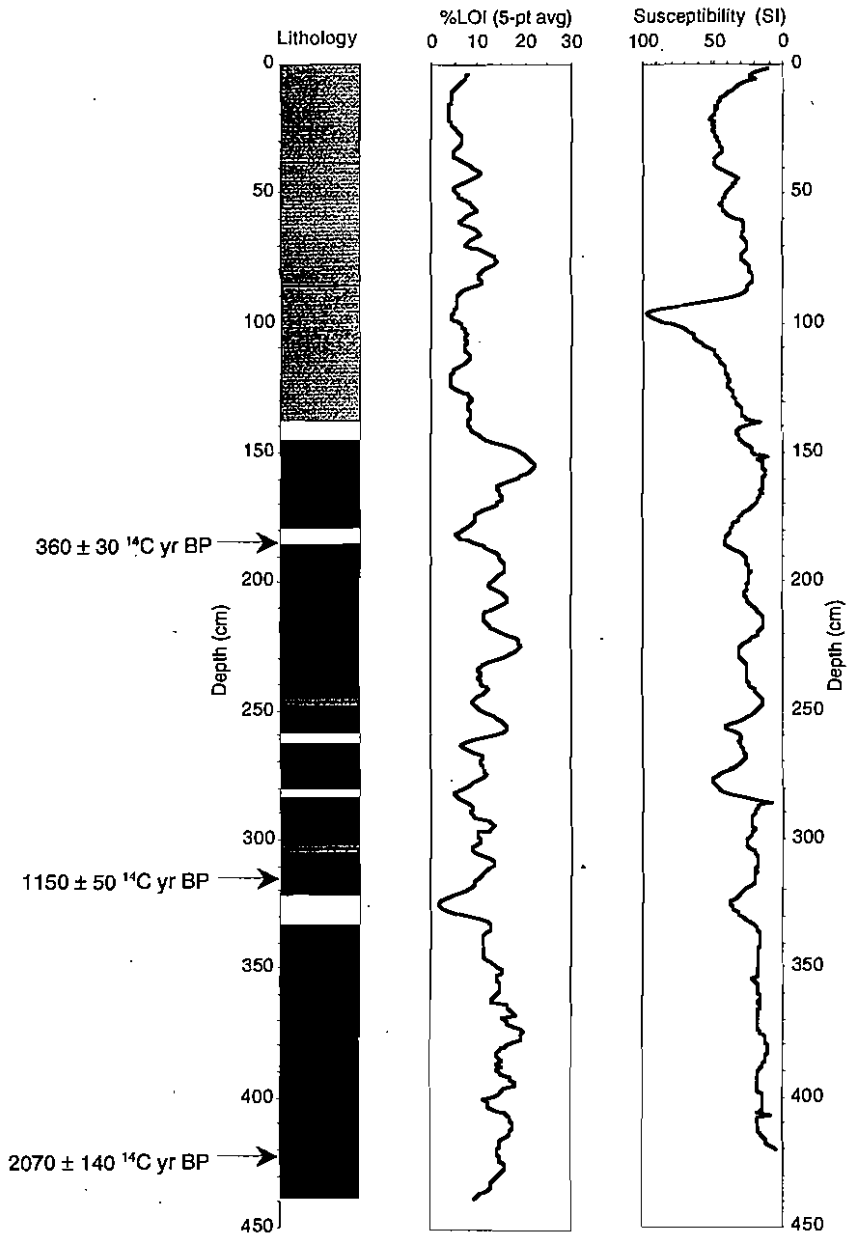

Figure 3. Whole-core data sets and initial radiocarbon dates from Echo Lake; all shifts to the left indicate the location of inorganic layers. Lithology was determined from visual logging; colors represent relative approximations of core appearance (and by inference, organic carbon content): dark colors correspond to gyttja, whereas lighter bands correspond to distinct layers of inorganic sediment; gray colors represent a mix of gyttja and inorganic sediment, or several thin laminae of each. %LOI = percent mass lost on ignition, which is a proxy for the percent organic carbon content (Brown, 1999). Samples for LOI measurements were taken and analyzed at 1-cm intervals by students in the 1999 Geohydrology class.

Work Completed to Date

Summer/Fall 1998

- Examined all USGS 1:24,000 topographic maps in eastern New York, Vermont, Massachusetts, and those maps bordering Vermont in Quebec and New Hampshire to determine candidate lakes
- Visited candidate lakes to perform initial visual survey and establish general bathymetry
- Communicated with the Vermont Department of Environmental Conservation (VT DEC) to gather background information for candidate lakes
- Selected seven lakes in Vermont for coring in the winter of 1999 and designated several additional lakes for coring if time permits

Winter 1999 (through March 10)

- Procured bathymetric charts for available lakes from VT DEC
- Completed bathymetric surveys of all candidate lakes in Vermont
- Successfully retrieved five cores

Timeline for Future Work

Winter 1999

- Retrieve cores from remaining Vermont lakes
- Survey bathymetry and core additional lakes in Vermont as time permits

Spring-Summer 1999

- Thesis proposal presentation to UVM Geology Department: April 12, 1999
- Lab analysis of cores
- ^{14}C measurements at Lawrence Livermore National Laboratory
- Prepare abstract for Geological Society of America Annual Meeting in Denver, Colorado
- Create surficial geology maps/descriptions for lake drainage basins
- Re-assess the parameters for candidate lake selection
- Visit more candidate lakes in New York and Massachusetts for initial surveys

Fall 1999

- Present findings at GSA Annual Meeting in Denver (poster session?): October 25-28
- Present progress report to UVM Geology Department
- Continue lab work and field surveys as needed

Winter 2000

- Core additional lakes in New York and Massachusetts
- Begin writing thesis

Spring-Summer 2000

- Lab analysis of new cores; ^{14}C measurements at Lawrence Livermore National Laboratory
- Prepare abstract for Geological Society of America Annual Meeting in Reno, Nevada
- Create surficial geology maps/descriptions for new lake drainage basins

Fall 2000

- Finish writing and defend thesis
- Present findings at GSA Annual Meeting in Reno: November 13-16

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