Report as of FY2006 for 2005VT22B: "Trophic status of Lake Champlain over 400 years of changing land use: A paleolomnological study"

Publications

- unclassified:
    - Burgess, Heather D. 2007. Geochemical Indicators of Productivity Change in Lake Champlain, USA-Canada. MS Thesis, The University of Vermont, Burlington, VT. 191 pages.

Report Follows

Trophic Status of Lake Champlain over 400 years of Changing Land Use: A Paleolimnological Study

Second Year Progress Report

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Project Objectives:

The purpose of this project is to use paleolimnological techniques to uncover the history of Lake Champlain's response to changing land use and eutrophication since European settlement. Our intent is to obtain and analyze sediment cores from several basins and bays in Lake Champlain that currently differ in trophic status, or have received waters from areas with different land uses in the past. Our hope is to provide managers with such important background information as the initial water quality and biological composition of the lake, and the lake's response to specific stressors, including the placement of causeways.
Our specific objectives are:

1) *To determine pre-settlement trophic conditions across the lake*
2) *To document changes in trophic state and algal assemblages over the period since settlement*
3) *To relate these changes to land use practices or other indicators of human activity*

The results of this study also will benefit public education. We plan to work with the staff of ECHO (Burlington's science museum) to create two linked displays. One will provide a time line comparing lake condition to activities in the Basin; the other will highlight the role of the paleolimnologist as a sort of environmental detective. Our goal is to have these displays in place by 2009, when Vermont will celebrate the 400th anniversary of Samuel Champlain's voyage of discovery into the lake.

Approach:

We analyzed four cores, two from regions of the lake where algal blooms are problematic (St. Albans and Missisquoi Bays) and two from open water areas that have been less stressed by excess nutrients and represent large expanses of water. For each location we assessed the following trophic state indicators over a 400 to 450 year period, with sediment age and accumulation rates determined by a combination of ^{210}Pb and ^{14}C dating:

- Sediment organic matter content (%C, %N, C/N)
- Stable carbon isotopes
- Nutrients (Phosphorous and biogenic Silica)
- Fossil pigment assemblages

- Diatom assemblages
- Soft algae

Records of forest cover, agricultural crops and livestock density, industrial and municipal discharges, human population density, and weather were gathered as well so that the relative impacts of these stressors can be evaluated. Our procedures are described in more detail in our original proposal (October 2004).

Analytical Methods:

Elemental Analyses (C and N content, C/N ratio)

Percent organic carbon (%C) and percent nitrogen (%N) in the sediment were determined at a resolution of 1 centimeter using a CE Instruments NC 2500 elemental analyzer (Environmental Stable Isotope facility, Geology Dept.) The carbon to nitrogen ratio (C/N) values was calculated from the %C and %N data.

Stable Isotope Analyses

Stable carbon isotopic analyses were performed with a CE Instruments NC 2500 elemental analyzer coupled to a VG SIRA II isotope ratio mass spectrometer (Environmental Stable Isotope facility, Geology Dept.) The analyses were conducted at 1-centimeter resolution and the results reported using the delta (δ) notation in units of per mil relative to the inorganic standard V-PDB. Analytical precision is ±0.05‰ (based on replicate standards).

Nutrient Analyses

Phosphorus: The phosphorus contained in lake sediments was analyzed by sequential extraction of functionally defined forms. Samples of known mass were sequentially extracted with 1M NH_4Cl, 0.1N NaOH, and 0.5N HCl, which remove loosely sorbed P, metal-bound P, and apatite P, respectively. After each extraction, the sample was centrifuged, and the supernatant analyzed for P using the molybdenum blue technique.

Biogenic Silica: Samples of known mass were incubated in hot (85°C) 0.1 M NaOH. Aliquots were withdrawn at hourly intervals and analyzed for silica using ion chromatography (IC available in the Geology Dept.) and wet chemistry (molybdosilicate method). The results were graphed against time, and the later, linear portion of the curve is extrapolated to the Y intercept to estimate biogenic (diatoms + sponge spicules) silica.

Total Nitrogen: Nitrogen content (% N) was determined with a CE Instruments NC 2500 elemental analyzer (Environmental Stable Isotope facility, Geology Dept.).

Fossil Pigment Analyses

Lipid-soluble (polar) pigments were extracted from the bulk sediments by soaking powdered sediments in a mixture of degassed acetone:methanol:water (80:15:5, by volume) for 24 h in the dark and under an inert N_2 atmosphere at 0° C. Pigment concentrations of the filtered and dried extracts were then determined in each sediment interval using a Hewlett Packard 1050 high performance liquid chromatography (HPLC) system calibrated with standards from the U.S. Environmental Protection Agency. Pigment concentrations are expressed as nmoles pigment g^{-1}

organic matter (the latter obtained from elemental analysis), an index that is linearly related to algal biomass in the water column.

Microfossils

Sediments for diatom analysis were digested with H_2O_2 (30%) and CH_3COOH (95%), and a standard solution of microspheres added to allow quantitative estimates of frustules concentration. Cleaned frustules were mounted on slides with Naphrax, and at least 500 valves or stomatocysts counted in each sample to determine % composition. For soft algae analysis, sediments were added to a 10% solution of KOH along with a standard solution of *Lycopodium* spores (to trace extraction efficiency) and boiled for 10 min. This process deflocculates sediment and removes humic acids. After sample settling, decanting, and washing with distilled water, the sample were stored in glycerol and slides made using Fuschin-B-glyceral as a mounting medium. Whole cells, resting propagules and identifiable fragments were counted.

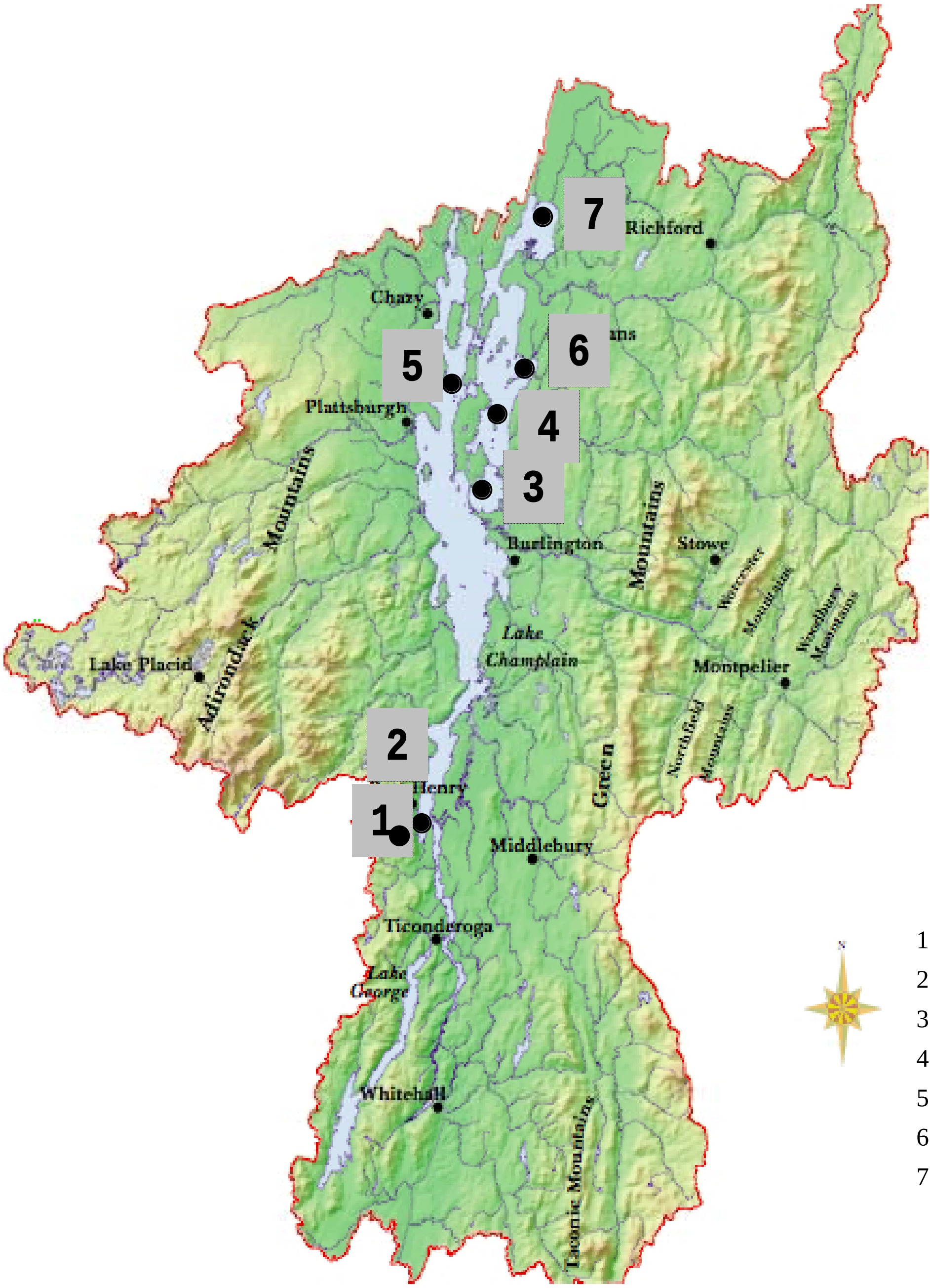
Sediment Chronology

Sediment chronologies are based on alpha spectrometric analysis of ^{210}Pb activities of recent sediments (1850–present), constant rate of supply calculations, and three accelerator mass spectrometric analyses of ^{14}C in macrofossils extracted from older sediments.

Progress to date:

This project began in March 2005 and has proceeded “on schedule” for its whole duration. We received funding to collect two cores in 2005 and two others in 2006. The 2005 cores were taken in summer from opposite ends of the lake, one near Port Henry and Crown Point, where settlement of the Lake Champlain Basin began (and thus where we expect to find the longest record of impacts) and one in the Northeast Arm (just north of Savage Island), a lake region settled late and thus likely to show pristine conditions until relatively recently. The two 2006 cores were obtained from regions of the lake that are currently strongly impacted by phosphorus inputs and cyanobacterial blooms, St. Albans and Missisquoi Bays. Because we knew from previous coring in these bays that sedimentation rates were high, we obtained 1.5-2 meter rather than 80 cm long cores. These were collected with a piston corer during the winter, using the ice cover as a coring platform. The VT DEC provided three additional cores that were also utilized for this study. The VT DEC cores were retrieved in Outer Mallets Bay, Cole Bay, and Point Au Roche Bay.

All cores were sectioned at 1 cm intervals and analyzed in our laboratory for %C, %N, C/N ratios, carbon stable isotopes, total and bioavailable P, and biogenic Silica (BSi). Paleopigment and soft algae analyses were performed at the University of Regina, Canada, and diatom assemblages were investigated at Paul Smith’s College, NY.



1. Port Henry
2. Cole Bay
3. Malletts Bay
4. Savage Island
5. Point Au Roche
6. St. Albans Bay
7. Missisquoi Bay

Figure 1: Map of coring locations. Cores from locations 1-3 were provided by the VT DEC

Table 1: Summary of physical characteristics for coring sites

Core Name	**Date Collected**	**Latitude**	**Longitude**	**Depth (meters)**	**Basin**	**Predominant Land-Use**
Port Henry	Jul-05	44.0518	73.4346	9	Poultney-Mettawee	Agriculture, industry, forested
Cole Bay	Jul-03	44.1289	73.4094	50	Poultney-Mettawee	Agriculture, industry, forested
Malletts Bay	Jul-02	44.5225	73.2817	25	Lamoille	Forested
Savage Island	Aug-05	44.7197	73.2539	11	Grand Isle Lamoille	Forested, developed shoreline
Point Au Roche	Aug-03	44.7686	73.3403	30	Lamoille	Forested
St. Albans Bay	Mar-06	44.7833	73.1500	6	Saranac-Chazy Grand Isle	Forested, developed shoreline
Missisquoi Bay	Mar-06	45.0367	73.1300	4	Missisquoi-Pike	Agriculture

Summary of Results:

Prior to settlement, most cores exhibit stable geochemical and biological trends, however, in longer cores, such as Port Henry, St. Albans Bay and Missisquoi Bay, there is more variability in the older sediments, possibly related to climatic impacts. The Mallets Bay core is the shortest, with an extrapolated date of ca. 1700 at the bottom, and therefore it is difficult to determine background trends for this core, and what, if any effects Abenaki settlements may have had on the bay.

All cores display clear increases in %C upcore, as well as decreasing C/N and δ^{13}C values, interpreted as increased algal organic matter accumulation (Figs. 2, 4, 6, 8, 10, 12, 14). The C/N ratios exhibit an initial increase between the late 17th and early 19th century at all core locations but St. Albans Bay, followed by decreasing C/N to the top of the core. This is accompanied by a less negative δ^{13}C trend at each site, including St. Albans Bay. These trends are interpreted as the signal of initial land-clearing (leading to increased terrestrial inputs), followed by nearly total deforestation, which resulted in increased nutrient run-off, and hence increased algal contribution to the sediments. More rapid increases in %C occur after the mid-20th century in all cores, most likely in correlation to the advent of chemical fertilization of agricultural fields, mechanized agriculture, urban/suburban sprawl (and hence increased run-off) as well as increased sewage inputs.

Overall, the geochemical trends are supported by the BSi, P, sediment accumulation (Figs. 3, 5, 7, 9, 11, 13, 15), paleopigment, and diatom data, and can be construed as increasing algal dominance within Lake Champlain over time due to enhanced anthropogenic nutrient inputs from the surrounding watershed. Remarkably, the two cores collected in the shallow embayments of Lake Champlain (St. Albans and Missisquoi bays) do not appear to record the recent increase in macrophyte populations along the shorelines. This suggests that macrophyte-derived organic matter is not transported very far from shore, and that the geochemical trends documented in this study are reflective of changes in algal, rather that macrophyte productivity.

Conclusions:

The dataset indicates that productivity levels within Lake Champlain were low prior to settlement within the watershed. Since settlement, productivity has increased; this increase can be related to anthropogenic disturbances, such as deforestation, suburban settlement, artificial fertilization and P and sewage inputs. However, the margins of error, which occur with sediment dating, present difficulties in relating geochemical and biological trends to very short term or localized events, such as flooding. In conclusion, this study found that trends toward eutrophication continue in Lake Champlain, suggesting that the effects of remediation (e.g. phosphorous reduction efforts) are not yet evident.

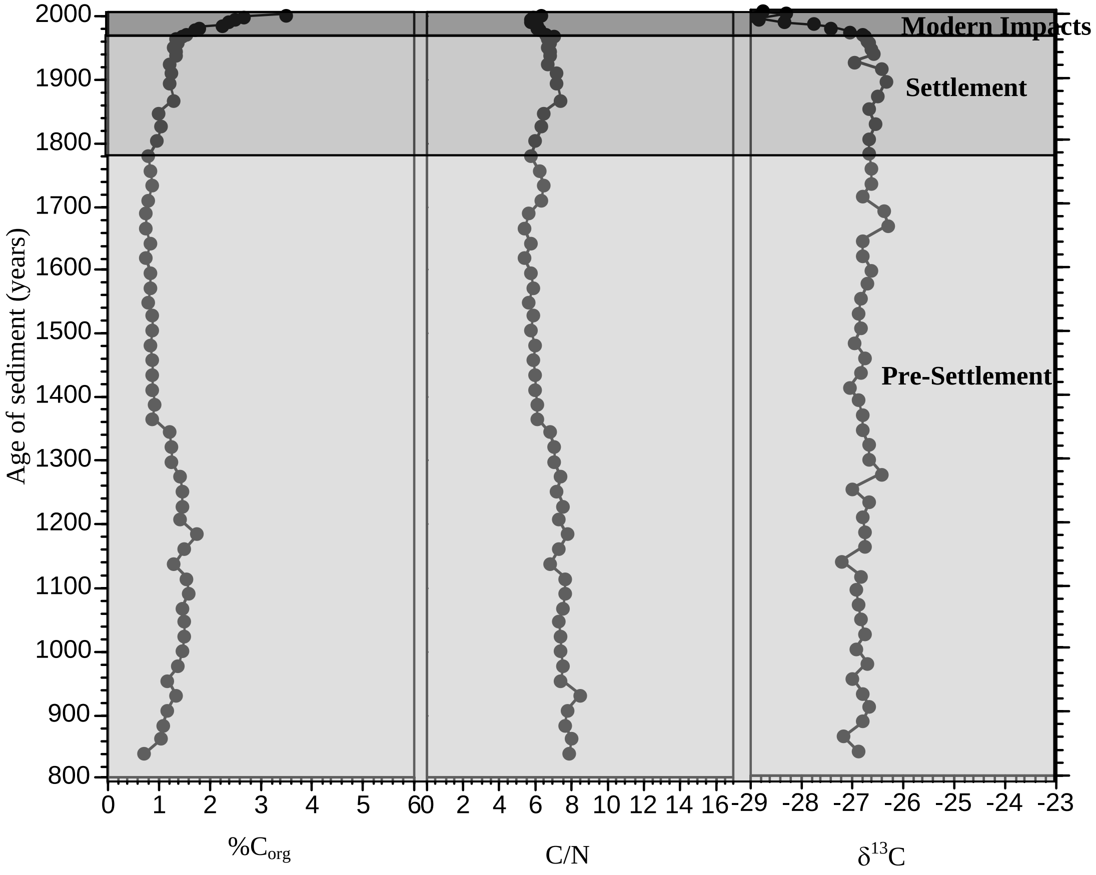


Figure 2: Port Henry $\%C_{org}$, C/N and $\delta^{13}C$ vs. age.

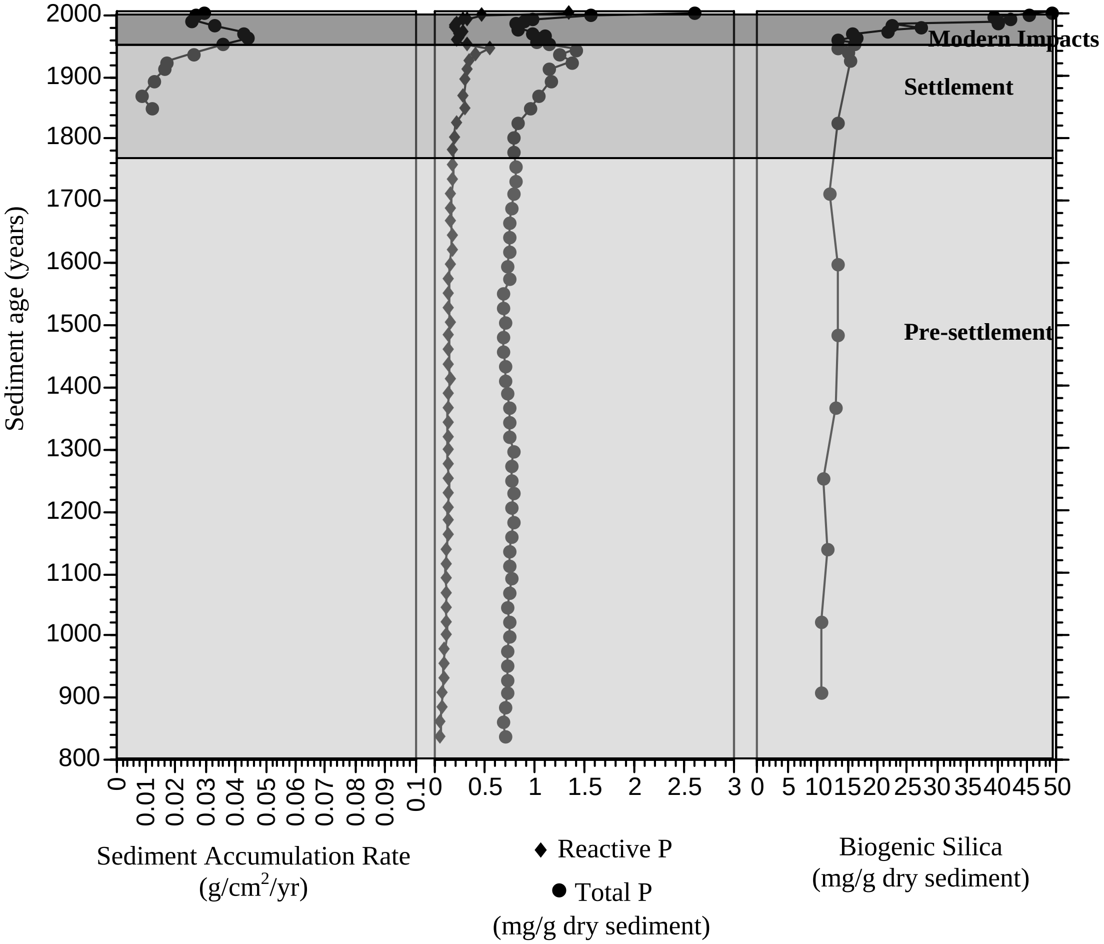


Figure 3: Port Henry sediment accumulation rates, phosphorus and biogenic silica vs. age.

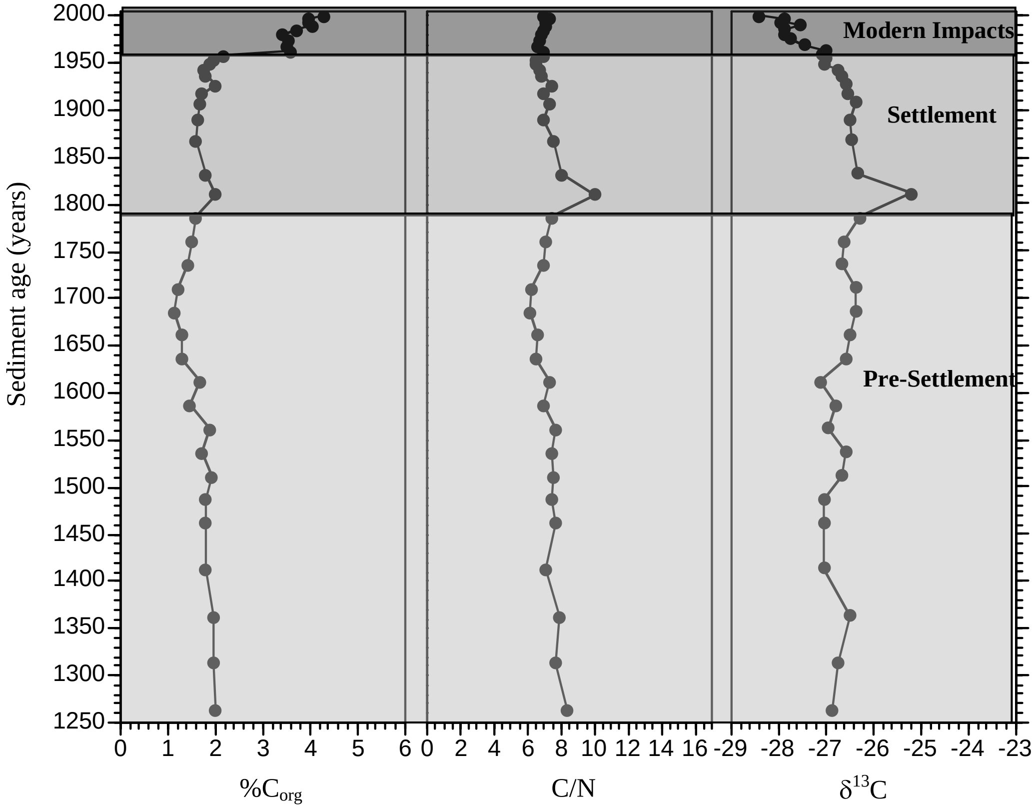


Figure 4: Cole Bay %C$_{org}$, C/N and δ^{13}C vs. age.

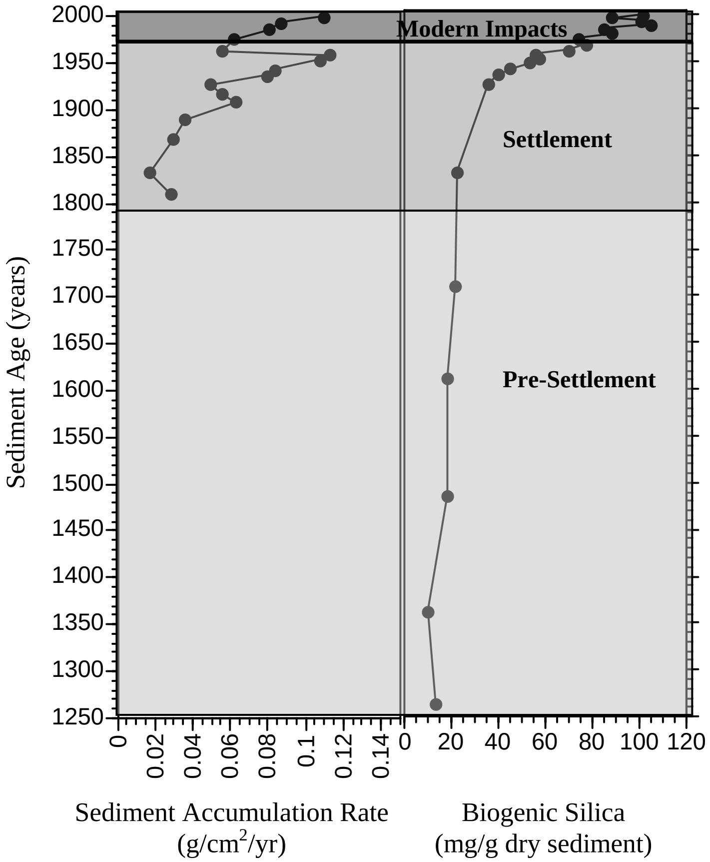


Figure 5: Cole Bay sediment accumulation rate and biogenic silica vs. age.

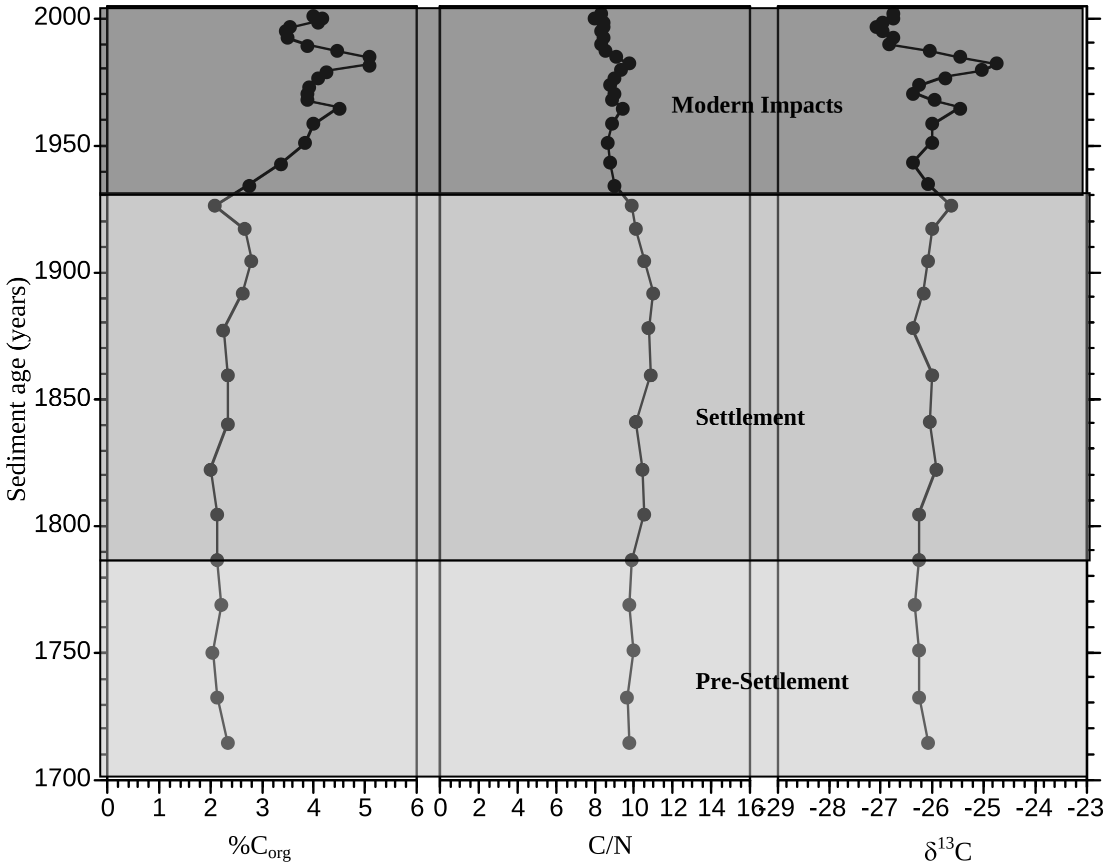


Figure 6: Malletts Bay %C_{org}, C/N and δ^{13}C vs. age.

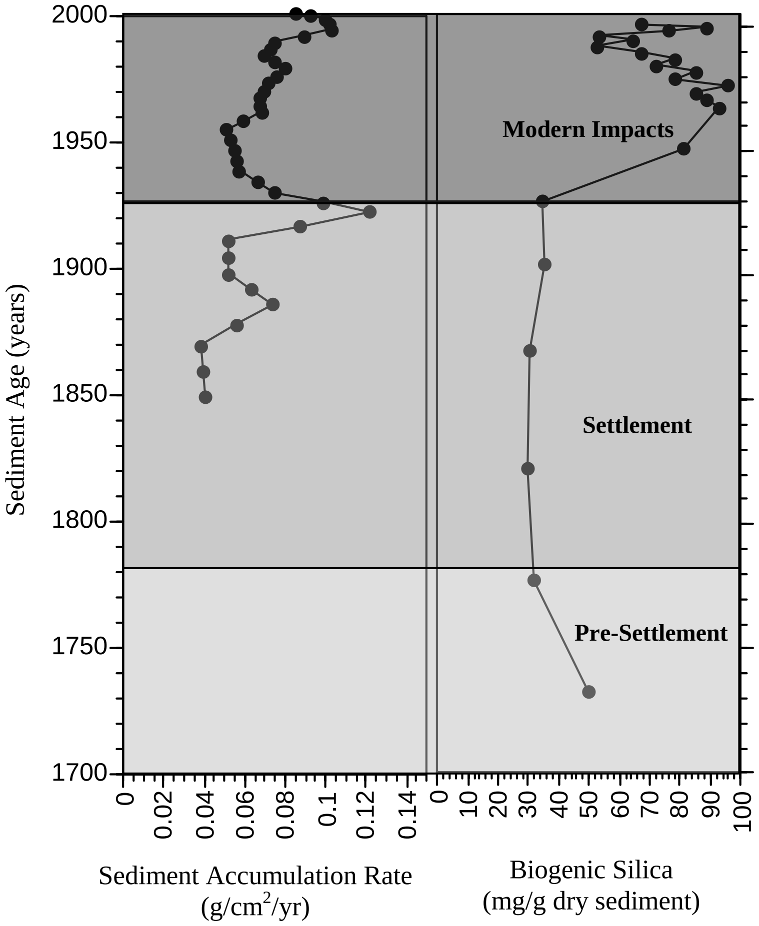


Figure 7: Malletts Bay sediment accumulation rate and biogenic silica vs. age

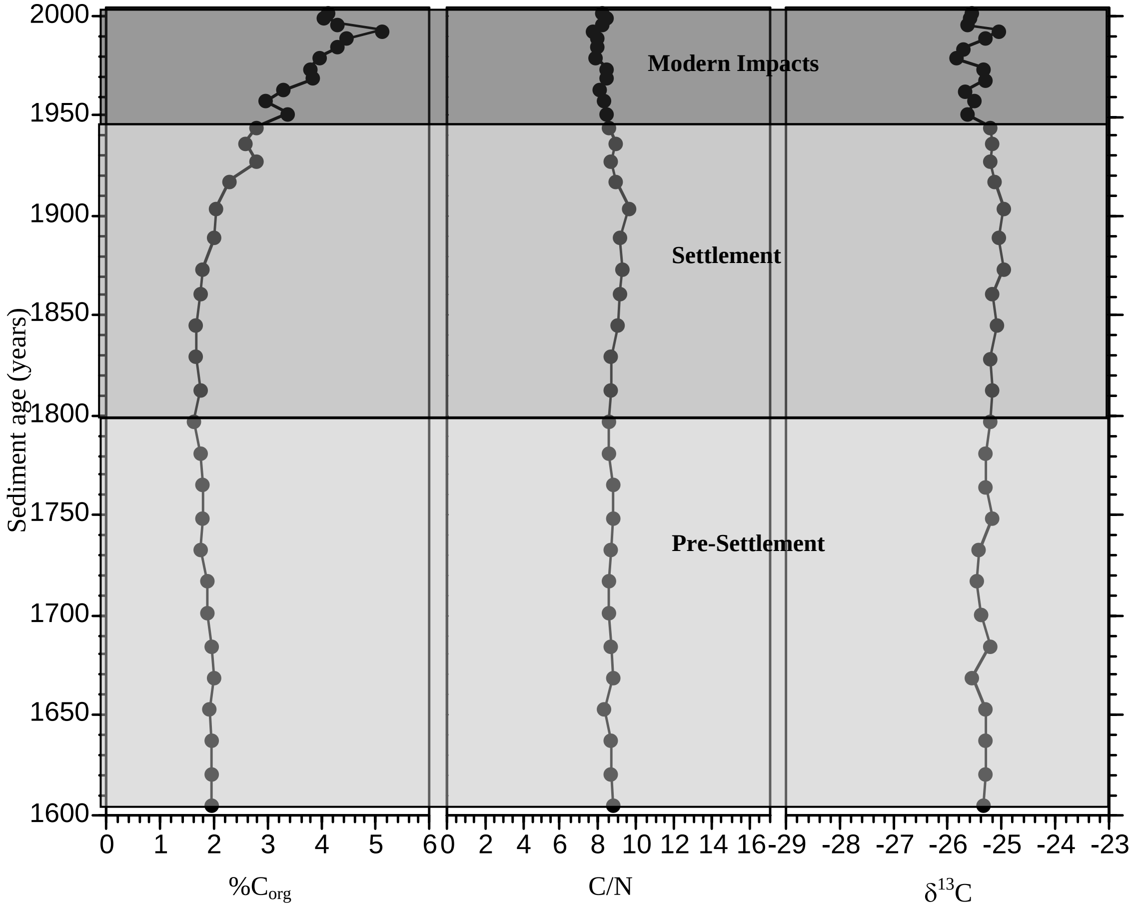


Figure 8: Point Au Roche %C_{org}, C/N and $\delta^{13}C$ vs. age.

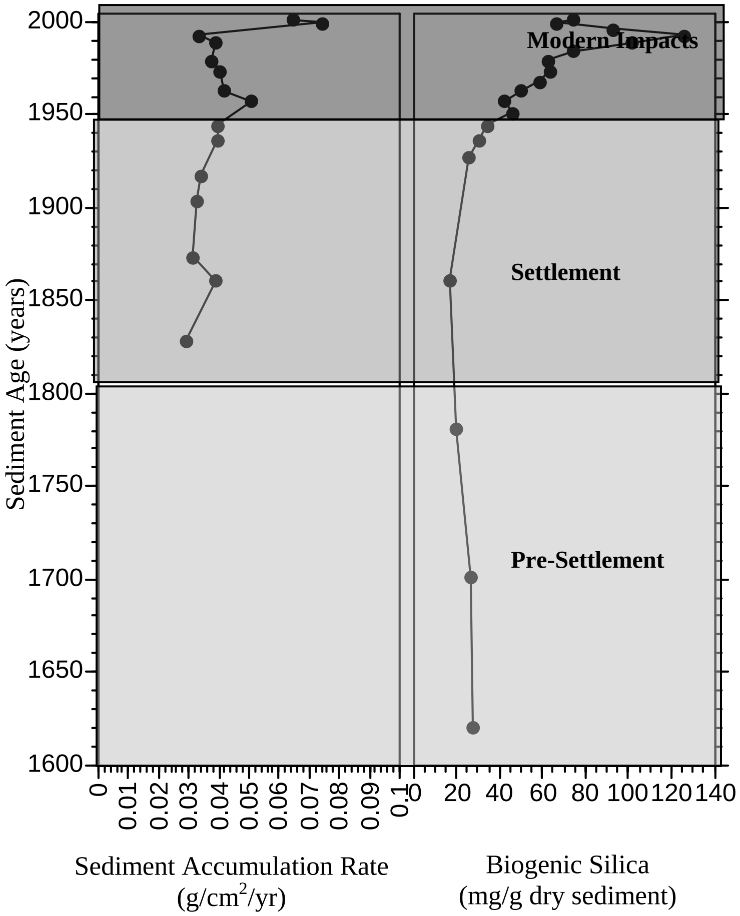


Figure 9: Point Au Roche sediment accumulation rate and biogenic silica vs. age.

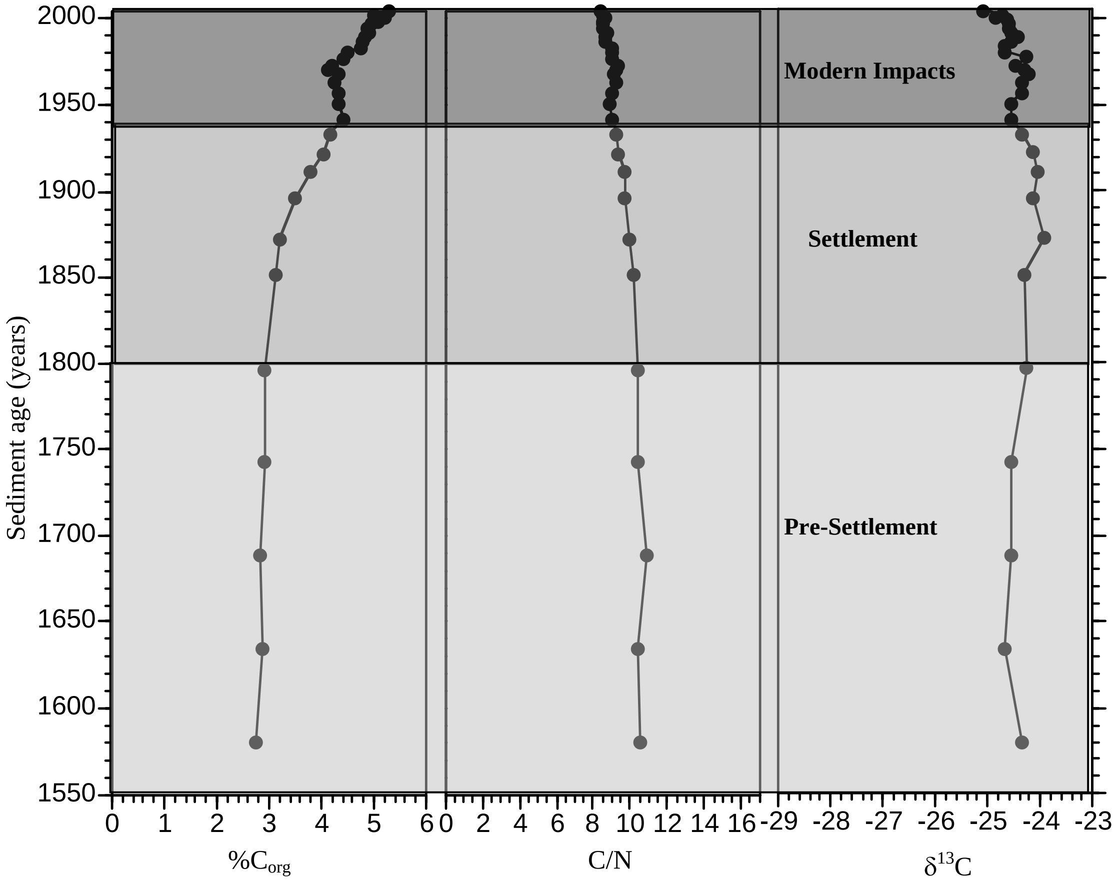


Figure 10: St. Albans $\%C_{org}$, C/N and $\delta^{13}C$ vs. age (recent sediment).

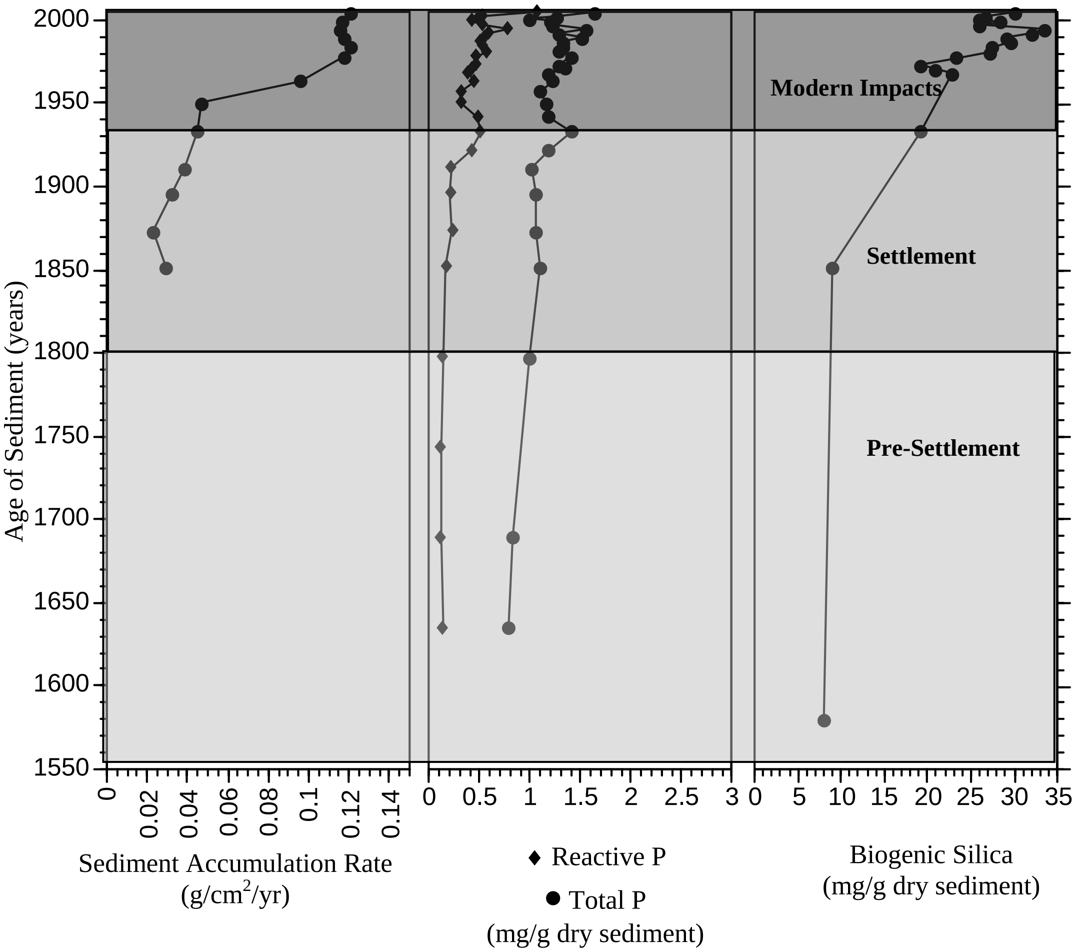


Figure 11: St. Albans Bay sediment accumulation rate, phosphorus and biogenic silica vs. age (recent sediment).

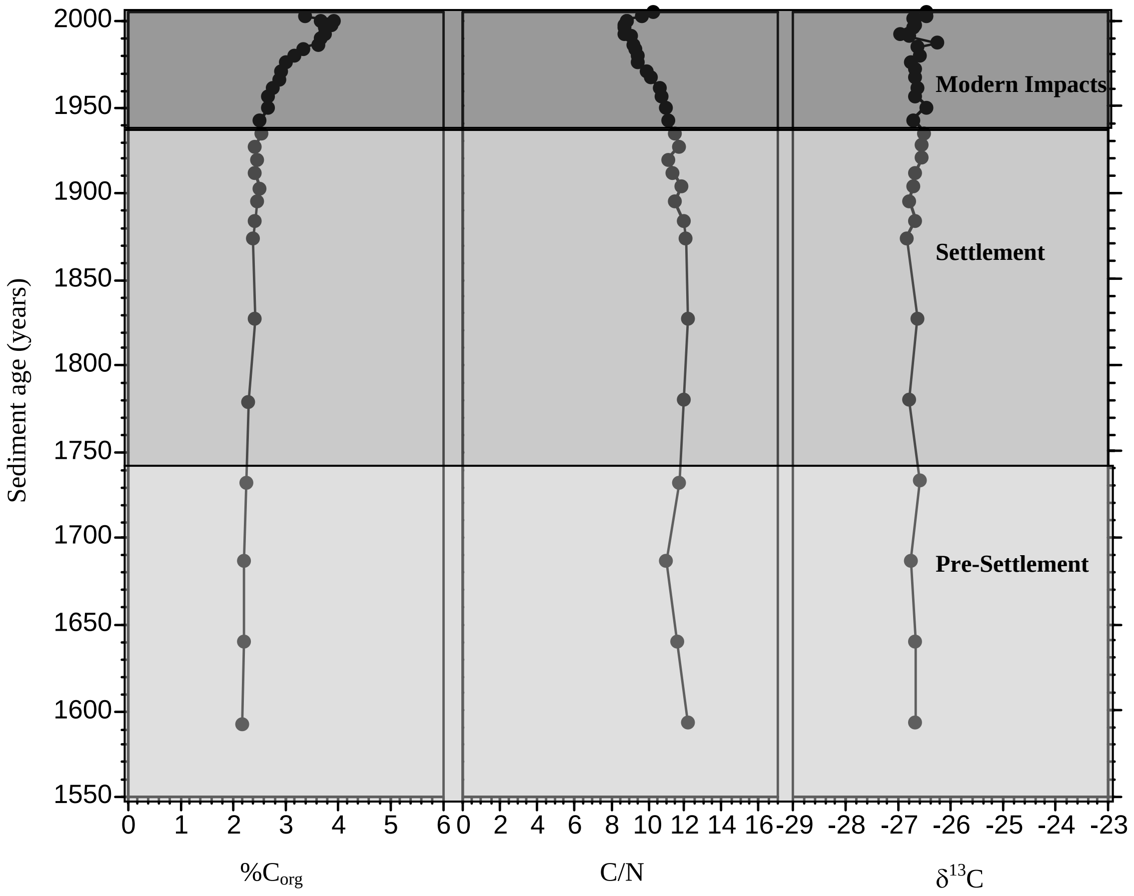


Figure 12: Missisquoi Bay %C_{org}, C/N and $\delta^{13}C$ vs. age (recent sediment).

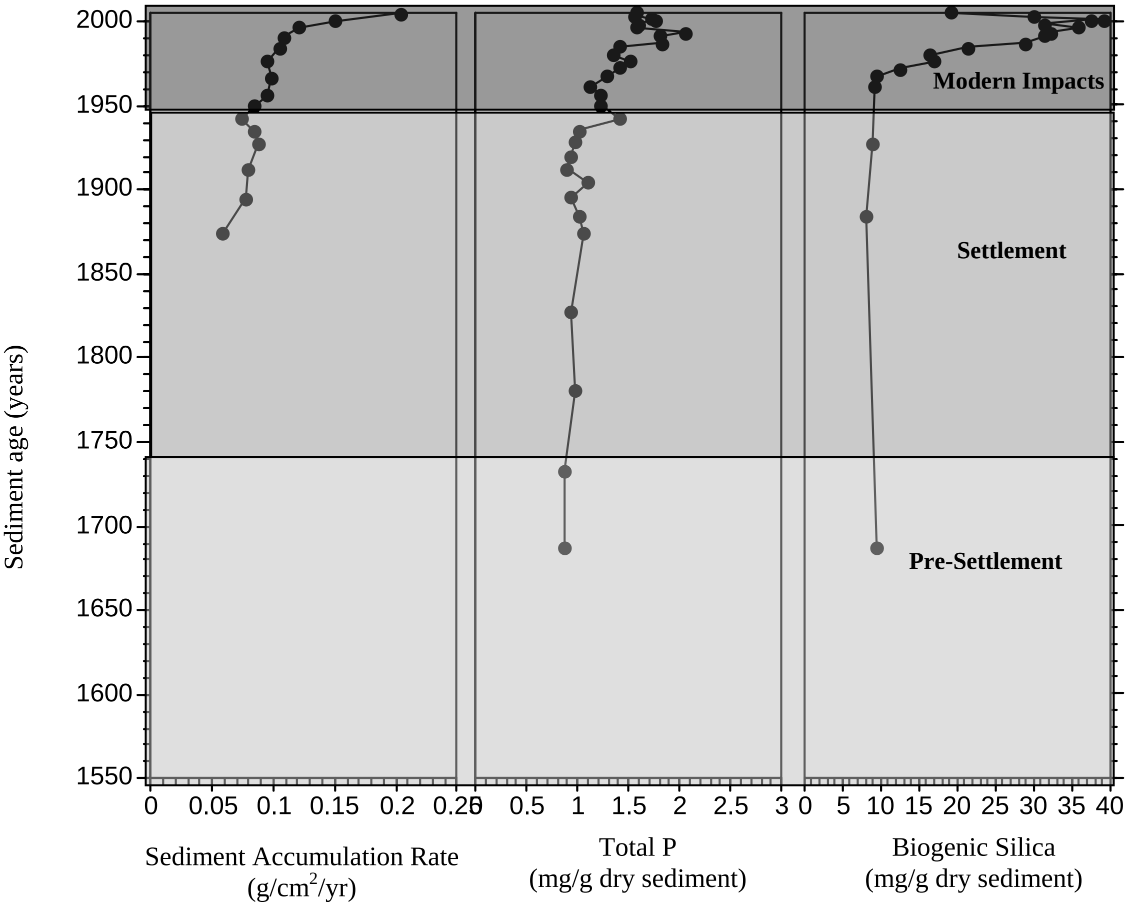


Figure 13: Missisquoi Bay sediment accumulation rate, phosphorus and biogenic silica vs. age (recent sediment).

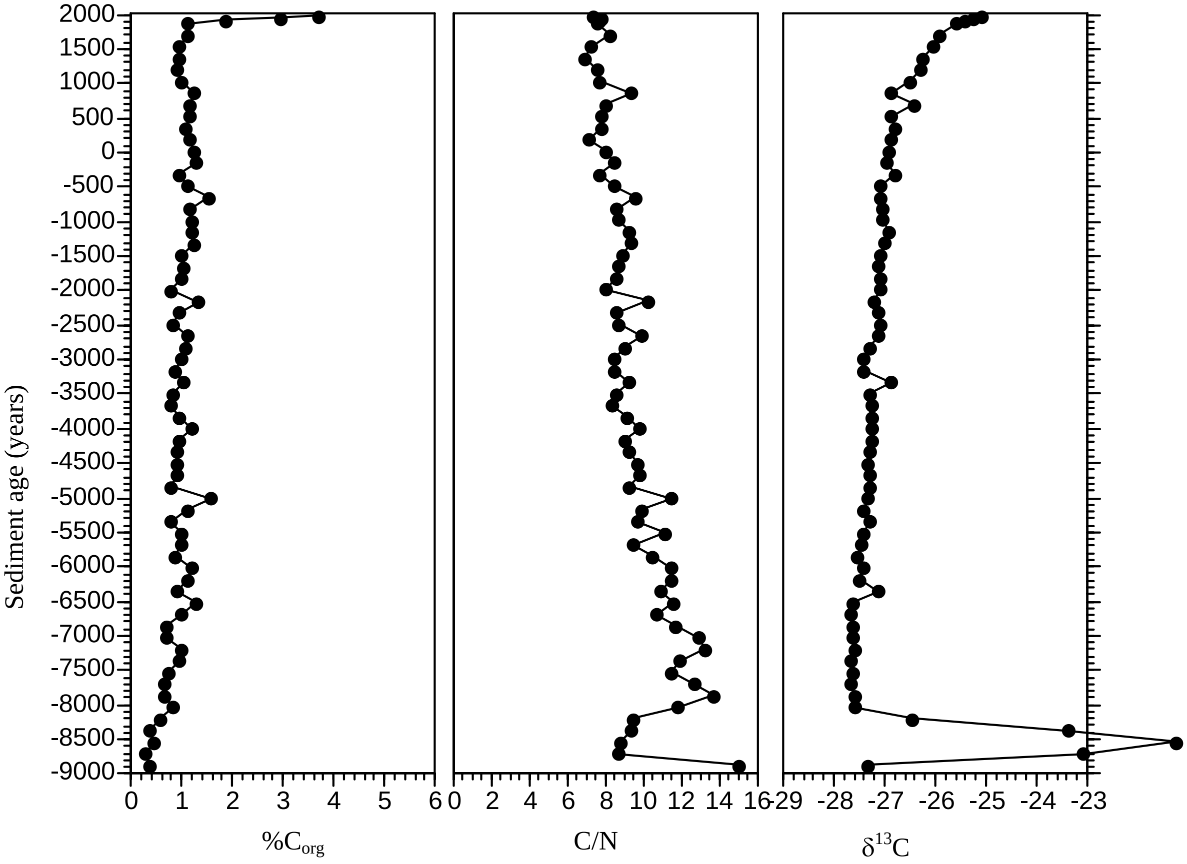


Figure 14: Savage Island $\%C_{org}$, C/N and $\delta^{13}C$ vs. age.

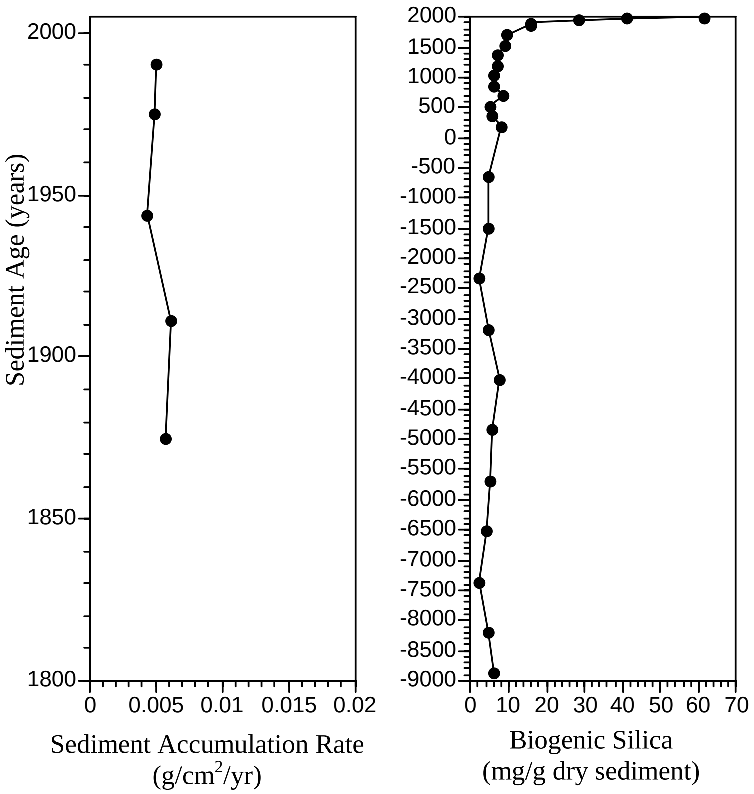


Figure 15: Savage Island sediment accumulation rate and biogenic silica vs. age. *Note different time scales.

A thesis with additional data about this report is on file with the Vermont Water Resources and Lake Studies Center at The University of Vermont. It can also be accessed at: www.uvm.edu/envnr/vtwater/pubs/yr2007.htm