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Paleolimnology of Selected Lakes in the Southwest Alaska Network: Understanding Past Trends of Salmon Abundance and Lake Productivity

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Abstract
Paleolimnological techniques on selected lakes in the Southwest Alaska Network of the National Park Service are utilized in this project to better understand processes and long-term trends in their biota and environments, with a focus on sockeye salmon lakes. Past changes in sockeye salmon abundance will be determined using stable nitrogen isotope analysis of sockeye nursery lake sediment cores. Data will be developed to reconstruct lake productivity and sockeye salmon abundance over the past 500 to 10,000 years. This data will help define the natural variability of sockeye salmon in these systems, and its relationship to past changes in climate, landscape processes, ocean condition and commercial fishing. Field and laboratory results from selected sites collected during the first 3years of the project are presented in this annual report. To date, cores have been collected from Brooks, Devil's Cove, Hammersley, Idavain, Jo-Jo, Klosterman (informal name) Murray, Naknek, and Pringle (informal name) Lakes of Katmai National Park and Preserve; Kukaklek and Nonvianuk Lakes of Alagnak Wild River; Kontrashibuna and Crescent Lakes from Lake Clark National Park and Preserve; and Surprise and Meshik Lakes of Aniakchak National Monument and Preserve. Sedimentary analyses and dating are well underway or complete on all of these lakes. Basal age dates on the cores range from relatively young, 230 years BP (before present) in Devil's Cove Lake, to >10,000 years BP in Nonvianuk and Idavain Lakes. Overall, the sediments recovered from these lakes are vastly different, reflecting the diverse lake types (i.e., glacial, deep clearwater, caldera and shallow). However, all have characteristics that will allow for reconstructing aspects of limnological and environmental history during the Holocene.

Executive Summary
This project is using paleolimnological techniques on selected lakes in the Southwest Alaska Network of the National Park Service to better understand processes and long-term trends in their biota and environments. A variety of lake types will be studied, but the focus will be on sockeye salmon systems, which are important for the economy and ecology of this region. Past changes in sockeye salmon abundance will be determined from new techniques utilizing stable nitrogen isotope analysis of sockeye nursery lake sediment cores. Long-term data will be developed to reconstruct lake productivity and sockeye salmon abundance over the past 500 to 10,000 years. This data will help address questions relevant to sustainable management of these systems by defining the natural variability of sockeye salmon, and its relationship to past changes in climate, landscape processes, ocean condition and commercial fishing. Further, this project will assess the importance of salmon-derived nutrients in regulating freshwater productivity and sockeye production. Such data will help determine if current escapement goals are compatible with the long-term paleoecological perspective. Studies of non-salmon systems will help distinguish how factors such as climate change, volcanic eruptions, geomorphologic change and human impacts, in the absence of salmon, influence freshwater systems. The long-term perspective developed through this project will provide baseline data on these systems, which will help determine how humans have influenced these lake ecosystems, through both

local and global activities. Finally, this work will provide insight into how future environmental changes may influence freshwater characteristics and salmon productivity in this region, and provide a better understanding of the significance of trends observed in the Network's future monitoring program. Field and laboratory results completed during 2005 are presented in this annual report.

Introduction

This project is a detailed paleoecological and paleoenvironmental study on selected lakes in the Southwest Alaska Network of the National Park Service. The research will help to better understand processes and long-term trends in the biota and physical/chemical limnology of these freshwater systems. Paleo-data can reveal how climatic, oceanographic and landscape processes interact with lakes. In addition, this long-term perspective will provide baseline data on these systems, which will help determine how humans have influenced lake ecosystems, through both local and global activities. Fieldwork for this project began in July of 2003, and cores from Brooks, Naknek, Surprise and Meshik Lakes were obtained. During the 2004 field season, cores were obtained from Nonvianuk, Jo-Jo, Devil’s Cove, Murray, Hammersley, Klosterman (informal name) and Pringle (informal name), Kontrashibuna and Crescent Lakes. Cores were collected from Kukaklek and Idavain Lakes in 2005.

Recent studies at the Institute of Marine Science, University of Alaska Fairbanks, have led to the development of a method to reconstruct long-term changes in salmon abundance from sediment core analysis. This method is based on the observation that salmon strongly impact freshwater environments via input of significant quantities of marine-derived nutrients released from carcasses after spawning. This input, which can be quantified through analysis of $\delta^{15}N$, will vary depending on escapement. Therefore, downcore changes in the abundance of $\delta^{15}N$ will reflect changes in the number of returning adult salmon. Rationale, evaluation and further details regarding the sedimentary nitrogen isotope technique are summarized in Finney et al. (2000).

The sediment ^{15}N method is well suited for sockeye systems because their life history generally requires a lake for habitat. Importantly, lake sediments are often ideal for high-resolution paleoenvironmental studies due to relatively rapid, continuous sedimentation, and minor bioturbation. Recent results on Alaskan sockeye nursery lake sediments show that this technique is applicable to many productive sockeye systems (Finney et al., 2000). Studies combining ^{15}N analysis with standard paleolimnological techniques provide an opportunity to address questions such as:

- What is the natural variability of sockeye salmon in these systems?
- How have past changes in factors such as climate change, ocean conditions, and commercial fishing effected salmon runs?
- How important are salmon-derived nutrients in regulating freshwater productivity?
- Are current escapement goals compatible with the long-term paleoecological perspective?

• Do different lake types respond differently to the same external forcing?
• How might future environmental change influence salmon productivity in these systems?
• How might future environmental change influence freshwater characteristics?

Very little is known about the aquatic ecosystems and prehistoric salmon production in the Southwest Alaska Network. Obtaining a better understanding of these lakes is important from both ecologic and economic viewpoints. This work will provide baseline information and a long-term perspective on these lake ecosystems. Cores will be retrieved from a suite of different lakes in Alagnak, Aniakchak, Katmai, and Lake Clark National Park units. Lake characteristics will include glacial, clearwater, anadromous and barriered systems.

The main objectives of this study are:

1. To reconstruct past changes in salmon abundance using the methods developed by Finney et al. (2000), for sockeye salmon systems and systems that may have had salmon in the past. The time frame of such reconstruction's ranges from detailed decadal-scale variability over the last 500 years, to long-term changes since the end of the last ice age (c.a. 12,000 years BP).
2. To determine past changes in lake primary productivity and nutrient status, for both salmonid and barriered systems. The time frame will match that in objective 1.
3. To compare these reconstructions to records of past environmental change to determine how factors such as climate change, volcanic eruptions, geomorphologic change and human impacts influence these freshwater systems.
4. To describe long-term trends in sockeye abundance, assess recent levels from a long-term perspective, and compare trends to those determined for other Alaskan systems. Time-series analysis will be used where applicable.
5. To determine the roles of lake primary productivity and carcass-derived nutrients in influencing sockeye production (e.g., Schmidt et al, 1998).

Methods

Methods relevant to the fieldwork and subsequent laboratory analyses are described here. High quality surface cores were obtained from each lake with a gravity or piston corer specially designed for sampling unconsolidated sediments and obtaining an undisturbed sediment-water interface. The coring is done in deep basins away from areas of steep topography determined from lake bathymetry. Such sites are chosen to avoid complications from processes such as turbidites. Multiple coring sites are selected in each lake to ensure that representative records are produced. The surface cores were continuously sampled in the field at 0.5 - 1.0 cm increments using a precision extruder until the sediments were consolidated enough for safe transport to the laboratory. For these lakes longer histories than contained in the surface cores are also desired, and longer cores were obtained using hammer, percussion and/or Livingstone coring systems (typical lengths ~2-6 m) at the same site. Long cores selected for detailed study are sampled continuously at 1 cm increments.

Coring methods and subsequent analyses have been divided into two levels based on the time frame of interest for each system:
Level 1: Gravity cores (~40-50 cm long); detailed analyses of last ~500 years.
Level 2: Hammer, percussion or Livingstone cores (coring method depends on lake characteristics, but cores are typically ~2- 5 m long); time frame ~3,000 - 12,000 years.
Level 1 coring and analyses will be conducted on all Level 2 lakes. The cores records will be spliced together at recognizable features such as volcanic ash layers (Finney et al., 2002).

The cores are described using standard sedimentological techniques (PALE, 1994). Physical properties measured on each sample include water content, and wet and dry bulk density. These measurements allow for determination of sediment compaction, necessary for developing accurate sediment chronologies. Magnetic susceptibility is measured on each sample to determine the distribution of volcanic ash layers and to provide other stratigraphic information. Magnetic susceptibility is a measure of the degree to which sediments may be magnetized and is expressed as SI units (SI=standard international, a unitless measure). Magnetic susceptibility is run in two ways. A pass-through ring sensor can be run on whole unopened cores, and individual samples in vials can also be analyzed. Ring SI units give a general idea of sediment content and can often detect differences in sedimentary layers that are not visible to the eye. Ring magnetic susceptibility is a useful tool for correlation between cores taken from the same lake or even cores from different lakes in the same region. The individual sample analyses reveal more detail and less smoothing than ring data. Dating of the cores will be determined by both radiometric (^{14}C [radiocarbon] and ^{210}Pb analysis) and tephrachronologic (tephra stratigraphy) methods. Where radiocarbon dates are used, they are calibrated and converted to Years AD or Years BP (Before Present) using the CALIB radiocarbon calibration program (e.g., Stuiver and Reimer, 1993; Stuiver et al., 1998). Tephra layers may be common given the close proximity to active volcanoes; chronologies will be refined if tephras of known events are found. Tephrachronology will assist dating and between lake correlation. Downcore analyses will be conducted for organic carbon, nitrogen, $\delta^{13}C$, $\delta^{15}N$ and biogenic silica. Organic matter and carbonate content is also estimated by the loss on ignition (LOI) technique.

Results and Discussion

Fieldwork 2005

In late June and early July 2005, cores were obtained from Kukaklek and Idavain Lakes in the Alagnak and Katmai National Park Units, respectively. These lakes were selected to study research questions focused on sockeye salmon population variability and to obtain additional control lake information. The coring operations were very successful, with total core lengths (surface to bottom of core) for Kukaklek Lake of 4.6 m, and for Idavain Lake of 15.9 m. The cores were shipped to Finney's laboratory in Fairbanks and are stored in a cold room at ~4°C. The coring device, location, water depth, core length and additional site analyses are summarized in Table 1.

Laboratory Results.

In addition to processing the cores collected in 2005, progress continued on the cores recovered in 2003 and 2004 including, Devil's Cove, Jo-Jo, Klosterman (informal name), Kontrashibuna, Naknek, Nonvianuk and Pringle (informal name) Lakes.

Devil's Cove Lake. Devil's Cove Lake is presently inaccessible to anadromous salmon. Core HC-1 (161 cm) has been opened, described and run for organic matter (LOI) and magnetic susceptibility (SI) at 5 cm intervals (Fig. 1). Initially, a thick layer of tephra at the bottom of the core appeared to be very similar in appearance to the 1912 Katmai ash, and thus the entire core was suspected to represent deposition since 1912. However, a radiocarbon sample from 132 cm depth was submitted to the Center for Accelerator Mass Spectrometry (CAMS), Lawrence Livermore National Laboratory and yielded a ^{14}C age of 260 $\pm$ 35 years BP (Table 2). This calibrates to approximately 1640 AD. Using the topmost sample as the year 2004 (the date the core was collected), what now appears to be the 1912 Katmai ash layer at 35 cm, and the 1640 date at 132 cm, an age model was generated. Figure 1 shows the age model (upper x axis) plotted against %LOI and magnetic susceptibility. Depth is shown in the lower x axis. Preliminary stable isotope data from 11 samples (Fig. 2) revealed low $\delta^{15}N$ values (mean = 1.5 ‰) with little variability, with C/N values averaging 12.5 (wt. percent basis) (Fig. 3).

Jo-Jo Lake. Core PC-1 (296 cm) has been opened, described and run for organic matter (LOI) and magnetic susceptibility (SI) (Fig. 4) and carbon and nitrogen isotopes (Fig. 5). The core ends in organic-poor sediments of glacial origin. Five AMS radiocarbon samples were submitted to CAMS in 2005 (Table 2). The uppermost sample submitted (40 cm) was determined to be of insufficient size for dating. The lowermost sample (284 cm) yielded a radiocarbon age of approximately 1600 years BP (uncalibrated). This relatively young date indicates connection to a glacial system such as the Savonski River in the period following the last ice age, probably due to geomorphic processes. The radiocarbon sample at 189 cm (1100 years BP) was collected from organic-rich lake sediments typical of today, indicating that the lake was no longer connected to a glacial system at that time. The radiocarbon sample collected at 53 cm (c.a. 1500 AD) was collected just above a prominent brown tephra that appears to be present in other cores in the region (e.g. Idavain, Klosterman and Kukaklek) and thus can be used to refine age models for other lakes.

The $\delta^{15}N$ isotope history (Fig. 5) indicates higher values from approximately 1200 to 1800 AD and near the bottom of the core. Such high levels may indicate times where Jo-Jo was connected to the Bering Sea via the Naknek drainage, allowing anadromous sockeye into the system. The upper high $\delta^{15}N$ interval also corresponds to the period known as the Little Ice Age (1250 to 1900 AD). The higher values of $\delta^{15}N$ from 1200 to 1800 AD indicate that Jo-Jo was probably connected to the Naknek system, probably through a channel that flowed into the Naknek system on the west side of the lake and thus glacial sediment would not reach Jo-Jo Lake. Figure 5 also shows a rise in the C (%)/N (%) ratio at the top of the core that corresponds to a decrease in $\delta^{15}N$ values. This represents an increase in the proportion of terrestrial organic material, possibly related to the Katmai Event.

Klosterman Lake. Klosterman Lake (informal name) is inaccessible to spawning salmon and is a control lake for this project. Core HC-2 (207 cm) has been opened, described and run for organic matter (LOI) and magnetic susceptibility (SI) (Fig. 6). Preliminary stable isotope analysis has begun.

A radiocarbon sample collected from organic rich sediments at 146 cm, yielded a radiocarbon age of 1865 Years BP (Table 2) (calibrated age of about 150 Years AD). In addition to the sample at 146 cm, other known intervals were used to construct and refine an age model: the topmost sample (2004 AD), the sample at the base of the Katmai ash layer at 75 cm (1912), and the dark brown tephra at 94 cm that is tentatively correlated to the 1500 AD tephra in Jo-Jo Lake. The age model result is shown on the top x axis.

Kontrashibuna Lake. Kontrashibuna Lake is inaccessible to spawning salmon and is a control lake for this project. Cores HC-2 and PC-1 have been opened, described and run for LOI and magnetic susceptibility analyses (Fig. 7). The two cores were combined for a total composite core length of 299 cm. In contrast to the other lakes, the LOI and magnetic susceptibility peaks show parallel trends rather than opposite. This is most likely due to debris flows that contain a mixture of both organic and mineral matter that produce a high susceptibility signal. A ^{14}C radiocarbon date from 283 cm yielded an age of 2810 years BP (Table 2) (calibrated 2900 years BP). Preliminary stable isotope analysis for this core has begun.

Nonvianuk Lake. Cores HC-1 and PC–1 have been opened, described and run for magnetic susceptibility and LOI (Fig. 8). In addition, carbon and nitrogen isotope data is complete at 3 cm resolution (Fig. 9). The two cores were correlated using a unique tephra layer, yielding a total core length of 501 cm. The magnetic susceptibility profile (Fig. 8) shows an abrupt increase in SI units/g at about 340 cm followed by a gradual decline. It is unclear what caused this shift, as the LOI profile shows minor changes over this interval. Since the magnetic susceptibility is a reflection of the magnetic mineral content, the increase may have been due to an abrupt change in sources of specific minerals, such as the opening of a river drainage. This event occurred during deglaciation, a time of fluctuating climate and abrupt environmental changes.

Six ^{14}C radiocarbon dates were submitted to CAMS in 2005 (Table 2). Two of the samples were determined to be of insufficient size for dating. The lowest sample at 358-359 cm was from a glacial silt unit and yielded an uncalibrated ^{14}C age of 10,280 years BP. The other sample at 196 cm was from organic-rich lake sediments and yielded an uncalibrated ^{14}C age of 8305 years BP. After calibration to years BP, a preliminary age model was constructed. A preliminary plot of $\delta^{15}N$ vs. age (Fig. 9) reveals oscillations on a millennial scale, with highest values in the last 2,000 years and around 10,000 yr BP.

Pringle Lake. Pringle Lake (informal name) is inaccessible to salmon and may be considered as another control lake. A 140 cm hammer core was collected from Pringle Lake, a shallow lake located in the uplands between Brooks and Naknek Lakes. The core has been opened and described. Sampling and sedimentary analyses have begun.

Progress on the cores recovered in 2005:

Idavain Lake. Idavain Lake is inaccessible to spawning salmon and is a control lake for this project. Previous cores have been collected from Idavain Lake (Brubaker et al., 2001) but the cores have deteriorated and it was determined that obtaining a new core was necessary. A 15.9 m core (Core A) was obtained using a modified Livingstone corer, and a supplemental shorter Livingstone core (Core B) was collected to ensure complete core recovery (no core breaks) for critical intervals within the Holocene. In addition, 2 surface cores were collected to obtain the sediment-water interface. All drives have been opened, described and sampled to date. Magnetic susceptibility and LOI are complete to 12.83m and 13.63m respectively (Fig. 10). The magnetic susceptibility profile is similar to that of Brubaker et al. (2001) (Fig. 11) indicating that the core spans at least the last 12,000 years. The bottom 4 drives of Idavain A recovered laminated glacial silt and ice-rafted dropstones. The similarity of the magnetic susceptibility profiles allows our core to be correlated to the existing radiocarbon dating and pollen data generated by Brubaker et al. (2001). Preliminary stable isotope data from 15 samples from the top 5 m, and 100 samples in the top 1 m of Idavain Lake (Figs. 12-14) revealed an average C(%)/N(%) value of 8**,** low $\delta^{15}N$ values of about 2.5 ‰, and oscillating $\delta^{13}C$ values. The Katmai ash tephra layer is at about 16 cm down in the core and appears to have affected the geochemical signatures in the lake.

Kukaklek Lake. Two piston and 2 hammer cores were collected at Kukaklek Lake. Core HC-2 contained a good sediment water interface and when combined with the longer PC-2 core, a total composite core length of 460 cm was obtained. Both cores have been opened, described and run for organic matter (LOI) and magnetic susceptibility (SI) (Fig. 15). A single ^{14}C radiocarbon date was obtained from 388cm depth (Table 2). To generate an age model the top sample (0 Years

BP), the 1912 Katmai ash (93 Years BP) and the brown tephra (380 Years BP) were utilized in addition to the sample at 388 cm depth (7900 Years BP, uncalibrated). This preliminary age model is depicted on the upper x-axis in Figure 15. Preliminary C (%)/N (%) and $\delta^{15}N$ data for 10 samples from the top 4 m of the core are shown in Figures 16 and 17. The relatively low C/N ratios (7-8 wt. %) indicate the predominance of aquatic organic matter, ideal for $\delta^{15}N$ salmon reconstructions. The $\delta^{15}N$ values indicate a progressive increase over the last ~ 10,000 years. Higher-resolution analyses are in progress.

Recent progress on cores collected in 2003.

Naknek Lake. Sedimentary analyses on Naknek Lake including magnetic susceptibility, LOI and $\delta^{15}N$ have been completed. Biogenic silica analyses (a proxy for total diatom content) were begun in 2005, and are nearly complete. The results for all analyses to date are shown in Figure 18. The preliminary biogenic silica trend roughly parallels the LOI trend. Both signals, and in particular, the biogenic silica, increase to higher levels after the 1912 Katmai Ash eruption, which is also a period of warmer climate following the Little Ice Age. The $\delta^{15}N$ signal is subtle and fairly consistent until after the Katmai ash eruption when the trend shifts downward. This may signal the influence of commercial salmon fishing on this system. In general, the lake productivity proxies (opal and organic matter) appear to not be strongly related to salmon-derived nutrients ($\delta^{15}N$ proxy). This may suggest that climate change and its effects on glacial silt input are more important to productivity than salmon-derived nutrients in this system.

<u>Future Work</u>

As final dating and N-isotopic results become available for cores, we will assess the data in terms of past salmon abundance. We will attempt to calibrate time-series of sedimentary $\delta^{15}N$ with historical records of escapement and estimate pre-historic escapements from downcore changes in $\delta^{15}N$. We will continue to assess paleoproductivity from downcore analyses of organic carbon, biogenic silica and organic $\delta^{13}C$. We will also begin initial comparisons of the salmon abundance and lake productivity time-series with published paleoclimatic and paleoceanographic data, as well as with paleoclimatic and paleoenvironmental data determined from analysis of the sediment cores recovered as part of this project and the closely related project by Heiser (UAA). Historical climatic and oceanographic data go back ~100 years. Sources of paleodata include coastal tree rings, glacial advance-retreat chronologies, coastal lake sediment core data and North Pacific Ocean sediment core data. The coastal areas of the Gulf of Alaska (GOA) were extensively glaciated during the Late Wisconsin; it is likely that sockeye spawning habitats were eliminated in the systems of this study. Deglaciation of the GOA region occurred relatively rapidly by about 12,000 - 13,000 ^{14}C yr BP (Mann and Hamilton, 1995). In the coastal areas adjacent to the northern GOA, temperatures warmed following the last ice age; summer temperatures peaked during the early Holocene Hypsithermal, about 9,000 to 6,000 yr BP (Mann et al., 1998). A general cooling trend followed, witnessed by readvances of coastal glaciers adjacent to the GOA (Wiles and Calkin, 1994). Glacial retreat ensued during the Medieval Warm Period ca. 800 - 1350 AD. Glaciers readvanced during the Little Ice age from about 1250 to 1900 AD. Tree ring-based temperature reconstruction exhibit decadal-scale periodicity and document cooler temperatures relative to the 20th century during the Little Ice Age (Wiles et al., 1998). The Hypsithermal and Medieval Warm periods likely had temperatures as warm or warmer than those experienced in the 20th century, and provide windows to study the effects of warm climates on sockeye salmon production.

We will consult with our Park Service Project sponsors/colleagues to discuss the need for any final fieldwork, which would be completed in 2006. All analytical results will be completed in 2006, and final reporting for this project will begin.

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TABLE 1. 2005 core information

LAKE	CORE TYPE	LOCATION	WATER DEPTH	CORE LENGTH	EXTRUDING NOTES	LIMNO	REMARKS
Kukaklek Lake Camp @ 59° 12.510' 155° 21.929	HC-1	59° 10.765' 155° 21.929' Iliamna A-7	69 m	8 ft	Not extruded		Overtopped tube. Cut into 2 sections and cut off soupy top. Top of HC-2 should overlap with bottom of HC-1
	HC-2 Surface core			128 cm	0-15.5 cm @0.5 cm intervals	Seechi disc = 628 cm (AK) Water temp. = 12.5°C 2 lake CO_2, 1 air (bottle #4) 3 zooplankton net hauls (153 µm mesh) 2 POM filters 1 *chl a* filter (1L) 1 POM - ^{14}C filter ^{18}O surface water sample	
	PC-1	59° 10.775' 155° 21.938'		409 cm	Not extruded		Core tilted. Cut into 3 sections. Cut off soupy top.
	PC-2	59° 10.776' 155° 21.935'		435 cm	Not extruded		Core straight. Cut into 3 sections: top 120cm, bottom and middle 150 cm. Cut off soupy top. Lost mud at top of middle section

Idavain Lake Camp: 58° 45.594' 155° 53.334'	Livingston			**Label Depth**	**Recovered length**	Seechi disk = 574 cm CO_2: 2 lake, 1 air Water temp = 20°C ^{18}O surface water sample 3 Zooplankton net hauls (153 μm mesh) 2 POM filters 1 *Chl a* filter (1 L) 1 POM - ^{14}C filter	
IDAVAIN A	Drive 1	58° 45.817' 155° 56.456'	8.7 m	8.8-9.8	99 cm		Katmai ash at top of drive
	Drive 2			9.6-10.6	96.5 cm		Gray band nr base
	Drive 3			10.4-11.4	95.5 cm		Sharp contact about 15cm bl top from gray to brown
	Drive 4			11.2-12.2	99 cm		Sandy tephra @67.5 cm and black tephra @ 97 cm bl top
	Drive 5			12-13	99 cm		Black tephra @ 20cm, light tephra @ 38 & 68 cm, and gray/black tephra? @ 80cm bl top.
	Drive 6			12.8-13.8	94 cm		Light tephra @ bottom
	Drive 7			13.6-14.34	74 cm		Light tephra @15 cm and dark tephra 26 cm bl top.
START CASING	Drive 8			13.2-14.2	101 cm		Recovered same tephras as D7
	Drive 9			14.2-15.2	101 cm		Dark tephra 44 cm bl top.
	Drive 10			15.2-16.2	99 cm		Dark tephra 60 cm bl top. Gray unit w/ tephra? 90 cm bl top.
	Drive 11			16.2-17.2	97 cm		
	Drive 12			17.3-18.3	98 cm		Note 10 cm off from previous drive. Upper part slightly banded olive brown. @36 cm mottled olive & gray seds, @50 cm grades into subtle banding.
	Drive 13			18.3-19.3	97.5 cm		Gray seds with gradual transition to mottled
	Drive 14			19.3-20.3	100 cm		Top 6.5 cm trash, cut off for total recovery of 93.5cm. Uniform to 36 cm, then mottled. Dark band @ 87 cm and sandy band @ 25 cm.
	Drive 15			20.20-21.2	93.5 cm		Top 3 cm questionable. Mottled to 43 cm followed by

	Drive 16			21.2-22.2	100 cm		Green gray seds to 12 cm, 36-66cm light gray. @ 66cm, gray tephra. 88-96cm, alternating layers of sand/tephra followed by gray silt.
	Drive 17			22.2-23.2	100cm		Top 4 cm questionable. Buff & pepper tephra @ 13-15cm followed by gray glacial seds to the bottom. Coarse grains in clay lower 10 cm. Banding (varves?) lower 10 cm.
	Drive 18			23.2-24.2	95 cm		Gray glacial silt. Black tephra @ 30 cm, blue band @ 56 cm, coarse laminations @ 67 cm that increase toward bottom.
	Drive 19			24.2-24.64	44 cm (drove 47 cm)		Gray glacial silt with laminations.
IDAVAIN B (overlap drives)	Drive 1			13.8-14.8	98 cm		Light tephra@ 12 cm, dark tephra @ 24 cm
	Drive 2			15-16	98 cm		No tephras or banding
	Drive 3			16-17	97 cm		Black tephra 7 cm, gray band @ 31 cm, pumice @ 53 cm.
	Drive 4			17-18	Not measured		Too windy to describe. Pulled casing.
Surface Cores	Surface #1	58° 45.833' 155° 56.444'	9.2m		93 cm	0-16 cm @ 0.5 cm intervals	
	Surface #2		9.1m		26 cm	0-13 cm @ 0.5 cm intervals	

HC = Hammer core
PC = Piston core
Livingston: Corer can recover maximum of 1 meter of sediment per drive from same hole.
Latitude/Longitude Data: Coordinates derived from recreational grade GPS (Garmin GPS 40 or Garmin GPS Map 76s with an external antenna that averaged >30 seconds). Data has not been differentially corrected. All positions are in degrees decimal minutes and NAD27 datum.

Table 2. 2005 ^{14}C AMS results.

CENTER FOR ACCELERATOR MASS SPECTROMETRY

Lawrence Livermore National Laboratory

^{14}C results

CAMS #	Sample Name	$d^{13}C$	fraction Modern	±	$D^{14}C$	±	^{14}C age	±
120926	Devil's cove 132 cm	-25	0.9680	0.0037	-32.0	3.7	260	35
120922	Jo-Jo 53 cm	-25	0.9540	0.0040	-46.0	4.0	380	35
115574	Jo-Jo Lake 135 cm	-25	0.9227	0.0038	-77.3	3.8	645	35
115575	Jo-Jo Lake 189 cm	-25	0.8720	0.0034	-128.0	3.4	1100	35
115576	Jo-Jo Lake 284 cm	-25	0.8245	0.0044	-175.5	4.4	1550	45
115527	Klosterman HC-2 146 cm	-25	0.7927	0.0036	-207.3	3.6	1865	40
115571	Kontrashibuna PC-1 283 cm	-25	0.7047	0.0055	-295.3	5.5	2810	70
120925	Kukaklek 388 cm	-25	0.3731	0.0014	-626.9	1.4	7920	35
120924	Nonvianuk PC-1 93 cm	-25	0.5319	0.0022	-468.1	2.2	5070	35
120923	Nonvianuk HC-1 119-120 cm	-25	0.6530	0.0042	-347.0	4.2	3420	60
115572	Nonvianuk PC-1 196 cm	-25	0.3557	0.0021	-644.3	2.1	8305	50
115573	Nonvianuk PC-1 358-359 cm	-25	0.2780	0.0050	-722.0	5.0	10280	150

1) $d^{13}C$ values are the assumed values according to Stuiver and Polach (Radiocarbon, v. 19, p.355, 1977) when given without decimal places. Values measured for the material itself are given with a single decimal place.

2) The quoted age is in radiocarbon years using the Libby half life of 5568 years and following the conventions of Stuiver and Polach (ibid.).

3) Radiocarbon concentration is given as fraction Modern, $D^{14}C$, and conventional radiocarbon age.

4) Sample preparation backgrounds have been subtracted, based on measurements of samples of ^{14}C-free wood. Backgrounds were scaled relative to sample size.

5)No background subtraction applied to the QL.

6) The following samples either yielded insufficient current or were below our nominal small sample cut-off:

Nonvianuk PC-1 263-264 cm
Nonvianuk PC-1 294-295 cm
Jo-Jo Lake 40 cm

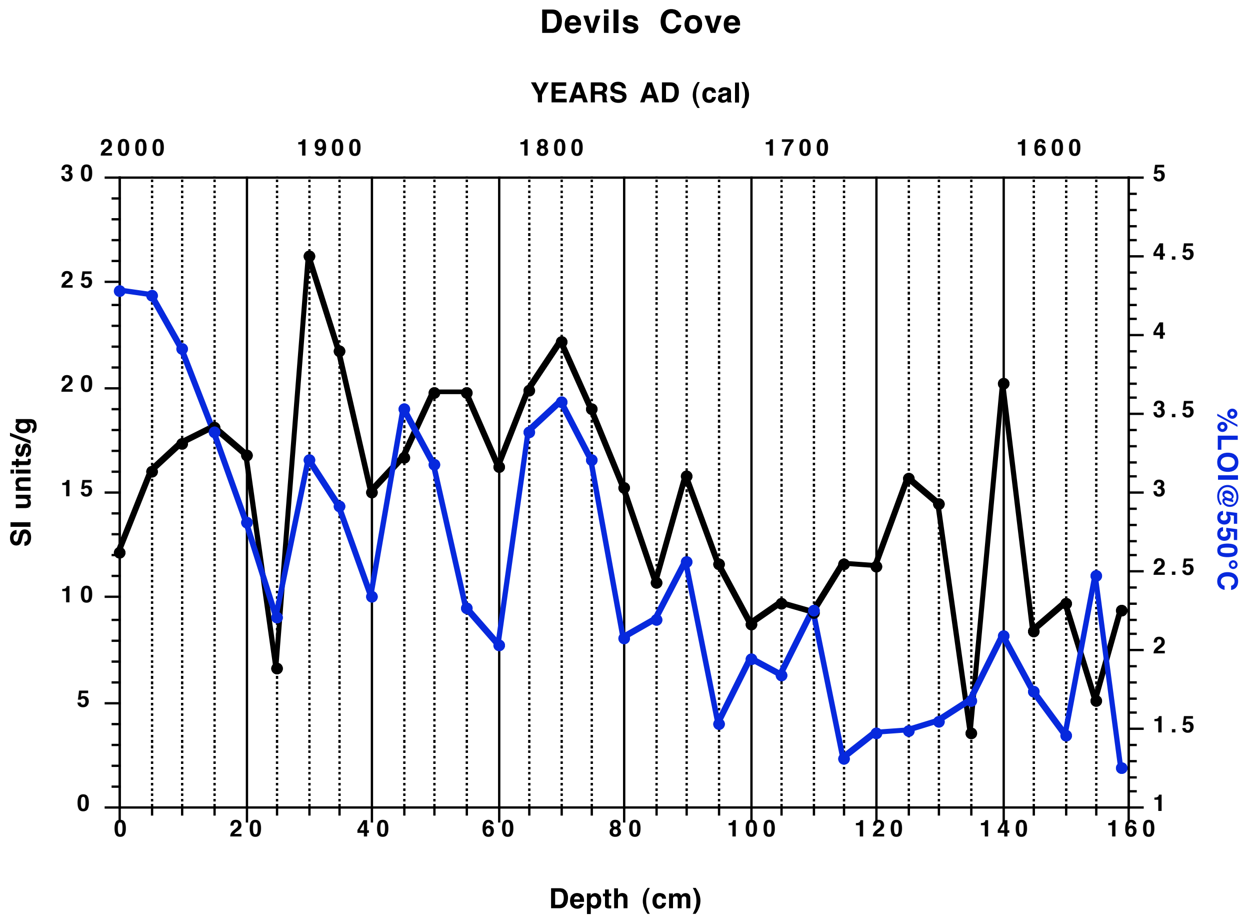

Figure 1. Organic matter (LOI) and magnetic susceptibility (SI units/g) profiles for Devil's Cove Lake.

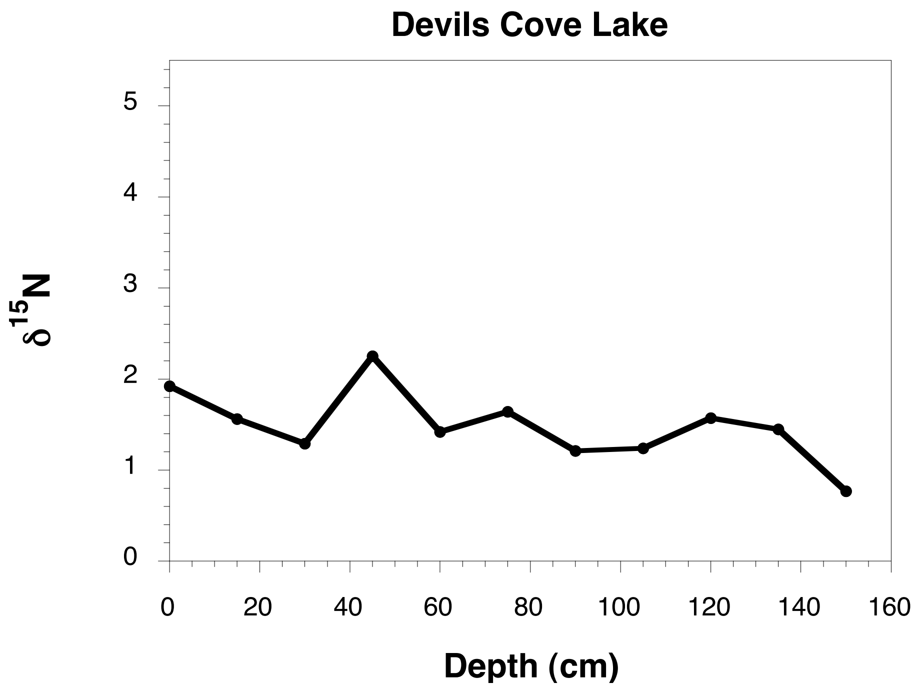

Figure 2. Preliminary $\delta^{15}N$ for Devil's Cove Lake.

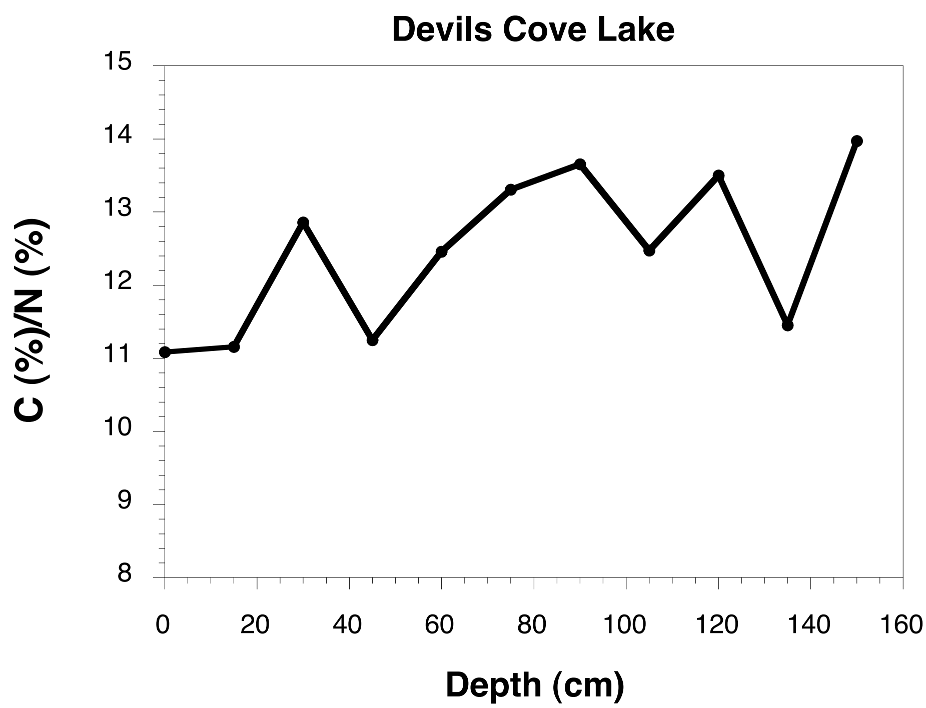

Figure 3. Preliminary C (%)/N (%) values for Devil's Cove Lake.

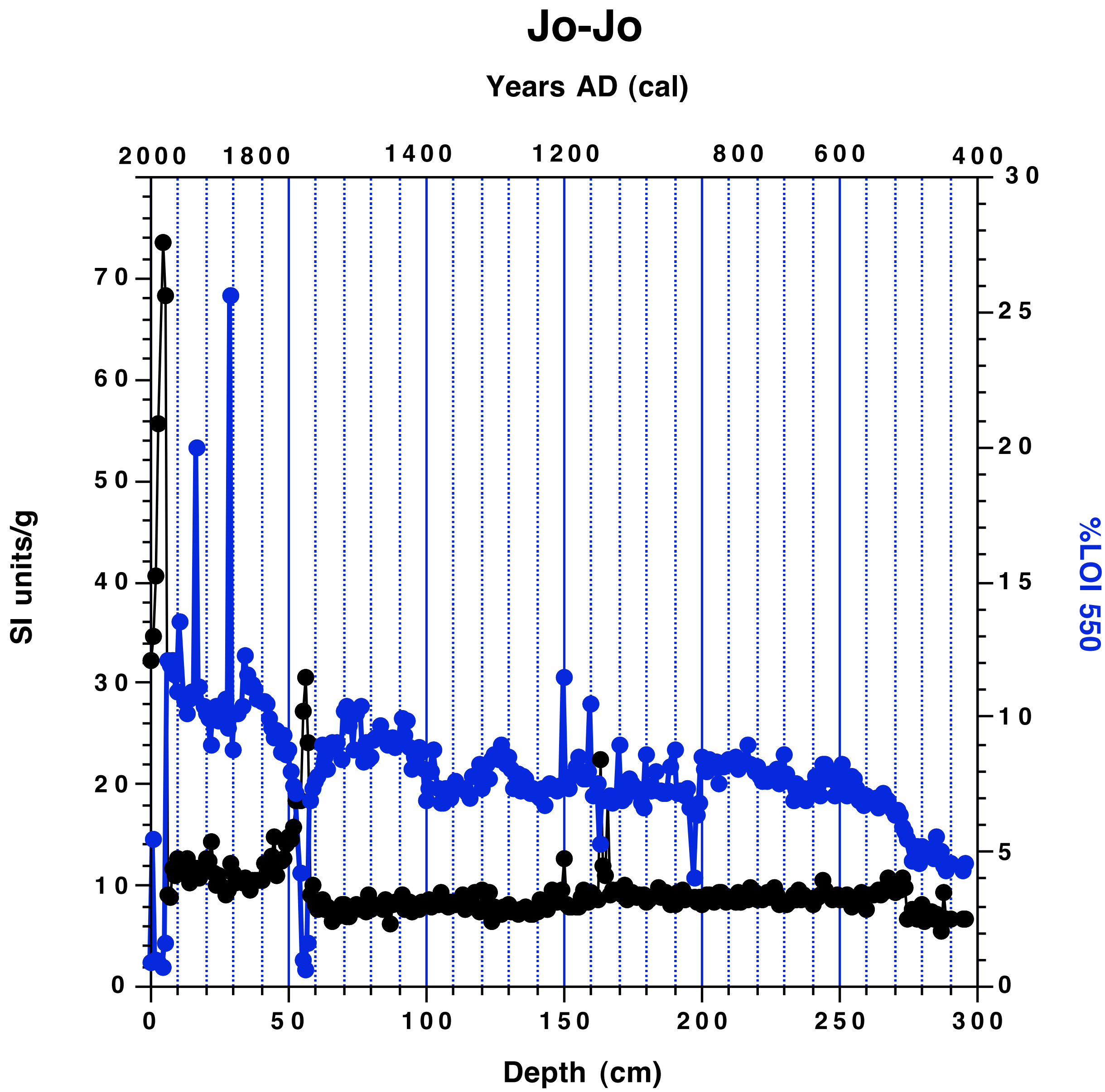

Figure 4. Organic matter (LOI) and magnetic susceptibility (SI units/g) profiles for Jo-Jo Lake. The SI peak in the top 10 cm of the core is the 1912 Katmai tephra.

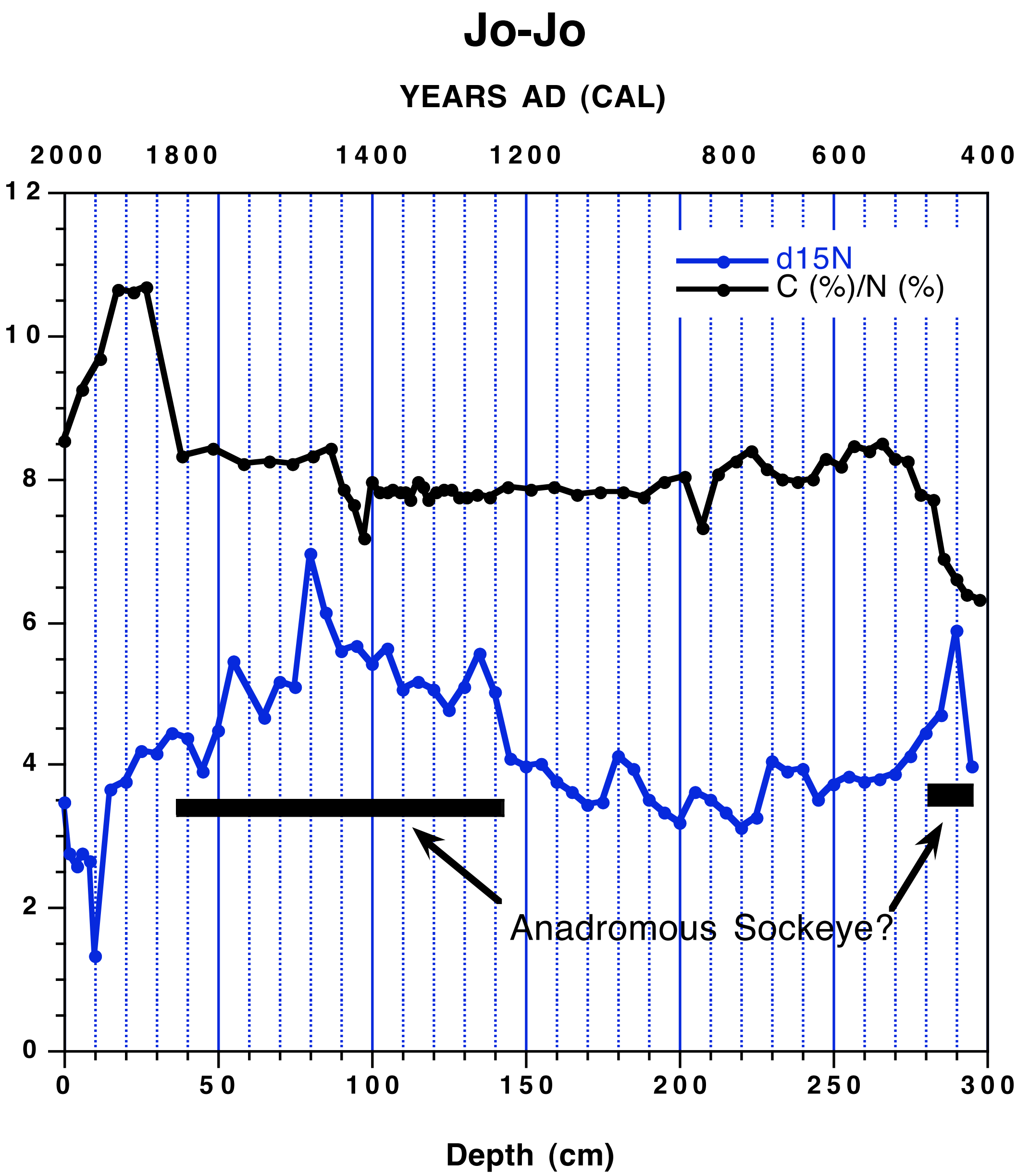

Figure 5. $\delta^{15}N$ and C (%)/N (%) profiles for Jo-Jo Lake over the past ~1600 years.

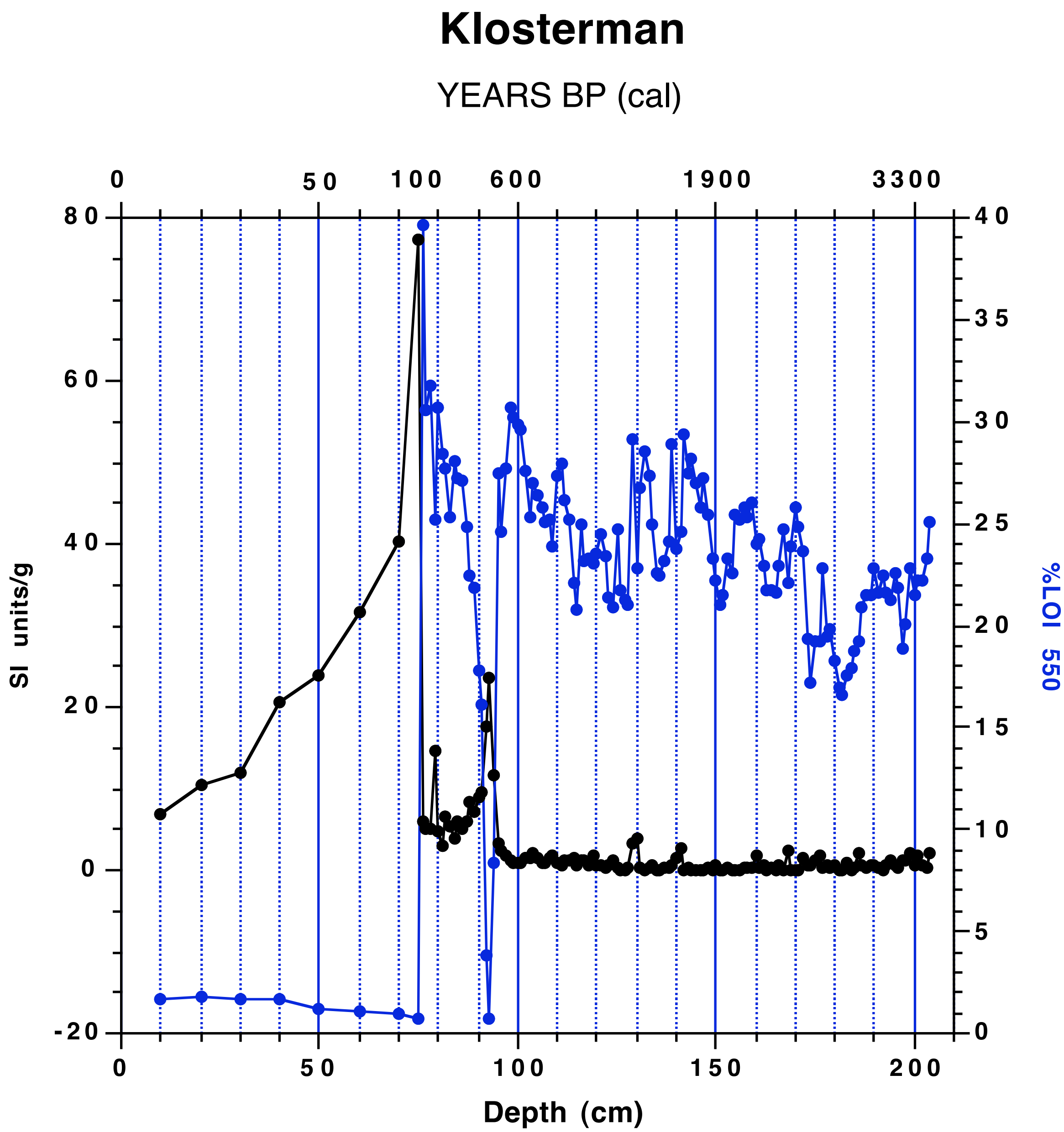

Figure 6. Organic matter (LOI) and magnetic susceptibility (SI units/g) profiles for Klosterman Lake. The top 80 cm of the core contains the 1912 Katmai tephra and was sampled at 10 cm intervals.

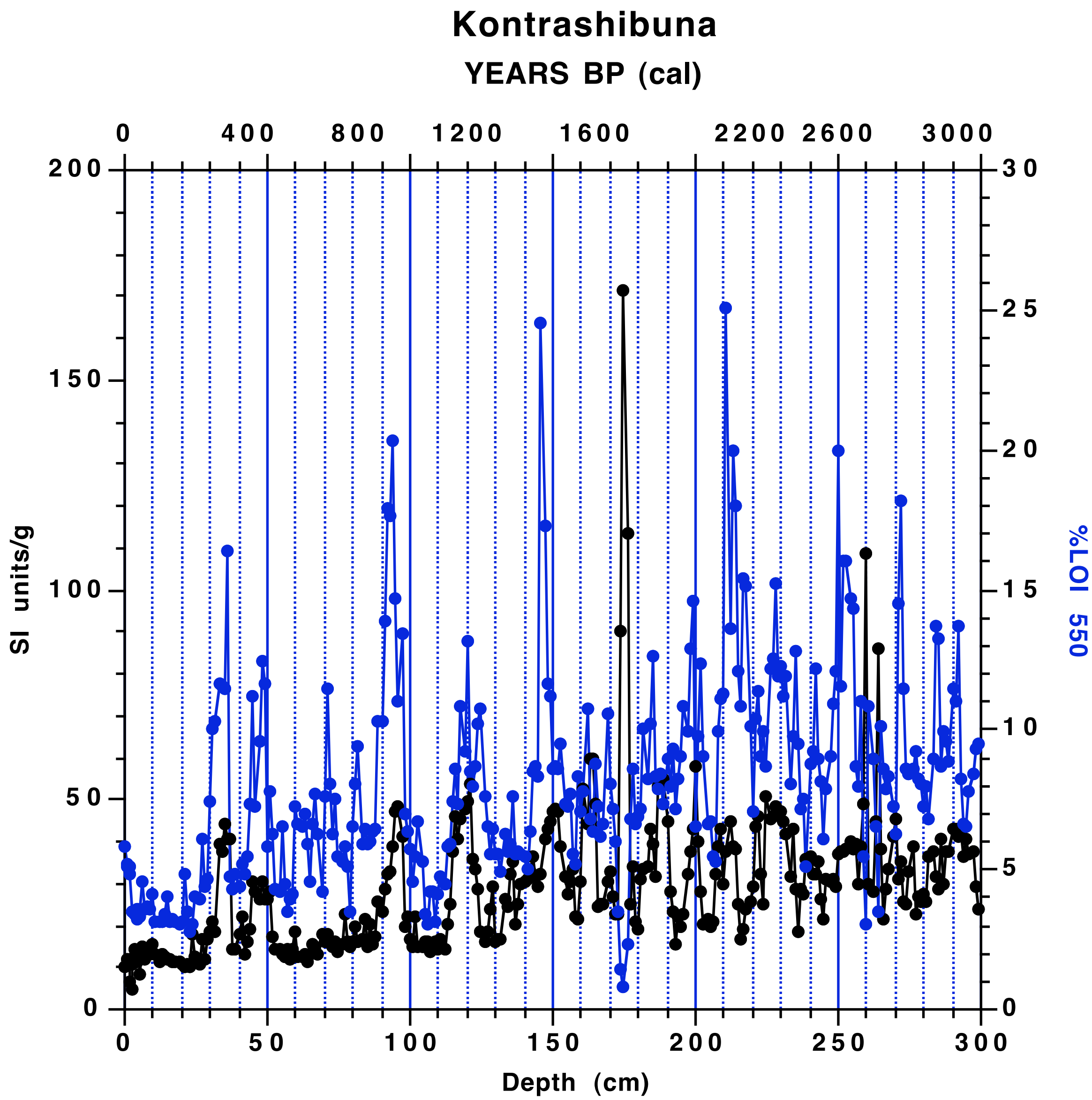

Figure 7. Organic matter (LOI) and magnetic susceptibility (SI units/g) profiles for Kontrashibuna Lake.

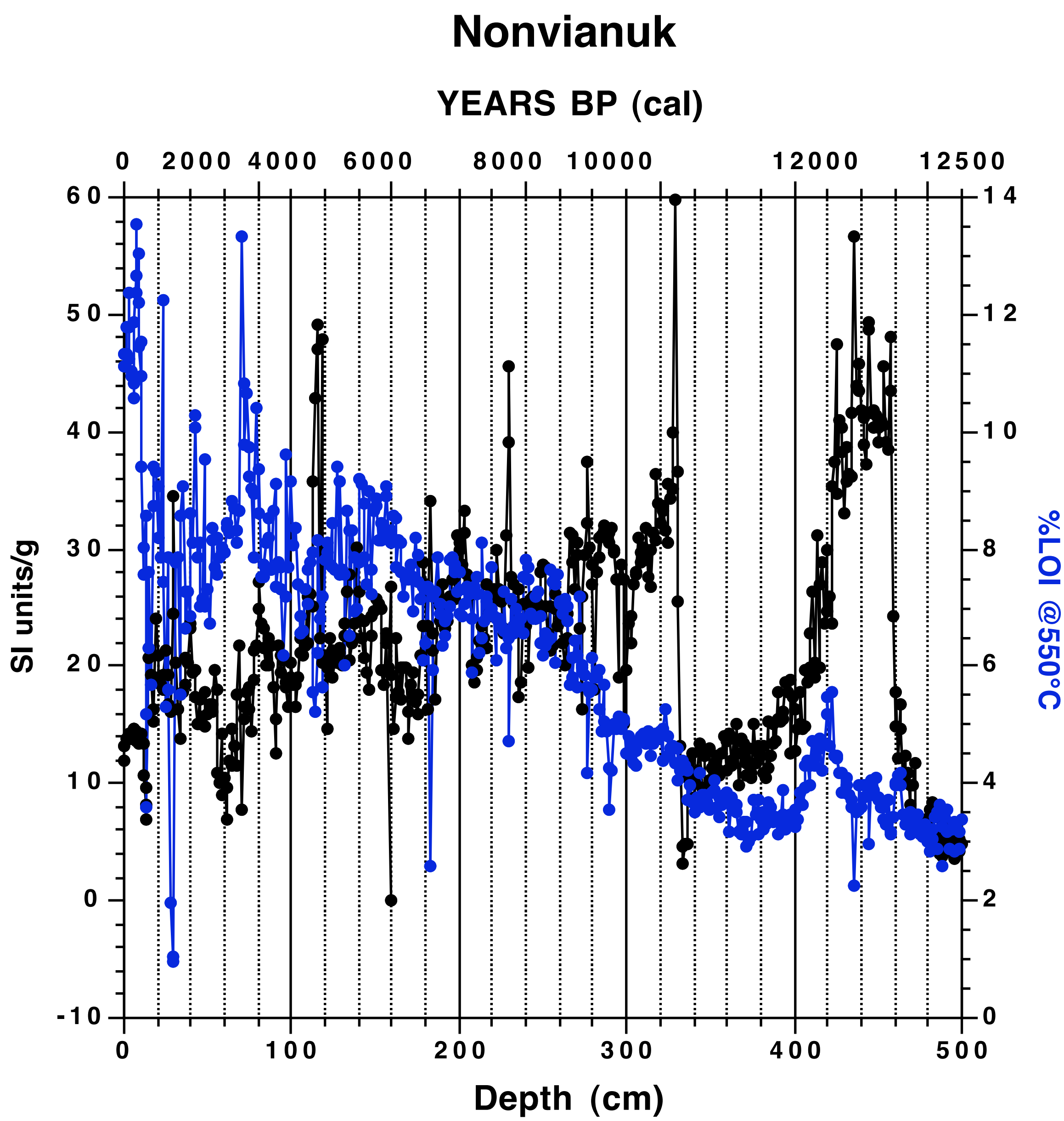

Figure 8. Organic matter (LOI) and magnetic susceptibility (SI units/g) profiles for Nonvianuk Lake.

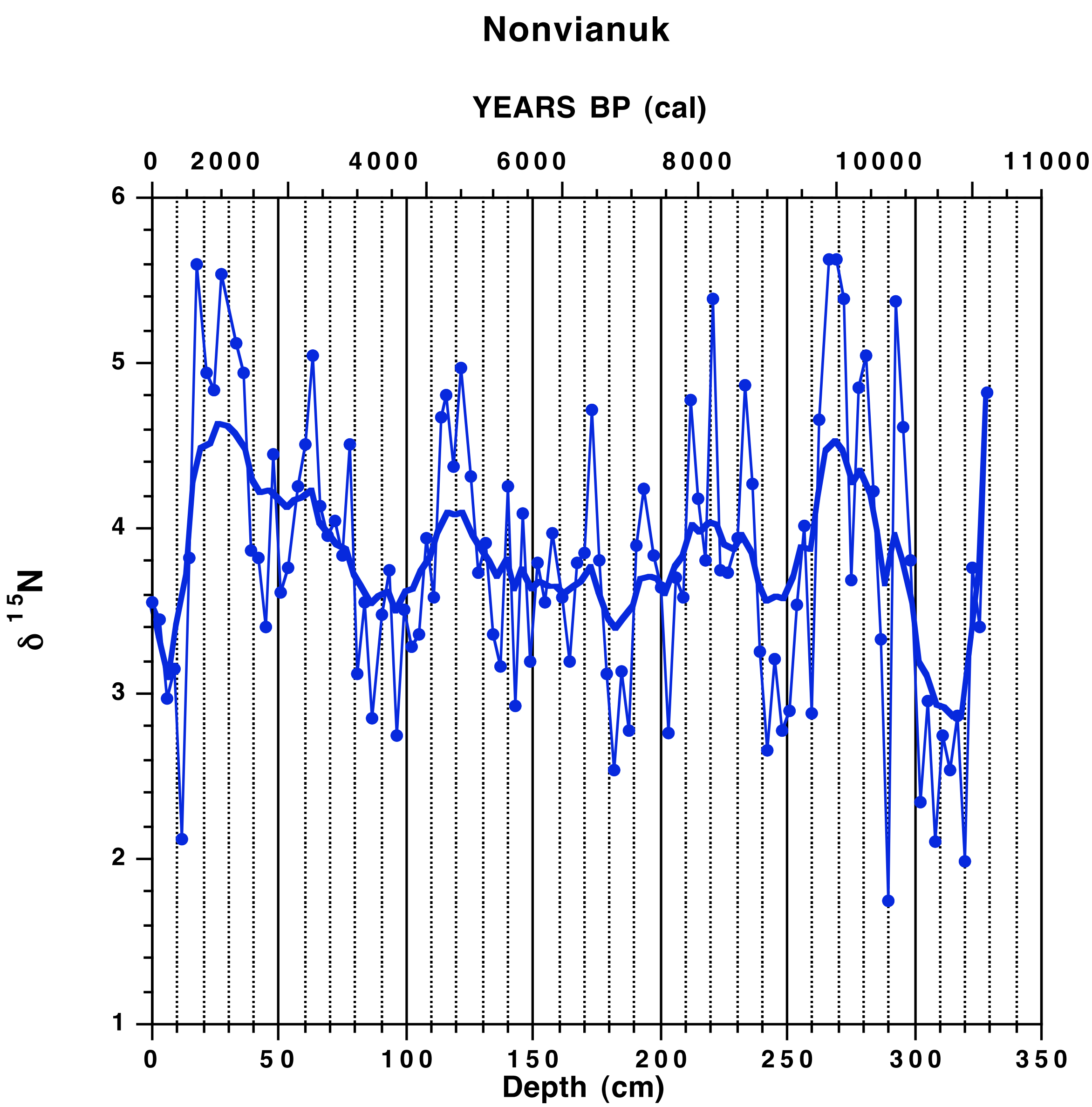

Figure 9. $\delta^{15}N$ profile for Nonvianuk Lake showing oscillations on a millennial scale

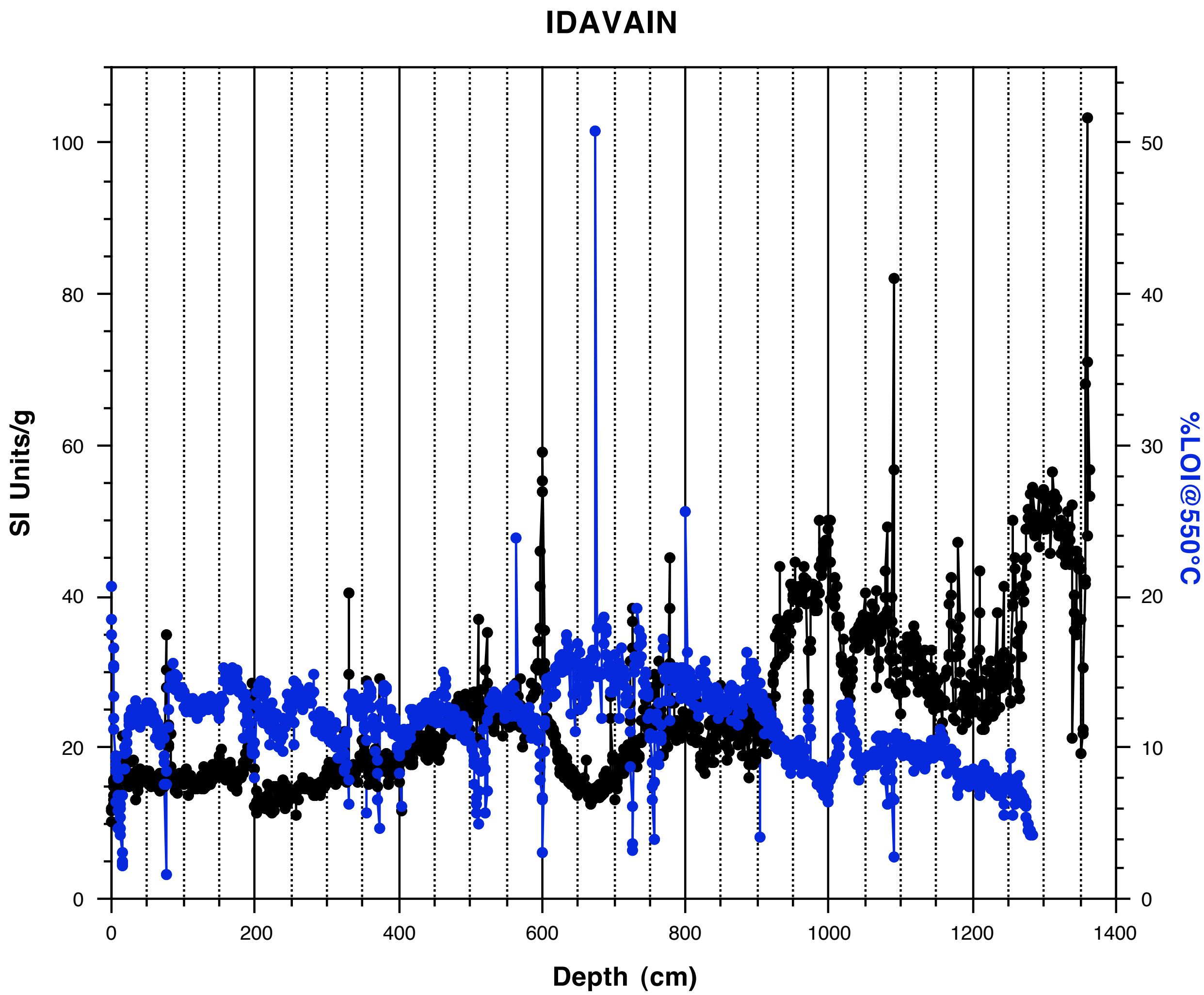

Figure 10. Organic matter (LOI) and magnetic susceptibility (SI units/g) profiles for Idavain Lake. Note: data in progress, total core length 1590 cm.

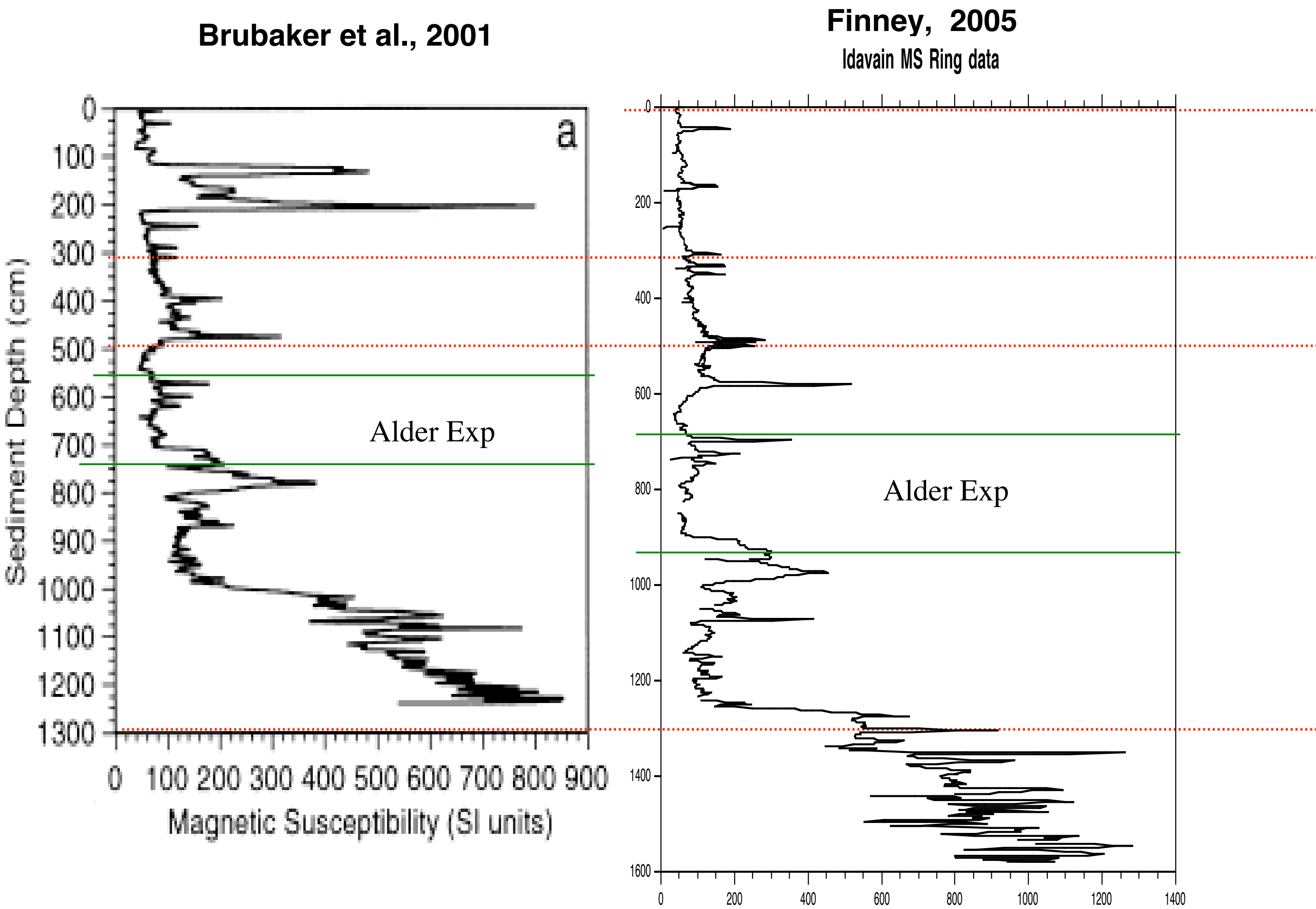

Figure 11. Comparison of magnetic susceptibility profiles for cores collected at Idavain Lake by the University of Washington in a previous study (Brubaker et al. 2001) and by this project in 2005. Note the similarity of the profiles.

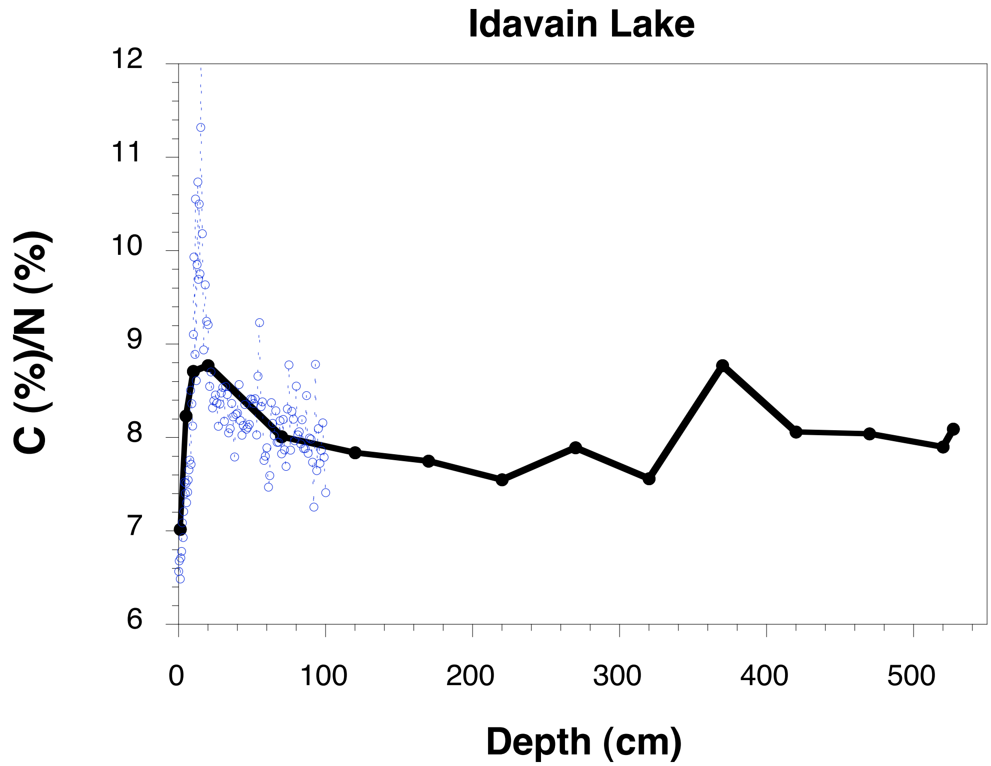

Figure 12. C (%)/N (%) values for Idavain Lake. The solid black lines represent preliminary test runs. The open circles represent samples processed at closer intervals.

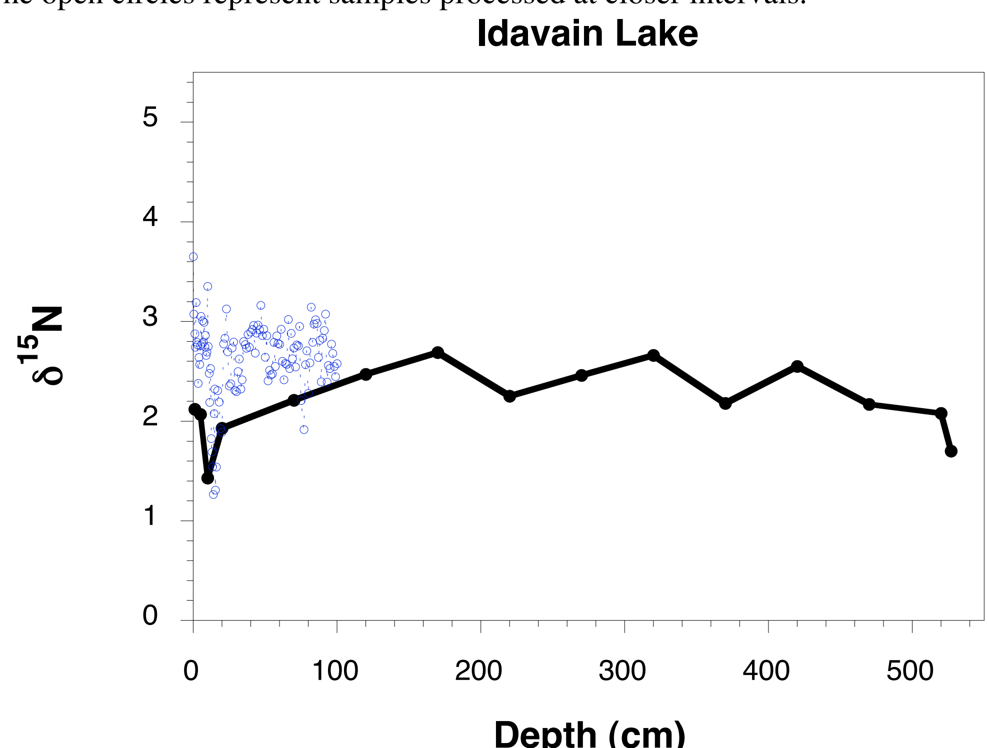

Figure 13. $\delta^{15}N$ values for Idavain Lake. The solid black lines represent preliminary test runs. The open circles represent samples processed at closer intervals.

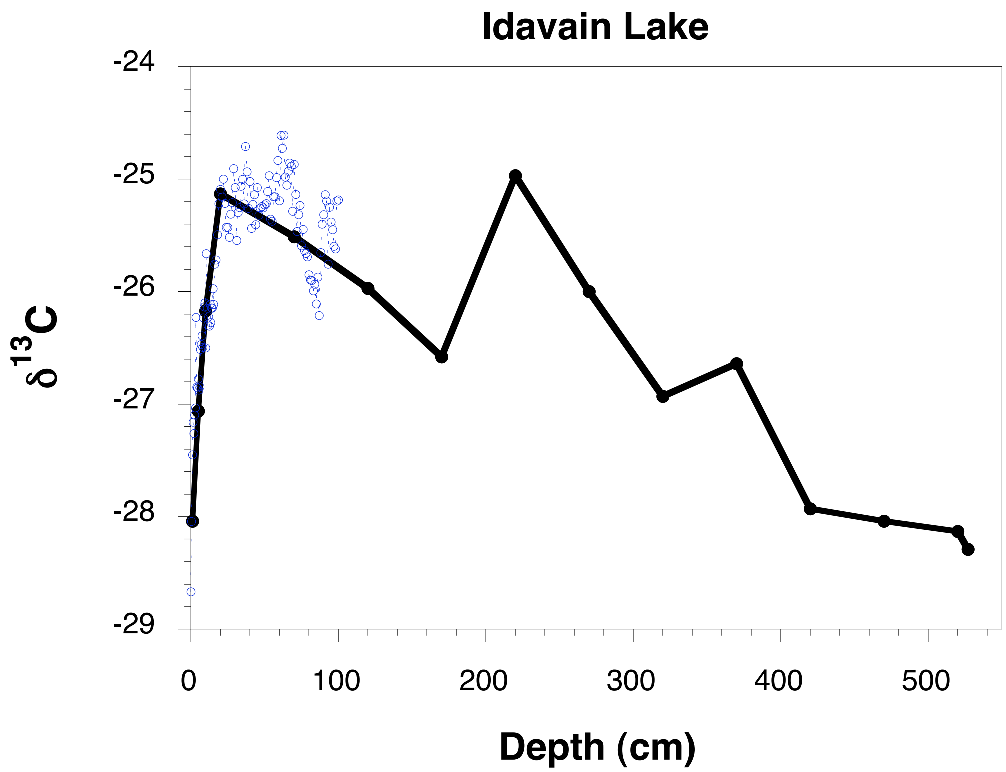

Figure 14. $\delta^{13}C$ values for Idavain Lake. The solid black lines represent preliminary test runs. The open circles represent samples processed at closer intervals.

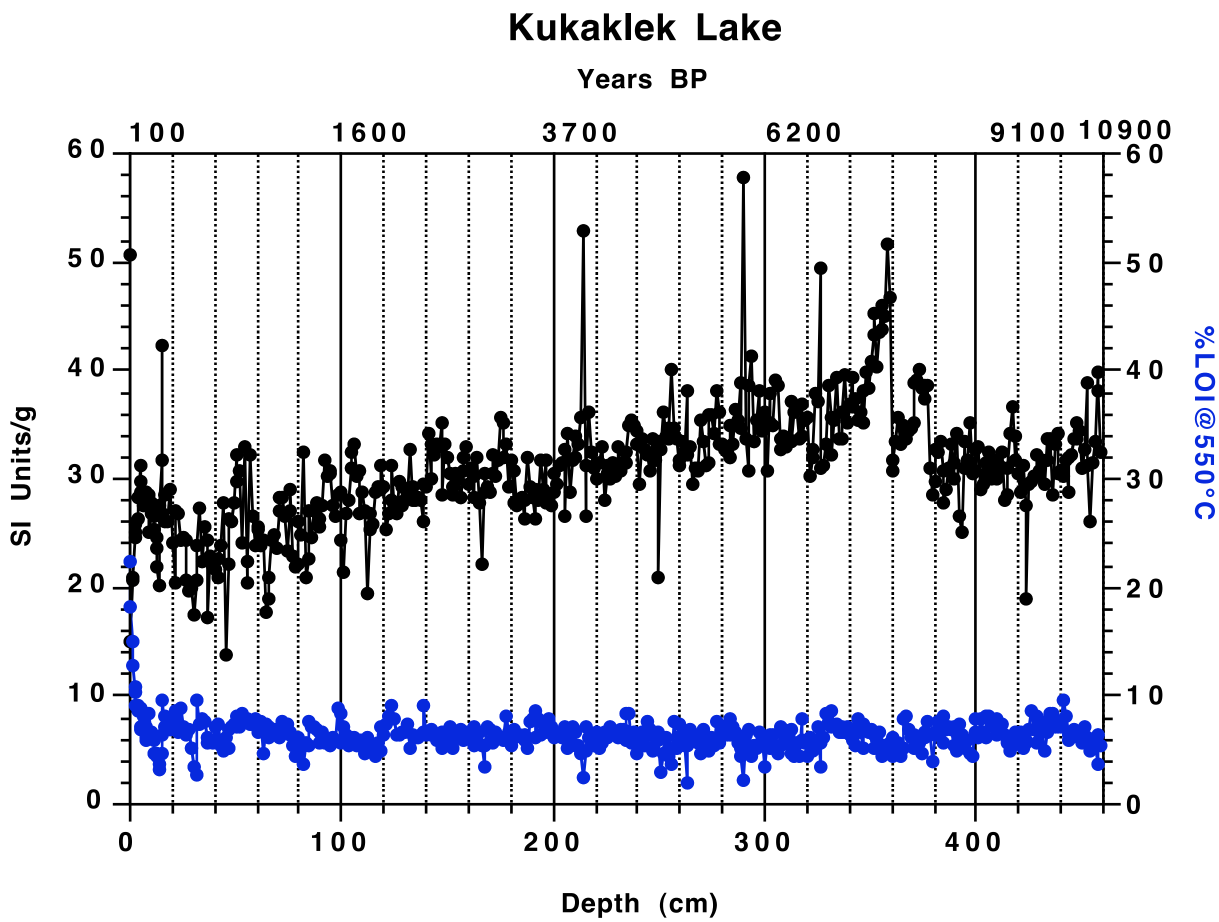

Figure 15. Organic matter (LOI) and magnetic susceptibility (SI units/g) profiles for Kukaklek Lake.

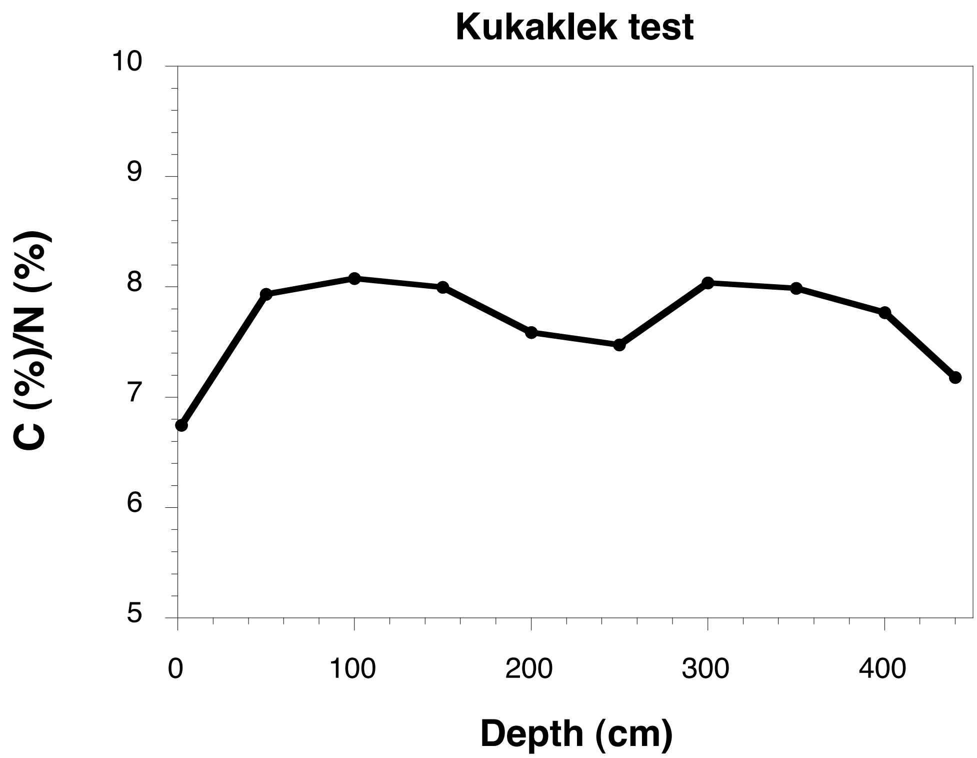

Figure 16. Preliminary C (%)/N (%) values for the top 4.5 m of Kukaklek Lake.

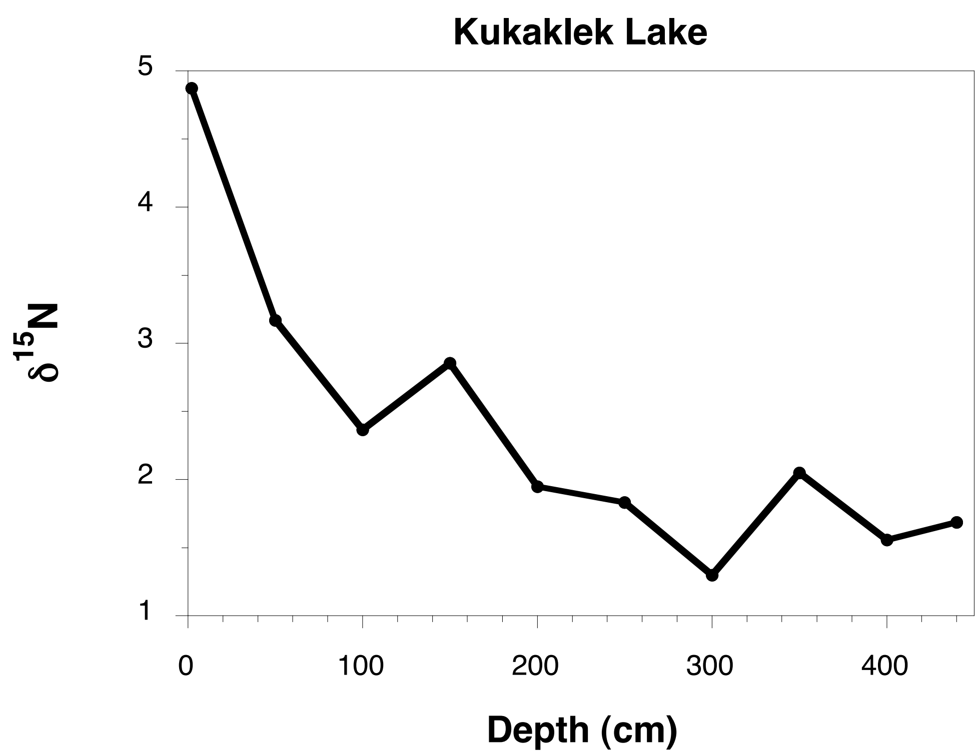

Figure 17. Preliminary $\delta^{15}N$ values for the top 4.5 m of Kukaklek Lake.

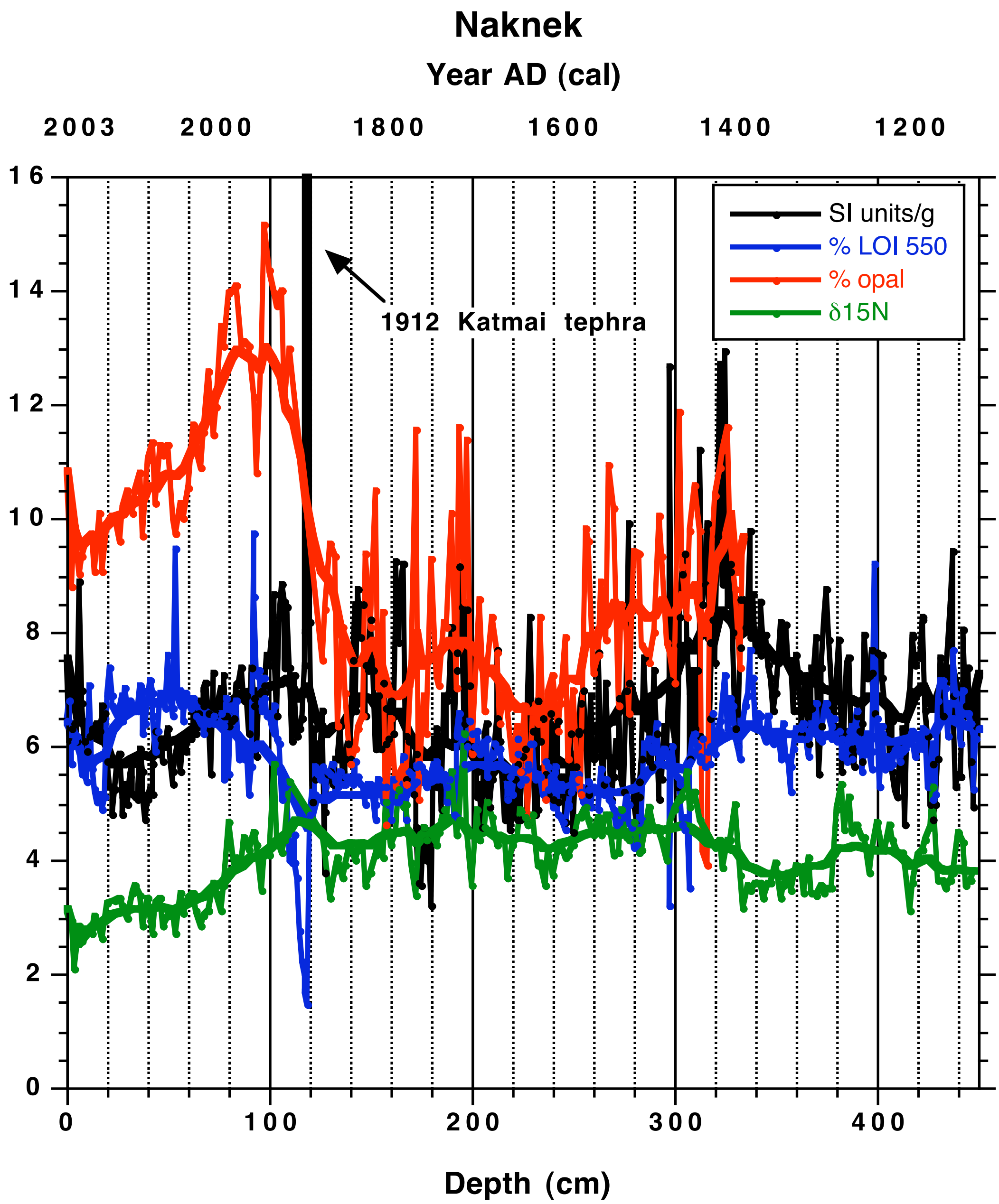

Figure 18. Downcore plots of $\delta^{15}N$, magnetic susceptibility (SI Units/g), organic matter (LOI @ 550 °C) and opal (biogenic silica). The preliminary age scale is depicted at the top of the graph. The opal analyses are in progress. All data have been smoothed (heavy line centered on each graph) to eliminate noise and aid in assessing longer-term trends.