**ANNUAL PROGRESS REPORT**

# 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 the first year of the project (2003) are presented in this annual report. Cores from Brooks and Naknek Lakes of the Katmai National Park, and Surprise and Meshik Lakes of the Aniakchak National Monument were recovered, and preliminary sedimentary analysis and dating has begun. The Brooks Lake cores span at least the past ~4,000 years, and contain sediments of moderate organic matter content, rich in diatoms. The Naknek Lake cores have rapidly accumulating glacially-derived sediments that appear to be annually laminated. The ~2.5 m-long core is probably less than 1,000 years old. The several cores recovered from Surprise Lake suggest that a consistent stratigraphy for the lake can be developed. The cores are rich in Fe, and contain lacustrine sandy muds deposited between 2 thick tephra units, the uppermost likely being the 1931 Aniakchak event. The several cores from Meshik Lake contain the entire history of the lake. The sediments consist of lacustrine organic-rich sediments with numerous tephra units overlying basal gravel or peat. A radiocarbon date from a basal peat unit suggests a shallow or non-existent lake prior to about 1700 years ago. Overall, the sediments recovered from these four 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.

**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 from the first year of the project 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. Initial results from these cores are described here.

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, Kenai Fjords 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 2003 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. 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 content is also estimated by the loss on ignition (LOI) technique.

**Results and Discussion**

During July 2003, the first campaign of fieldwork for this project was conducted. In Katmai National Park, Naknek and Brooks Lakes were cored, and in Aniakchak National Monument, Surprise and Meshik Lakes were cored. These lakes were selected to study research questions focused on sockeye salmon colonization timing and population variability (Table 1).

Table 1. Summary of lakes cored in 2003, including National Park Unit, level of analyses and main research questions.

Aniakchak National Park Unit
Surprise Lake (Level 2): Sockeye salmon colonization date
Meshik Lake (Level 2): Sockeye salmon colonization date

Katmai National Park Unit
Naknek Lake (Level 2): Sockeye salmon population variability
Brooks Lake (Level 1): Sockeye salmon population variability

A variety of coring devices was used depending on objectives and water depth, and multiple cores were obtained from each lake. The coring device, location, water depth and core length are summarized in Table 2. The cores were shipped to Finney's laboratory in Fairbanks and are stored in a cold room at ~4°C.

Laboratory analyses of the cores have begun. At least one core from each lake has been "opened" (split lengthwise and stored in plastic D-tubes in a cold room). Opened cores have been described, and magnetic susceptibility was run on each core using a ring sensor. Sampling and additional laboratory analyses are underway for cores from these lakes. The sections below describe preliminary laboratory results for each lake.

BROOKS LAKE

Two Hammer cores and one Percussion core were recovered from Brooks Lake. The hammer cores were extruded to ~6 cm (the depth of the Katmai 1912 tephra) in the field to preserve the recent sediments. Initial laboratory work has focused on core HC-1, the longer of the hammer cores. The 187 cm long core consists of relatively homogeneous brown, diatom-rich mud, except for a few intervals of tephra. The core has been analyzed for physical properties (wet and dry bulk density, water content), magnetic susceptibility and LOI. Samples have been prepared for stable isotope analyses, but the results are not available. The magnetic susceptibility profile shows 3 prominent peaks (Fig. 1). The peaks at 6 and 36 cm are tephras, with the uppermost peak originating from the "Katmai 1912" eruption. The susceptibility peak at ~90 cm appears to correspond with a gravity flow deposit. Minor, thin tephras may occur at 43 and 162 cm. The LOI data (Fig. 2) averages about 10%, except for the zones of high magnetic susceptibility. A terrestrial macrofossil sample from 179 cm was submitted for AMS radiocarbon analysis (Table 3) and yielded a calibrated date of about 3730 yr BP (Table 4). The age-depth diagram suggests that this date is reasonable, based on the post 1912 sedimentation rates (Figure 3). The age depth relationships indicates that the tephra at 36 cm occurred at about 1300 AD, the gravity flow

deposit occurred about 2000 yr BP, and that the core spans about the last 4,000 years. The characteristics of the sediments indicate high potential for paleolimnological reconstructions.

NAKNEK LAKE

Two Hammer cores and one Percussion core were recovered from Naknek Lake. The tops of the hammer cores were extruded in the field to preserve the recent sediments. Initial laboratory work has focused on core HC-1, the longer of the hammer cores. The 244 cm long core consists of laminated grey mud, excepting for a few intervals of tephra. The core has been analyzed for physical properties (wet and dry bulk density, water content), magnetic susceptibility and LOI starting below the Katmai tephra at 25 cm. Samples have been prepared for stable isotope analyses, but the results are not available. The magnetic susceptibility profile shows 1 prominent peak below Katmai (Fig. 4), a tephra at 220 cm. The LOI data (Fig. 5) averages about 6%, except for the zones of tephra. A terrestrial macrofossil sample was submitted for AMS radiocarbon analysis, but the sample was of insufficient size. The age depth relationships based on the post 1912 sedimentation rates suggest that the tephra at 220 cm occurred at about 1300 AD, and that the core spans about the last 800 years. The physical characteristics and age estimates for the tephras at 36 cm in Brooks HC-1 and at 220 cm in Naknek HC-1 indicate they represent the same event. Samples have been submitted to Judy Fierstein (U.S. Geological Survey) for chemical analyses to determine interlake and regional correlations.

The Naknek sediments contain continuous faint laminations throughout the core. The average thickness of the lamination couplets (light and dark grey laminations) suggests they are annual (varves) based on sedimentation rates estimated from the Katmai tephra. The sediments are dominated by glacially-derived lithogenic material, but diatoms and other micro and macro fossils are present. The characteristics of the sediments are such that annual reconstructions can be achieved. In particular, records of glacial discharge are directly recorded by summer varve thickness. Other limnological parameters can be reconstructed as well, as sufficient diatoms and organic materials are present in the sediments. Due to fast sedimentation rates, obtaining long records from the sites cored in 2003 will be challenging.

SURPRISE LAKE

Seven cores were recovered from Surprise Lake. These cores represent 5 different sites, as Hammer cores HC-2 and HC-6, recovered undisturbed core-top sediments to match longer Hammer cores HC1 and HC-5, respectively. The tops of undisturbed hammer cores were extruded in the field to preserve the recent sediments. Initial laboratory work has focused on cores HC-1, HC-4 and HC-5. The cores have a generally consistent stratigraphy. A surface unit that consists of orange-red sandy muds overlies a coarse tephra that occurs between 10-50 cm, depending on core site (Fig. 6). This uppermost magnetic susceptibility peak likely corresponds to the 1931 Aniakchak event (T. Neal, personal communication, 2003). A second tephra unit with similar characteristics in all the cores is found between 70 - 105 cm (Fig. 6). Below the

orange surface unit, the non-tephra sediments consist of orange-brown to brown-black sandy, mud. Diatoms are present, as well as occasional organic macrofossils. The cores are currently being sampled and/or analyzed for physical properties (wet and dry bulk density, water content), magnetic susceptibility and LOI. Results are not yet complete.

The relatively consistent stratigraphy recorded in the widespread cores is encouraging that they contain a representative recent history of the lake. Based on the core correlations (e.g. Fig. 6), core HC-5 contains the oldest sediments.

MESHIK LAKE

A Livingstone corer was used at Meshik Lake. Multiple drives were used to take 4 cores, though cores C and D are from the same site (Table 2). Surface sediments were taken with a clear tube and piston, and these upper portions were extruded in the field. The cores all appear to have penetrated the entire lacustrine sequence at each site, and range from 180 – 420 cm in length. The sediments consist of lacustrine diatom and organic rich muds overlying basal gravels and/or peats, with several prominent tephras. The magnetic susceptibility profiles for cores A and B (Fig. 7) reveal the presence of several high SI units, rich in tephra. A date on the basal terrestrial peat from core A (254 cm below the water surface or 162 cm below the core top) is 1690 yr BP cal. This indicates a much shallower or non-existent lake at or prior to this time.

**Plans for Coming Year**

Tasks to be completed for the coming year include opening and describing all cores, and continuing the analyses of water content, wet and dry bulk density, magnetic susceptibility and LOI. As each lake has multiple cores, we will assess the suite of cores to determine a representative stratigraphy, and carefully determine which cores are best suited for detailed and more expensive geochemical, isotopic and microfossil analyses (i.e. C%, C/N, opal, $\delta^{15}N$, diatom species). We will assess the time-frame of the cores by more radiocarbon dating. Basal samples are needed for Surprise and Naknek Lakes, and once the overall time-frame of each core is determined, detailed dating will continue. The challenge for some lakes and intervals will be finding suitable dating materials. Tephrachronologic (ash stratigraphy) methods are also being used for dating. This work will continue with help from our colleagues at the U.S.G.S. and UAA. Initial stable isotope results should be available shortly, and this will help determine which sites are good targets for detailed studies.

We will conduct our second major field campaign in 2004. Detailed planning, with Park Service logistical concerns in mind, will be finalized well before the initial fieldwork in May/June, in consultation with Park Service personnel. Some of the control lakes are yet to be determined, and these sites will be identified in consultation with UAA and Park Service colleagues. Following the fieldwork, initial core analyses will be initiated.

As 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 $\delta^{15}N$. Paleoproductivity will be assessed 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.

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**Table 2. 2003 Katmai/Aniakchak Core Information**

| Lake | Core Type/Name | Location (lat °N, long °W) | Water Depth | Core Length |
|---|---|---|---|---|
| Brooks Lake | HC-1 | 58° 29.285’ 155° 58.503’ | 76 m | 187 cm |
| | HC-2 | 58° 29.333’ 155° 58.489’ | 76 m | 98 cm |
| | PC-1 | | | 230 cm |
| Naknek Lake | HC-1 | 58° 36.819’ 155° 58.676’ | 61 m | 244 cm |
| | HC-2 | | | 210 cm |
| | PC-1 | | | ~400 cm |
| Surprise Lake | Livingston Drive1 | 56° 55.271’ 158° 06.01’ | 13.1 m | 73 cm |
| | HC-1 | 56° 55.446’ 158° 06.688’ | 16.5 m | 240 cm |
| | HC-2 (surface) | 56° 55.573’ 158° 06.609’ | 16.5 m | 79 cm |
| | HC-3 | 56° 55.507’ 158° 06.471’ | 17.7 m | 120 cm |
| | HC-4 | 56° 55.392’ 158° 06.319’ | 16.5 m | 164 cm |
| | HC-5 | 56° 55.498’ 158° 06.496’ | 17 m | 240 cm |
| | HC-6 (surface) | 56° 55.462’ 158° 06.551’ | 17 m | 120 cm |
| Meshik Lake | Surface #2 | 56° 47.49’ 157° 55.631’ | 1.1 m | 57 cm |
| | Livingston Core A Drive 1 | 56° 47.645’ 157° 55.67’ | 0.92 m | 96 cm (100-196) |
| | Drive 2 | | | 100 cm (170-270) |
| | Drive 3 | | | 10 cm (170-180) |
| | Surface #3 | | | 46 cm |

| | | | | |
|---|---|---|---|---|
| Meshik Lake (cont.) | Livingston Core B Drive 1 | 56° 47.472’ 157° 55.65’ | 1.01m | 80 cm (110-190) |
| | Drive 2 | | | 94 cm (180-274) |
| | Drive 3 | | | 88 cm (274-362) |
| | Drive 4 | | | 80 cm (348-421) |
| | Surface #4 | | | 57 cm |
| | Livingston Core C Drive 1 | 56° 47.645’ 157° 55.473’ | 1.02m | 95 cm (110-205) |
| | Drive 2 | | | 94 cm (190-284) |
| | Drive 3 | | | 33 cm (284-317) |
| | Livingston Core D Drive 1 | Same as Core C | | 99 cm (150-250) |
| | Drive 2 | | | 100 cm (250-350) |
| | Drive 3 | | | 40 cm (295-335) |

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.

**Additional samples for each lake included:**
Lake water $\delta^{18}O$ and $\delta D/H$ (deuterium to hydrogen ratio)
Zooplankton for stable isotope analysis ($\delta^{13}C$ and $\delta^{15}N$)
$CO_2$ concentration (lake and air)
Filtered water for C/N and stable isotope analysis ($\delta^{13}C$ and $\delta^{15}N$)

Table 3. AMS Radiocarbon results for samples from Brooks and Meshik Lakes.

**CENTER FOR ACCELERATOR MASS SPECTROMETRY**

Lawrence Livermore National Laboratory

$^{14}C$ results

Submitter: Finney
DATE: 1/22/2004

| CAMS# | Sample Name | fraction Modern | ± | $D^{14}C$ | ± | $^{14}C$ age | ± | Calibrated age range Year BP |
|---|---|---|---|---|---|---|---|---|
| 103818 | Meshik A 254-255 | 0.8023 | 0.0056 | -197.7 | 5.6 | 1770 | 60 | 1570 - 1810 |
| 103822 | Brooks HC-1 177-181 | 0.6502 | 0.0078 | -349.8 | 7.8 | 3460 | 100 | 3590 - 3860 |

1) $\delta^{13}C$ values are the assumed values (-25) according to Stuiver and Polach (Radiocarbon 19: 355, 1977)

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 coal. Backgrounds were scaled relative to sample size.

5) Calibrated ages are at the 1 sigma level. See Table 4 for details.

Table 4. Radiocarbon calibration results using program CALIB REV4.4.2 (Stuiver, M., and Reimer, P.J., 1993, *Radiocarbon* **35**: 215-230).

```
Sample ID: Brooks HC-1 177
Radiocarbon Age BP   3460 +/- 100
Calibration data set: intcal98.14c                (Stuiver et al., 1998)
   % area enclosed       cal AD age ranges            relative area under
                                                   probability distribution
   68.3 (1 sigma)     cal BC 1912- 1902                    0.024
                             1893- 1679                    0.888
                             1670- 1658                    0.039
                             1652- 1636                    0.050

Brooks HC-1 177
Age BP   3460 +/- 100
Calibration data set: intcal98.14c                (Stuiver et al., 1998)
   % area enclosed       cal BP age ranges            relative area under
                                                   probability distribution
   68.3 (1 sigma)     cal BP 3585 - 3601                    0.050
                             3607 - 3619                    0.039
                             3628 - 3842                    0.888
                             3851 - 3861                    0.024

Sample ID:  Meshik A 254
Radiocarbon Age BP   1770 +/-   60
Calibration data set: intcal98.14c                (Stuiver et al., 1998)
   % area enclosed       cal AD age ranges            relative area under
                                                   probability distribution
   68.3 (1 sigma)     cal AD 138- 151                       0.062
                             176- 192                       0.075
                             212- 343                       0.840
                             372- 377                       0.023

Meshik A 254
Age BP   1770 +/-   60
Calibration data set: intcal98.14c                (Stuiver et al., 1998)
   % area enclosed       cal BP age ranges            relative area under
                                                   probability distribution
   68.3 (1 sigma)     cal BP 1573 - 1578                    0.023
                             1607 - 1738                    0.840
                             1758 - 1774                    0.075
                             1799 - 1812                    0.062


NOTE:  Cal ages and ranges are rounded to the nearest year which
        may be too precise in many instances.  Users are advised to
        round results to the nearest 10 yr for samples with standard
        deviation in the radiocarbon age greater than 50 yr.
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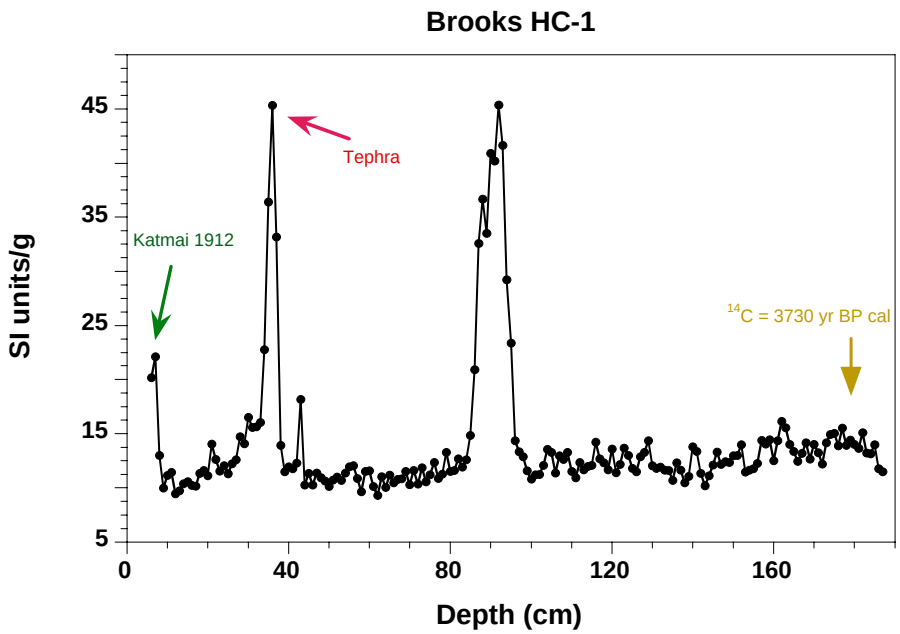


Figure 1. Magnetic susceptibility profile for Brooks Lake Core HC-1 showing tephras and radiocarbon dates.

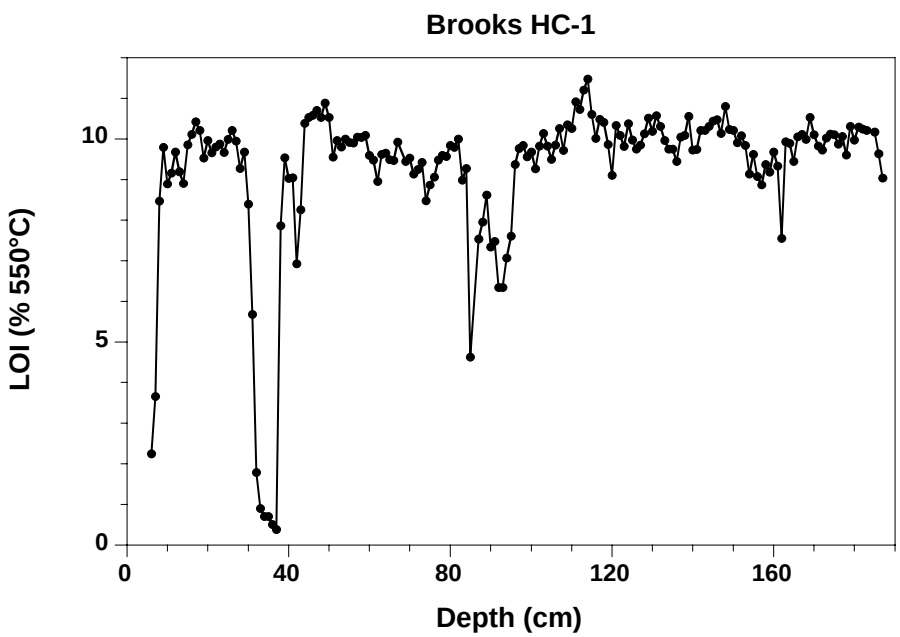


Figure 2. Loss on ignition (LOI = organic matter) profile for Brooks Lake core HC-1.

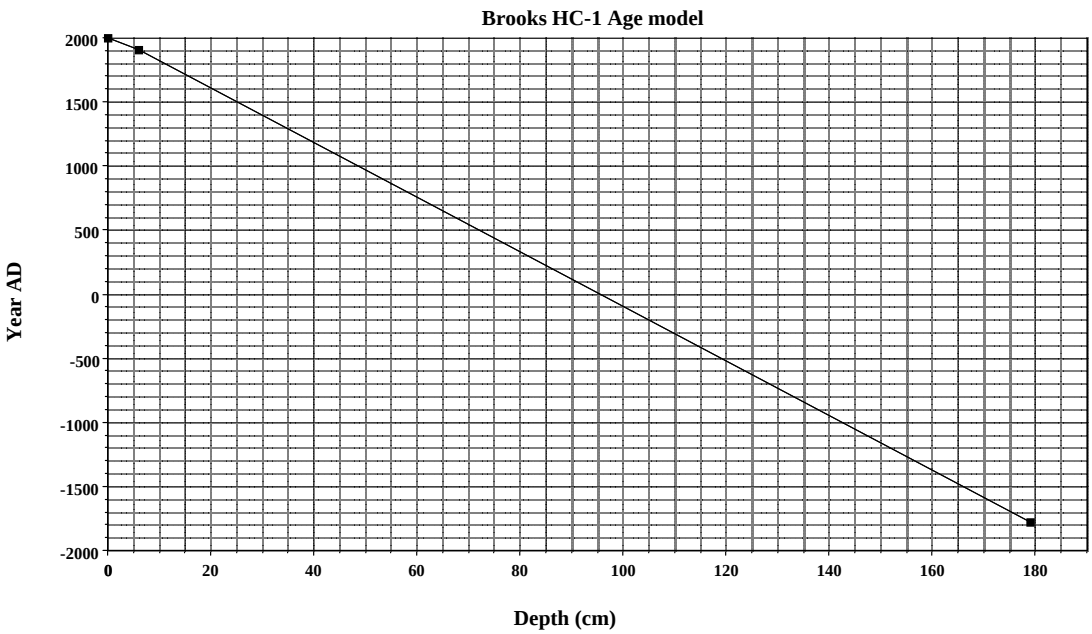


Figure 3. Age-depth diagram for Brooks Lake core HC-1. The points are based on coring date (0 cm), Katmai 1912 tephra (6 cm) and a near-basal radiocarbon date (179 cm).

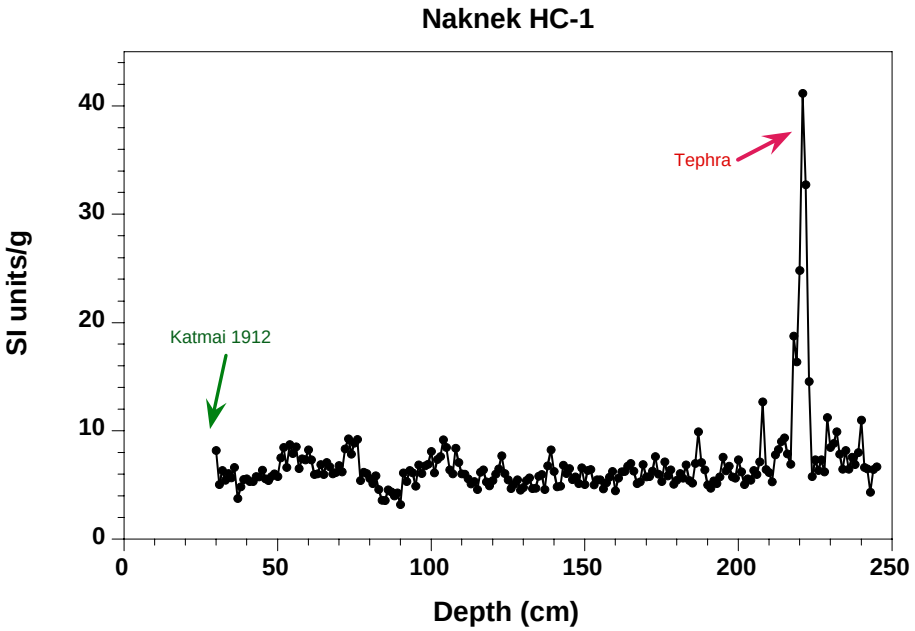


Figure 4. Magnetic susceptibility profile for Naknek Lake Core HC-1 showing tephras.

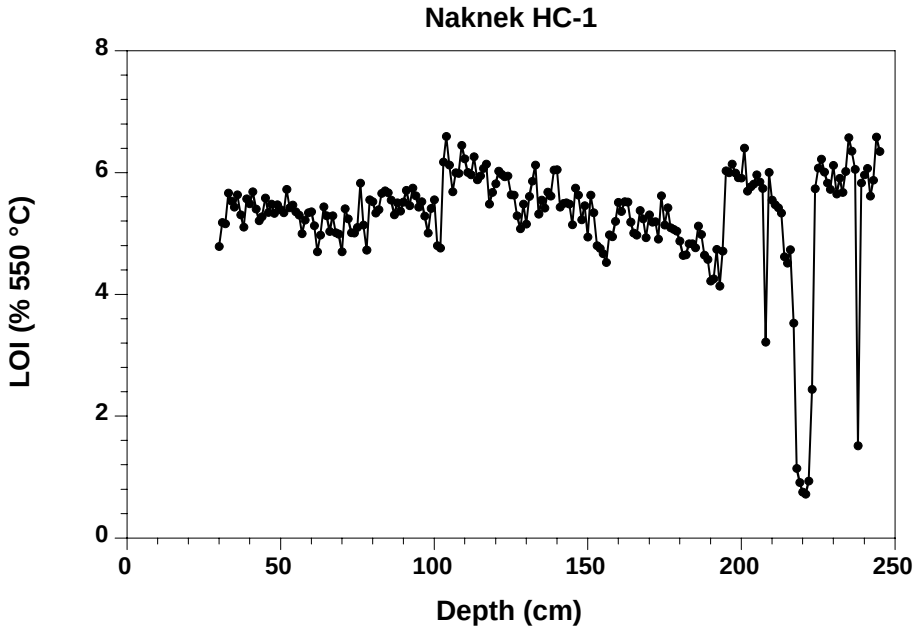


Figure 5. Loss on ignition (LOI = organic matter) profile for Naknek Lake core HC-1.

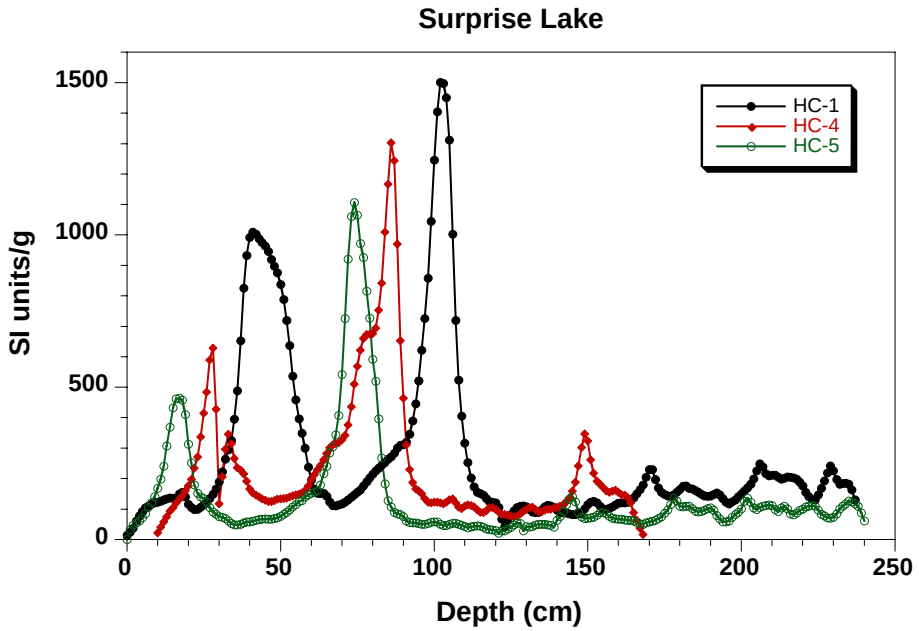


Figure 6. Downcore magnetic susceptibility profiles (ring sensor) for cores HC-1, HC-4 and HC-5 from Surprise Lake. The uppermost susceptibility peak may correspond to the 1931 Aniakchak event (T. Neal, personal communication, 2003).

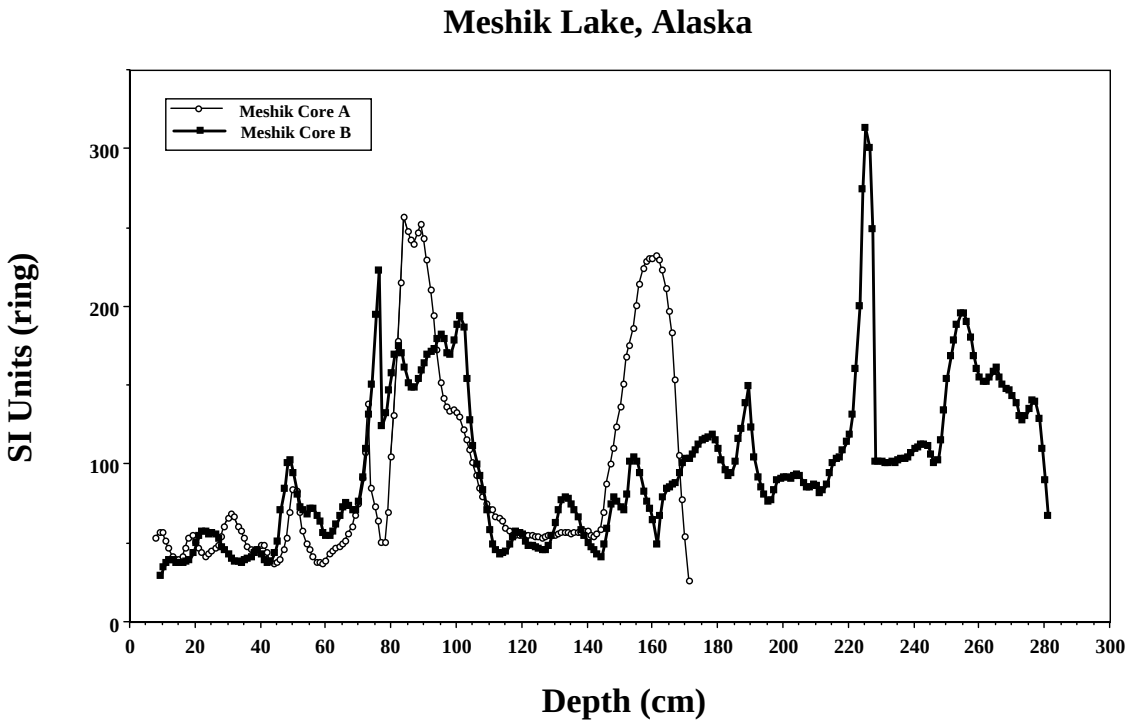


Figure 7. Downcore magnetic susceptibility profiles (ring sensor) for Livingstone cores A and B from Meshik Lake. Both cores appear to have penetrated the entire lacustrine sequence.