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Post-glacial Vegetation and Climate History of the Matanuska Valley, Alaska: A Multiple Proxy...

May 2005

POST-GLACIAL VEGETATION AND CLIMATE HISTORY OF THE MATANUSKA VALLEY, ALASKA: A MULTIPLE PROXY APPROACH

By

Karina N. Walker

A Thesis

Presented to the Graduate and Research Committee

of Lehigh University

in Candidacy for the Degree of

Master of Science

In

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Lehigh University

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This thesis is accepted and approved in partial fulfillment of the requirements for the Master of Science.

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Date

Approved by:

Dr. Zicheng Yu
(Thesis Advisor)

Dr. Peter Zietler
(Chairperson of Department)

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Post-glacial Vegetation and Climate History of the Matanuska Valley, Alaska: A Multiple Proxy Approach

ABSTRACT

Climate change in high latitude regions has shown sensitive responses to broad-scale forcings at the present and in the past. In this thesis I present multi-proxy data from Hundred Mile Lake (HML) in the Matanuska Valley of south-central Alaska to investigate climate change and vegetation of the last 15,000 years. The chronology of the sediment cores was controlled by five AMS dates. Sediment lithology changes from clay at ~15-13.5 ka (1 ka = 1,000 cal BP), through marl at 13.5-8 ka, to gyttja at 8-0 ka. The transition from clay to marl suggests increased productivity of the lake in a stabilizing watershed, induced probably by initial warming after ice retreat. The change from marl to gyttja suggests a climate shift to cool and wet conditions in the mid-Holocene, consistent with other regional records.

The $\delta^{18}O$ record obtained from *Pisidium* mollusk shells from HML shows several large shifts between 13.5 and 8 ka. A negative excursion of ~2‰ in $\delta^{18}O$ occurred at 12.4-11.4 ka, probably a regional expression of the Younger Dryas (YD) cooling event. A 4.5‰ negative shift occurred around 10.5 ka, from -10.5‰ at 13.5 – 11 ka to -15‰ at 10 – 8 ka. This surprisingly large and dramatic shift in $\delta^{18}O$ values in the early Holocene suggests a major change in atmospheric circulation patterns, which has not been documented elsewhere in the region. Possible causes of this isotopic shift include a change in precipitation seasonality, a shift in regional wind directions, and a change in precipitation source regions modulated by retreating ice sheets/glaciers. Pollen results

from marl sediments at HML indicate vegetation change from a herb tundra, through shrub birch-dominated tundra, to an alder forest. Regional vegetation around HML closely follows other regional pollen diagrams for south-central Alaska, but does not appear to follow climate shifts closely.

The data from this study suggest that the climatic shift in the region during the early Holocene was more abrupt and in greater magnitude than the YD event. This implies a differential regional response in south-central Alaska to large-scale climate forcing, possibly caused by the stronger regional feedback processes in high latitudes.

INTRODUCTION

Climate change has become an important environmental concern for human society at a global scale. Arctic and high latitude climates are especially sensitive to global climate forcing as documented by instrumental records (ACIA, 2004). However, instrumental data are too short to show the full range of natural climate variability. Studies of past climate change can not only reveal climate variability but also provide insight into understanding the mechanisms of climate change.

Several broad-scale climate changes have been documented in Alaska during the postglacial period. During the last glacial-interglacial transition climate reversals to cold conditions punctuated deglacial warming trends, which have been documented in Glacier Bay (Engstrom et al., 1990), southwestern Alaska (Hu et al., 2002), and Kodiak Island (Peteet and Mann, 1994). Kaufman et al. (2003) reviewed paleoclimate evidence for the western Arctic and found that timing and magnitude of early Holocene warming period, referred to as the Holocene Thermal Maximum (HTM), vary in different places. Also, the spatial pattern of warming during the HTM is similar to the warming patterns currently observed in the Arctic during the last few decades (Kaufman et al., 2003). Several pollen diagrams have been published in south-central Alaska (Ager and Brubaker, 1985; Ager, 1999, 2001). In addition, there have been extensive studies on modern processes of the Matanuska Glacier (Larson et al., 2003). However, the late-glacial climate oscillations and even Holocene climate changes have been poorly documented, especially in the Matanuska Valley.

The goal of this study is to document and understand postglacial environmental history of the Matanuska Valley, Alaska. Specific objectives of the project include:

1) To derive new multiple proxy sedimentary records of climate and vegetation change from lake sediments from the upper Matanuska Valley;
2) To provide a better constraint on the deglacial history of the region;
3) To evaluate the presence of climate oscillations during the last deglaciation and the Holocene; and
4) To investigate vegetation response to late-glacial and Holocene climate changes, using multiple biological and geochemical data.

STUDY REGION AND SITES

The Matanuska Valley is located in south-central Alaska (Fig. 1) between the Talkeetna Mountains in the north and Chugach Mountains in the south (Table 1). The region is within the physiographic region of the Pacific mountain system, with a transitional maritime-continental climate, and is located within the interior boreal forest (Fig. 2). Two study sites (Hundred Mile Lake and Bench Lake) are located approximately 5-8 km from the valley head, the Matanuska Glacier (Fig. 3). The local climate of the study region is influenced by the orographic effect of the Chugach mountains and its proximity to the glacier. The temperatures range from -15 to -6 °C in January, and from 7 to 19 °C in July. Mean annual precipitation is 419 mm, including 127 cm as snow. Vegetation in the area is interior boreal forest dominated by white spruce (*Picea glauca*) on the uplands and black spruce (*P. mariana*) in the lowlands. The forest also includes birch (*Betula*), alder (*Alnus*), and various grasses (Poaceae).

Geology of the region consists largely of surficial Quaternary deposits. The bedrock surrounding the majority of the HML and BL watersheds is comprised of the Cretaceous Matanuska Formation, which includes diverse fossiliferous marine shales and calcareous concretions, volcanic-lithic siltsone, sandstone and conglomerates (Winkler, 1992). Deglaciation of the study area is dated at ~13,000 radiocarbon years BP (Fig. 4).

Hundred Mile Lake (HML) is approximately 150 x 80 m in size and is located approximately at 61.808° north and 147.842° west at an elevation of 506.3 m (Fig. 5). HML sits between two discontinuous moraines (Fig. 4). The maximum water depth of HML is unknown, but it is at least 2.4 m deep as measured during lake coring in January of 2004. Calcite precipitation is active under shallow water around the lake at HML (S. Johnson, 2004, personal communication).

PREVIOUS STUDIES OF THE REGION

There are several paleoecological studies in south-central Alaska, mostly from fossil pollen analysis of lake sediments and peat sections (Fig. 6). The only published paleo-record in the Matanuska Valley was from Kepler Lake, near the mouth of the Matanuska River. At Kepler Lake, Forester et al. (1989) derived a pollen and ostracode assemblage record from 240 cm long calcareous sediments deposited during the last 2500 years and found a cold and dry climate period, possibly corresponding to the Little Ice Age. Outside the Matanuska Valley in south-central Alaska, Point Woronzorf (PW) peat section near Anchorage and Seventy Mile Lake northeast of the Chugach Mountains in the Copper River Basin are two other sites closest to the study region. During the last 12,000 radiocarbon years BP at PW, vegetation changed from birch-sedge herb tundra, through birch shrub tundra and mixed poplar-willow-alder vegetation zone, to birch-alder- spruce zone (Ager and Brubaker, 1985). At Seventy Mile Lake, vegetation changed from birch-sedge, through birch-willow-poplar, to spruce-alder dominated forest (Ager and Brubaker, 1983). The longest pollen record from south-central Alaska was from Hidden Lake on the Kenai Peninsula, where the 14,500 year radiocarbon record shows vegetation succession from herb tundra, through birch-alder shrub tundra, to spruce-dominated forest (Ager, 1983).

METHODS

Field Coring

Two sediment cores were recovered from Hundred Mile Lake and one core from Bench Lake (see Appendix) in the Matanuska Valley in January 2004 with a Livingstone-Wright piston corer (Wright et al., 1967). The complete core I is 265 cm long under 2.3 m of water, and core II, 16.4 m apart, only covers the lowest 2 m of sediments under 2.4 m of water. One meter long core segments were extruded in the field and wrapped in plastic wrap and aluminum foil in split PVC pipes for transportation back to the laboratory. Sediment characteristics were noted in the field and then described in detail in the laboratory at Lehigh University. The cores have been stored in a cold room at 4°C.

Loss-on-ignition (LOI) Analysis

LOI samples were taken at 1 cm intervals for two HML cores. Weight loss after 1 hr combustion at 550 °C was used to estimate organic matter content, and weight loss after 1 hr at 1000 °C for calcium carbonate content. Silicates are the rest of the dry sediments.

Macrofossil Analysis and AMS Radiocarbon Dating

Subsamples of 2 cm sections were taken at 10 intervals from HML cores and sieved for terrestrial plant macrofossils, but only one sample produced adequate material for dating. One macrofossil from core II at 462-464 cm and one bulk organic-rich sediment at 373 cm from core I were submitted for AMS ^{14}C dating at the University of Arizona. Four *Pisidium* shell samples were picked, cleaned and sent to the Institut fur Teilechenphsik, Eidgenossische Technishe Hochschule Zurich, Switzerland for AMS ^{14}C dating (Table 2). The ^{14}C dates were corrected for old carbon effect, if needed, and calibrated using the calibration program CALIB v.4.4.2 using INTCAL 98 data set (Stuiver et al. 1998) (Table 2).

Stable-isotope Analysis

Stable isotope (O, C) analysis was performed on three types of carbonates: (1) *Pisidium* mollusk shells (aragonite), (2) ostracode shells (low Mg-calcite), and (3) *Chara* encrustations (calcite) (see appendix 5). Sieved and freeze-dried marl samples were examined under a stereo microscope, and mollusk/ostracode shells or calcite crystals (encrustations) were picked and cleaned. Most analysis were from *Pisidium* mollusk shells (Table 3), which were abundant and provided adequate materials at most levels.

The analytical procedure and methodology are similar to that used for deep-sea sediment (McCrea, 1950). Each carbonate sample was reacted with 100% phosphoric acid (H_3PO_4) at a constant temperature of 25°C overnight to produce CO_2 [$2H_3PO_4 + 3CaCO_3 \rightarrow (Ca_3PO_4)_2 + 3CO_2 + 3H_2O$]. The released CO_2 was analyzed for its $^{18}O/^{16}O$ and $^{13}C/^{12}C$ ratios with a Finnigan MAT 252 mass spectrometer in the stable isotope lab at Lehigh University. Results were presented as conventional delta notation (δ), defined as $[(R_{sample} - R_{standard})/R_{standard}] \times 1000$ (where R is the absolute ratio of $^{18}O/^{16}O$ or $^{13}C/^{12}C$, and the Vienna-PDB (Pee Dee belemnite) is the standard). The analytical precision is ± 0.1 ‰ for both $\delta^{18}O$ and $\delta^{13}C$.

Pollen Analysis

Pollen analysis was carried out at 18 levels from the marl section of HML core II. Pollen samples were prepared using modified standard preparation procedure as described in Yu (2003), including treatments of HCl, KOH, HF, and acetolysis. Pollen was identified under a compound microscope at 400x magnification aided with the use of published pollen keys and reference slides. Pollen concentration was calculated with an added known number of *Lycopodium* spores (Maher, 1981). Pollen diagram was generated using Tilia and TGView programs. CONISS was carried out using pollen taxa having >2% of the total pollen sum.

RESULTS

Lithology

Lithology of the two cores from HML is based on visual sediment inspection and LOI analysis results. Lithology of the 265 cm long core I consists of a basal section of 12 cm mineral material (gravels, clays and silts) from 495 to 483 cm below lake surface (Fig. 7). Above that is 93 cm marl sediment (from 483 to 390 cm), which gradually changes to gyttja between 390 and 383 cm (Fig. 8). The section of core from 383 to 377 cm is the transitional gyttja, with the presence of mollusk shells, until total disappearance of mollusk shells (Fig. 8). Gyttja then completely dominates from 377 to 230 cm, with several lighter bands located at 366, 330, and 310-305 cm.

Lithology of the 200-cm-long HML core II shows the same sequence of mineral materials, marl, and gyttja as core I. A mineral material layer (gravels, clays, and silts) comprises the lower 25 cm (550 to 525 cm) of HML core II (Fig. 7). Above that is 120 cm of marl sediments that change into gyttja at 405 cm. Visibly distinct bands throughout HML core I are also present in HML core II (Fig. 7).

LOI analysis has been completed for both cores (Figs. 9, 10). Both cores show similar stratigraphy of sediment composition. The basal clay contains > 90% silicates. Marl contains 20-80% carbonate, and 10-30% organic matter. Gyttja contains 30-40% organic matter and <10% carbonate. LOI curves and distinct banding for both HML cores were used to generate a combined LOI curve for HML (Fig. 11) on age scale (see below).

^{14}C dates and Chronology

Six ^{14}C AMS dates from HML were obtained, corrected for shell dates and calibrated to calibrated ages (Table 2). An age model was developed based on linear interpolation of calibrated ages of five accepted dates and the age of the sediment surface (2004 AD = -54 cal BP) (Fig. 12). Extrapolation of the age-depth relationship to the base of the core (550 cm) provides an estimated age of 14.5 ka. This chronology of the sediment core will be used for the following discussion.

Stable-isotope Analysis

The $\delta^{18}O$ and $\delta^{13}C$ values obtained from bivalve *Pisidium* shells range from -10 to -16‰ and from -1.8 to -8‰, respectively (Figs. 13 and 14). The lower marl sediments (13.4 to 12.3 ka) have the highest $\delta^{18}O$ values of -10.5‰. A decrease in $\delta^{18}O$ values of ~2‰ occurs from 12.3 to 11.4 ka, with fluctuations. A rapid increase to the high value of -10.5‰ occurs at 11.4 to 10.9 ka, which is followed by the large decrease of $\delta^{18}O$ values of - 4.5‰ at 10.9 to 10.2 ka. From 10.2 to 7.9 ka there is considerable fluctuation in values from -13.6‰ to the lowest of the $\delta^{18}O$ values at -16‰.

The $\delta^{13}C$ values show a general decline trend from -1.8‰ at 13.4 ka to -8‰ at 9 ka. Superimposing on this declining trend, it appears that variability increases from a fluctuating range of 1-1.5‰ at 13.4-11.4 ka to 2-3‰ at 11.4-8 ka. The $\delta^{18}O$–$\delta^{13}C$ covariance plot appears to show three groupings. During the late glacial period from 13.5 to 11.4 ka and the early Holocene at 10.4 to 8 ka $\delta^{18}O$ shows positive relation with $\delta^{13}C$. However, during the transition in the earliest millennium of the Holocene, decreasing

$\delta^{18}O$ appears to correlate with increasing $\delta^{13}C$.

Pollen Analysis

The pollen diagram at HML was divided into three pollen zones based on visual examination and cluster analysis (CONISS, Fig. 15).

Zone I (525-515 cm; >13.4 – 13 ka). This lowest zone is characterized by *Artemisia* (35%), Cyperaceae (up to 20%) and *Salix* (around 20%). At the end of this first zone a steady increase in *Betula* is concomitant with decreases in *Artemisia*, Cyperaceae, and *Salix*.

Zone IIa (515-467 cm; 13 – 11 ka). This subzone is characterized by high *Betula* (80%) with variable amounts of *Artemisia* (10%), Cyperaceae (<10%), *Salix* (<10%) and *Alnus* (10%). Within this subzone there is a period of increased *Alnus*.

Zone IIb (467-430 cm; 11 – 9.2 ka). This subzone is still characterized by high *Betula* (~70%), but with increased amounts of *Artemisia* (<10%), Cyperaceae (<15%) and *Salix* (~10%), and a decrease in *Alnus*. In addition, this subzone represents the time period when Polypodiaceae was prominent on the landscape. At the end of this subzone *Alnus* begins to increase while most other taxa begin a gradual decline.

Zone III (430-409 cm; 9.2 – 8 ka). This uppermost zone is characterized by abundant *Alnus* (up to 60%) and decreases in *Betula* (70-40%). Also, the zone has steady increases in *Picea* (<5%) and *Pinus* (up to 15%). *Artemisia*, Cyperaceae and *Salix* are still present but at low amounts.

Discussion

Lithology as a Proxy of Lake Development and Watershed Stability

Lithology can be used as an indicator of lake productivity and watershed stability. HML is an open basin seepage lake, where the surface water outflow is minor. The presence of marl sediments in HML is likely the result of hardwater chemistry derived from groundwater in the surrounding bedrock on the north side of the Matanuska River, which contains calcareous concretions within the Matanuska Formation (Winkler, 1992). Shallow lake water tends to favor calcite precipitation (Kelts and Hsu, 1978). The occurrence of gyttja throughout the upper core is likely the result of the lake deepening.

At Hundred Mile Lake, the sharp increase in carbonates around 13.4 ka suggests the initial warming after ice retreat and an increase in lake productivity (Fig. 11). This initial marl represents the Allerod warm period. The low carbonates and high silicates from 12.4 ka to 11.2 ka may represent the lithological response to the YD cooling event, caused by elevated erosion from the watershed. The increase in carbonate and decrease in silicates at the end of the YD (11.2 ka) indicate Holocene warming and subsequent peak carbonate around 10.5 ka may correspond with Holocene Thermal Maximum in Alaska (Kaufman et al., 2003). The major lithology shift from marl to gyttja at 8.2 ka indicates change in lake chemistry and/or lake level, likely responding to 8.2 ka cooling event (Alley et al., 1997). However, the shift at HML appears to cause permanent changes in lake conditions rather than short-lived oscillations.

Paleoclimatic Interpretation of Stable Isotopes in Lacustrine Carbonates

The $^{18}O/^{16}O$ ratios in freshwater carbonates as in HML when in equilibrium depend on the isotopic composition of lake water and on water temperature. So, $\delta^{18}O$ values indicate air temperatures, precipitation sources and/or changes in local hydrology, potentially providing an independent proxy of climate change (Kelts and Hsu, 1978). In high latitudes, the isotopic signal of the water reflects atmospheric temperature (Yu, 2000).

The stable isotope record from HML demonstrates considerable shifts in both $\delta^{18}O$ and $\delta^{13}C$ values. A negative excursion in $\delta^{18}O$ of ~2‰ occurred at 12.3 ka (Figs. 13 and 16), likely representing cooling corresponding to the YD climate reversal as documented in Alaska and elsewhere (Yu and Wright, 2001). The interval of high $\delta^{18}O$ values before the YD indicates warm climate during the Allerod. The absence of the Bolling period might be caused by the late retreat of local glacial ice and then delayed lake formation. The surprisingly large and dramatic shift of -4.5‰ in $\delta^{18}O$ values in the early Holocene suggests a major change in climate, which has not been documented elsewhere in the region (see below).

The $\delta^{13}C$ values are a function of aquatic production, organic matter input, and decomposition (Yu et al., 1997). The $\delta^{13}C$ values of the HML core show a decrease from ca. -2‰ to -8‰ (from 13.3 to 9 ka), perhaps indicating an increased input of organic matter from the watershed as vegetation succeeded from treeless shrub *Salix*-herb tundra to *Betula*-dominated dense shrub tundra and *Alnus*-dominated forest. Increased organic matter input would increase decomposition in the lake, causing the decline in

$\delta^{13}C$ values. The lack of covariance before 10 ka suggests that the local hydrology did not play a significant role in driving the $\delta^{18}O$ shifts in carbonates (Talbot, 1990). Instead the $\delta^{18}O$ shifts most likely reflected temperature changes. After 10 ka the stronger covariance suggests possible closed-basin conditions during lower lake level, which appears to be consistent with peak carbonate content.

Regional Vegetation History

Vegetation at HML changed from herb tundra (13.5-13 ka), through *Betula* shrub tundra (13-9.2 ka), to *Alnus* forest (9.2-8 ka). Before 13 ka, the vegetation around HML was largely dominated by herbaceous and shrub taxa. High percentages of *Salix*, Ericaceae, Caryophyllaceae, *Artemisia*, *Ambrosia*, Cyperaceae, and Poaceae were present at 13 ka likely indicating sparse vegetation cover. Vegetation history at this site was similar to other sites in south-central Alaska following glacial ice retreat. This pollen assemblage includes pollen types of varying ecological preference indicating a tundra environment, or a varied environment from mesic to dry conditions. This landscape is similar to that found at Hidden Lake, Point Woronzof, and 70 Mile Lake shortly after deglaciation (Ager and Brubaker, 1985). Hundred Mile Lake documents warm-loving plant types and increase in *Betula* after 13 ka. Ager and Brubaker (1985) also note this *Betula* dominated zone at Hidden Lake, Point Woronzof, and 70 Mile Lake.

The increase of Polypodiaceae after 11 ka is a widespread phenomenon in the region as similar increases in this taxon have been documented by Ager and Brubaker (1985) at Point Woronzof. By 9.2 ka vegetation composition at Hundred Mile Lake begins to shift from shrub-tundra to an *Alnus* forest landscape, with the arrival of *Pinus* and *Picea*, which is in accordance with other regional records (Ager and Brubaker, 1985). Ager and Brubaker (1985) indicate that Hidden Lake, Point Woronzof, and 70 Mile Lake all recorded a *Populus-Salix* zone prior to the appearance of the *Alnus-Betula-Picea* forest. However, Hundred Mile Lake does not contain a *Populus* zone in the pollen record.

Responses of Watershed, Lake and Vegetation to Climate Change

If we use $\delta^{18}O$ as a proxy of climate changes, then lithology and pollen can be used to indicate responses of lake, watershed, and vegetation to these climate changes (Wright, 1984). The highest $\delta^{18}O$ values (-10 to -11‰) reflect initial warming after ice retreat. During this period the landscape and watershed begin to stabilize. The landscape consists largely of shrub *Salix*-herb tundra. An increase in carbonate (close to 60%) also reflects stabilization in the watershed and lake. Around 12.5 ka a decrease in carbonate and $\delta^{18}O$ values represents the YD. Beginning around 11.4 ka carbonate begins increasing as does the $\delta^{18}O$ values, but reaches peak values at different times (Fig. 16). There is a possible delay of several hundred years in lake response to Holocene warming.

The marl to gyttja transition around 8 ka suggests an increase in lake level, due possibly to a climate shift to cool and wet conditions, which is consistent with other regional records (e.g. as reviewed in Bigelow and Edwards, 2001). Vegetation responds similarly to a wetter environment, as an *Alnus-Betula* dominated forest interspersed with *Picea*, *Pinus*, and herbaceous taxa dominate the landscape surrounding HML.

Possible Causes of Early Holocene Climate Shift and Implication

The mechanisms that could possibly cause the 4.5‰ decline in $\delta^{18}O$ from the early Holocene include changes in air/water temperatures, precipitation seasonality, and a change in precipitation source regions. Current climate of south-central Alaska can be examined through large-scale atmospheric conditions. The winter climate of the region is strongly affected by cold and very dry air masses from well north of the main position of the polar jet stream. An intensive high-pressure system dominates western Beringia (Siberian high) due to intensive radiation cooling.

Temperatures are a bit higher in eastern Beringia (Alaska) due to more winds from the south around a low-pressure system in the North Pacific (Aleutian low). During July, atmospheric circulation patterns generally shift northward as more radiation and warm high pressure systems (subtropical highs) become more dominant. A positive correlation of +0.6‰ per °C occurs between $\delta^{18}O$ values in precipitation and air temperature at middle and high latitudes. If the shift in $\delta^{18}O$ values is caused by a decrease in air temperature, it would represent 7-8 °C change. If using -0.25‰ as the negative temperature-dependent fractionation between calcite precipitation and water temperature, then a -4.5‰ shift in $\delta^{18}O$ would represent ~ 20°C increase in water temperature. However, such a decrease in air temperature and an increase in water temperature is unrealistic and is not supported by any records in the region. So, the 4.5‰ decrease in $\delta^{18}O$ values was unlikely caused entirely by air and water temperature changes.

The jet stream is most prominent over Beringia during the summer, causing summer precipitation maxima at most locations as storms travel from west to east. If temperature effects are relatively minor, then the decline in the $\delta^{18}O$ values are likely the result of changes in the seasonal distribution of precipitation or precipitation source regions. Winter precipitation has lower isotopic values than summer precipitation therefore; the 4.5‰ decrease in $\delta^{18}O$ values could reflect a change from an initial summer to a winter season precipitation source. The 4.5‰ decrease may also be the result of precipitation originating from oceanic regions that typically have higher isotopic values like Bethel in western Alaska, transitioning to lower continental values similar to Whitehorse in western Yukon, Canada (Fig. 17).

Possible causes of the dramatic isotopic shift at 10.5 ka recorded at Hundred Mile Lake include a change in precipitation seasonality, a shift in regional wind directions, a change in precipitation source regions modulated by retreating ice sheets/glaciers or rising sea level. Bigelow and Edwards (2001) note that during the early Holocene there may have been improved climatic conditions in central Alaska as indicated by several studies inferring an increase in effective moisture. This study suggests that the climatic shift in the region during the early Holocene was more abrupt and in greater magnitude than the YD event, implying a differential regional response in south-central Alaska to large-scale climate forcing, possibly caused by the stronger regional feedback processes in high latitudes.

Summary and Implications

The multiple proxy data from Hundred Mile Lake in the Matanuska Valley of south-central Alaska provide complementary information for changes in vegetation and climate. These data also offer insight into ecological responses to abrupt climate change.

1. The $\delta^{18}O$ values from bivalve *Pisidium* mollusk shells provide independent and convincing records for climate change. A negative excursion of 2‰ in $\delta^{18}O$ values at 12.4 – 11.4 ka represents a regional expression of the YD climate reversal after the warm Allerod period during the last deglaciation. The magnitude and timing of the YD are similar to other records in Alaska as well as in the North Atlantic region.
2. During the early Holocene, $\delta^{18}O$ values shift dramatically from -10.5 ‰ to -15‰ at ~10.5 ka. The large decline in $\delta^{18}O$ values in the early Holocene suggests a major shift in atmospheric circulation patterns, which has not been documented elsewhere in Alaska.
3. During the mid-Holocene around 8 ka a dramatic shift takes place in HML lithology from carbonate-rich marl to organic-rich gyttja sediments, indicating a climatic shift to cooler and wetter conditions, which are consistent with other regional records.
4. The lithology change from clay to marl at 13.5 ka suggests a delayed response of the aquatic system to deglacial warming after ice reatreat. Pollen data show vegetation changes from herb tundra, through *Betula* shrub tundra, to an

Alnus forest. The increase in *Betula* at ~13 ka appears to lag behind climate warming by a few centuries.

5. The data from this study suggest that the climatic shift in the region during the early Holocene was more abrupt and in greater magnitude than the YD event, implying a differential regional response in south-central Alaska to large-scale climate forcing, possibly caused by the stronger regional feedback processes in high latitude regions.
6. Increasing spatial coverage of data will shed light on understanding mechanisms and causes of large-scale climate change. As documented by Kaufman et al. (2003) the spatial variation in past climate change will help in understanding regional response to global climate change. Also, understanding the vegetational response to such global climate shifts will help researchers project the possible response of ecosystems to ongoing and future climate change.

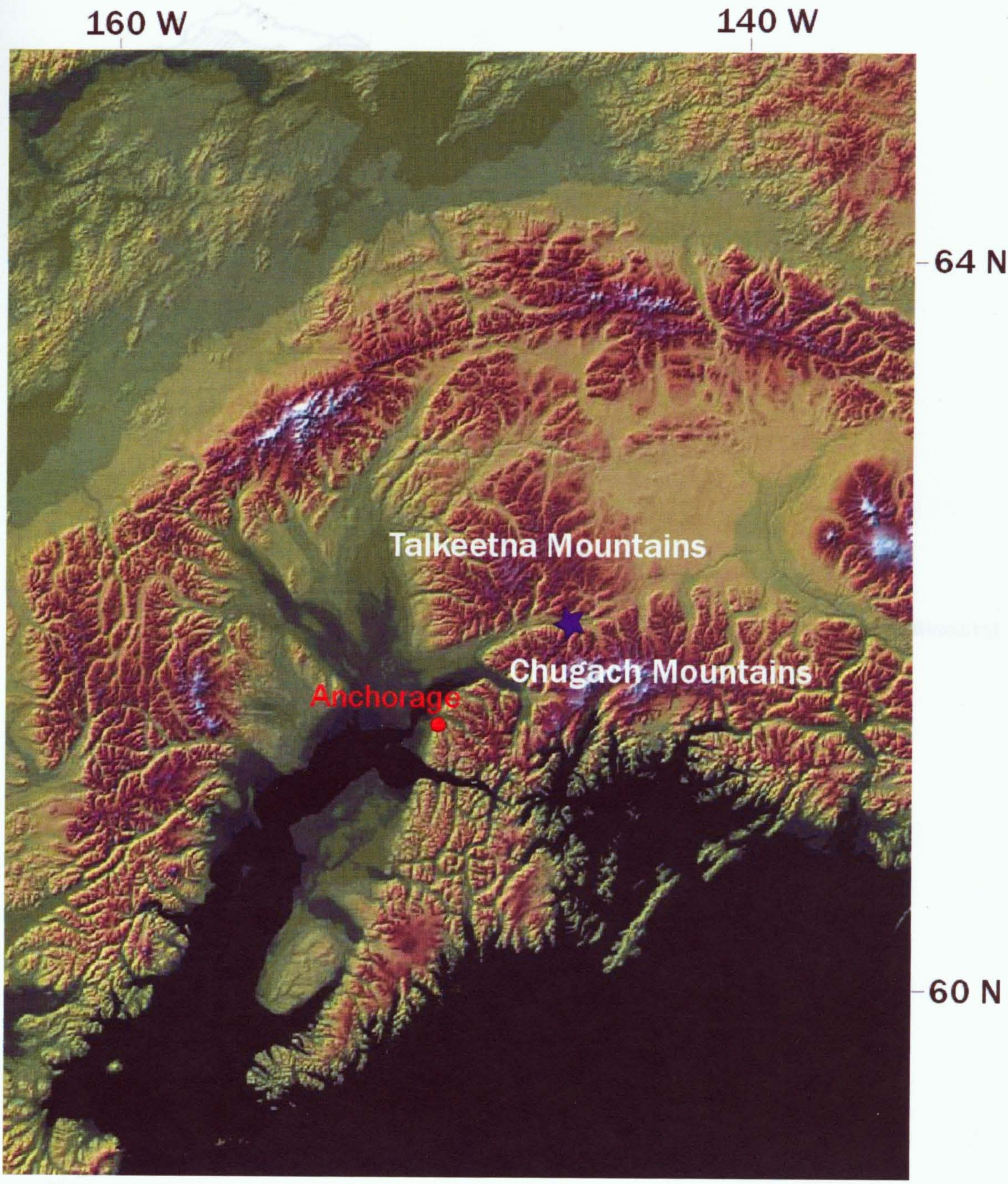


Figure 1. Satellite image of south-central Alaska. Location of the study area is indicated by the blue star between the Chugach and Talkeetna Mountains. Hundred Mile Lake is located at 61.8° N and 147.8° W.

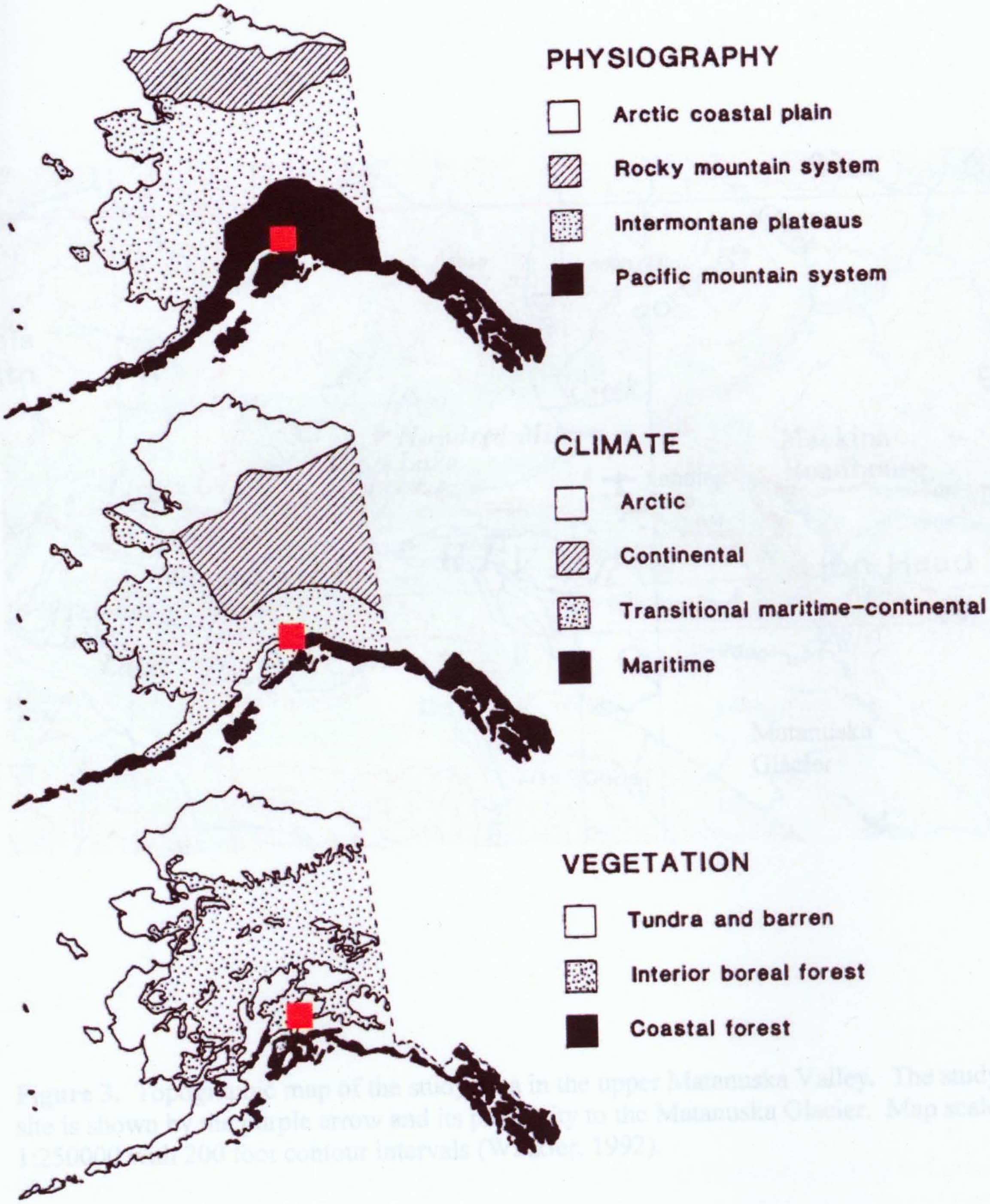


Figure 2. Physiography, climate, and vegetation regions of Alaska. The study region is shown as a red square (From Anderson and Brubaker, 1993).

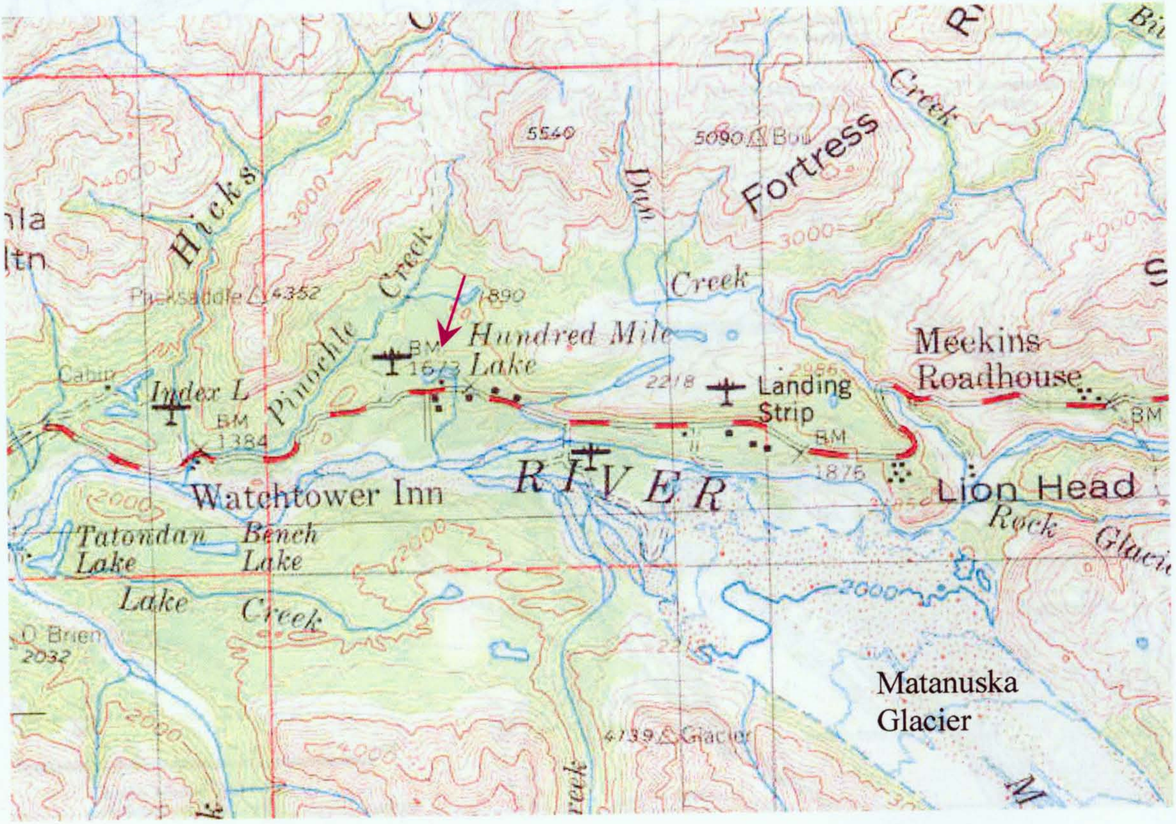


Figure 3. Topographic map of the study area in the upper Matanuska Valley. The study site is shown by the purple arrow and its proximity to the Matanuska Glacier. Map scale 1:250000 with 200 foot contour intervals (Winkler, 1992).

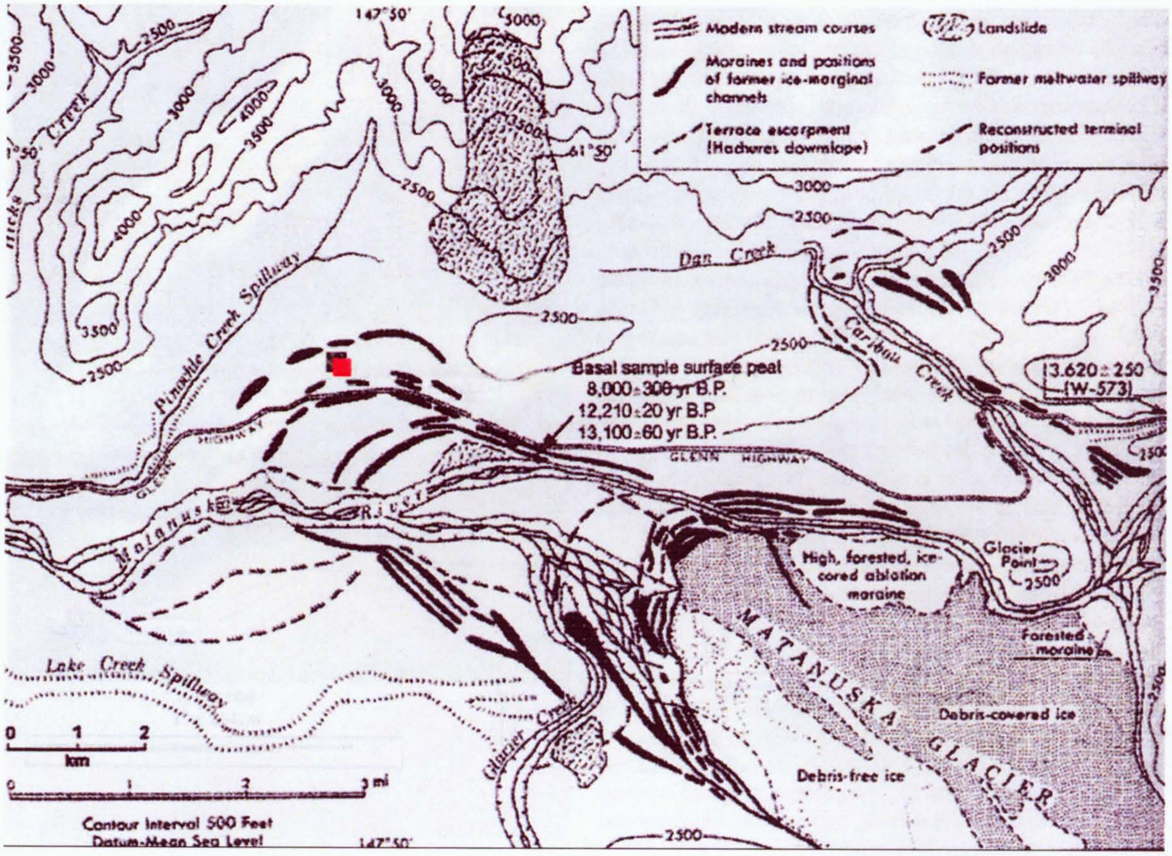


Figure 4. Glacial deposits of the study region (Williams and Ferrians, 1961 as in Larsen et al., 2003). The location of Hundred Mile Lake is shown by a red square between two discontinuous moraines. Several basal dates from peat are shown here, with the oldest being 13,100 radiocarbon years B.P.

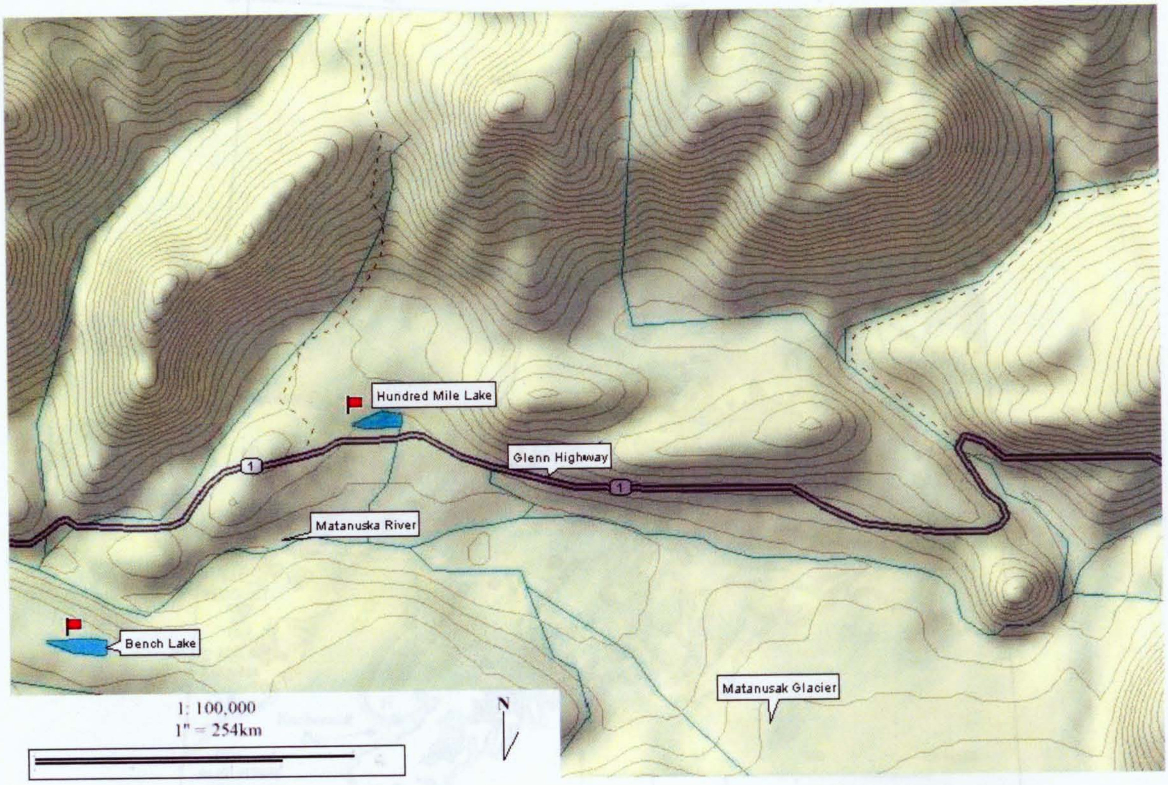


Figure 5. Shaded relief map emphasizing topographic features and catchment area around Hundred Mile Lake.

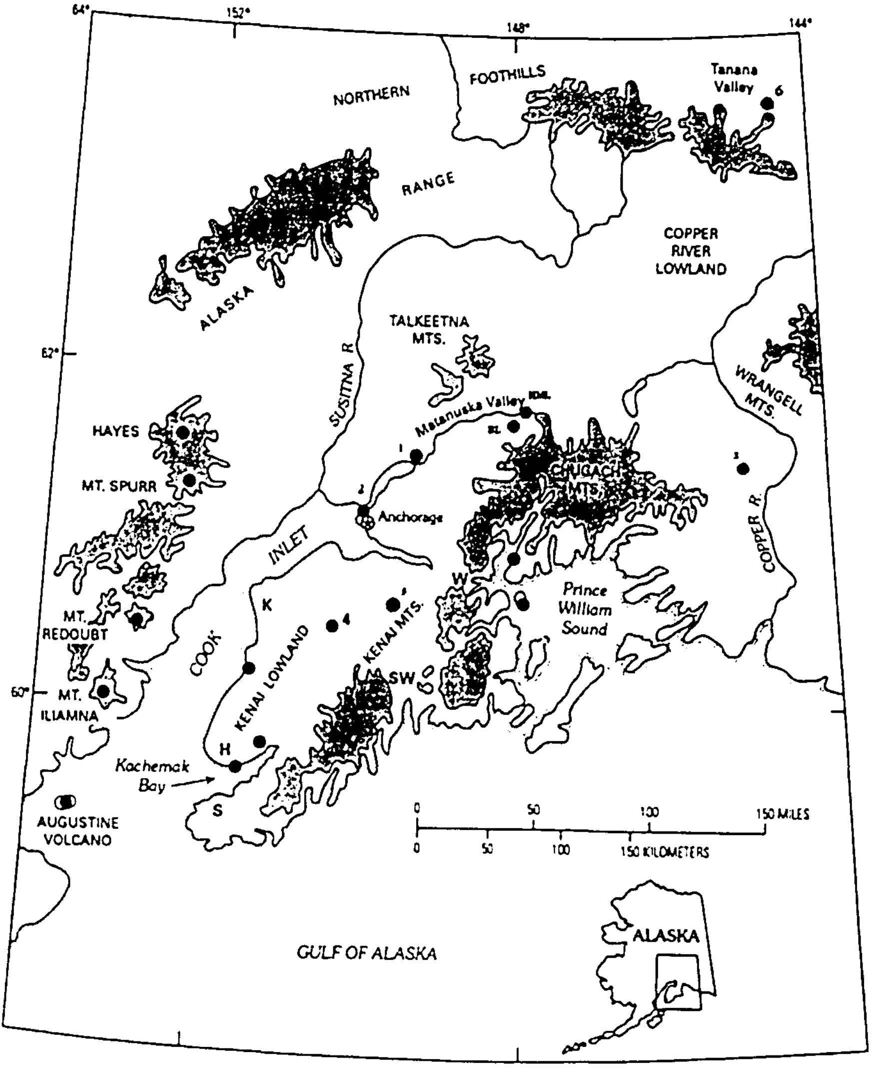
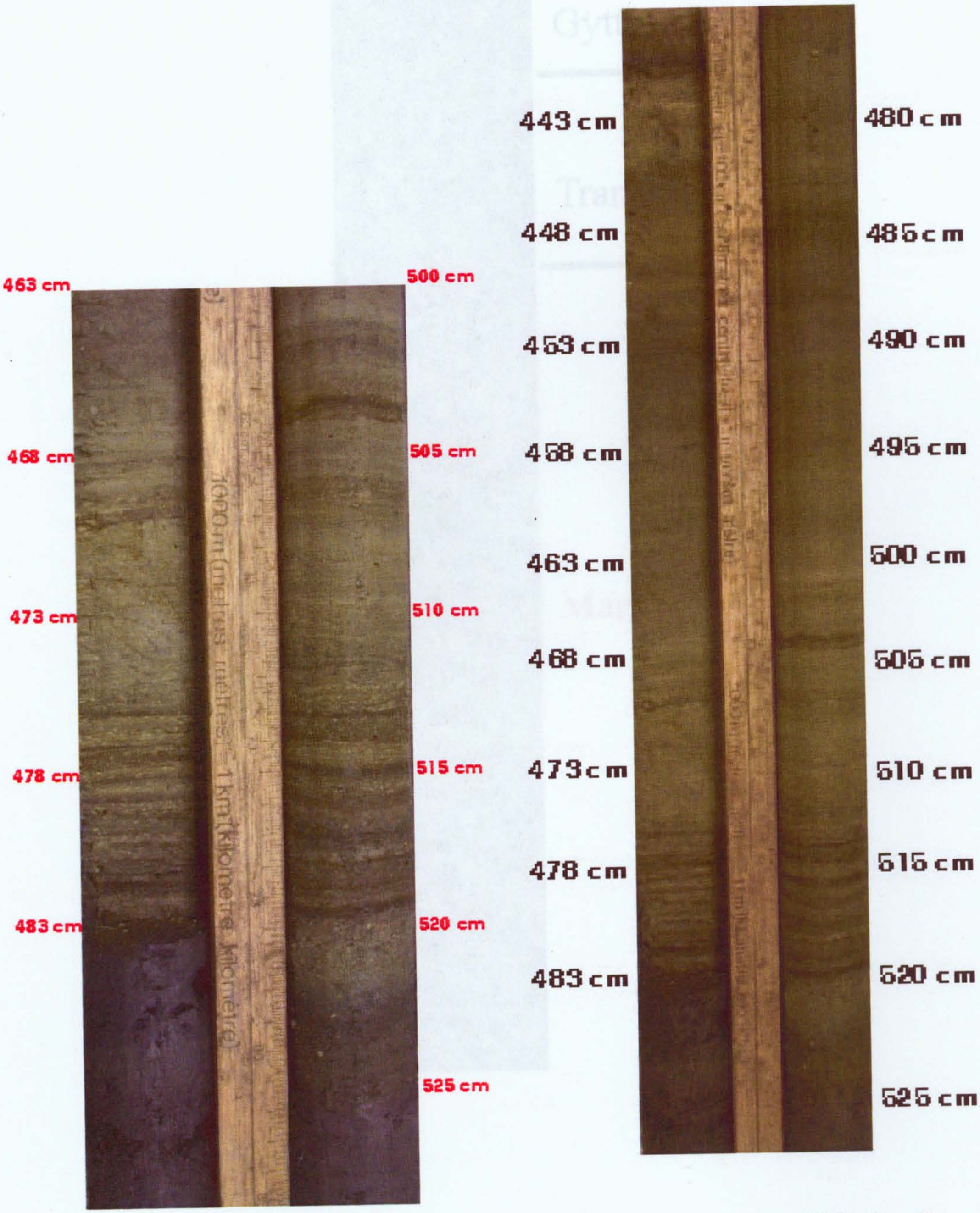


Figure 6. Map of south-central Alaska showing Hundred Mile Lake (this study) and other paleoecological sites (map Modified from Ager, 2000). **(1)** Kepler Lake (Forester et al., 1989); **(2)** Point Woronzof (Ager, 1983); **(3)** 70 Mile Lake (Ager and Brubaker, 1985); **(4)** Hidden Lake (Ager, 1983); **(5)** Tera Lake (Ager, 2001); **(6)** Tangle Lakes (Schweger, 1981).



HML Core I HML Core II HML Core I HML Core II

Figure 7. Core photos of basal sections of Cores I and II at Hundred Mile Lake. Here the differences between the two cores are easily seen as core II provides needed additional basal materials. Figure on the left is a close-up of the lower sections of the cores around the clay-marl transition.

Figure 8. Core photo of Hundred Mile Lake core I showing the transition from marl to gyttja.

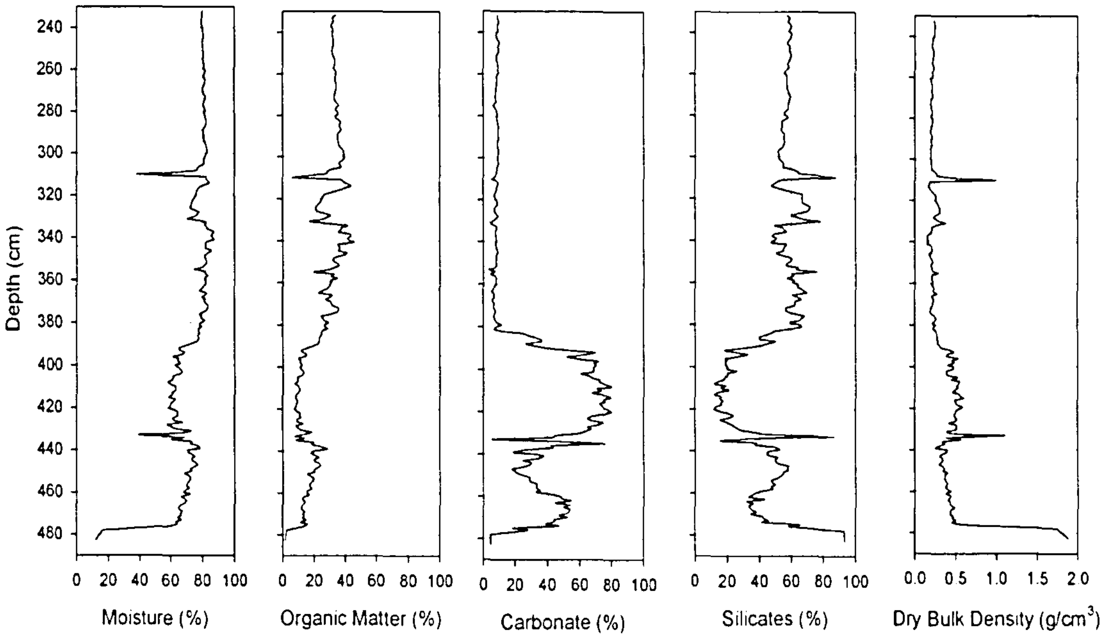


Figure 9. Loss-on-ignition results from Core I at Hundred Mile Lake.

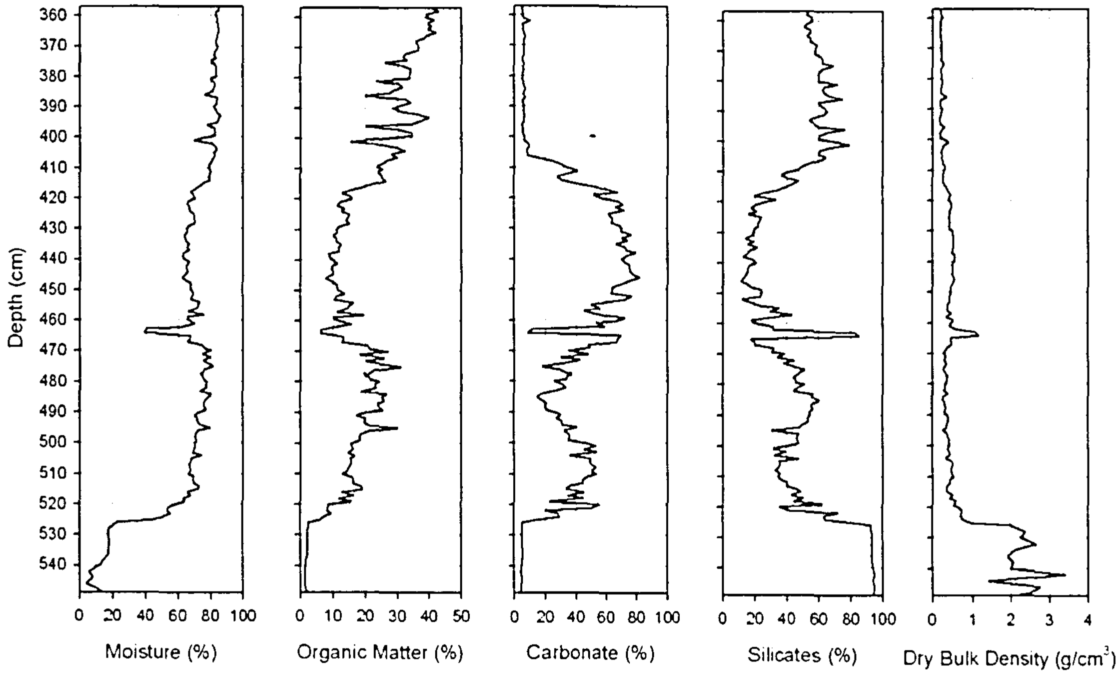


Figure 10. Loss-on-ignition results from Core II at Hundred Mile Lake.

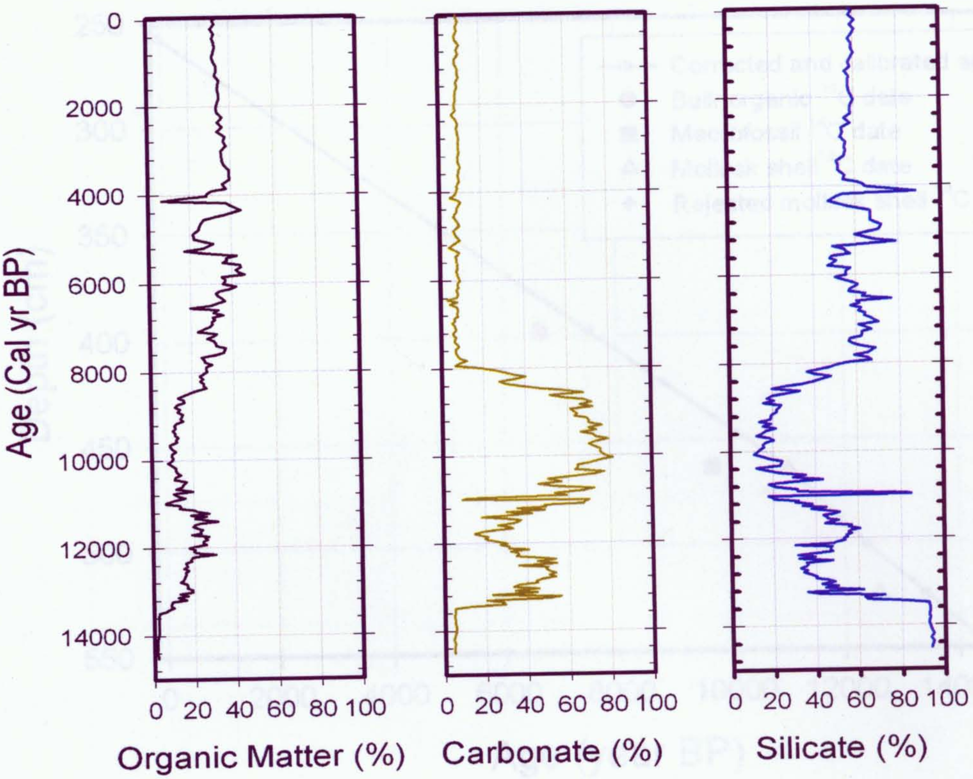


Figure 11. Loss-on-ignition results of composite core at Hundred Mile Lake on calibrated age scale. Lithology of the core changes abruptly from basal clay to marl at 13.5 ka and from marl to gyttja at 8 ka. Within the marl sediment, carbonate decreases to < 20% at 12.4 – 11.2 ka.

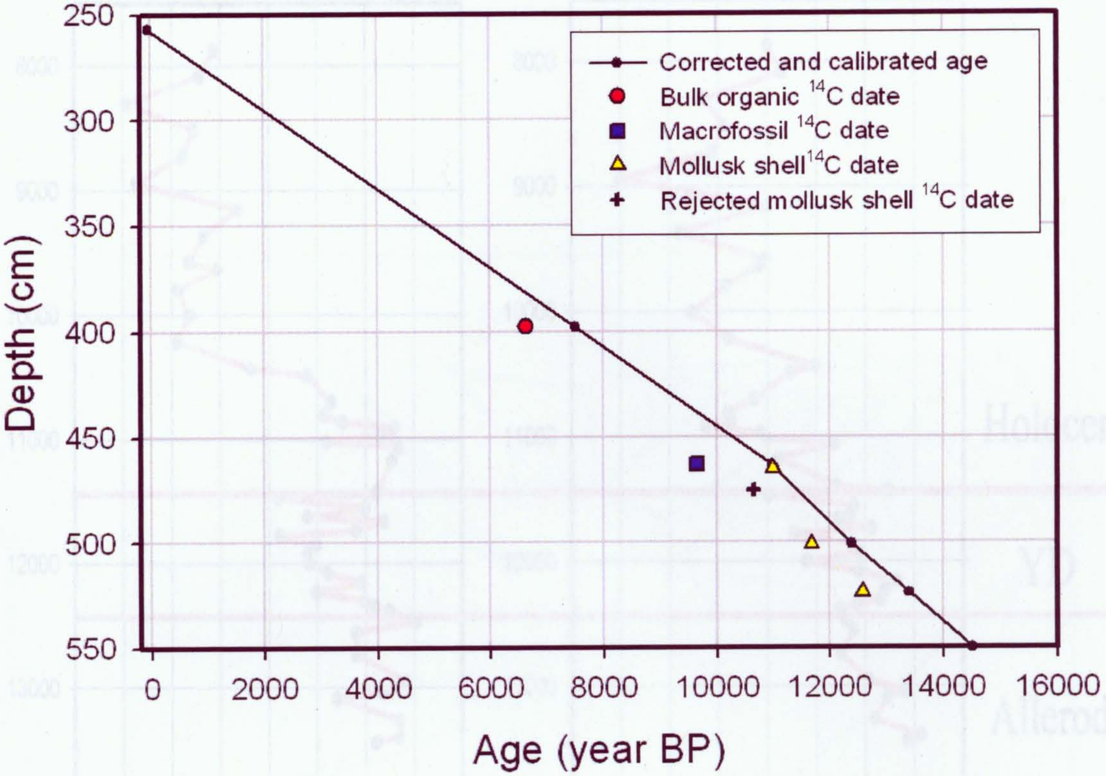


Figure 12. Age model (depth-age plot) for Hundred Mile Lake composite core. An age model was developed based on linear interpolation of five dates and the age of the sediment surface (2004 AD = -54 cal BP). Extrapolation of the age-depth relationship to the base of the core (550 cm) provides an estimated age of 14.5 ka cal yr BP.

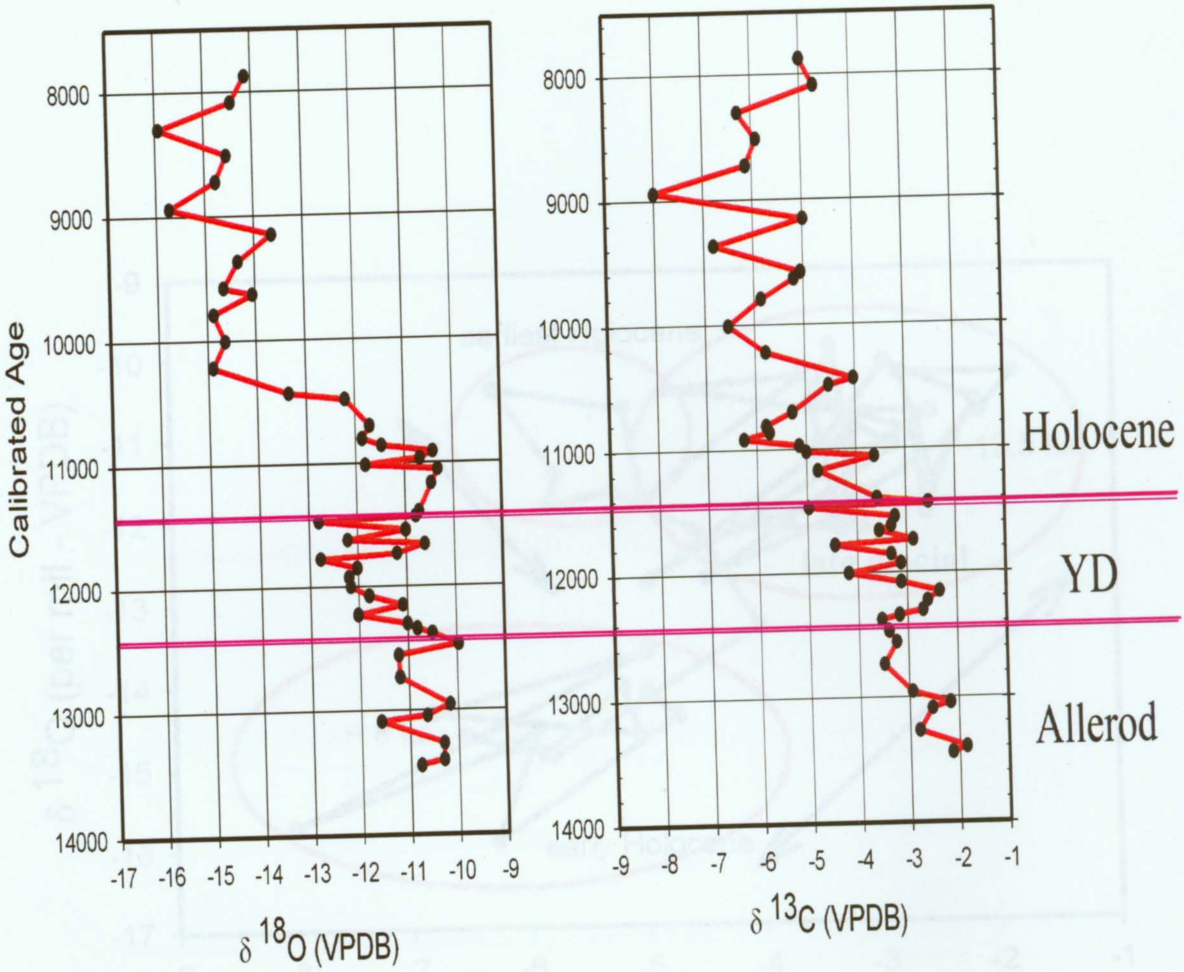


Figure 13. Stable oxygen and carbon isotopes of Hundred Mile Lake Core II on calibrated age scale.

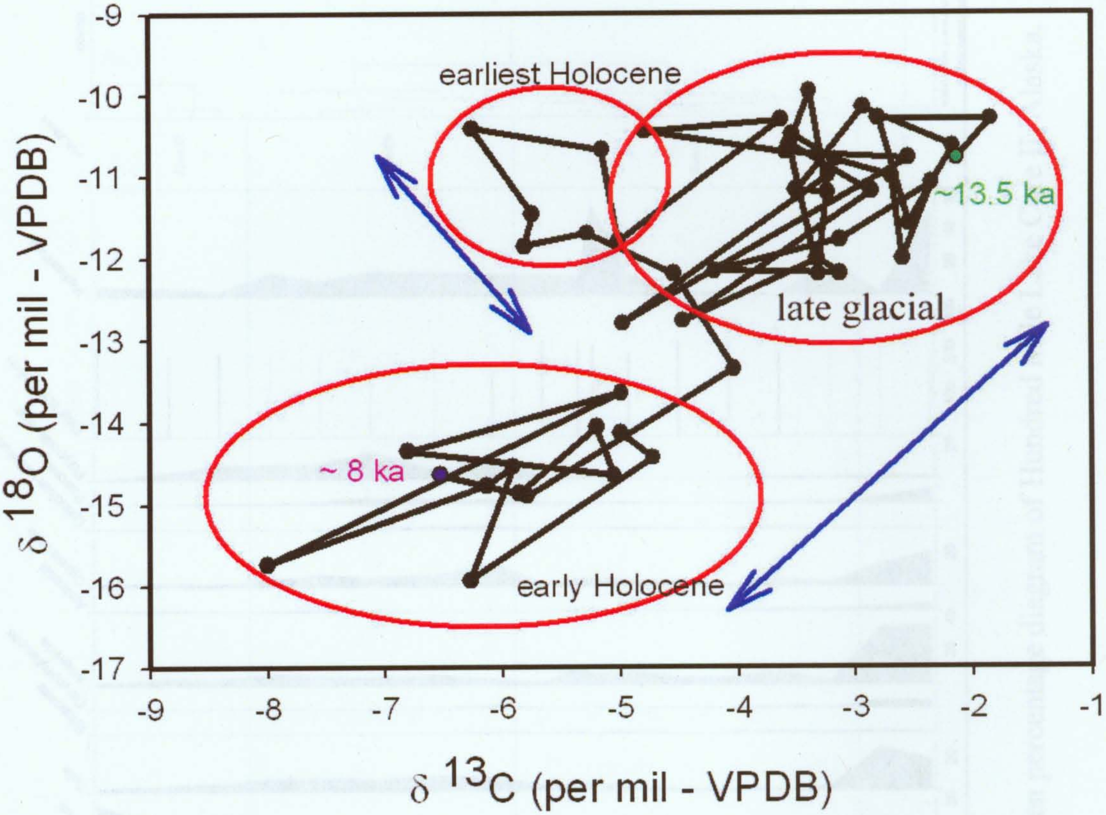


Figure 14. Covariance of δ^{18}O and δ^{13}C. Both isotopes show a positive relation in the late glacial (Allerod warm period and YD), but a negative relation during the earliest Holocene (11.4 – 10.5 ka) before the abrupt 4.5‰ shift in δ^{18}O.

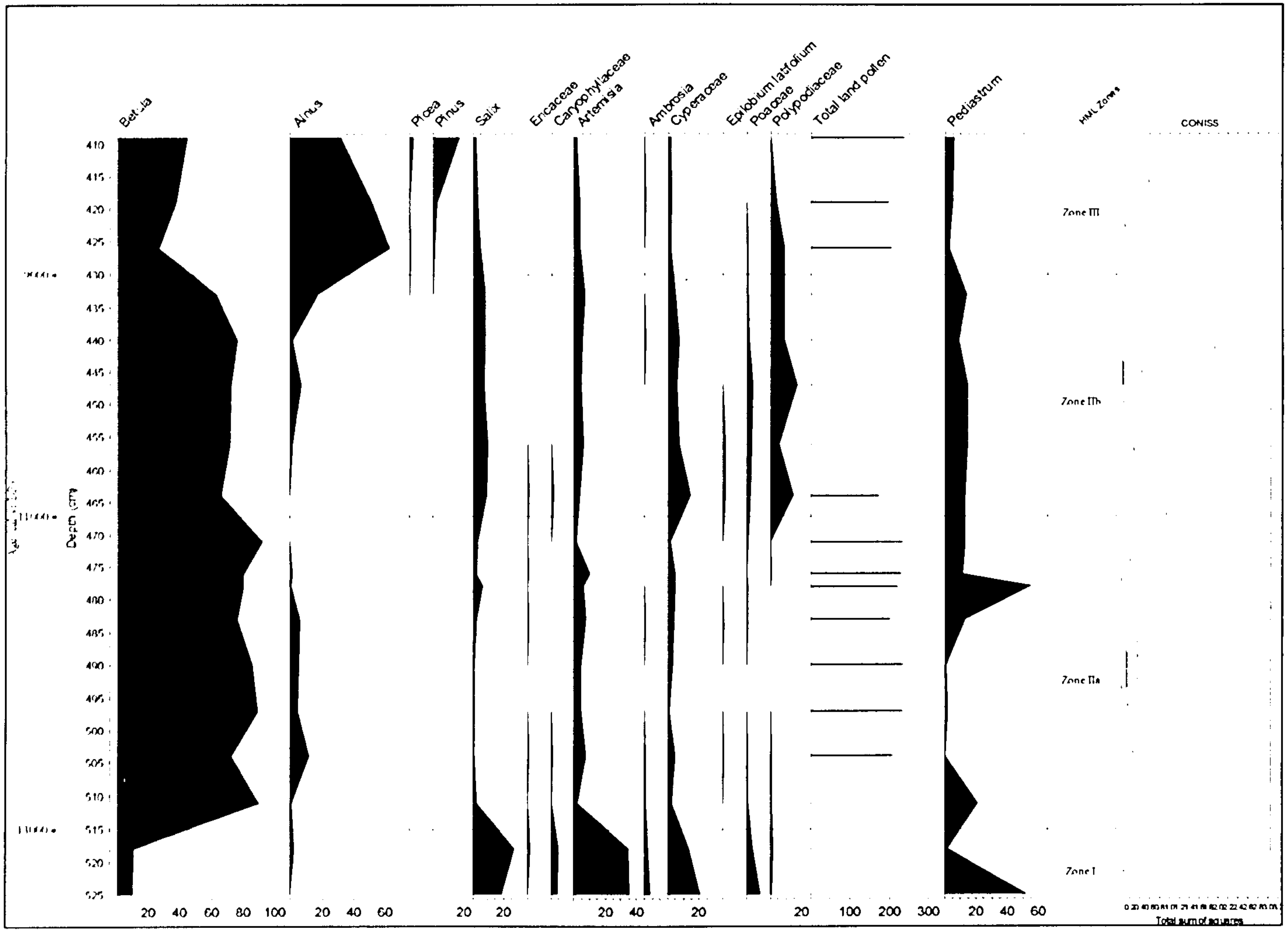


Figure 15. Pollen percentage diagram of Hundred Mile Lake Core II, Alaska.

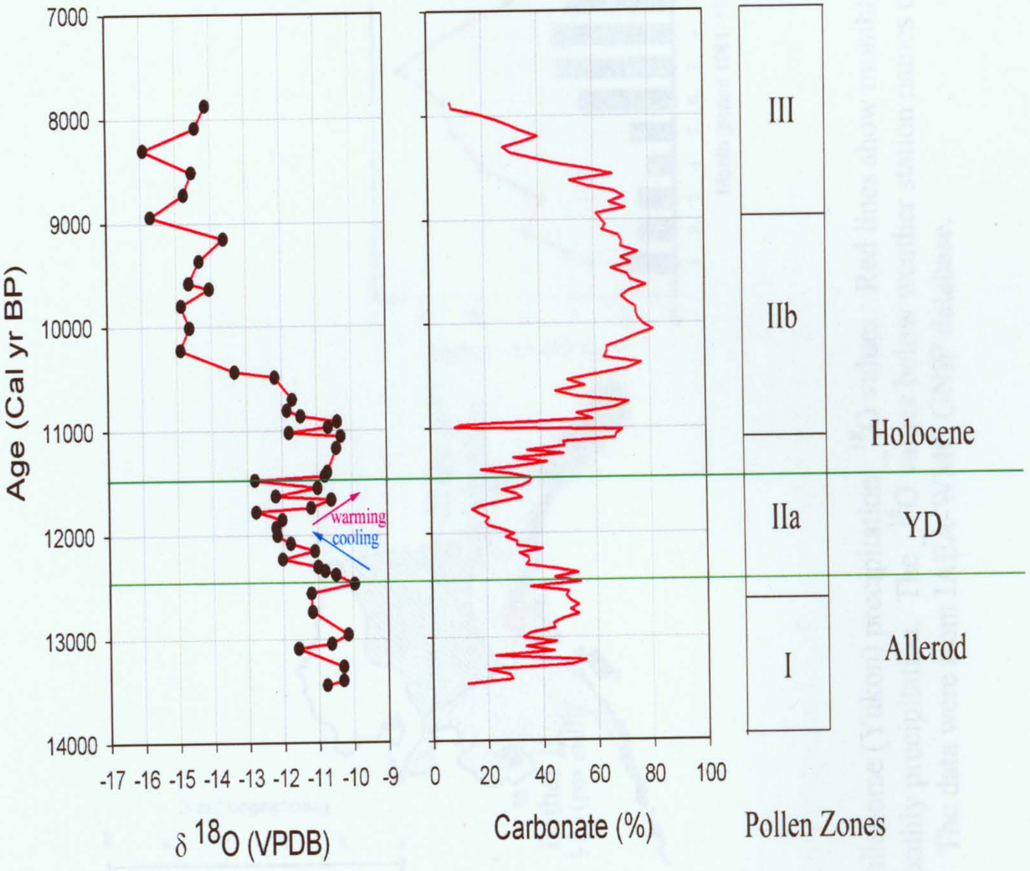


Figure 16. Hundred Mile Lake δ^{18}O and carbonate on calibrated age scale. The δ^{18}O record obtained from *Pisidium* mollusk shells shows a 4.5‰ negative shift from -10.5 to -15‰ around 10.5 ka. A minor negative excursion in δ^{18}O occurred 12.4 – 11.4 ka, representing the YD event. The carbonate plot from Hundred Mile Lake indicates warming and cooling trends as represented by the δ^{18}O record but with different timing.

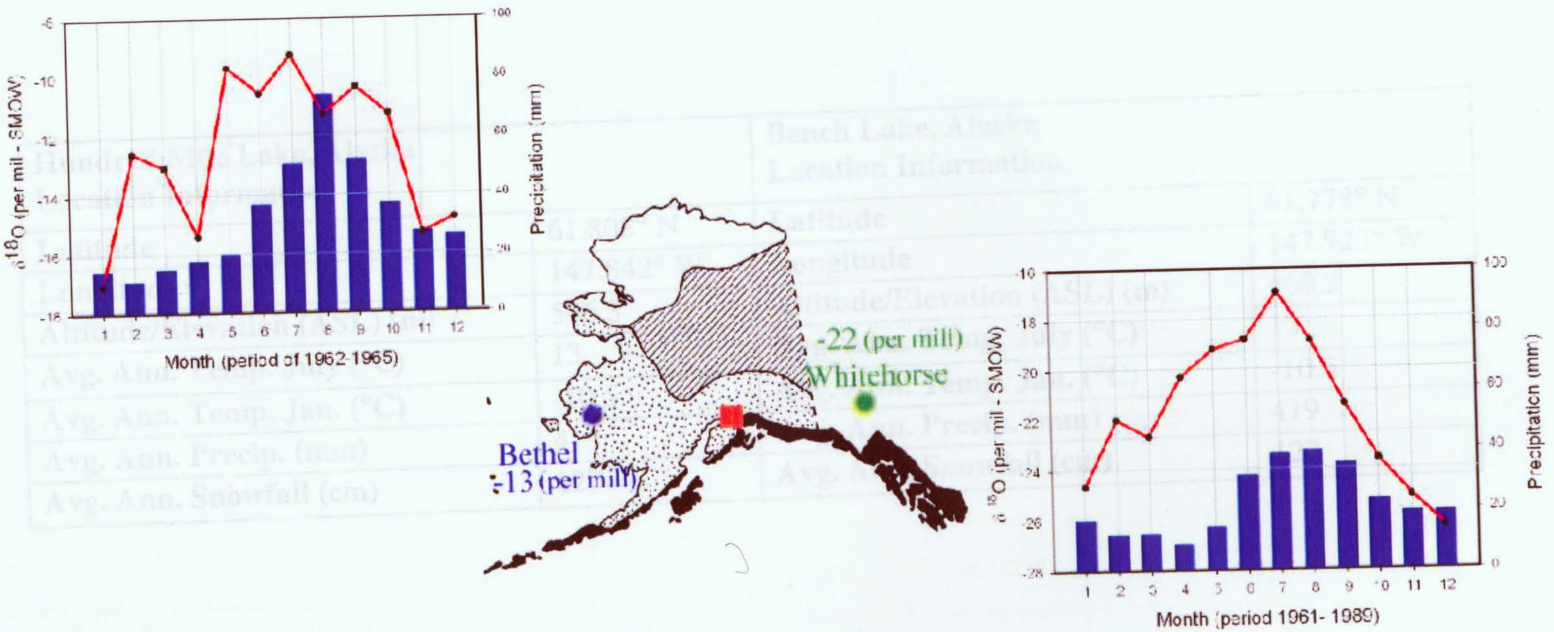


Figure 17. Bethel (Alaska) and Whitehorse (Yukon) precipitation _^{18}O values. Red lines show monthly _^{18}O in precipitation and blue bars show monthly precipitation. The _^{18}O values below weather station names on map are annual means of precipitation _^{18}O. The data were from IAEA-WMO GNIP database.

Hundred Mile Lake, Alaska Location Information		Bench Lake, Alaska Location Information	
Latitude	61.808° N	**Latitude**	61.778° N
Longitude	147.842° W	**Longitude**	147.923° W
Altitude/Elevation (ASL) (m)	506.3	**Altitude/Elevation (ASL) (m)**	460.2
Avg. Ann. Temp. July (°C)	13	**Avg. Ann. Temp. July (°C)**	13
Avg. Ann. Temp. Jan. (°C)	-10.5	**Avg. Ann. Temp. Jan. (°C)**	-10.5
Avg. Ann. Precip. (mm)	419	**Avg. Ann. Precip. (mm)**	419
Avg. Ann. Snowfall (cm)	127	**Avg. Ann. Snowfall (cm)**	127

Table 1. Site location information for Hundred Mile Lake and Bench Lake in the Matanuska Valley, Alaska.

HML Core	Depth (cm)	Material Dated	AMS Lab Number*	$\delta^{13}C$	^{14}C date (±SE)	Hardwater Effect Corrected ^{14}C date **	Calibrated age (2σ range in Cal BP) ***	Calendar Age (Cal yr BP)	Notes
I	373	Bulk organic	AA-59593	-26.9	6630 ±40	NA	7431 – 7572	7502	398 cm of equivalent depth in core II
II	462 - 464	Terrestrial macrofossil	AA-59592	-25	9650 ± 50	NA	10755 - 11180	10968	
II	464 - 466	*Pisidium* mollusk shells	ETH-29987	1.3 ± 1.2	10990 ± 100	9740 ± 100	10702 – 11336	11019	
II	474 - 476	*Pisidium* mollusk shells	ETH-29988	.8 ± 1.2	10660 ± 80	9410 ± 80	10292 – 11070		Rejected
II	500 - 502	*Pisidium* mollusk shells	ETH-29989	.3 ± 1.2	11670 ± 80	10420 ± 80	11946 – 12811	12380	
II	523 - 525	*Pisidium* mollusk shells	ETH-29990	1.0 ± 1.2	12570 ± 85	11320 ± 85	13022 - 13775	13400	

Note:

* AA- University of Arizona, NSF-funded AMS lab;.ETH- Eidegenossische Technishe Hochschule, Institut fur Teilechenphsik.

** Correction of 1250 years based on difference between macrofossil date of 9650 and shell date of 10990 ^{14}C BP and the 2-cm depth difference (46 years/cm sediment-accumulation rate between 398 (373) and 463 cm).

*** Calibrated by the program CALIB Rev4.4.2 (Stuiver and Reimer 1993) using INTCAL 98 data set (Stuiver et al. 1998).

Table 2. AMS ^{14}C dates from the HML core I and II depth.

Stable Isotopes (VPDB) HML Core II Matanuska Valley, Alaska							
Depth (cm)	Age (cal BP)	*Pisidium*		Ostracodes		*Chara* encrustations	
		$\delta^{18}O$	$\delta^{13}C$	$\delta^{18}O$	$\delta^{13}C$	$\delta^{18}O$	$\delta^{13}C$
405	7875	-14.1	-4.9				
409	8088	-14.4	-4.7				
413	8301	-15.9	-6.3				
417	8515	-14.5	-5.9				
421	8728	-14.8	-6.1				
425	8941	-15.7	-8.0				
429	9155	-13.6	-4.9				
433	9368	-14.3	-6.8				
437	9581	-14.6	-5.0				
438	9634	-14.1	-5.2				
441	9794	-14.9	-5.9				
445	10008	-14.6	-6.5				
449	10221	-14.9	-5.8				
453	10434	-13.4	-4.0				
454	10488	-12.2	-4.5				
458	10701	-11.7	-5.3				
460	10808	-11.9	-5.8				
461	10861	-11.5	-5.7	-12.2	-2.2		
462	10914	-10.4	-6.3				
463	10968	-10.7	-5.1				
465	11019	-11.8	-5.0				
466	11056	-10.3	-3.6				
469	11170	-10.5	-4.8				
475	11397	-10.7	-3.6				
476	11434	-10.8	-2.6				
477	11472	-12.8	-4.9				
479	11548	-11.0	-3.2				
481	11623	-12.2	-3.3				
482	11661	-10.6	-3.6				
484	11737	-11.2	-2.9				
485	11775	-12.8	-4.5				
487	11850	-12.0	-3.3				
489	11926	-12.2	-3.1				
491	12001	-12.2	-4.2				
493	12077	-11.8	-3.1				
495	12153	-11.1	-2.4				
497	12228	-12.0	-2.6				
499	12304	-11.0	-2.7				
500	12342	-10.8	-3.2				
501	12380	-10.5	-3.5	-11.2	-0.6		
503	12468	-9.9	-3.4	-10.2	-0.9		
505	12557	-11.2	-3.2	-9.2	-0.6		
509	12734	-11.2	-3.5				
514	12956	-10.2	-2.9				
516	13045	-10.6	-2.2			-12.5	3.1
517	13089	-11.6	-2.5				
521	13267	-10.3	-2.8				
524	13400	-10.3	-1.9				
525	13444	-10.8	-2.1				

Table 3. $\delta^{18}O$ and $\delta^{13}C$ from carbonate at Hundred Mile Lake.

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Appendices

Appendix 1. Loss-on-ignition data table for Hundred Mile Lake Core I.

Depth (cm)	Moisture	Organic Matter	Carbonate	Silicates
232	80.05819	33.98176	8.708936	57.3093
233	79.91891	31.7696	8.912352	59.31805
235	79.49317	32.40319	9.712415	57.8844
237	79.24252	30.72396	8.699823	60.57622
239	79.53349	32.32028	9.170427	58.50929
241	80.3085	31.5856	7.900821	60.51358
243	80.65633	32.20676	8.589662	59.20358
245	80.62306	32.42161	10.16398	57.41441
247	79.77486	31.97279	9.000371	59.02684
249	80.17008	31.3238	9.751771	58.92443
251	80.41395	32.0287	8.010176	59.96112
253	80.82192	33.24433	8.045527	58.71015
255	80.13033	33.29208	9.146658	57.56126
257	81.15278	32.56558	9.165835	58.26859
259	81.33523	34.43456	9.67967	55.88577
261	81.9539	33.96226	8.581132	57.4566
263	80.91791	33.73984	8.935772	57.32439
265	81.96328	34.33134	8.321357	57.34731
267	81.39358	34.31105	8.06603	57.62292
269	80.3607	33.62888	7.920836	58.45028
271	80.77781	32.99492	7.420595	59.58448
273	82.23819	33.45376	8.051012	58.49523
275	81.2766	35.72443	6.298722	57.97685
277	80.7142	33.5522	8.212081	58.23572
279	81.80645	35.8156	8.870213	55.31418
281	81.38189	33.41969	8.542228	58.03808
283	82.01675	37.11201	9.053036	53.83495
285	82.3418	36.12303	9.434335	54.44263
287	82.05337	37.43396	9.267623	53.29842
289	79.97635	35.03937	9.251181	55.70945
291	81.14909	35.26053	9.414133	55.32534
293	80.85135	35.47038	8.874146	55.65547
295	81.81818	36.16398	8.989458	54.84656
297	82.60204	38.70968	9.836217	51.45411
299	82.83235	38.75458	9.162637	52.08278
301	81.79799	38.98062	8.978464	52.04092
303	81.07352	35.53835	9.441661	55.01999
305	81.03494	37.34177	8.155696	54.50253
306	78.45918	30.42705	8.497153	61.0758
307	76.74072	28.01494	8.130096	63.85496
308	76.7934	27.83669	7.716649	64.44666
309	63.6226	15.20973	7.354275	77.43599

310	37.48654	6.533601	5.159276	88.30712
311	82.46273	37.25055	8.571619	54.17783
312	82.37873	38.92456	9.855217	51.22022
314	84.73784	44.12252	8.471026	47.40646
316	78.42155	35.88457	7.988959	56.12647
318	76.39964	26.30446	6.605487	67.09005
320	76.3123	24.79015	8.271405	66.93844
322	74.21456	23.8732	9.235661	66.89113
324	73.00337	21.2037	6.6325	72.1638
326	72.42252	21.69725	7.406147	70.89661
328	78.21508	30.72519	9.547328	59.72748
330	75.73448	25.88652	5.990274	68.1232
331	70.46943	16.94852	4.358286	78.6932
332	77.83181	28.14339	6.691814	65.16479
333	82.80356	41.85552	8.857649	49.28683
334	81.40005	37.02446	8.34212	54.63342
335	82.3573	37.32493	7.32521	55.34986
336	82.85926	35.13709	7.711255	57.15166
337	86.66667	43.43525	7.770863	48.79388
338	87.08963	43.90476	8.229714	47.86552
339	85.42061	41.28015	8.015955	50.7039
340	86.23609	42.62848	8.237742	49.13378
341	87.52449	45.63297	7.587439	46.77959
342	82.29399	34.87072	7.945493	57.18379
343	81.93605	36.09756	8.240279	55.66216
344	82.08042	36.23693	8.715679	55.04739
345	81.65091	35.3022	9.370879	55.32692
346	85.82186	41.41079	8.303402	50.28581
347	83.87626	38.44949	8.191386	53.35912
348	81.75	33.1651	8.525451	58.30944
349	81.57071	31.83007	7.58	60.58993
350	81.68293	32.75632	8.024101	59.21957
351	82.32682	34.67337	8.325485	57.00115
352	82.77372	36.08757	7.387288	56.52514
353	81.3198	32.6087	3.089674	64.30163
354	80.22169	29.37205	7.677245	62.95071
355	74.6665	19.48819	4.364469	76.14734
356	81.85665	32.85322	7.174486	59.97229
357	81.44048	30.563	8.077882	61.35912
358	83.46315	34.92754	7.909565	57.1629
359	81.38198	30.05671	7.737618	62.20567
360	81.82175	31.02952	8.02203	60.94845
361	81.90499	29.59252	6.37996	64.02752
362	81.6465	29.82132	6.585213	63.59347
363	81.14326	28.49057	5.291698	66.21774
364	79.54284	25.40574	6.38764	68.20662
365	78.02849	23.02905	6.840871	70.13008
366	82.78051	31.91933	7.116134	60.96453
367	82.59939	30.29126	5.740194	63.96854
368	79.74338	27.44868	5.868387	66.68293

369	81.99008	30.40973	7.133547	62.45672
370	81.19172	31.22988	6.442756	62.32737
371	82.0365	31.48396	6.384225	62.13182
372	83.60209	35.93637	7.399132	56.6645
373	83.37048	35.59196	8.127476	56.28057
374	83.01985	35.07692	6.822	58.10108
375	81.29919	31.15578	6.713442	62.13078
376	78.06995	24.38325	6.91463	68.70212
377	79.09972	25.68157	7.687459	66.63097
378	79.21236	26.14861	8.512989	65.3384
379	81.51292	29.37205	11.82296	58.805
380	79.35743	26.57032	8.216231	65.21345
381	77.98699	26.72956	6.578868	66.69157
382	79.47382	28.80711	11.68744	59.50546
383	77.48812	25	25.47175	49.52825
384	77.69276	24.59103	28.44	46.96897
385	78.26945	24.74613	32.32945	42.92443
386	77.22587	23.61111	36.73025	39.65864
387	77.39783	23.1418	36.56141	40.29678
388	77.41611	23.22932	26.58068	50.19
389	76.60012	22.85419	32.21696	44.92885
390	72.57172	19.5122	40.10432	40.38349
391	69.31941	15.81971	53.05665	31.12364
392	65.13844	12.02572	69.82862	18.14566
393	65.54457	12.42904	63.1176	24.45336
394	68.92211	15.15371	51.73042	33.11588
395	67.35883	14.88095	58.62656	26.49249
396	61.05854	9.853138	71.77218	18.37469
397	65.50262	11.80466	68.47005	19.72529
398	64.26088	10.99646	70.3921	18.61144
399	66.35322	12.6478	68.19556	19.15665
400	62.76109	11.36773	68.47918	20.15309
401	64.65136	11.52439	68.49732	19.97829
402	66.23099	13.39784	60.59486	26.00729
403	67.56006	13.62114	66.26505	20.11381
404	66.65458	12.61784	67.28006	20.1021
405	61.20833	9.317938	72.54329	18.13878
406	61.51353	9.977324	72.11681	17.90586
407	61.04158	9.481865	76.34984	14.16829
408	57.99467	7.745176	80.1881	12.06672
409	59.6186	10.10771	70.46197	19.43032
410	63.27853	10.39349	73.6813	15.92521
411	63.12292	11.39204	67.40715	21.20081
412	63.10117	10.14447	75.70477	14.15075
413	60.46291	8.355508	79.63236	12.01213
414	61.33587	9.142709	74.62207	16.23522
415	59.00469	8.323396	75.87231	15.80429
416	63.26138	9.802211	72.55899	17.6388
417	61.71132	9.480813	74.23866	16.28053
418	59.97567	8.565902	75.02503	16.40906

419	60.18724	8.606061	78.39098	13.00296
420	58.78159	7.784279	80.00361	12.21211
421	62.19679	9.111111	75.54733	15.34156
422	64.84824	11.50316	67.84165	20.65519
423	64.48002	11.16348	64.56954	24.26698
424	64.58119	11.76641	66.5287	21.70488
425	61.12171	9.162803	75.03518	15.80202
426	61.8635	9.14446	71.76017	19.09537
427	67.83248	13.40028	64.64522	21.9545
428	57.61894	8.363434	67.22801	24.40856
430	63.10472	11.95021	59.94805	28.10174
431	72.9448	18.6422	45.48	35.8778
432	67.51099	13.72423	43.29684	42.97893
433	38.93404	7.870489	4.889071	87.24044
434	69.1358	14.45283	51.48679	34.06038
435	60.48605	8.377626	75.97267	15.64971
436	73.9321	19.79301	42.06753	38.13946
437	72.46531	18.64341	43.71721	37.63938
438	77.30435	24.42529	25.48448	50.09023
439	78.61001	28.5073	18.8862	52.60651
440	71.12484	20.09431	33.32231	46.58339
441	70.88825	17.81377	37.91395	44.27229
442	73.52774	20.56799	34.34484	45.08718
443	75.5787	23.22275	25.111	51.66626
444	73.35353	20.08421	30.16042	49.75537
445	73.51357	20.6639	29.43934	49.89676
446	75.85027	23.1178	24.87502	52.00717
447	77.21227	23.87844	17.77077	58.3508
448	74.75185	22.20828	20.35282	57.4389
449	72.4984	19.97673	22.05198	57.9713
450	73.3476	20.32108	24.97845	54.70046
451	68.41229	15.59536	29.71296	54.69168
452	70.83858	17.96783	28.99372	53.03845
453	72.62793	19.6929	29.24338	51.06372
454	72.12167	19.39773	33.61643	46.98584
455	71.07393	18.48771	33.44371	48.06858
456	70.2763	16.94673	33.17097	49.8823
457	69.9178	17.17134	35.85665	46.97201
458	71.81092	18.52986	32.99564	48.4745
459	69.00422	15.63284	43.70255	40.66461
460	68.12474	15.14369	47.87368	36.98263
461	72.16385	16.77469	48.3756	34.84971
462	66.40463	12.93468	54.31882	32.74651
463	68.5528	12.2408	44.3392	43.42
464	69.87159	14.29083	53.99936	31.70981
465	68.9999	13.80235	50.12704	36.07062
466	67.05491	12.6936	54.28505	33.02135
467	65.15609	12.29929	53.45434	34.24637
468	65.45455	12.33918	52.59456	35.06626
469	67.7318	14.38312	47.03045	38.58643

470	66.27271	13.07592	52.53368	34.3904
471	66.98954	13.73791	44.20614	42.05595
472	64.41863	12.81741	44.75133	42.43126
473	67.43264	15.45426	38.97677	45.56897
474	63.33402	11.2328	47.57456	41.19264
475	64.61039	16.03923	18.27257	65.6882
476	60.20478	13.26076	28.63597	58.10327
478	16.44378	2.433448	4.456639	93.10991
483	12.00347	1.916231	4.546967	93.5368

Appendix 2. Loss-on-ignition data table for Hundred Mile Lake Core II.

Depth (cm)	Moisture	Organic Matter	Carbonate	Silicates
357	84.32529	40.66714	5.648687	53.68417
358	84.61868	42.96657	4.433983	52.59944
359	82.71339	38.80597	5.373881	55.82015
360	82.91759	39.18669	4.763771	56.04954
361	84.12065	41.27095	5.875559	52.85349
362	83.63616	39.44828	10.03697	50.51476
363	84.50382	40.53483	4.800844	54.66432
364	84.35135	39.38332	5.577435	55.03924
365	85.0334	41.83056	5.676399	52.49304
366	84.10857	38.98072	6.107851	54.91143
367	84.0067	38.24145	7.140963	54.61759
368	82.84024	35.58881	6.065973	58.34522
369	82.95543	36.30406	5.811664	57.88427
370	83.66883	36.49025	5.384123	58.12563
371	83.23327	36.13281	6.217969	57.64922
372	81.79279	32.62175	5.764643	61.61361
373	81.50023	31.46766	5.939552	62.59279
374	82.73054	32.87101	4.888627	62.24036
375	79.54853	25.99186	5.089318	68.91882
376	82.22087	31.85438	5.820819	62.3248
377	83.44254	34.17085	5.570729	60.25842
378	83.50708	33.99867	6.051896	59.94943
379	83.55872	33.82808	5.625232	60.54669
380	83.09205	33.86581	5.666837	60.46735
381	79.59533	23.45226	5.010913	71.53683
382	81.94846	30.33846	6.017354	63.64418
383	82.19877	31.53094	5.925733	62.54332
384	81.25152	28.69226	7.249577	64.05817
385	80.90428	27.58186	6.587154	65.83098
386	76.09324	19.9298	5.587441	74.48276

387	83.75675	32.62562	7.242038	60.13234
388	83.60322	34.11602	5.025414	60.85856
389	83.22186	31.28378	5.377703	63.33851
390	81.49558	28.67514	6.190563	65.1343
391	82.87548	31.22945	5.980276	62.79027
392	83.86531	35.89395	6.183549	57.9225
393	85.65625	39.65382	6.440913	53.90527
394	84.44054	37.4247	5.821988	56.75331
395	83.73558	34.35673	6.150439	59.49284
396	77.54527	20.1352	4.282279	75.58252
397	81.9859	30.20222	5.191781	64.606
398	82.63192	34.28357	5.288372	60.42806
399	82.30523	34.44444	5.527083	60.02847
400	78.20455	24.81752	6.283733	68.89875
401	69.46029	15.33764	6.207759	78.4546
402	80.33322	25.96899	8.68804	65.34297
403	82.26468	29.45831	9.54997	60.99172
404	83.57058	32.27437	8.209386	59.51625
405	81.32203	27.82305	8.206519	63.97043
406	81.85776	29.46667	8.7928	61.74053
407	80.93096	26.87877	18.08722	55.03401
408	80.00428	25.1606	24.59036	50.24904
409	78.39062	23.42753	29.5392	47.03327
410	77.93805	24.83528	33.76999	41.39473
411	79.12334	23.62078	40.07209	36.30712
412	79.31149	25.22813	34.54332	40.22856
413	78.70671	25.15971	27.3774	47.4629
414	78.81827	26.351	30.07813	43.57087
415	75.69573	22.0476	38.59775	39.35465
416	73.24827	18.79547	47.24479	33.95974
417	70.28297	15.49543	59.2071	25.29747
418	67.22387	12.89111	67.16696	19.94193
419	69.59335	15.67038	51.53171	32.79791
420	70.21908	15.81299	57.22131	26.96569
421	66.15522	12.34279	67.50834	20.14887
422	65.54648	11.35488	71.1257	17.51942
423	67.11548	13.6063	65.74904	20.64466
424	67.02806	12.63701	71.62147	15.74152
425	69.45023	14.96251	61.15153	23.88596
426	69.96039	14.50304	62.57728	22.91968
427	69.79375	13.87665	64.25588	21.86746
428	70.10268	15.11785	63.0901	21.79205
429	65.89582	11.74891	69.00624	19.24485
430	64.89477	10.77962	70.08247	19.13791
431	65.28981	11.34535	69.82852	18.82613
432	63.33867	10.0519	76.02775	13.92035
433	64.03066	11.16806	69.74745	19.08449

434	64.41358	11.21495	73.38307	15.40198
435	66.32671	12.62396	66.12946	21.24658
436	64.92449	11.54599	71.90087	16.55315
437	66.21418	11.875	73.16054	14.96446
438	63.03709	8.72466	78.83433	12.44101
439	62.71107	8.930818	72.59638	18.47281
440	63.93795	9.929654	69.83198	20.23837
441	66.66013	11.41848	72.20853	16.37298
442	64.8492	9.698155	75.05852	15.24332
443	65.13255	9.327304	75.07157	15.60113
444	65.53837	10.20111	75.75581	14.04308
445	64.17585	9.445983	77.66875	12.88526
446	61.99291	7.772021	81.18062	11.04736
447	65.16237	9.715573	75.11692	15.1675
448	67.73775	11.41355	70.19647	18.38998
449	67.59514	11.34988	64.352	24.29812
450	67.87761	11.88388	64.36238	23.75373
451	69.11854	13.51706	63.19154	23.2914
452	68.65641	11.07166	76.7787	12.14964
453	67.3904	10.72343	71.84501	17.43156
454	73.17344	16.41623	60.82224	22.76153
455	72.08793	14.93094	49.82598	35.24308
456	71.986	14.40647	56.16053	29.433
457	66.09586	11.37881	45.41399	43.2072
458	75.51678	19.34663	52.77378	27.87959
459	65.36595	10.11267	71.98813	17.8992
460	66.66667	11.75932	66.81698	21.4237
461	69.80595	15.67968	53.10081	31.21952
462	62.02223	9.781772	58.79122	31.42701
463	39.64588	6.400853	11.12892	82.47022
464	38.79205	6.557582	8.691531	84.75089
465	67.3377	12.81972	69.5865	17.59378
466	66.96067	13.2556	67.40362	19.34078
467	65.4112	12.82942	66.84361	20.32696
468	74.1374	20.35046	47.99761	31.65193
469	76.07705	21.25541	48.53169	30.2129
470	79.67292	26.94965	35.01915	38.03119
471	74.50611	18.36818	48.01599	33.61583
472	79.43527	25.54404	29.80943	44.64653
473	74.96891	20.28986	41.99602	37.71412
474	77.44837	24.16138	31.74941	44.08921
475	80.97238	31.12583	18.07152	50.80265
476	75.52521	22.57511	29.18137	48.24352
477	74.05287	20.09627	36.48616	43.41757
478	73.21411	19.29177	35.81697	44.89126
479	75.11218	21.55136	32.79899	45.64964
480	77.3104	23.83562	25.6474	50.51699

481	76.41569	22.66187	30.77671	46.56142
482	76.97268	23.06517	32.7669	44.16792
483	73.17698	18.48034	25.09301	56.42665
484	79.81651	26.75026	17.94013	55.30961
485	78.63357	24.86428	14.69088	60.44484
486	76.88333	25.88288	17.48449	56.63263
487	75.83528	23.99824	20.82748	55.17428
488	75.52971	23.89643	19.59346	56.5101
489	77.05988	25.36801	20.53072	54.10128
490	73.15464	19.81279	25.54259	54.64462
491	70.03546	17.26418	29.83982	52.896
492	71.61847	19.87844	26.74816	53.3734
493	72.00269	19.56696	30.90962	49.52342
494	73.03065	20.86889	30.96098	48.17013
495	78.92886	29.77921	40.16543	30.05536
496	72.27151	20.81727	31.73431	47.44842
497	70.85083	18.42305	34.91168	46.66528
498	70.55522	18.07352	35.21681	46.70967
499	71.11706	18.29101	34.18023	47.52876
500	70.11886	15.66932	44.91366	39.41702
501	70.06159	15.79721	52.96532	31.23747
502	69.78425	16.36488	44.43895	39.19617
503	68.73203	14.58465	53.6416	31.77375
504	74.27184	16.8495	35.62168	47.52883
505	68.01681	15.38232	49.37867	35.23901
506	67.42396	15.51381	48.67771	35.80848
507	66.363	15.17857	49.94679	34.87464
508	66.99949	14.51065	53.00617	32.48317
509	67.16477	14.40627	50.03074	35.56299
510	65.75966	12.93735	53.0415	34.02116
511	69.2767	15.86493	47.30558	36.8295
512	68.91733	16.22131	43.75002	40.02867
513	69.54436	15.98425	44.31614	39.69961
514	72.62719	18.46935	35.60617	45.92448
515	71.63624	18.65125	32.77364	48.57511
516	64.90525	12.60785	44.93571	42.45644
517	67.5481	16.23054	33.82001	49.94945
518	62.58035	11.73006	44.08491	44.18503
519	64.01665	15.50964	22.74	61.75036
520	58.31874	8.823529	55.51738	35.65909
521	53.69536	8.44775	50.08524	41.46701
522	52.66311	8.206447	20.01048	71.78307
523	55.15847	9.403811	27.9067	62.68949
524	50.46522	7.21592	28.92721	63.85687
525	44.89847	5.944798	12.62184	81.43336
526	22.51068	2.610587	4.765671	92.62374
528	17.42181	2.267696	4.871011	92.86129

530	17.01431	2.379892	4.61601	93.0041
532	17.83184	2.270293	4.894774	92.83493
534	17.60445	2.242214	4.850828	92.90696
536	17.51577	2.301177	5.215831	92.48299
538	15.17452	1.707029	5.128374	93.1646
540	11.59732	1.652361	4.603305	93.74433
542	5.33798	1.422297	4.01434	94.56336
544	7.905739	1.599257	4.927156	93.47359
546	4.030463	1.1852	4.265361	94.54944
548	11.12134	1.755497	4.279947	93.96456
549	13.51746	1.90399	4.483208	93.6128

Appendix 3. Loss-on-ignition data of composite core from Hundred Mile Lake on depth and age scales.

Age (cal BP)	Depth (cm)	Moisture (%)	Organic Matter (%)	Carbonate (%)	Silicate (%)
-54	257	80.05819	33.98176	8.708936	57.3093
-0.4	258	79.91891	31.7696	8.912352	59.31805
106.8	260	79.49317	32.40319	9.712415	57.8844
213.9	262	79.24252	30.72396	8.699823	60.57622
321.1	264	79.53349	32.32028	9.170427	58.50929
428.3	266	80.3085	31.5856	7.900821	60.51358
535.5	268	80.65633	32.20676	8.589662	59.20358
642.7	270	80.62306	32.42161	10.16398	57.41441
749.8	272	79.77486	31.97279	9.000371	59.02684
857.0	274	80.17008	31.3238	9.751771	58.92443
964.2	276	80.41395	32.0287	8.010176	59.96112
1071.4	278	80.82192	33.24433	8.045527	58.71015
1178.5	280	80.13033	33.29208	9.146658	57.56126
1285.7	282	81.15278	32.56558	9.165835	58.26859
1392.9	284	81.33523	34.43456	9.67967	55.88577
1500.1	286	81.9539	33.96226	8.581132	57.4566
1607.2	288	80.91791	33.73984	8.935772	57.32439
1714.4	290	81.96328	34.33134	8.321357	57.34731
1821.6	292	81.39358	34.31105	8.06603	57.62292
1928.8	294	80.3607	33.62888	7.920836	58.45028
2036.0	296	80.77781	32.99492	7.420595	59.58448
2143.1	298	82.23819	33.45376	8.051012	58.49523
2250.3	300	81.2766	35.72443	6.298722	57.97685
2357.5	302	80.7142	33.5522	8.212081	58.23572
2464.7	304	81.80645	35.8156	8.870213	55.31418
2571.8	306	81.38189	33.41969	8.542228	58.03808
2679.0	308	82.01675	37.11201	9.053036	53.83495
2786.2	310	82.3418	36.12303	9.434335	54.44263
2893.4	312	82.05337	37.43396	9.267623	53.29842

3000.6	314	79.97635	35.03937	9.251181	55.70945
3107.7	316	81.14909	35.26053	9.414133	55.32534
3214.9	318	80.85135	35.47038	8.874146	55.65547
3322.1	320	81.81818	36.16398	8.989458	54.84656
3429.3	322	82.60204	38.70968	9.836217	51.45411
3536.4	324	82.83235	38.75458	9.162637	52.08278
3643.6	326	81.79799	38.98062	8.978464	52.04092
3750.8	328	81.07352	35.53835	9.441661	55.01999
3858.0	330	81.03494	37.34177	8.155696	54.50253
3911.6	331	78.45918	30.42705	8.497153	61.0758
3965.1	332	76.74072	28.01494	8.130096	63.85496
4018.7	333	76.7934	27.83669	7.716649	64.44666
4072.3	334	63.6226	15.20973	7.354275	77.43599
4125.9	335	37.48654	6.533601	5.159276	88.30712
4179.5	336	82.46273	37.25055	8.571619	54.17783
4233.1	337	82.37873	38.92456	9.855217	51.22022
4340.3	339	84.73784	44.12252	8.471026	47.40646
4447.4	341	78.42155	35.88457	7.988959	56.12647
4554.6	343	76.39964	26.30446	6.605487	67.09005
4661.8	345	76.3123	24.79015	8.271405	66.93844
4769.0	347	74.21456	23.8732	9.235661	66.89113
4876.2	349	73.00337	21.2037	6.6325	72.1638
4983.3	351	72.42252	21.69725	7.406147	70.89661
5090.5	353	78.21508	30.72519	9.547328	59.72748
5197.7	355	75.73448	25.88652	5.990274	68.1232
5251.3	356	70.46943	16.94852	4.358286	78.6932
5304.9	357	77.83181	28.14339	6.691814	65.16479
5358.5	358	82.80356	41.85552	8.857649	49.28683
5412.0	359	81.40005	37.02446	8.34212	54.63342
5465.6	360	82.3573	37.32493	7.32521	55.34986
5519.2	361	82.85926	35.13709	7.711255	57.15166
5572.8	362	86.66667	43.43525	7.770863	48.79388
5626.4	363	87.08963	43.90476	8.229714	47.86552
5680.0	364	85.42061	41.28015	8.015955	50.7039
5733.6	365	86.23609	42.62848	8.237742	49.13378
5787.2	366	87.52449	45.63297	7.587439	46.77959
5840.8	367	82.29399	34.87072	7.945493	57.18379
5894.3	368	81.93605	36.09756	8.240279	55.66216
5947.9	369	82.08042	36.23693	8.715679	55.04739
6001.5	370	81.65091	35.3022	9.370879	55.32692
6055.1	371	85.82186	41.41079	8.303402	50.28581
6108.7	372	83.87626	38.44949	8.191386	53.35912
6162.3	373	81.75	33.1651	8.525451	58.30944
6215.9	374	81.57071	31.83007	7.58	60.58993
6269.5	375	81.68293	32.75632	8.024101	59.21957
6323.0	376	82.32682	34.67337	8.325485	57.00115
6376.6	377	82.77372	36.08757	7.387288	56.52514
6430.2	378	81.3198	32.6087	3.089674	64.30163
6483.8	379	80.22169	29.37205	7.677245	62.95071
6537.4	380	74.6665	19.48819	4.364469	76.14734

6591.0	381	81.85665	32.85322	7.174486	59.97229
6644.6	382	81.44048	30.563	8.077882	61.35912
6698.2	383	83.46315	34.92754	7.909565	57.1629
6751.8	384	81.38198	30.05671	7.737618	62.20567
6805.3	385	81.82175	31.02952	8.02203	60.94845
6858.9	386	81.90499	29.59252	6.37996	64.02752
6912.5	387	81.6465	29.82132	6.585213	63.59347
6966.1	388	81.14326	28.49057	5.291698	66.21774
7019.7	389	79.54284	25.40574	6.38764	68.20662
7073.3	390	78.02849	23.02905	6.840871	70.13008
7126.9	391	82.78051	31.91933	7.116134	60.96453
7180.5	392	82.59939	30.29126	5.740194	63.96854
7234.1	393	79.74338	27.44868	5.868387	66.68293
7287.6	394	81.99008	30.40973	7.133547	62.45672
7341.2	395	81.19172	31.22988	6.442756	62.32737
7394.8	396	82.0365	31.48396	6.384225	62.13182
7448.4	397	83.60209	35.93637	7.399132	56.6645
7502.0	398	83.37048	35.59196	8.127476	56.28057
7555.3	399	83.01985	35.07692	6.822	58.10108
7608.6	400	81.29919	31.15578	6.713442	62.13078
7662.0	401	78.06995	24.38325	6.91463	68.70212
7715.3	402	79.09972	25.68157	7.687459	66.63097
7768.6	403	79.21236	26.14861	8.512989	65.3384
7821.9	404	81.51292	29.37205	11.82296	58.805
7875.3	405	79.35743	26.57032	8.216231	65.21345
7928.6	406	77.98699	26.72956	6.578868	66.69157
7981.9	407	80.93096	26.87877	18.08722	55.03401
8035.2	408	80.00428	25.1606	24.59036	50.24904
8088.6	409	78.39062	23.42753	29.5392	47.03327
8141.9	410	77.93805	24.83528	33.76999	41.39473
8195.2	411	79.12334	23.62078	40.07209	36.30712
8248.5	412	79.31149	25.22813	34.54332	40.22856
8301.8	413	78.70671	25.15971	27.3774	47.4629
8355.2	414	78.81827	26.351	30.07813	43.57087
8408.5	415	75.69573	22.0476	38.59775	39.35465
8461.8	416	73.24827	18.79547	47.24479	33.95974
8515.1	417	70.28297	15.49543	59.2071	25.29747
8568.5	418	67.22387	12.89111	67.16696	19.94193
8621.8	419	69.59335	15.67038	51.53171	32.79791
8675.1	420	70.21908	15.81299	57.22131	26.96569
8728.4	421	66.15522	12.34279	67.50834	20.14887
8781.8	422	65.54648	11.35488	71.1257	17.51942
8835.1	423	67.11548	13.6063	65.74904	20.64466
8888.4	424	67.02806	12.63701	71.62147	15.74152
8941.7	425	69.45023	14.96251	61.15153	23.88596
8995.0	426	69.96039	14.50304	62.57728	22.91968
9048.4	427	69.79375	13.87665	64.25588	21.86746
9101.7	428	70.10268	15.11785	63.0901	21.79205

9155.0	429	65.89582	11.74891	69.00624	19.24485
9208.3	430	64.89477	10.77962	70.08247	19.13791
9261.7	431	65.28981	11.34535	69.82852	18.82613
9315.0	432	63.33867	10.0519	76.02775	13.92035
9368.3	433	64.03066	11.16806	69.74745	19.08449
9421.6	434	64.41358	11.21495	73.38307	15.40198
9475.0	435	66.32671	12.62396	66.12946	21.24658
9528.3	436	64.92449	11.54599	71.90087	16.55315
9581.6	437	66.21418	11.875	73.16054	14.96446
9634.9	438	63.03709	8.72466	78.83433	12.44101
9688.2	439	62.71107	8.930818	72.59638	18.47281
9741.6	440	63.93795	9.929654	69.83198	20.23837
9794.9	441	66.66013	11.41848	72.20853	16.37298
9848.2	442	64.8492	9.698155	75.05852	15.24332
9901.5	443	65.13255	9.327304	75.07157	15.60113
9954.9	444	65.53837	10.20111	75.75581	14.04308
10008.2	445	64.17585	9.445983	77.66875	12.88526
10061.5	446	61.99291	7.772021	81.18062	11.04736
10114.8	447	65.16237	9.715573	75.11692	15.1675
10168.2	448	67.73775	11.41355	70.19647	18.38998
10221.5	449	67.59514	11.34988	64.352	24.29812
10274.8	450	67.87761	11.88388	64.36238	23.75373
10328.1	451	69.11854	13.51706	63.19154	23.2914
10381.4	452	68.65641	11.07166	76.7787	12.14964
10434.8	453	67.3904	10.72343	71.84501	17.43156
10488.1	454	73.17344	16.41623	60.82224	22.76153
10541.4	455	72.08793	14.93094	49.82598	35.24308
10594.7	456	71.986	14.40647	56.16053	29.433
10648.1	457	66.09586	11.37881	45.41399	43.2072
10701.4	458	75.51678	19.34663	52.77378	27.87959
10754.7	459	65.36595	10.11267	71.98813	17.8992
10808.0	460	66.66667	11.75932	66.81698	21.4237
10861.4	461	69.80595	15.67968	53.10081	31.21952
10914.7	462	62.02223	9.781772	58.79122	31.42701
10968.0	463	39.64588	6.400853	11.12892	82.47022
10993.5	464	38.79205	6.557582	8.691531	84.75089
11019.0	465	67.3377	12.81972	69.5865	17.59378
11056.8	466	66.96067	13.2556	67.40362	19.34078
11094.6	467	65.4112	12.82942	66.84361	20.32696
11132.4	468	74.1374	20.35046	47.99761	31.65193
11170.2	469	76.07705	21.25541	48.53169	30.2129
11208.0	470	79.67292	26.94965	35.01915	38.03119
11245.8	471	74.50611	18.36818	48.01599	33.61583
11283.6	472	79.43527	25.54404	29.80943	44.64653
11321.4	473	74.96891	20.28986	41.99602	37.71412
11359.3	474	77.44837	24.16138	31.74941	44.08921
11397.1	475	80.97238	31.12583	18.07152	50.80265

11434.9	476	75.52521	22.57511	29.18137	48.24352
11472.7	477	74.05287	20.09627	36.48616	43.41757
11510.5	478	73.21411	19.29177	35.81697	44.89126
11548.3	479	75.11218	21.55136	32.79899	45.64964
11586.1	480	77.3104	23.83562	25.6474	50.51699
11623.9	481	76.41569	22.66187	30.77671	46.56142
11661.7	482	76.97268	23.06517	32.7669	44.16792
11699.5	483	73.17698	18.48034	25.09301	56.42665
11737.3	484	79.81651	26.75026	17.94013	55.30961
11775.1	485	78.63357	24.86428	14.69088	60.44484
11812.9	486	76.88333	25.88288	17.48449	56.63263
11850.7	487	75.83528	23.99824	20.82748	55.17428
11888.5	488	75.52971	23.89643	19.59346	56.5101
11926.3	489	77.05988	25.36801	20.53072	54.10128
11964.1	490	73.15464	19.81279	25.54259	54.64462
12001.9	491	70.03546	17.26418	29.83982	52.896
12039.8	492	71.61847	19.87844	26.74816	53.3734
12077.6	493	72.00269	19.56696	30.90962	49.52342
12115.4	494	73.03065	20.86889	30.96098	48.17013
12153.2	495	78.92886	29.77921	40.16543	30.05536
12191.0	496	72.27151	20.81727	31.73431	47.44842
12228.8	497	70.85083	18.42305	34.91168	46.66528
12266.6	498	70.55522	18.07352	35.21681	46.70967
12304.4	499	71.11706	18.29101	34.18023	47.52876
12342.2	500	70.11886	15.66932	44.91366	39.41702
12380.0	501	70.06159	15.79721	52.96532	31.23747
12424.3	502	69.78425	16.36488	44.43895	39.19617
12468.7	503	68.73203	14.58465	53.6416	31.77375
12513.0	504	74.27184	16.8495	35.62168	47.52883
12557.4	505	68.01681	15.38232	49.37867	35.23901
12601.7	506	67.42396	15.51381	48.67771	35.80848
12646.1	507	66.363	15.17857	49.94679	34.87464
12690.4	508	66.99949	14.51065	53.00617	32.48317
12734.8	509	67.16477	14.40627	50.03074	35.56299
12779.1	510	65.75966	12.93735	53.0415	34.02116
12823.5	511	69.2767	15.86493	47.30558	36.8295
12867.8	512	68.91733	16.22131	43.75002	40.02867
12912.2	513	69.54436	15.98425	44.31614	39.69961
12956.5	514	72.62719	18.46935	35.60617	45.92448
13000.9	515	71.63624	18.65125	32.77364	48.57511
13045.2	516	64.90525	12.60785	44.93571	42.45644
13089.6	517	67.5481	16.23054	33.82001	49.94945
13133.9	518	62.58035	11.73006	44.08491	44.18503
13178.3	519	64.01665	15.50964	22.74	61.75036
13222.6	520	58.31874	8.823529	55.51738	35.65909
13267.0	521	53.69536	8.44775	50.08524	41.46701
13311.3	522	52.66311	8.206447	20.01048	71.78307

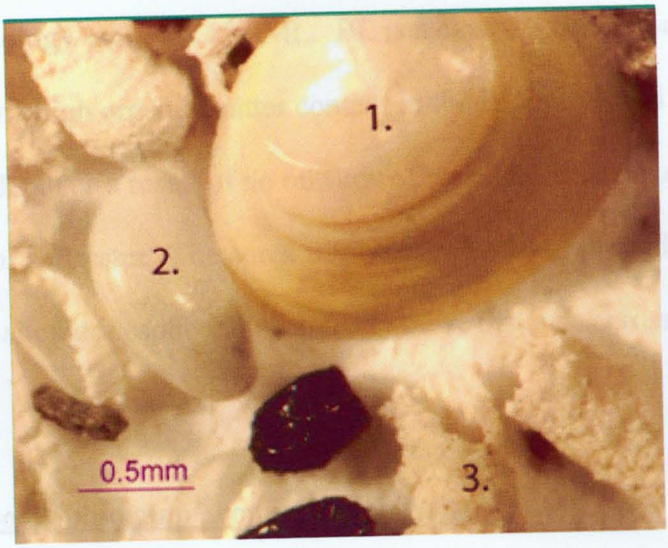
13355.7	523	55.15847	9.403811	27.9067	62.68949
13400.0	524	50.46522	7.21592	28.92721	63.85687
13444.3	525	44.89847	5.944798	12.62184	81.43336
13488.7	526	22.51068	2.610587	4.765671	92.62374
13577.4	528	17.42181	2.267696	4.871011	92.86129
13666.1	530	17.01431	2.379892	4.61601	93.0041
13754.8	532	17.83184	2.270293	4.894774	92.83493
13843.5	534	17.60445	2.242214	4.850828	92.90696
13932.2	536	17.51577	2.301177	5.215831	92.48299
14020.9	538	15.17452	1.707029	5.128374	93.1646
14109.6	540	11.59732	1.652361	4.603305	93.74433
14198.3	542	5.33798	1.422297	4.01434	94.56336
14287.0	544	7.905739	1.599257	4.927156	93.47359
14375.7	546	4.030463	1.1852	4.265361	94.54944
14464.3	548	11.12134	1.755497	4.279947	93.96456
14508.7	549	13.51746	1.90399	4.483208	93.6128

Appendix 4. Pollen counts of core II from Hundred Mile Lake.

Depth (cm)	Betula	Alnus	Picea	Pinus	Salix	Ericaceae	Caryophyllaceae	Artemisia	Ambrosia	Cyperaceae	Epilobium latifolium	Poaceae	Pediastrum	Polypodiaceae	Pre-Quaternary	Indeterminable	Unknown	Lycopodium
409	106	75	6	39	5	0	0	2	0	4	0	0	13	0	0	0	0	47
419	74	102	0	4	7	0	0	7	1	4	0	0	10	8	0	0	0	60
426	53	128	2	1	10	0	0	7	0	3	0	1	6	18	1	0	1	130
433	138	37	0	0	18	1	0	15	0	10	0	1	30	19	6	0	0	166
440	154	3	0	0	17	0	0	11	1	14	0	3	18	17	5	0	0	109
447	131	12	0	0	13	0	0	8	0	10	0	7	26	30	3	0	2	151
456	155	3	0	0	21	0	0	13	0	15	3	6	31	11	2	4	3	244
464	113	0	0	0	16	2	3	6	0	25	3	4	22	24	9	7	8	230
471	216	0	0	0	9	0	0	3	0	4	0	2	30	0	0	2	1	148
476	183	3	0	0	7	3	0	22	0	10	0	0	26	1	0	0	0	134
478	178	1	0	0	15	0	1	13	0	11	0	2	122	0	0	2	2	110
483	152	12	0	0	6	2	1	15	2	7	1	2	26	0	0	0	0	196
490	200	13	0	0	3	1	0	10	0	7	0	0	2	0	0	0	0	176
497	207	10	0	0	3	1	0	10	0	2	0	0	5	0	0	0	0	202
504	148	23	0	0	3	2	2	16	1	9	1	1	0	1	0	0	0	167
511	207	1	0	0	7	0	1	5	2	5	0	2	48	1	0	1	1	108
518	21	4	0	0	52	3	10	68	5	26	0	8	3	3	5	0	0	372
525	19	21	0	0	39	1	9	72	7	42	0	17	107	2	17	2	0	200

Appendix 5. Photograph of carbonate materials used for isotopic analysis.

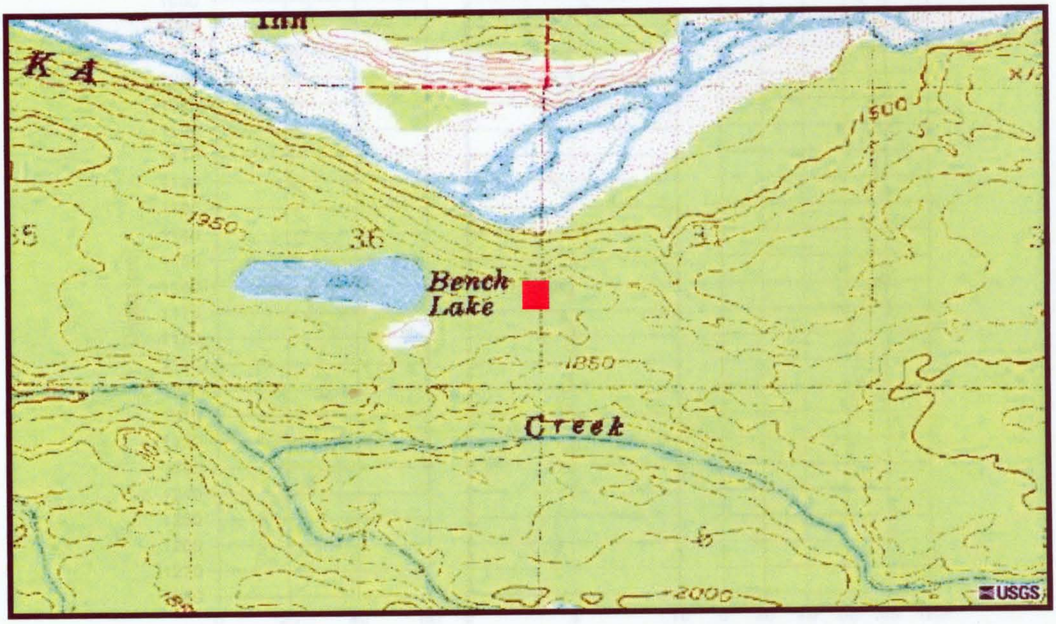
Stable isotopes (O, C) from **(1)** *Pisidium* mollusk shells, **(2)** ostracode shells, and **(3)** *Chara* encrustations were analyzed in the stable isotope lab at Lehigh University.



Appendix 6. Site Location information for Bench Lake.

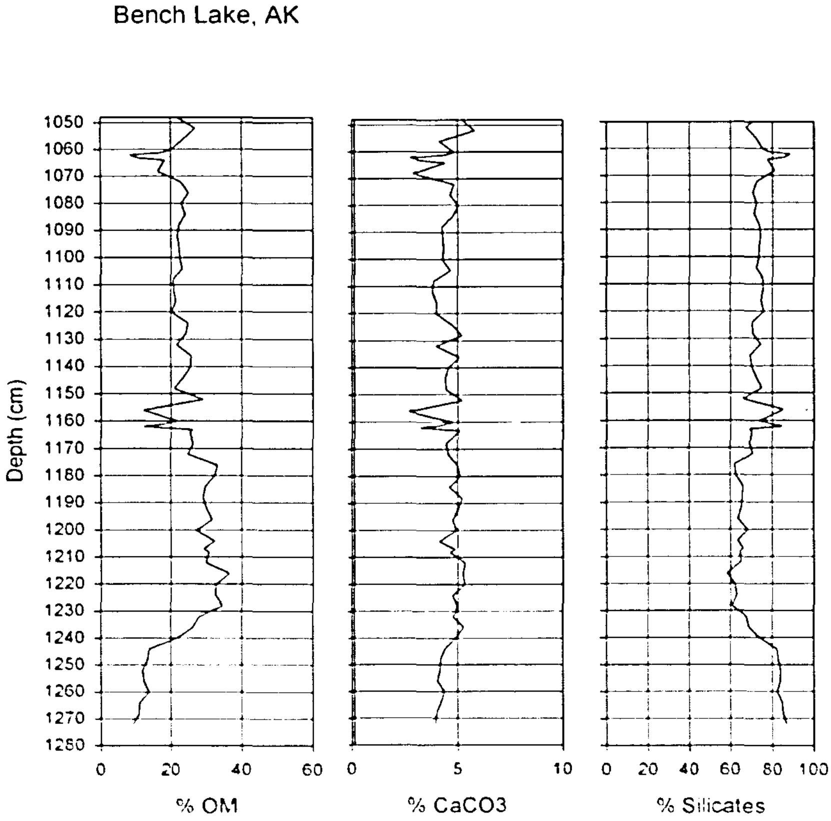
Bench Lake sits on top of a topographic bench at approximately 460.2 m above sea-level and is located at 61.778° north and 147.923° west. BL is comparable in size and surrounding geology with that of HML. BL is a closed basin seepage lake. The lack of marl sediment and high organic matter content in the BL core could be due to overall deeper lake water depth as a result of no outflow of water from the lake in juxtaposition with the presence of softwater. The cores from these two lakes proved to be very different from one another despite their relatively close distance across the Matanuska River.

Appendix 7. Topographic map around Bench Lake.



Appendix 8. Loss-on-ignition analysis and results from Bench Lake.

The core from Bench Lake was taken under 1045 cm of water. Lithology was completed on BL in order to corroborate signals detected in HML. Lithology of the 277 cm long BL core is predominately dark organic material and fine silts with approximately 11 cm of basal mineral/clay material. LOI analysis completed for BL indicates an abundance of silicate materials and a very low CaCO3 percentage. This is a dramatic contrast with that of HML, where CaCO3 percentages were much greater.



Vita

Karina Nicole Walker, the daughter of Randy and Jane Walker, was born and raised in Cherokee, Iowa spending a fair amount of time at the family gravel pit. Karina graduated from Cherokee Washington High School in 1999. She then earned a B.S. degree in Environmental Geology in May of 2003 at Northwest Missouri State University in Maryville, Missouri. Karina was accepted into the Department of Earth and Environmental Sciences in 2003. While at Lehigh Karina was a T.A. for the department, including the summer Lehigh Field Camp.

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TITLE