KECK GEOLOGY CONSORTIUM

PROCEEDINGS OF THE TWENTY-FOURTH ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

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Keck Geology Consortium: Projects 2010-2011
Short Contributions— Glacier National Park

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VEGETATION HISTORY OF THE LATE HOLOCENE IN EAST GLACIER NATIONAL PARK, MONTANA: A PALEOENVIRONMENTAL STUDY

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Research Advisor: Louisa Bradtmiller

INTRODUCTION

The Medieval Warm Period (MWP) was first identified as a prolonged interval of warmth from about 900-1200 AD throughout Northern Europe (Lamb, 1965). Palynological and tree ring evidence from other sites in the Northern Hemisphere, such as the Western United States, suggest that the anomaly may have affected more than just the Northern European region (e.g., Cook et al., 2004; Whitlock et al., Power et al., 2008). However, various parts of the northern hemisphere experienced peak temperatures at different times, and some parts of the world, including Siberia and China, experienced cooling during portions of the MWP (Crowley and Lowrey, 2000). Lamb (1965) also discussed the Little Ice Age (LIA), a period of modest cooling in Northern Europe from 1400-1800 AD. Outside of Northern Europe, the large-scale signature becomes more varied, with different regions experiencing colder conditions anywhere from the 13th to the 19th centuries.

The apparent temporal and spatial variability of both the MWP and LIA suggests that more research is necessary to determine how these climate anomalies extended across the northern hemisphere. In addition to reconstructing climatic parameters such as temperature and precipitation, it can also be instructive to examine the changes in vegetation that result from climate variability since these records tend to integrate over time and space. High elevation and alpine settings such as the Northern Rocky Mountains are of particular interest because of their increased sensitivity to variation in climate, but there are few records from alpine areas due to the difficulty and expense of accessing such regions. This study uses a record of pollen accumulated in alpine lake sediment to examine the response of vegetation to climate changes during the MWP and the LIA.

METHODS AND FIELD SETTING

Field Setting and Vegetation

Swiftcurrent Lake is located to the east of the Continental Divide in Many Glacier Valley, Glacier National Park, Montana, USA, at an elevation of 1,488 m. Swiftcurrent Lake is 1.6 km long and ~0.5 km wide. The forest surrounding Swiftcurrent Lake is characterized as Rocky Mountain Cordilleran Flora (Lesica, 2002). The primary arboreal species are *Pinus flexilis* (limber pine), *Pinus contorta* var. *latifolia* (lodgepole pine), *Abies lasiocarpa* (sub-alpine fir), *Picea englemannii* (Englemann spruce), and *Alnus viridis* (mountain alder). This study tracks changes in the relative amounts of the various taxa, which reflects the response of the vegetation to climate changes. Each species has a particular climatic significance that reflects both temperature and available moisture (see Table 1). Xeric (adapted to drier environments) pollen taxa include arboreal members (*Pinus flexilis* and *Pinus contorta*) and herbaceous members (*Artemisia* and Poaceae, and *Chenopodiaceae*). Several arboreal (*Abies lasiocarpa*, *Picea engelmannii*, and *Alnus*

Species Name	Common Name	Climate Associations
Abies lasiocarpa	Subalpine Fir	Cold, high elevations; long winters with precipitation and a short growing season with frequent summer frosts; drier, lower parts of the upper elevation
Alnus viridis-type	Alder	Cool, moist
Picea engelmannii	Engelmann Spruce	Cold, high elevations; long, cold winters and short, cool, moist summers
Pinus contorta var. *latifolia*	Lodgepole Pine	Varied climates, Precipitation ~46 cm/year
Pinus flexilis	Limber pine	Varied climates, can survive droughts
Psuedotsuga menziesii	Douglas Fir	Mild temperatures, moist

Table 1. The key pollen taxa are listed with their climate associations.

viridis-type) constitute the mesic (moisture dependent) pollen taxa. Small xeric to mesic ratios reflect a more moist precipitation regime, while large ratios indicate a drier climate.

Field and Laboratory Methods

Lake core SWF-05-3A was taken from the southwest basin in July 2005 using Bolivia and Livingstone-type coring techniques (Wright, 1991). The 6.58-meter core was taken ~200 m from the shorelines and downstream from the low-gradient inlet stream from Lake Josephine, thereby avoiding deltaic features (see project summary Figure 2). The cores were taken to LacCore, University of Minnesota – Minneapolis, where they were logged, split, photographed, and described using smear slides. The cores are stored in the LacCore repository. Chronology for core SWF-05-3A was established using four calibrated radiocarbon ages, the Mazama ash age of 7630 ± 150 years, and 210Pb data from a core from the same location in the summer of 2010, SWF-10.

Pollen analysis

During the summer of 2010, 20 1-cm3 samples were extracted at 3-5 cm intervals and submitted to LacCore for pollen processing methods adapted from Faegri and Iversen (1975). Pollen taxa were identified to species, genus, or family based on modern phytogeography and comparison with pollen reference slides. Key pollen taxa (*Pinus, Picea, Abies, Alnus, Artemisia,* Poaceae*,* and fern spores) constituted the majority of pollen counted and were selected for the purpose of constraining pollen-vegetation relationships. The pollen assemblage diagrams were divided into four pollen assemblage zones based on a constrained cluster analysis of the key pollen taxa counts (Fig. 1), arboreal pollen to non-arboreal pollen (AP/NAP) and xeric to mesic pollen taxa ratios (Fig. 2). The pollen graph (Fig. 1) was created from sample depths.

RESULTS

The cluster analysis, AP/NAP and xeric to mesic pollen ratios indicated four distinct pollen assemblage zones. All zones were dominated by arboreal pollen,

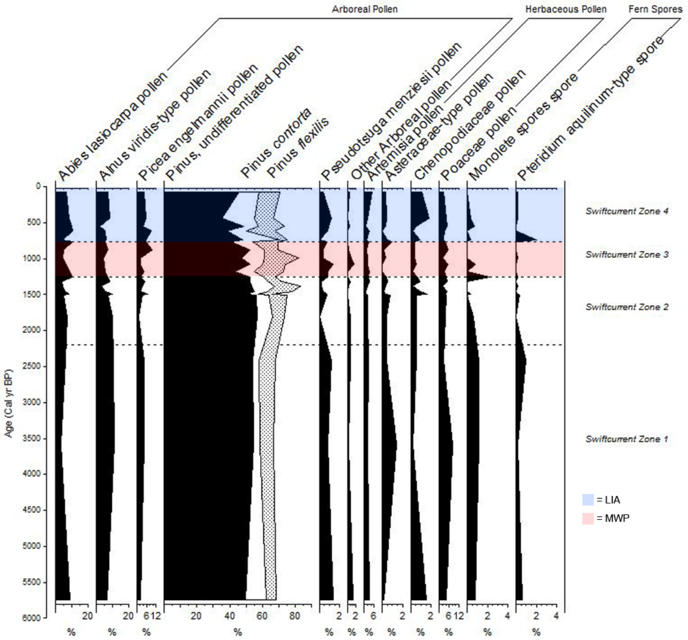

Figure 1. A pollen percentage diagram showing the delineation between the four pollen assemblage zones. The graph is based on the depths of the samples. See 'Pollen analysis' for how zones were delineated.

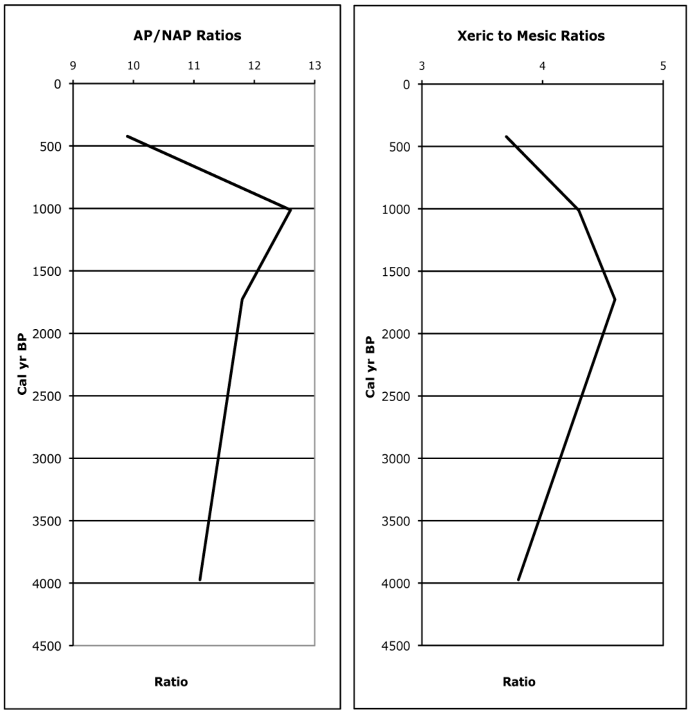

Figure 2. Arboreal to non-arboreal pollen ratios and xeric to mesic pollen ratios are shown. The average ratio for each zone is shown at the mid-point of the time interval of each zone. See 'Field Setting and Vegetation' for definitions of xeric and mesic taxa.

primarily *Pinus* pollen. Swiftcurrent Zone 3 (1255-770 cal yr BP) and Swiftcurrent Zone 4 (770-75 cal yr BP) overlap with the MWP and the LIA. See Figures 1 and 2 for specific values for each of the 20 samples and the average AP/NAP and xeric to mesic pollen ratios.

DISCUSSION

Swiftcurrent Zone 1 vegetation and climatic reconstruction (5660 - 2200 cal yr BP)

Less forest cover and slightly more xeric taxa characterize Zone 1 of Swiftcurrent Lake. When compared with modern pollen rain studies from the Yellowstone National Park region, Zone 1 represents a period of steppe vegetation with patches of forest (Whitlock, 1993). Steppe vegetation most likely grew on the dry slopes, while the *Picea/Abies/Pinus* forest cover grew in the low, cool valley around the lake and in upper elevations where cooler temperatures prevent the growth of steppe vegetation.

Specifically, the Zone 1 levels of *Picea engelmannii* (3.7%) and *Poaceae* (5%) are similar to the modern pollen rain of steppe vegetation (Whitlock, 1993). Lower levels of *Artemisia* pollen (2.6%) and higher levels of *Abies lasiocarpa* pollen (6.3%) more closely align with the *Picea/Abies/Pinus* forest type. This bimodal pollen record most likely reflects the large change in elevations from the base of the valley floor (1488 m) to the upper reaches of the valley (2000 m). Steppe vegetation most likely grew on the dry slopes, while the *Picea/Abies/Pinus* forest cover grew in the low, cool valley around the lake and in upper elevations where cooler temperatures prevent the growth of steppe vegetation.

Swiftcurrent Zone 2 vegetation and climate reconstruction (2200 - 1050 cal yr BP)

The increase in *Pinus* pollen and decrease of Abies lasiocarpa, *Alnus viridis, Artemisia*, and *Poaceae* indicate the initial development of forest at the expense of steppe vegetation in Zone 2. Decreased amounts of *A. lasiocarpa, A. viridis,* and *P. engelmanni* pollen possibly reflect a slow and steady warming throughout the time period. Arboreal to non-arboreal pollen ratios increased suggesting an increase in forest cover. The increase in the xeric to mesic pollen ratio indicates decreased moisture availability. Total conifer taxa (*Pinus, Abies, and Picea*) increased, which suggests and expansion of a *Picea/Abies/Pinus* forest that characterizes modern vegetation. The high percentages of *Pinus* likely reflects a cool, dry forest. A. lasiocarpa is an indicator of cool, moist climate, and thus the decrease in Abies alongside the increase in the xeric to mesic ratio suggests a drier climate. The persistence of high *P. engelmannii* indicates that the climate was not warming, as *Picea* grows in colder conditions.

Two potential explanations exist for the change in pollen abundance, specifically the increase in Pinus, the maintainance of high *P. engelmannii*, and the decrease in *A. lasiocarpa*. The transition from steppe to a developing forest may be the result of a decrease in available moisture. However, as the abundance of *P. engelmannii* did not change and it is characteristic of cold and moister conditions, this does not fully explain the change in vegetation. Alternatively, the increase of *Pinus* and the decrease in *Abies lasiocarpa* could be argued as an indication of changing seasonality. *Pinus contorta* and *P. flexilis* are suited for a variety of growing seasons, but generally dominate in longer summers. Both *A. lasiocarpa* and *P. engelmannii* require long, cold winters and short, cool summers to germinate and grow (Uchytil, 1991a, 1991b). If the summer season became either warmer or wetter in the valley, then both *Picea* and *Abies* would be affected. Because the abundance of *Picea* did not change, the argument for a warmer summer does not hold, but a wetter summer could explain the decrease in *Abies*. The average January and July precipitation for *P. engelmannii* are 24 mm and 200 mm respectively, while the mean values for *A. lasiocarpa* are 125 mm and 75 mm respectively. However, the increase in the xeric to mesic pollen ratio indicates that total moisture availability decreased. If the summers between 2200 and 1255 cal yr BP became slightly wetter and the winters drier, then *A. lasiocarpa* would decrease in abundance. The lack of change in the abundance of *A. engelmanni* may indicate the rate at which *Pinus* replaced the *A. lasiocarpa* to become the dominant species in the lower parts of the valley.

Swiftcurrent Zone 3 vegetation and climate reconstruction (1050 - 565 cal yr BP)

The decrease in the AP/NAP ratio (11.8 to 11.1) indicates a slight contraction of the forest cover and an increase in steppe vegetation during this period. The average percentage of *A. lasiocarpa* and *P. engelmannii* increased relative to *Pinus*. This most likely represents the fluctuation of the modern *Picea/Abies/Pinus* forest and steppe vegetation of the lowest part of the valley. *Alnus viridis* decreased <1% compared to Zone 2, and thus does not significantly affect the interpretation of climate. While the averages of *A. lasiocarpa* and *P. engelmannii* pollen increased, it is telling to examine each of the taxa through Zone 3. At the beginning of Zone 3, *A. lasiocarpa* abundance is at a high value (11%), and decreases steadily to a minimum value (5.2%) in the youngest sample of this zone. *P. engelmannii* abundance fluctuates between 2.2% and 4.8% in the first part of Zone 3, and then increases to the highest value of any of the *Picea* samples (9.8%). The abundance of *A. viridis* decreases (7.4% to 4.9%) through the first part of Zone 3, only to return to the original abundance (7.3%) in the shallowest sample. The xeric to mesic pollen ratio decreased from that of Zone 2, indicating a moister climate. Combined, the data indicate warming environmental conditions throughout Zone 2. The final years of Zone 3 (880 – 770 cal yr BP) likely experienced slightly colder winters and wet summers, indicated by the increase in both *A. viridis* and *P. engelmannii* pollen.

Zone 3 (1050 - 565 cal yr BP) closely corresponds with time period of the MWP (1200 – 700 cal yr BP). The decreasing abundances of *A. lasiocarpa* and *A. viridis* and the low abundance of *P. engelmannii* in the first three samples of Zone 3 indicate a warming climate. The minimum abundance of *A. lasiocarpa* and the increase of *A. viridis* and *A. engelmannii* in the final sample of Zone 3 may indicate an increase in summer precipitation, similar to that of Zone 2. The middle of Zone 3 (ca. 1075 cal yr BP) was likely the driest and warmest of the period, indicated by a low abundance of *A. lasiocarpa*, the minimum abundance of both *P. engelmannii* and *A. viridis*, and the maximum value of Pinus within Zone 3. Additionally, the xeric to mesic pollen ratio was significantly different than the other samples (6.1 compared to 3.5, 3.8, and 3.9). At Swiftcurrent, the MWP was probably one of gradual warming, peaking ca. 950 - 750 cal yr BP, and increased summer precipitation.

Swiftcurrent Zone 4 vegetation and climate history (565 cal yr BP - present).

The increase in *A. lasiocarpa* and *P. engelmannii* in Zone 4 reflect the final establishment of the *Picea/Abies/Pinus* forest that is characteristic of the modern Glacier National Park region. The levels of *A. lasiocarpa* and *P. engelmanni* are steadier throughout the time period, with the exception in a small peak at the depth of 41.5 cm (ca. 600 cal yr BP). *Artemisia* and Poaceae abundances are more even during this interval than in previous zones, indicating established steppe and forest regions. Zone 4 was likely one of cool and moist conditions as indicated by the increase of *Abies* and *Picea*. This time period directly overlaps with the interval of the LIA. The summers were likely cool and short with less precipitation than summers during Zones 2 and 3, which is consistent with the findings of other studies in the Northern Rocky Mountains (e.g., Power et al., 2006).

CONCLUSIONS

The vegetation record of Swiftcurrent Lake reflects changes in environmental conditions during past 6000 years. Evidence from pollen indicates that the effects of the Medieval Warm Period and the Little Ice Age were present in eastern Glacier National Park. During the MWP, Pinus and more xeric vegetation dominated the forest. The mesic and steppe vegetation increased to pre-MWP levels during the LIA. Pollen and charcoal studies of other lakes in the East Glacier National Park should be conducted to verify the regional extent of vegetation changes.

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