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

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KECK GEOLOGY CONSORTIUM
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FIRE FREQUENCY IN THE LAST MILLENNIUM IN THE GRINNELL GLACIER AND SWIFTCURRENT LAKE DRAINAGE BASINS, GLACIER NATIONAL PARK, MONTANA

MADISON ANDRES, Colorado College
Research Advisor: Eric Leonard

INTRODUCTION

Fire is a natural process, influenced by climate and vegetation fuel source. Its frequency and severity has significant impacts on landscape morphology, atmospheric chemistry, global carbon cycling, terrestrial ecosystems, and biodiversity (Gill et. al, 1995). The relationships between fire, climate and vegetation under changing climatic conditions are important to understand. Fire frequency in the western United States has significantly increased in the past three decades (Westerling et al., 2006; Whitlock et al., 2003), with the greatest increase occurring in middle to high elevation (1680 m +) northern Rocky Mountain region forests (Westerling et al., 2006). Recent work suggests that this increase is associated with earlier spring snowmelt dates in the region (Westerling et al., 2006). This study aims to reconstruct fire history in the Grinnell Glacier and Swiftcurrent Lake drainage basin, northeastern Glacier National Park, Montana to understand whether this trend is similar to or divergent from natural fire frequency patterns.

I examined the top two meters of a sediment core taken from the northern sub-basin of Swiftcurrent Lake with the goal of using variability in charcoal concentration as a proxy for fire history in the drainage (Whitlock and Larson, 2001). Core chronology, which is critical to development of fire history, is established using an age model based on a combination of two radiocarbon ages from the core and stratigraphic correlation to a well-dated core taken from a nearby site (Oddo, 2011). A previous study quantified charcoal concentrations in a lake sediment core just upvalley in the southern sub-basin of Swiftcurrent Lake (Kutvirt, 2011); this record likely reflects only Grinnell Glacier valley dynamics, and a comparison to my record will provide insights into the dynamics of charcoal distribution and sediment transport in two geomorphically distinct drainages. Initial results suggest that the northern, downstream sub-basin has higher sedimentation rate, which would lead to increased charcoal accumulation, and thus indicates an increase in the area assessed by charcoal accumulation. Previous work suggests that there will be an increase in fire frequency in the western United States over the more recent record (Westerling et. al, 2006), and because this location has a higher sedimentation rate, the fire record will be more finely resolved in time.

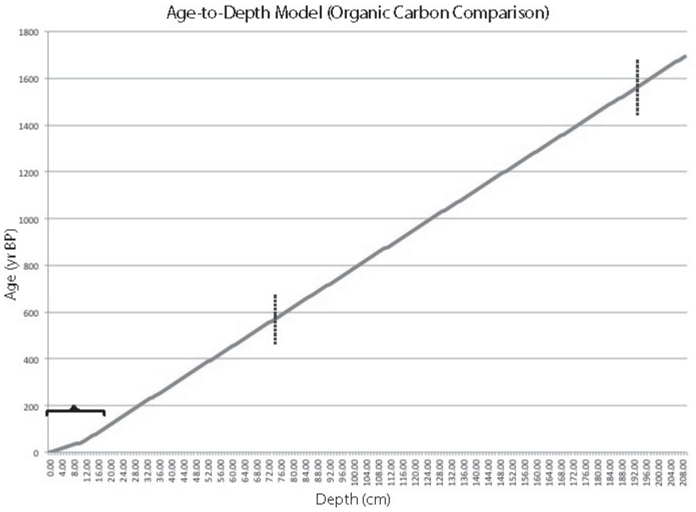

Figure 1. Comparison of the loss-on-ignition data for organic carbon versus the % total organic carbon in Oddo (2011)'s core. Peaks between cores were correlated based on location within the record. Lines across graphs represent correlations.

FIELD SETTING

Swiftcurrent Lake is located east of the Continental Divide in Glacier National Park (GNP), Montana (Project Overview, Fig. 1). The roughly 400 m^2 lake contains two sub-basins of similar depth (12 m), divided by a discontinuous ridge (3-4 m) (MacGregor et al., 2011). The northern sub-basin (Swiftcurrent Valley) has a catchment area of 44 km^2 and the southern sub-basin (Grinnell Glacier Valley) has a catchment area of 36 km^2 (MacGregor et al., 2011). The coring site (GNP-SWF14-1A/1B) is at the deepest point in the northern sub-basin at a water depth of 12m (Project Overview, Fig. 2). Local topography near Swiftcurrent Lake (1,486 m) is steep, and the peaks that lie west of the lake are all roughly 2500 m, the highest being Mount Gould which sits at 2910 m. Vegetation surrounding Swiftcurrent Lake is composed of sub-alpine forest due to its northern latitude and proximity to the Continental Divide. Primary arboreal species in the forest surrounding the lake are the lodgepole pine, sub-alpine fir, Engelmann spruce and mountain alder (Johnson, 2001). Sub-alpine forests in the northern Rocky Mountains are characterized by stand-replacing fires, which are fire events with variable return intervals and high intensity (Barrett et al., 1991, Brown et al., 2000). The only historical fire in the region was the Heavens Peak Fire, which occurred in the Swiftcurrent Valley in 1936 (Larson, 2012). The fire began directly on the Garden Wall, located on the Continental Divide near the Swiftcurrent Valley, but traveled west, never reaching closer than 6,600 m distance from the lake (Larson, 2012).

METHODS

Field Methods

Lake sediment cores were taken from the northern sub-basin of Swiftcurrent Lake (Project Overview, Fig. 2). Bathymetric mapping using a Garmin GPSMAP 541S was conducted from a kayak prior to coring. Coring methods varied for the section of core that was taken; a Griffith surface piston corer was used to obtain the sediment-water interface and the Bolivia square rod piston corer was used for long cores after that. For this study, samples were taken from one surface core and two deeper cores, each roughly 1.5 m long: GNP-SWF14-1B-1P (length used: 1.2m), GNP-SWF-1A-2B (length used: .68m), and GNP-SWF14-1B-2B (length used: .2m). Sites 1A and 1B were collected within 2 meters of each other in order to obtain alternating cores for the long core site. Then, a continuous depth model was developed using magnetic susceptibility and visual correlation of core laminations. The top 2.10 m of this continuous depth core was used for this study.

Initial Core Descriptions

All cores were initially described following LacCore's protocol for initial core description (ICD). First, the core was run through the Geotek Multisensor Core Logger (MSCL) to obtain measurements of sediment density and magnetic susceptibility at 0.5-cm resolution. Cores were then split, digitally imaged using the Geotek CIS, and scanned using the Geotek XYZ for high resolution (0.5 cm) point-sensor magnetic susceptibility and color reflectance. Cores were described on the macroscopic and microscopic scales (using smear slides) in order to better compare cores and finalize the ICD sheets.

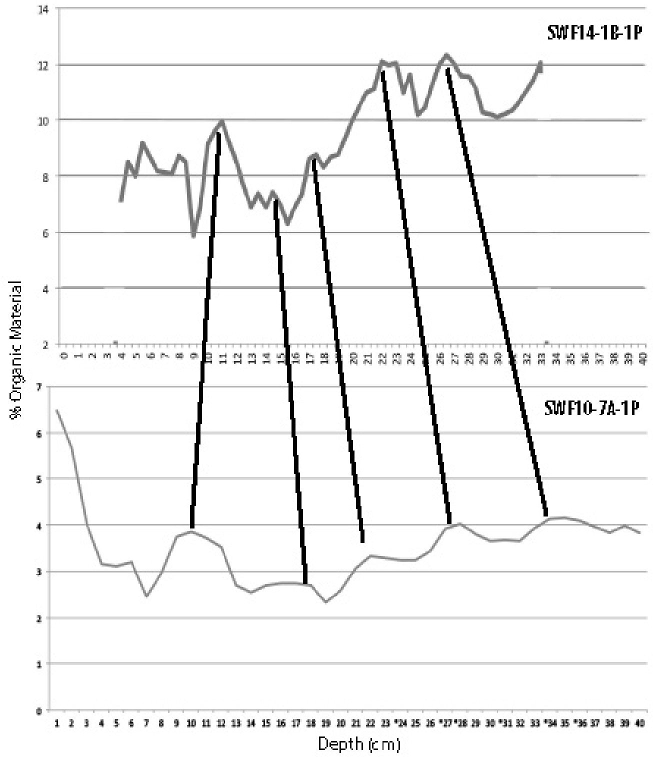

Figure 2. Age-to-Depth Model based on organic carbon correlation. Bracket represents depths that are controlled by the correlation and dashed lines represent locations of pending radiocarbon dates.

Depth Model and Core Chronology

Core chronology was established by a combination of two radiocarbon dates at two levels in the mid and lower sections of the core and by correlating loss on ignition (LOI) profiles. LOI was completed for the upper part of this core and compared to the % Total Organic Carbon (% TOC) from the ^{210}Pb-dated core of Oddo (2011). LOI samples were collected separately from charcoal samples, and were used to compare organic carbon profiles between cores (%TOC and low temperature LOI) (Fig. 2). Field notes on coring depths, along with color matching of laminations were also used to correlate the two cores into a continuous depth series. Radiocarbon charcoal samples were taken at the bottom of the core (194 cm core depth) and mid-core, at a peak in the charcoal counts (74 cm core depth). An age-to-depth model was created using the %TOC/LOI correlations in order to create an average sedimentation rate for the remainder of the core (Fig. 3).

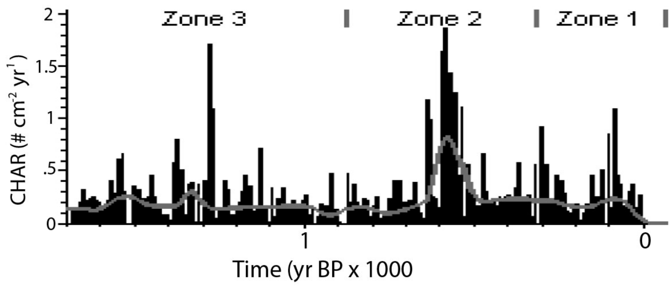

Figure 3. CharAnalysis graph showing the charcoal accumulation rate over the 1700 year record. Black line shows charcoal abundance (grains/cm^3/year) and the gray line shows background charcoal levels (BCHAR).

Charcoal Methods

The core was sampled at continuous 1 cm intervals to obtain a high-resolution charcoal record. Sediment was extracted from the core using dental spatulas, measured volumetrically in a 1 cm^3 cut-tip syringe, then placed in Erlenmeyer flasks and treated with 6% H_2O_2 (50□ for 24 hours) in order to remove organic matter. Samples were sieved through a 125 µm sieve and dried in plastic petri dishes (50□ for 24 hours). This sieve size was consistent with theoretical and empirical charcoal studies that show charcoal particle size is correlated to the proximity to the source, and that a 125 µm sieve captures charcoal from within ~7 km of the deposition site (Whitlock and Larson, 2001). The resulting particles were examined using a binocular microscope, and charcoal grains were counted. Charcoal type was classified as either grass- or miscellaneous-type, which largely tend to be wood charcoal, in order to determine fire severity (Whitlock and Larson, 2001).

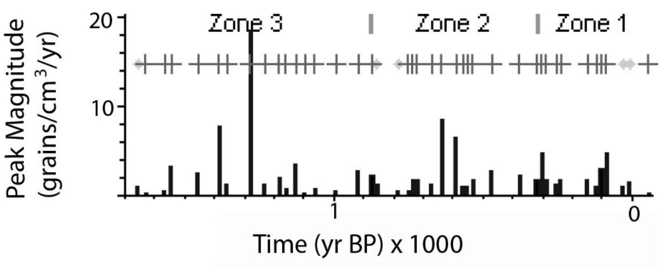

Figure 4. CharAnalysis graph of peak magnitudes (grains/cm3/peak) of the 1703 year BP record. Zones were defined by trends in fire frequency. Plus signs indicate a fire event and grey dots indicate peaks that failed the peak magnitude test.

After charcoal counts were complete, values for each cubic centimeter sample were entered into the computer program CHARanalysis. CHARanalysis produces results which separate background levels of charcoal (BCHAR) from events which rise above that line in order to recreate a local fire history for the area. Fire frequency results varied depending on the smoothing interval. A range of values were tried for this (500-100 year), and Figure 5 is an example of a 200-year smoothing interval. Results of the program also included running mean, mode, etc., cumulative fire events, and BCHAR.

RESULTS

Because radiocarbon age analysis is pending, a preliminary age-to-depth model was created on the basis of correlation of the recent core's LOI to that of the ^{210}Pb-dated core of Oddo (2011). The correlation, made on the basis of organic matter profiles (Fig. 1), extends only for the uppermost 17.5 cm of the core (or approximately 200 years) of the new core. Sedimentation rate in the bottom of the correlated section was then extrapolated to the base of the core (Fig. 2). The preliminary model suggests that the

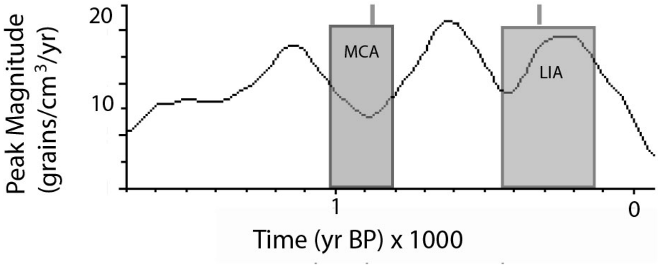

Figure 5. CharAnalysis graph of fire frequency (fires/200 years) over the 1703 year record. Zones are indicated by grey bars and were defined in order to separate the larger peaks. Little Ice Age (LIA) and Medieval Climate Anomaly (MCA) are represented by gray boxes for reference to widespread cooling and warming events (MacGregor et. al, 2011; Mann et. al., 2009)

core represents the last ~1700 years of sedimentation, at an average sedimentation rate of 1.2 mm/yr. The subsequent discussion of fire history is based on this preliminary age-depth model. Once radiocarbon ages for the lower core sections become available, both the age-depth model and the inferred fire history discussed below will be recalculated.

The ~1700-year record shows variation in charcoal accumulation in Swiftcurrent Lake. Charcoal concentration vary from 0 to 914 charcoal grains per cm^3. Based on the sedimentation rates and the charcoal concentrations, charcoal accumulation rates (CHAR) range from 0 to 101 grains/cm^3/yr. CHAR peaks were distinguished between BCHAR using a locally weighted scatterplot smoother (LOWESS) regression (Fig. 3). Peak magnitudes ranged from .041 to 18 grains/cm^3/peak, with the largest magnitude occurring at roughly 1280 yr BP (Fig. 4). There are three distinct peaks in the 1700 year fire frequency record, one at ~864 yr BP, one at ~614 yr BP and one at ~210 yr BP (Fig. 5).

DISCUSSION

The ~1700 year record taken from the northern sub-basin in Swiftcurrent Lake contains a short record of the recent fire history in the Many Glacier area. A promising correlation in the record is evidence of the Heaven's Peak fire in 1936 (peak at ~1924 AD). Though the age of the peak doesn't match exactly, it is close in age and we argue is likely the result of this particular crown fire. The 12-year discrepancy missing between these new dates is likely due to uncertainties in our current age model.

There are three distinct zones in the record, centered around a single peak in fire frequency: one from 1139-310 AD, one from 1704 -1139 AD, and one from present to ~1704 AD (Fig. 5). The peaks in fire frequency which occur in each of these zones are not dated to correspond to the expected trends given climate history. The Little Ice Age (LIA), which occurred from roughly 1500-1850 AD, was a time of cooler temperatures in the northern hemisphere. The peak in fire frequency during the LIA could be the result of the ecosystem's recovery and development towards becoming a stand forest, which results in lower fire frequency from the LIA to the present. Grassland environments in north-central Montana are characterized by higher fire frequency than later-successional hardwood tree forests, and occur earlier in ecological succession of the northern Rocky Mountain region (Brown et. al, 2000).

Another unexpected result in fire frequency is that the global Medieval Climate Anomaly (roughly 950-1250 AD), which is represented by warmer, drier climate in the western United States, is represented in the record by a trough in the fire frequency. Given the history of the region, where increases in temperature correlate to increases in fire frequency (Westerling et. al, 2006), the decrease in fire frequency is unanticipated. A possible explanation for this trough in the record is that the sub-alpine environments may not be as affected due to the lower amount of vegetation compared to lower elevation regions. Another explanation could be that a warmer, more arid environment leads in increase ice and snowpack melt in these sub-alpine environments. This melt would increase water in the system, which may lead to a decrease in large fires.

Comparison of raw charcoal counts between the northern and southern sub-basin also produces interesting results. Raw charcoal concentrations per cm^3 did not exceed 88 grains in Kutvirt's (2011) core from the southern sub-basin, whereas peaks in this core reached 914 grains per cm^3 in the northern sub-basin. This is likely the result of the larger drainage area in the northern sub-basin. This core correlates to sections of Kutvirt's (2011) core that were determined to be periods of cooling and lower fire frequency than the rest of the 7630 year record. This result was supported by a lower fire frequency and lower severity in the last 2100 yr BP (Kutvirt, 2011). The large increase in charcoal abundance for my core in the more recent 700 yr BP may be a result of the larger drainage size, and still represent this lower charcoal accumulation rate, but it could be a result of a different fire record from the northern sub-basin. Though this study represents a shorter amount of time, there seems to be an increase in peaks (based on the raw charcoal data), and therefore an increase in the number of local fires, in recent history. Figure 1 shows this increase in the most recent 600 years, where charcoal peaks rise higher above the BCHAR levels.

The 1700-year fire record shows a higher amount of fire events than previously found in a nearby, upvalley core. The fire return interval of the northern Swiftcurrent sub-basin is roughly 46 years between fires, whereas the southern sub-basin had an average return interval of 363 years between fires. The fire record in the northern sub-basin shows significant fire events 7.9 more times than fire events in the southern sub-basin. Although uncertainty in the preliminary age-depth model limits confidence in the dating of specific intervals of high and low fire frequency, comparison of this record and the Kutvirt (2011) record provides interesting insight into how charcoal is transported through the system. The lower accumulation rates in the southern sub-basin could be due to the two large lakes (Lake Josephine and Lower Grinnell Lake) that serve as sediment sinks in the watershed, or it could be the result of the smaller drainage area. This shorter, more detailed record provides a new evaluation of the fire record of the Swiftcurrent Lake drainage basin.

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