KECK GEOLOGY CONSORTIUM

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

April 2011
Union College, Schenectady, NY

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2010-2011 PROJECTS

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Faculty: *CHRISTINE SIDDOWAY, MEGAN ANDERSON*, Colorado College, *ERIC ERSLEV*, University of Wyoming
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Students: *JESSE DAVENPORT*, College of Wooster, *KRISTINA DOYLE*, Amherst College, *B. PARKER HAYNES*, University of North Carolina - Chapel Hill, *DANIELLE LERNER*, Mount Holyoke College, *CALEB O. LUCY*, Williams College, *ALIANORA WALKER*, Smith College.

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Faculty: *DAVID P. DETHIER*, Williams College, *WILL OUIMET*. University of Connecticut
Students: *ERIN CAMP*, Amherst College, *EVAN N. DETHIER*, Williams College, *HAYLEY CORSON-RIKERT*, Wesleyan University, *KEITH M. KANTACK*, Williams College, *ELLEN M. MALEY*, Smith College, *JAMES A. MCCARTHY*, Williams College, *COREY SHIRCLIFF*, Beloit College, *KATHLEEN WARRELL*, Georgia Tech University, *CIANNA E. WYSHNYSZKY*, Amherst College.

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Faculty: *KELLY MACGREGOR*, Macalester College, *CATHERINE RIIHIMAKI*, Drew University, *AMY MYRBO*, LacCore Lab, University of Minnesota, *KRISTINA BRADY*, LacCore Lab, University of Minnesota

Students: *HANNAH BOURNE*, Wesleyan University, *JONATHAN GRIFFITH*, Union College, *JACQUELINE KUTVIRT*, Macalester College, *EMMA LOCATELLI*, Macalester College, *SARAH MATTESON*, Bryn Mawr College, *PERRY ODDO*, Franklin and Marshall College, *CLARK BRUNSON SIMCOE*, Washington and Lee University.

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Students: *BRIANA BERKOWITZ*, Beloit College, *DAENA CHARLES*, Union College, *MELLISSA CROSS*, Colgate University, *JOHN MICHAELS*, North Carolina State University, *ERDENEBAYAR TSAGAANNARAN*, Mongolian University of Science and Technology, *BATTOGTOH DAMDINSUREN*, Mongolian University of Science and Technology, *DANIEL ROTHBERG*, Colorado College, *ESUGEI GANBOLD*, *ARANZAL ERDENE*, Mongolian University of Science and Technology, *AFSHAN SHAIKH*, Georgia Institute of Technology, *KRISTIN TADDEI*, Franklin and Marshall College, *GABRIELLE VANCE*, Whitman College, *ANDREW ZUZA*, Cornell University.

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Students*: SHANNON BRADY*, Union College. *LOGAN SCHUMACHER*, Pomona College, *HANNAH ZELLNER*, Trinity University.

KECK SIERRA: MAGMA-WALLROCK INTERACTIONS IN THE SEQUOIA REGION
Faculty: *JADE STAR LACKEY*, Pomona College, *STACI L. LOEWY*, California State University-Bakersfield
Students: *MARY BADAME*, Oberlin College, *MEGAN D'ERRICO*, Trinity University, *STANLEY HENSLEY*, California State University, Bakersfield, *JULIA HOLLAND*, Trinity University, *JESSLYN STARNES*, Denison University, *JULIANNE M. WALLAN*, Colgate University.

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

GEOMORPHIC AND PALEOENVIRONMENTAL CHANGE IN GLACIER NATIONAL PARK, MONTANA, U.S.A.
Project Faculty: KELLY MACGREGOR, Macalester College, CATHERINE RIIHIMAKI, Drew University, AMY MYRBO, KRISTINA BRADY LacCore Lab, University of Minnesota

LINKAGES BETWEEN CLIMATE CHANGE, VOLCANISM, AND DIATOM PRODUCTIVITY OVER THE PAST 12,900 YEARS IN SWIFTCURRENT LAKE, GLACIER NATIONAL PARK, MONTANA
HANNAH BOURNE, Wesleyan University
Research Advisor: Tim Ku

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JONATHAN GRIFFITH, Union College
Research Advisor: Donald Rodbell

HOLOCENE FIRE HISTORY OF THE SOUTHERN SWIFTCURRENT BASIN: A PALEOENVIRONMENTAL STUDY OF GLACIER NATIONAL PARK
JACQUELINE KUTVIRT, Macalester College
Research Advisor: Kelly MacGregor

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EMMA LOCATELLI, Macalester College
Research Advisor: Louisa Bradtmiller

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SARAH MATTESON, Bryn Mawr College
Research Advisor: Don Barber

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PERRY ODDO, Franklin and Marshall College
Research Advisor: Christopher J. Williams

SUBSURFACE SEISMIC REFRACTION IMAGING OF GLACIAL TILL/BEDROCK INTERFACE IN GRINNELL VALLEY, GLACIER NATIONAL PARK, MONTANA
CLARK BRUNSON SIMCOE, Washington and Lee University
Research Advisor: Romain Meyer

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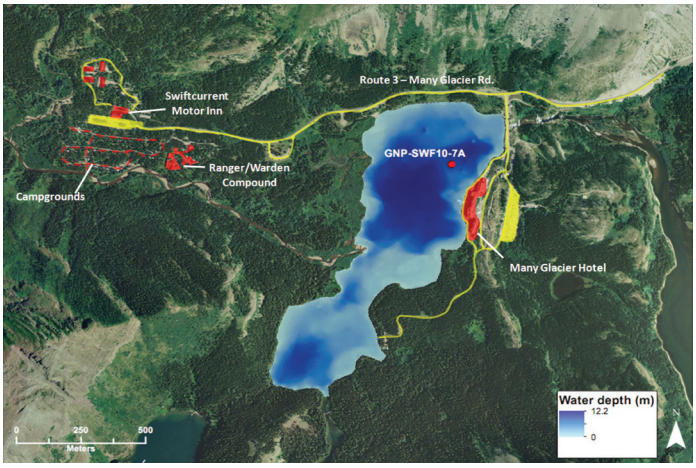

Figure 2. Bathymetric map showing core location of GNP-SWF10-7A-1P-1, as well as the extent of development in the region. Yellow areas indicate roads and paved surfaces, while red areas indicate campgrounds and lodgings.

Swiftcurrent Lake in July 2010 at a water depth of 10.76 m using a drive rod surface corer (detailed description: http://lrc.geo.umn.edu/laccore/muck.html). The core was encased in 7-cm diameter polycarbonate tubing, and was extruded vertically in 0.5 cm increments in the field.

Core Preparation

Initial core description was conducted at the National Lacustrine Core Facility (LacCore) at the University of Minnesota, Minneapolis. The extruded Swiftcurrent samples were described using smear slides, and were subjected to loss-on-ignition analysis to determine organic C content. Each increment was also subsampled and freeze-dried for further geochemical analyses.

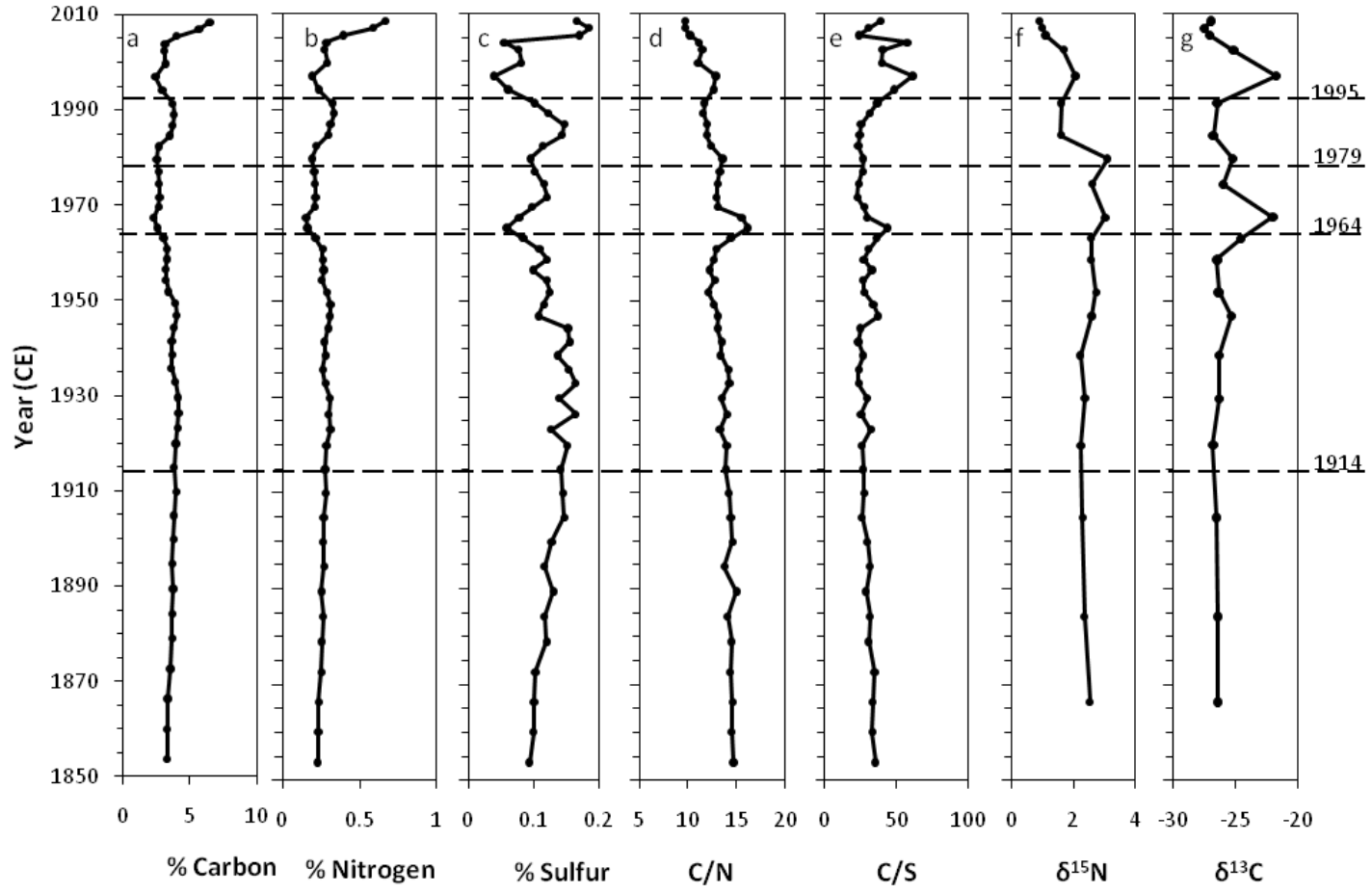

Figure 3. Geochemical results for GNP-SWF10-7A-1P-1 over the last 160 years. (a) Percent carbon (b) percent nitrogen and (c) percent sulfur versus depth as determined through ECA; (d) Carbon-nitrogen and (e) carbon-sulfur ratios versus depth; (f) δ15N and (g) δ13C abundances versus depth. Overlaid are dates corresponding to potential anthropogenic influence in the Park.

Geochemical Analyses

Sediment composition was assessed at Franklin and Marshall College using a Costech ECS 4010 Elemental Combustion Analyzer, as outlined on the F&M College website (www.fandm.edu/earth-and-environment/elemental-combustion-analysis). Each of the 82 samples were analyzed, with replicates at every fourth sample.

X-ray diffraction analyses (XRD) were performed at 10 cm intervals to determine mineralogical changes in sediment composition, as outlined on the F&M College website (http://fandm.edu/x7985).

Isotopic analysis of the Swiftcurrent samples was conducted at the Stable Isotope Laboratory at the University of New Hampshire (Durham, NH). The samples were analyzed for $\delta^{13}C$ and $\delta^{15}N$ abundances. Lead-210 age dating was completed by the St. Croix Watershed Research Station, MN. A Bayesian age-depth modeling program, Bacon (Blaauw and Christen, 2010), was used to establish an age-depth model using the ^{210}Pb data, indicating that the core represents 160 years of sedimentation.

RESULTS

The results of the XRD and smear slide analyses revealed the core to be relatively clastic-rich and diatomaceous, with little bulk compositional variation. The samples indicated the sediment consisted primarily of clay minerals (e.g. illite) and quartz.

Figure 3 shows the geochemical trends found in core GNP-SWF10-7A-1P-1. Both total percent carbon and total percent nitrogen show a close covariation in their trends, with significant fluctuations in the upper sediments that decrease with depth. Total sulfur content displays much more dramatic fluctuations throughout the length of the core, and indicates a slight increasing trend with depth until leveling off at ca. 1910. A sharp decrease in sulfur content corresponds to an increase in the carbon-sulfur (C/S) ratio at 1995. Carbon-nitrogen (C/N) ratio data indicate at the possible source of organic matter within the Swiftcurrent Lake watershed. C/N shows a gradual increasing trend with depth throughout the entire core, with a distinct spike ca. 1964.

Year	Natural or Anthropogenic Stressor
1910	Glacier National Park established as 10th national park
1911	Roads built to Many glacier area
	Visitation: 4,000
1914	Construction of Many Glacier Hotel at Swiftcurrent Lake begins
1934	Cabins and campgrounds added north of the lake
1936	Heaven's Peak Fire burns 14,000 acres
1940	Shower facilities installed in campgrounds
	Visitation: 177,307
1955	Swiftcurrent Motor Inn constructed
1964	June 8, major flood event (6700 cfs)
1974	June 20, major flood event (3310 cfs)
1995	June 7, major flood event (3150 cfs)
2010	Centennial Anniversary of Glacier National Park
	Visitation: 2.2 million (record)

Table 1. Brief History of Development at Swiftcurrent Lake. Information gathered from "Many Glacier Hotel Historic Structure Report," USGS stream gauge data, and NPS.gov/glac.

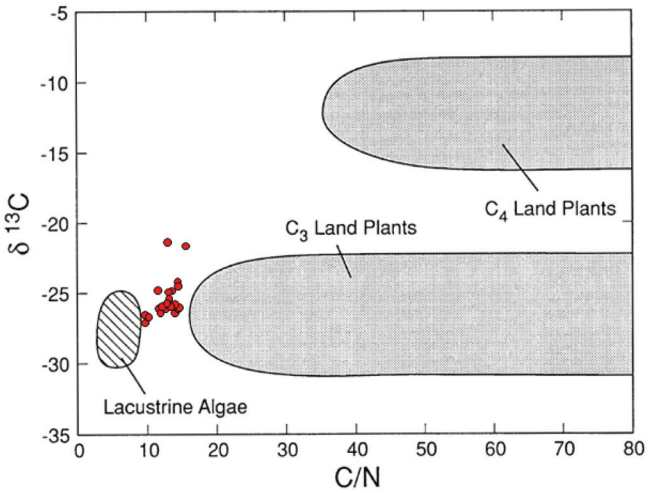

Figure 4. Distribution of organic matter sources by composition. GNP-SWF10-7A-1P-1 samples shown in red. Figure adapted from Meyers (1999).

Both $\delta^{13}C$ and $\delta^{15}N$ levels remain essentially constant for the oldest ~100 years on record before displaying significant variation towards the surface of the core. The largest spikes in the $\delta 1\ ^{3}C$ record correspond to dates around 1967 and 1995, with more muted responses in the nitrogen data.

DISCUSSION

Our findings illustrate the impact of both anthropogenic and natural factors on lake sediment source and chemistry. Table 1 is an abridged timeline of natural and human-induced changes in the Many Glacier area, and Figure 2 provides additional context about the extent of development within the Park. Total percent carbon and nitrogen trends are essentially parallel, decreasing dramatically with depth in the top 5 cm, whereas the C/N ratio gradually increases with depth. These patterns are common in oligotrophic lake systems, with changes likely due to the diagenetic loss of labile surface N compounds post-sedimentation (Last and Smol, 2001). Diagenesis may also help explain the rapid increase in C/S over the past two decades. As lake surface matter breaks down, sediments often become preferentially enriched in sulfur relative to organic carbon (Urban et al., 1998).

Sediment $\delta^{15}N$ levels gradually begin increasing ca. 1931, peaking at 1982, which could reflect increasing anthropogenic enrichment through effluent additions. Campgrounds were added in 1934 (see Table 1, Figure 2) and evidence suggests that prior to 1970, poor waste management practices led to human waste being diverted directly into Swiftcurrent Lake (Gaufin 1970). Additionally, the concurrent increase in total N and decrease in $\delta^{15}N$ over the last two decades could potentially be due to atmospheric fractionation of isotopically depleted N-compounds; Wolfe et al. (2001) suggest that increased automobile emissions and other NOx-emitting sources, for example, can cause similar trends, even in seemingly pristine lakes.

It is possible that severe flooding may have also contributed to the lake's geochemical trends. Data gathered from USGS stream gauge system indicates major flood events took place in June of 1964, 1975, and 1995, which roughly correspond to the most prominent peaks in the $\delta^{13}C$ column. Flooding may help explain the peaks in C/N and $\delta^{13}C$ abundances at these depths, as it would increase terrestrial organic matter input. Figure 4 shows the distribution of potential organic matter sources to Swiftcurrent Lake (Meyers 1999). The values of the Swiftcurrent Lake data indicate a mixture of source organic matter, likely a blend of lacustrine algae and C_3 land plants, with the two outliers corresponding to the 1964 and 1995 floods.

The extent to which geochemical variations in the sediment record can be attributed to human influence is still a matter of debate. There is evidence to suggest that anthropogenic stressors may act synergistically to compound the effects of natural variations in lake chemistry (Wolfe et al, 2001). Yet much is still unknown about how processes like diagenesis or seasonal variations may also affect the trends we observe in the sediment. Further investigation of both Swiftcurrent Lake and less impacted areas from up valley could help determine the true cause of environmental perturbations at Glacier National Park, and will provide useful insight to the impacts humans have on alpine lake systems

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