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

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Dr. Robert J. Varga, Editor
Director, Keck Geology Consortium
Pomona College

Dr. Holli Frey
Symposium Convener
Union College

Carol Morgan
Keck Geology Consortium Administrative Assistant

Christina Kelly
Symposium Proceedings Layout & Design
Office of Communication & Marketing
Scripps College

Keck Geology Consortium
Geology Department, Pomona College
185 E. 6th St., Claremont, CA 91711
(909) 607-0651, keckgeology@pomona.edu, keckgeology.org

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KECK GEOLOGY CONSORTIUM
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Robert J. Varga
Editor and Keck Director
Pomona College

Keck Geology Consortium
Pomona College
185 E 6th St., Claremont, CA
91711

Christina Kelly
Proceedings Layout & Design
Scripps College

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DOLOMITE ABUNDANCE IN LAKE JOSEPHINE SEDIMENTS, GLACIER NATIONAL PARK, MONTANA: A PROXY FOR GLACIAL EXTENT?

KARLY CLIPPINGER, Beloit College
Research Advisor: Carl Mendelson

INTRODUCTION

Alpine glacial deposits are often studied to understand past changes in climate because such glaciers are sensitive to variations in precipitation and temperature. Fluctuations in glacial extent influence erosion rates and therefore, sediment delivery to proglacial environments (Hallet et al., 1996; Koppes and Hallet, 2002). Ice-proximal lakes act as sediment traps, providing continuous records of sediment production, and therefore glacier activity (Leonard, 1985). If a lithologic break exists in the landscape, the composition of sediment produced by glacial erosion may change over time as the glacier footprint varies. The mineralogical composition of lake sediments may therefore record a history of glacial response to climate change.

Glacier National Park, Montana, is one of the last locations in the continental United States where glaciers are still active (Carrara, 1993). An incomplete Pleistocene-Holocene climate history of northeastern Glacier National Park has been inferred from moraines and a few lacustrine records (Carrara, 1987; MacGregor et al., 2011; Munroe et al., 2012; Schachtman et al.; in press). Grinnell Glacier in northeastern Glacier National Park actively erodes the only source of carbonate material in the valley (Helena Formation, see Project Summary, Fig. 1). Previous work on a sediment core from Swiftcurrent Lake in the Grinnell Glacier valley suggested that carbonate concentrations in lake sediments can be used as a proxy for glacial activity (MacGregor et al., 2011; Schachtman et al., in press). Swiftcurrent Lake is farther downstream than Lake Josephine, and thus has one more lake acting as a sediment sink; we therefore expect to find more carbonate minerals and recover a more sensitive record of glacial activity from Lake Josephine (Schachtman et al., in press).

OBJECTIVE

The goal of my project is to better constrain the relationship among carbonate abundance, glacier fluctuations, and climate. I quantified carbonate concentrations in a core from the mid-valley Lake Josephine during the late Pleistocene, Younger Dryas, and early Holocene. This record is closer to Grinnell Glacier and likely a more efficient sediment trap than Swiftcurrent Lake; in addition, I focused on a temporal window when the glacier was responding to major climate shifts. I show that carbonate concentration in Lake Josephine sediments is higher during periods when we expect Grinnell Glacier to be more extensive, and decreases during times of ice retreat. Percent organic matter is anticorrelated with percent carbonate, which suggests clastic sedimentation increases when the ice is more proximal to Lake Josephine, swamping the organic matter production/delivery to the lake. Additionally, the strong correlation between carbonate records taken from upper and lower portions of Lake Josephine spanning the same period strongly suggests that carbonate concentration is an excellent proxy for Grinnell Glacier position, and therefore climate, during this time.

BACKGROUND SETTING

Grinnell Glacier lies to the east of the Continental Divide, within the Many Glacier region of northeastern Glacier National Park, Montana (see Project Summary Fig. 2). The proglacial U-shaped valley is composed of steep slopes and a low-relief valley floor. Lake Josephine is the third in a chain of four proglacial lakes; glacier meltwater flows from Upper Grinnell Lake, over a steep ~400-m-tall bedrock step into Lower Grinnell Lake, then into Lake Josephine and Swiftcurrent Lake. The total catchment area of the valley is just under 36 km^2 (MacGregor et al., 2011).

Rocks exposed in Glacier National Park comprise sandstones, siltstones, and shales of the Middle Proterozoic Belt Supergroup (Whipple, 1992; MacGregor et al., 2011). Underlying Grinnell Glacier (~2000 m elevation) is the Helena Formation, which is the only bedrock source of dolomite and calcite in the valley (see Project Summary Fig. 1) (MacGregor et al., 2011). Lake Josephine is underlain by upper Pleistocene tills that are 1-3 m thick (Carrara, 1990; MacGregor et al., 2011). Several ash layers have been found overlying moraines in the area, constraining the period of deglaciation to be between 13.1 ka and 11 ka (Carrara, 1987, 1993).

METHODS

Field Methods

In July 2014, a series of overlapping lake sediment core samples were collected from the up-valley portion of Lake Josephine (see Project Summary Fig. 2). Cores were collected using modified Livingstone square-rod piston corers (Wright, 1967, 1991). Each core was about 99 to 102 cm long; cores were taken successively up to a depth of 11.5 m below the sediment-water interface.

Laboratory Methods

Cores were scanned, split, digitally imaged, and described at the National Lacustrine Core Facility (LacCore) in Minneapolis in August 2014. Smear slides were taken and analyzed for each significant change in sediment type and color to aid in core descriptions. Individual samples were taken at 1-cm resolution between two volcanic ash layers, the Mazama ash (7,630 ybp; MacGregor et al., 2011) and the Glacier Peak G ash (~13,500 ybp; Schachtman et al., in press). Each 3-cc sample was taken using a small spatula; care was taken to avoid sampling near sources of contamination, such as the edges of the core. Samples for X-ray diffraction (XRD) were freeze-dried whereas loss on ignition (LOI) samples were refrigerated before being analyzed to prevent mold growth and water loss.

Analytic Methods

Samples were analyzed using LOI to determine organic matter and carbonate percentages and XRD to identify the minerals present.

LOI was conducted on 323 samples of volume 1 cc. Initially, samples were heated to 100°C for 8 hours to remove water using a Quincy Lab AF Model 40 oven, then weighed using an electronic scale. Percent organic matter was determined by heating samples to 550°C for 4 hours using a BarnsteadThermolyne 1300 furnace; samples were weighed on an electronic scale. Percent carbonate was determined by heating the samples to 1000°C for 2 hours using a BarnsteadThermolyne 1300 furnace and then weighed on an electronic scale.

X-ray diffraction analysis gives semiquantitative data on the types and relative abundances of minerals, and is used to determine the composition of the lake sediments, specifically if the carbonate mineral present is dolomite or calcite. XRD analysis was performed on every 10th sample, with 35 of the original 323 samples analyzed. Around 1 cc of freeze-dried sample was ground in ethanol using a mortar and pestle with a 10% spike of corundum (Al_2O_3). The sample was then transferred to a metal slide, and a glass slide was used to level the sample. Care was taken to avoid packing or otherwise orienting the mineral faces. Samples were x-rayed from 4° to 65° 2Θ, with a step width of 0.01° 2Θ and a counting time of 1 second, on a Rigaku miniFlex II X-Ray Diffractometer. Dominant minerals were identified using MDI Jade 8.

RESULTS

Core Lithology

Based on initial core descriptions and smear-slide analysis, core material is predominantly dark gray to brown silts and clay from 806 cm to 1068 cm where it grades into gray, pink and tan silts and clay (Fig.

1). The cores are predominantly massive from 806 cm until around 930 cm where laminae become more distinct (Fig. 1). Slush from recore and pressure-induced folding and suction was common at the top of the cores; this material was not sampled.

Age-Depth Model

A depth model was created by correlating seven overlapping cores by depth, visual, and color analysis of laminations, creating a composite core record (Fig. 1). In the absence of radiocarbon ages, the age-depth model for the core was set using the bracketing ash ages and assuming a constant sedimentation rate. The sediment thickness (344.7cm) was divided by 5,870 years (as constrained by ash layers). This yielded a rate of 0.06 cm/year or about 17 years for 1 cm of sediment deposition.

Organic Matter and Carbonate

On the basis of changes in % organic matter, % carbonate, and bulk density, the data were divided into four zones (Fig. 2). In addition, those zones were compared with the GISP2 temperature model for the Northern Hemisphere (Alley, 2004).

Percent organic matter varies between 1 and 7% over the time represented by the composite core (Fig. 2a). In zone 1-3 % organic matter is low averaging around 3%. There is a slight drop followed by an increase in % organic matter around 11.5 ka moving into zone 3. In zone 3, % organic matter increases abruptly (at 10.5 ka) then drops only to increase again around 10.2 ka and remain elevated (at 5%) throughout zone 4.

Percent carbonate varies between 6 and 16% over the time represented by the composite core (Fig. 2b). Percent carbonate is low, dropping to 7% in zone 1. In zone 2, % carbonate is variable with the highest values at around 16% and the lowest at around 5%. Zone 3 is characterized by an increase in % carbonate followed by a decrease and another increase, with the lowest % carbonate value around 5% occurring at 10.5 ka. In zone 4, % carbonate drops to an average of 8% at 10.2 and remains low. Percent carbonate is mimicked closely by bulk density.

X-ray Diffraction

Minerals present in the cores include quartz, dolomite, calcite, and clay. Although quartz was the most abundant mineral, carbonate minerals (dolomite

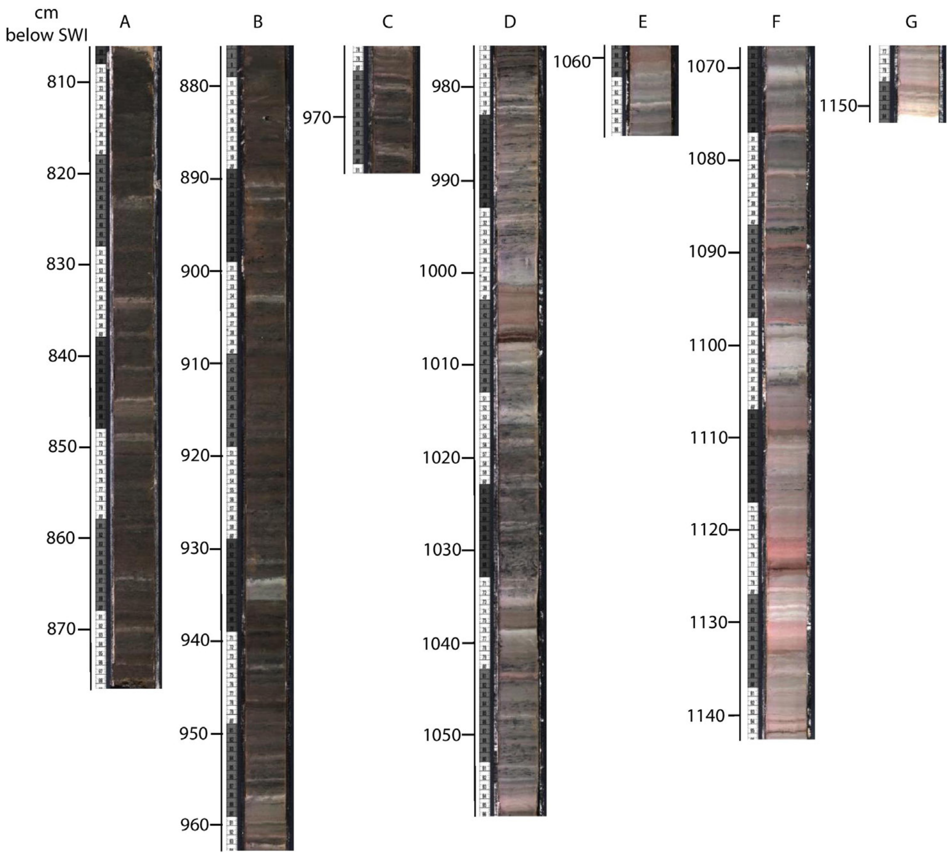

Figure 1. Composite core record created by correlating seven overlapping core sections from Lake Josephine: A) GNP-JOS14-1B-11L, B) GNP-JOS14-1C-12L, C) GNP-JOS14-1B-12L. D) GNP-JOS14-1C-13L, E) GNP-JOS14-1B-13L, F) GNP-JOS14-1C-14L, and G) GNP-JOS14-1B-14L. Measurements are cm below the sediment water interface (SWI). The record spans from base of the Mazama ash at 806.4 cm to the top of the Glacier Peak G ash at 1151.1 cm.

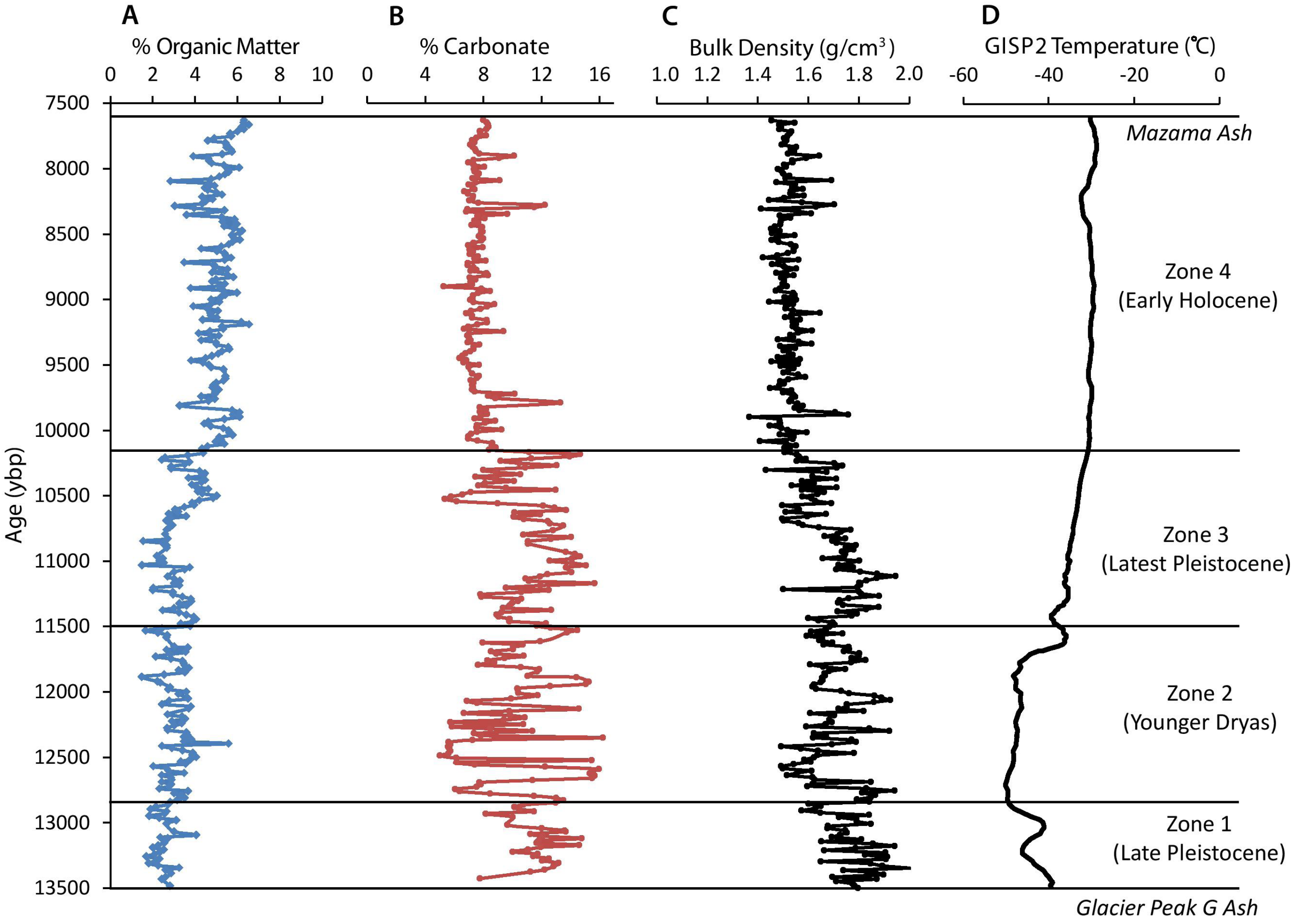

Figure 2. Percent organic matter (A), percent carbonate (B), and bulk density (g/cm3) (C) from cores GNP-JOS14-1B/1C compared to GISP2 temperature data for the Northern Hemisphere. (D) The bracketing Mazama and Glacier Peak G ashes are identified by lines at 7630 ybp and 13,500 ybp, respectively. The analyzed period was split into four zones. Zone 1 corresponds to late Pleistocene warming and glacial retreat. Zone 2 comprises the Younger Dryas, a period of cooling and high % carbonate. Zone 3 corresponds to decreasing % carbonate and relatively low % organic matter indicating warming into the Holocene. A relative stabilization of climate is shown in zone 4 by low % carbonate and high % organic matter.

and calcite) were present in every sample (Fig. 3). Dolomite concentrations, while semi-quantitative, are almost always higher than calcite concentrations. The concentrations appear to be well correlated; when dolomite concentrations are high, calcite concentrations are as well, and vice versa. There is a decrease in dolomite concentrations after 10.2 ka (Fig. 3).

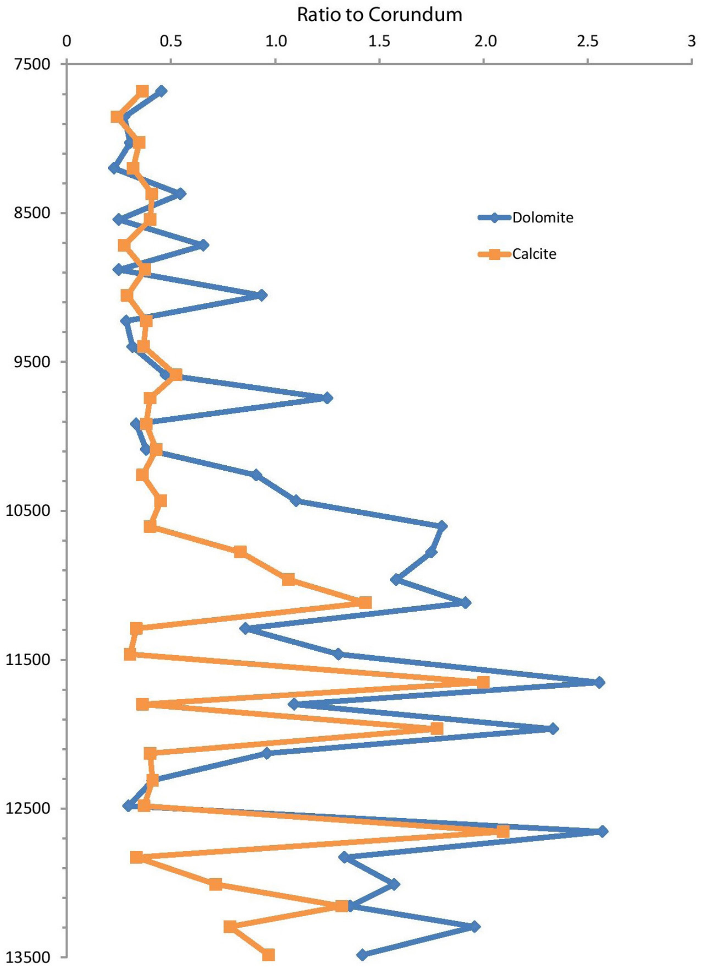

Figure 3. Fluctuations in dolomite and calcite concentrations measured by XRD as compared to a 10% spike of corundum. Carbonate minerals (dolomite and calcite) were present in every sample; however, dolomite concentrations, while semi-quantitative, are almost always higher than calcite concentrations. The concentrations appear to be well correlated.

DISCUSSION

Zone 1: Late Pleistocene (13.5-12.8 ka)

Following the Last Glacial Maximum there was a period of warming in the late Pleistocene, the Bølling-Allerød which corresponds to low values of % carbonate, that occur in the beginning of zone 1 (Fig. 2b) (Alley, 2004). At 13,300 ybp % carbonate rises and stays elevated for the rest of the zone.

Zone 2: Younger Dryas (12.8-11.5 ka)

The highest % carbonate values and lowest % organic matter values occur in zone 2, which corresponds roughly to a period of cooling, and subsequent glacial advance, known as the Younger Dryas (12.8-11.5 ka) (Alley, 2004; Muscheler et al., 2008). The Lake Josephine record is slightly offset from the GISP2 record due either to a lag in glacial response to the onset of cooling, later onset of Younger Dryas cooling in this area, or uncertainties in our age model (Fig. 2). Low levels of % organic matter and high % carbonate are expected during times of glacial advance due to the proximity of ice to the lake. Generally high % carbonate indicates more erosive power of Grinnell Glacier and fewer sediment sinks due to a more extensive glacier. Low % organic matter during this period reflects decreased organic matter production during colder periods. However, it has also been shown that % organic matter decreases during periods of glacial advance due to increased clastic sediment flux and therefore increased sedimentation rates, effectively 'swamping' the organic matter percentage (Leonard and Reasoner, 1999; Schachtman et al., in press). Variations in % carbonate could be a result of glacial proximity and high levels of sediment influx. Figure 4 shows % carbonate and % organic matter are anticorrelated during the Pleistocene and positively correlated during the Holocene. Additional age and mass accumulation rate constraints are needed to fully constrain this relationship.

Zone 3: Latest Pleistocene (11.5-10.2 ka)

Zone 3 (Fig 2) corresponds to subsequent warming following the Younger Dryas (Alley, 2004). Percent carbonate is variable but generally lower than values

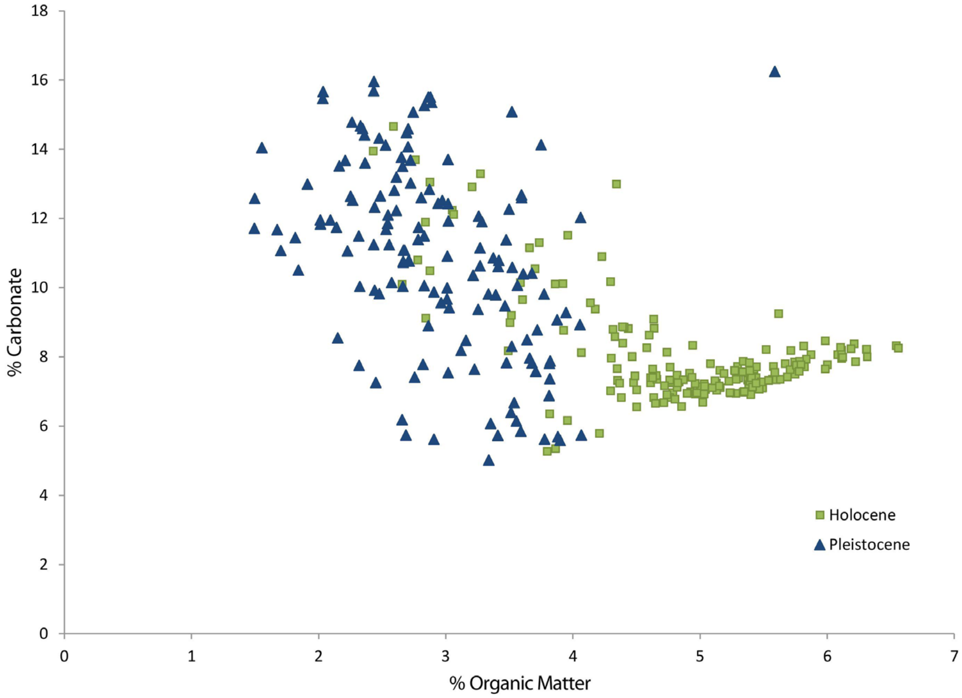

Figure 4. Comparison of % organic matter and % carbonate from 13,500 ybp to 7630 ybp. Values are anticorrelated in the Pleistocene and positively correlated in the Holocene.

in zone 2. Following a rapid decline the lowest % carbonate value (5 %) occurs at 10.5 ka.

Zone 4: Early Holocene (10.2-7.6 ka)

Zone 4 (Fig. 2) shows stabilization of climate into the Holocene (Alley, 2004). At about 10,200 ybp, both % carbonate and % organic matter have reduced temporal variability, and % carbonate is at its lowest values (~7%) compared to the whole period (Fig. 2B). Bulk density (Fig. 2C) also decreases and stabilizes. Less carbonate is reaching the lake either due to a loss of erosive power of the glacier or the presence of intervening sinks. Either way this likely reflects documented climate stabilization (Alley, 2004), and suggests Grinnell Glacier either disappeared entirely or had a small footprint in the cirque basin.

Comparing carbonate trends

Comparisons of % carbonate among upper Lake Josephine (GNP-JOS14-1B/1C), lower Lake Josephine (GNP-JOS14-2A), and Swiftcurrent Lake (GNP-SWF10-3D) are shown in Figure 5. Both records in Lake Josephine follow the same trends with high % carbonate from 13,500 ybp to ~10,000 ybp (zones 1-3) and stable low % carbonate from ~10,000 ybp to 7,600 ybp (zone 4, early Holocene). During the Pleistocene (zones 1-3) % carbonate is lower in upper Lake Josephine and higher in lower Lake Josephine. During the Pleistocene Grinnell Glacier was much larger, with high hydraulic and erosive power, and it likely terminated in or close to Lake Josephine. Clastic sedimentation increases when the ice is more proximal to Lake Josephine leading to large amounts of coarse material being deposited in upper Lake Josephine (Fig. 2C). Finer material would be carrier farther settling in the lower Lake Josephine site, thereby boosting the % carbonate signal in that record. Conversely, during the Holocene (zone 4), % carbonate is higher in upper Lake Josephine and lower in lower Lake Josephine. This is likely due to the decreased hydraulic and erosive power of a substantially smaller and more distal Grinnell Glacier during the Holocene. The fine grained carbonate material settles out at the upper site in Lake Josephine, being more proximal to Grinnell Glacier, before reaching the lower Lake Josephine site. The record from Swiftcurrent shows overall lower % carbonate with the highest % carbonate from 13,500 ybp to 11,500 ybp, which corresponds to high % carbonate values in Lake Josephine during the

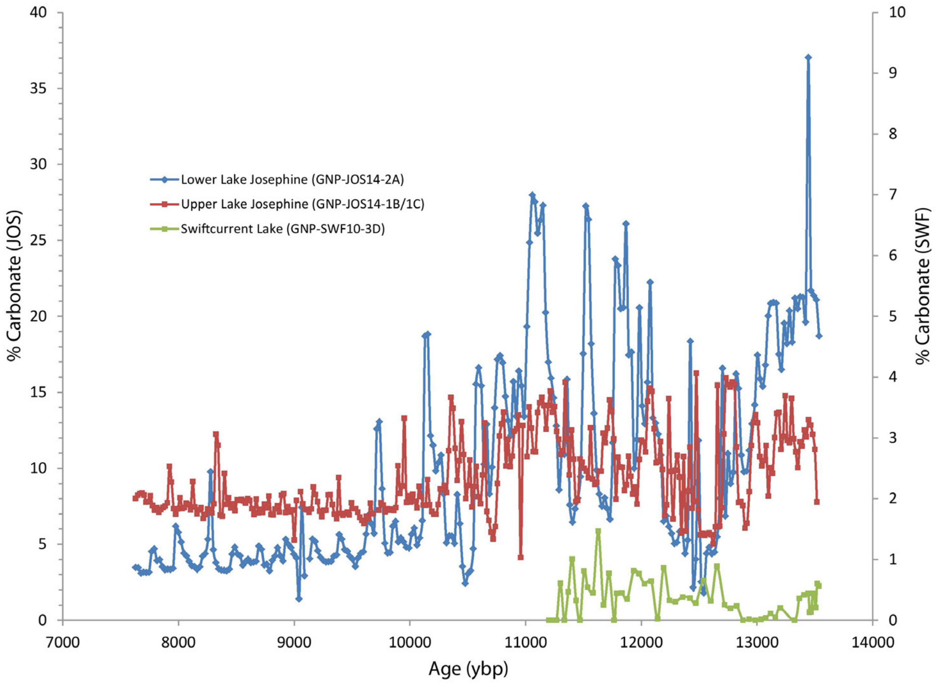

Figure 5. Comparison of % carbonate between upper Lake Josephine (GNP-JOS14-1B/1C), lower Lake Josephine (GNP-JOS14-2A), (Carlie, this volume), and Swiftcurrent Lake (GNP-SWF10-3D) (Schachtman et al., in press). Both records in Lake Josephine are closely matched with high % carbonate from 13,500 ybp to ~10,000 ybp and stable low % carbonate from ~10,000 ybp to 7,600 ybp. The record from Swiftcurrent shows overall lower % carbonate with the majority of % carbonate showing up from 11,500 ybp to13,5000 ybp which corresponds to high % carbonate values in Lake Josephine. Overall lower % carbonate in Swiftcurrent Lake when compared to Lake Josephine demonstrates the efficiency of sediment trapping in Lake Josephine.

Younger Dryas (zone 2). Overall lower % carbonate in Swiftcurrent Lake when compared to Lake Josephine demonstrates the efficiency of sediment trapping in Lake Josephine.

CONCLUSIONS

Grinnell Glacier actively erodes the carbonate-rich Helena Formation, and the resulting sediment is more effectively transported and deposited in Lake Josephine during periods of increased glacial extent. Percent carbonate is high and % organic matter is low during known cold periods such as the end of the late Pleistocene and the Younger Dryas. During warmer, more climatically stable periods such as the early Holocene, % carbonate values are generally low and % organic matter are high. Percent carbonate and % organic matter are anticorrelated during periods of active glacial advance and retreat (e.g., the late Pleistocene), whereas they are positively correlated during the warmer and more stable early Holocene (Fig. 4). This suggests Grinnell Glacier was either very small or not varying in size during this time. Fluctuations in % carbonate closely correspond to regional climate shifts indicating the percentage of carbonate in Lake Josephine sediments can be used as a proxy for the position and extent of Grinnell Glacier.

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