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Dr. Robert J. Varga, Editor
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Christina Kelly
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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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MAJOR AND TRACE ELEMENT CHEMISTRY AND MINERALOGY OF BELT GROUP ROCKS, GRINNELL VALLEY, GLACIER NATIONAL PARK, MONTANA: IMPLICATIONS FOR LAKE CORE SEDIMENTS AS GEOMORPHIC TRACERS

ERIC STEPHENS, Macalester College
Research Advisor: Kelly MacGregor

INTRODUCTION

Alpine glaciers are highly sensitive to climate, and therefore records of their advance and retreat are potential tools in understanding how the environment responds to changes in climate. Alpine glaciers are efficient erosional agents in these landscapes, with erosion rates ranging from 0.10 mm/yr to 10 mm/yr depending on bedrock hardness, altitude, and temperature (e.g., Hallet et al., 1996; Riihimaki et al., 2005). During times of climate cooling, glacier footprints increase in size, and therefore the potential for increased sediment flux due to glacial erosion increases. Examining the material eroded from glaciers allows us to understand how glacial erosion rates have changed over time, which can provide some clues as to how erosion rates are affected by changes in climate (e.g., Koppes and Hallet, 2006). Variability in clastic sediment flux, in particular the accumulation rate of glacial flour in proglacial lakes, has been used as a proxy for glacier position in alpine landscapes (e.g., Leonard and Reasoner, 1999; Rodbell, 2003). However, in environments where sediment may also come from hillslopes or other sources, sediment accumulation rates may not accurately reflect glacial processes.

Tracers in the landscape are often used in geomorphic and hydrologic research in order to better understand the flow of sediment or water (e.g., Abbott, 2003; Leonard, 1986). Previous work by MacGregor et al. (2011) in the Many Glacier Valley of Glacier National Park, Montana suggested that detrital dolomite found in lacustrine sediments reflected erosion of bedrock from under Grinnell Glacier. The geologic unit directly below Grinnell Glacier is the Helena Formation, comprised of stromatolitic dolomite. Geologic maps of the valley show that carbonate rocks of the Belt Group outcrop only at the elevation of Grinnell Glacier’s cirque basin and above. MacGregor et al. argued that the presence of dolomite in Swiftcurrent Lake, the fourth in a chain of lakes downvalley from the glacier, reflected enhanced erosive activity, and likely an advanced glacier terminus position. Additional research on cores from Swiftcurrent Lake (Schachtman et al., in press) and in the upvalley Lake Josephine (Anderson et al., in review) found that percent total inorganic carbon (%TIC, a proxy for carbonate minerals) was high during known periods of glacier advance over the past ~17 ka. However, limited mineralogic and geochemical analyses have been conducted on the Belt Group rocks in this part of Glacier National Park, making it impossible to rule out the other rock units in the valley as sources of dolomite and calcite to the lakes.

The goal of my research is to conduct a comprehensive geochemical survey of the rock formations and tills present in the Grinnell Glacier Valley in Glacier National Park, Montana. In addition to excluding units downsection from the Helena Formation as sources of inorganic carbon in lake sediments, I identify several geochemical tracers unique to certain units that could be used to further explore geomorphic sources of lake sediments over time.
STUDY AREA

The Grinnell Glacier Valley of Glacier National Park, Montana contains a chain of lakes directly downstream of Grinnell Glacier, all of which act as sediment traps for eroded material sourced from the glacier and the valley slopes. The geology of the valley is comprised of six formations from the Belt Supergroup (Fig. 1), deposited around 1.2-1.4 Ga in a broad, periodically hypersaline lake (Winston 2006). Notable units include the only igneous unit in the valley, the Purcell Sill, which intrudes the uppermost Snowslip Formation, and the Helena Formation, a series of stromatolitic calcites and dolomites. The Empire, Appekunny, and Grinnell formations contain argillites and arenitic quartzites, and display prevalent sedimentary structures indicative of broad, distal sand and mudflats. Lastly, the Altyn Formation is another stromatolitic carbonate formation but is only present at low elevations at the far downstream end of the valley, and likely does not contribute to the sediment in Lower Grinnell Lake or Lake Josephine.

The geology of Grinnell Glacier valley provides a natural experiment in which the rock formations above the glacier (Snowslip and Helena) are markedly different than the units below the glacier (Empire, Appekunny, and Grinnell), in that they are carbonate rich and contain an igneous intrusion. While previous work on these rocks has described their depositional environments and sedimentary structures (Kuhn, 1987; Whipple, 1988; Winston, 2006), little research has been done characterizing their geochemical compositions.

METHODS

Data Collection

Hand samples (ranging from 3 to 15 kg) were collected in July 2014 from every geologic unit in a vertical transect, following the hiking trail to Grinnell Glacier (Fig 2.) Additional samples had been collected in summer 2012 using a similar methodology. Till samples of surface sediment/regolith were collected from the landscape around both Lake Josephine and Swiftcurrent, in addition to samples collected at the terminal moraine near the current Grinnell Glacier terminus.

Figure 1. Geologic map of the Grinnell Glacier valley. Grinnell Glacier in the southeast sits directly above the Helena Formation, with sediments draining into the string of pro-glacial lakes to the northeast.
Data Analysis

Samples were transported to Macalester College and processed using the Geology department facilities. Thirty-nine rock and till samples were selected for processing, including at least four samples from each formation. Samples were cut using a tile saw, and crushed to 2-cm size clasts. Thirty ml of the resulting rock chips were crushed with approximately 17 ml of Vertrel in the shatterbox to further reduce rock clasts to µm-scale rock powder.

X-ray fluorescence (XRF) analysis was conducted on 39 samples; rock powder as either compressed into pellets bound by polyvinyl alcohol for trace element analysis, or prepared for melting into a glass bead for major element analysis. The latter samples were dried and underwent loss-on-ignition (LOI) before being homogenized in a eutectic flux (12 lithium tetraborate: 22 lithium metaborate) in a 1:5 ratio, and suspended in a glass bead. Samples were then scanned for individual elements using a PANalytical PW2400 X-ray Fluorescence Spectrometer.

X-ray diffraction (XRD) samples were prepared by lightly compressing rock powder into disks which were oriented on a plate, and analyzed using a PANalytical X’Pert Pro MPD X-ray Diffractometer. Samples were scanned continuously from a 2θ angle of 10˚ to 90˚. Clay mineralogy was not analyzed.

RESULTS

Major Elements

XRF analysis shows distinct geochemical differences between units (Fig. 3). For the two elements shown (Ca and Ti, as their oxides CaO and TiO$_2$), there is distinct variation in composition between samples. However, this variation occupies discrete ranges which are differentiable and unique between formations. The formations stratigraphically above the Grinnell Glacier cirque floor (Snowslip, Purcell Sill and Helena) all display significant average CaO values, whereas those downvalley and stratigraphically below the cirque lip (Empire, Appekunny and Grinnell) all display little or negligible CaO. Tills near Lake Josephine and Swiftcurrent display low, but measurable, amounts of CaO (2.77 wt% on average). TiO$_2$ is present in every igneous Purcell Sill sample, and is unique in its concentration (3.83%); all other formation samples have average concentrations that are several orders of magnitude less, ranging from a low of 0.17% in the Helena Formation to a high of 0.60% in the till samples.

Figure 3. Weight Percentages of CaO and TiO2. Each formation is represented as a horizontal bar, with the mean concentration printed below each bar. Each bar represents the extent of the standard error between samples for each formation.

Every other major element analyzed displays significant overlap between units, such as SiO$_2$ with an average near 65% for all argillitic units, or Fe$_2$O$_3$ with averages near 4.30% for every unit except the Purcell Sill (12.75%).

Trace Elements

Certain trace elements vary dramatically from formation to formation (Fig. 4, 5). Each sample shows trace element patterns similar to those of post Archean Upper Continental Crust (pA-UCC), in that there is significant enrichment in Large Ion Lithophiles Elements (LILE), High Field Strength Elements (HFSE), Heavy Rare Earth Elements (HREE). However, there are certain outliers from the expected trace element pattern, which are unique to distinct formations. The average concentration of strontium is 1239.23 ppm in the Purcell Sill; the amount in the other units are ~100 times less, between 17 and 73 ppm. Samarium also varies between units, with the Purcell Sill containing an average of 13.08 ppm, and the Appekunny and Empire containing 7.67 and 5.82 ppm respectively.
XRD Mineralogy

Mineralogy is similar between samples in the same rock type, even across formation boundaries. For example, agrillites (Empire, Grinnell, Appekunny) contain significant quartz and clay, occasionally augmented with alteration minerals from the chlorite group, such as clinochlore and chamosite. The Snowslip formation contains minerals similar to those of the Empire, Grinnell and Appekunny, but additionally contains some carbonate minerals (both dolomite and calcite). The Helena Formation is primarily carbonate minerals (both calcite and dolomite), with a small percentage of quartz. Lastly, the Purcell Sill contains igneous minerals such as albite, quartz, Mn-rich amphibole, and some alteration minerals. These mineralogical compositions are
reasonably close to the values published by different authors (Winston, 2006; Whipple, 1988; Kuhn, 1987) of samples from different locations in the same formation.

**DISCUSSION**

**Elemental Tracers**

Geochemical analyses of the formations in the Grinnell Glacier valley show that several units contain distinct major and trace element signatures. These results suggest that elemental tracers such as CaO, TiO$_2$, Sm and Sr identified in lake sediment cores can be used to constrain valley source rock, which could provide geomorphic constraints on the locating and timing of erosion and deposition. CaO is present in the highest concentrations in the Helena Formation, which is in line with previous work that suggests carbonate minerals are produced by erosion of this formation (MacGregor et al., 2011). CaO concentrations are elevated in the Snowslip as well, whereas formations below Grinnell Glacier contain little to no CaO. It is therefore likely that all formations stratigraphically at and above the Grinnell Glacier cirque basin are the source of carbonates in proglacial lake sediments.

In addition to CaO, high concentrations of TiO$_2$, Sm and Sr from the Purcell Sill are unique to the formations in the valley, potentially adding another geochemical tracer with which to analyze sediment flux. While MacGregor et al. (2011) were able to detect a change in %TIC, further analysis must be conducted on cores in order to test the viability of using TiO$_2$, Sm and Sr as tracers for glacial activity. CaO is a viable tracer presumably due to the high weight percentage found in the Helena and Snowslip formations, whereas TiO$_2$ from the intrusive sill might be present in such a small percentage as to be below detection limits by some methods.

Gonzalez (2005) conducted a geochemical analysis on two of the argillitic formations present in the Grinnell Glacier valley with similar results. Argillites from the Grinnell and Appekunny are compositionally equivalent, and only differ in color due to oxidation at time of deposition. When compared to pA-UCC, he found these samples were enriched in Sm and Gd, but were otherwise relatively consistent with pA-UCC. His results showed the primary mineral in these samples were quartz-feldspar-smectite clays. While these formations are not the focus of my analysis, these geochemical and mineralogical analyses agree with my findings.

Till samples showed low levels of CaO, TiO$_2$, Sr and Sm; all elements unique to Belt units stratigraphically at and above Grinnell Glacier. This suggests the Helena, Snowslip, and Purcell units are not major contributors to till deposits surrounding Lake Josephine and Swiftcurrent Lake. In addition, it is unlikely the tills are providing significant carbonates to the lakes, isolating the Helena Formation as the primary source of %TIC in lake sediments. Geochemical indicators suggest the tills are genetically close to the argillite units (the Empire, Grinnell and Appekunny Formations), which are arguably the major contributor to these deposits. In order to further strengthen the argument that certain elements are direct tracers of glacial activity, analyzing other inputs into the lake cores proved to be a necessary step. Based on the trace element plots presented in Figure 4 and 5, and comparison of major elements in Figure 3, it appears that tills are not significant contributors of CaO, TiO$_2$, Sr or Sm. While the tills do contain a small amount of each element, it is highly doubtful that hillslope failures would explain the spikes documented in CaO in the lake sediment cores (MacGregor et al., 2011).

**CONCLUSION**

Geochemical analyses of the formations present in the Grinnell Glacier valley in Glacier National Park, MT, suggests that the concentration of CaO in proglacial sediments can be used as a tracer for glacial bedrock erosion of the Helena and Snowslip Formations. Periods of global cooling are likely to be represented in lake cores as increases in %TIC, where increases in the footprint of Grinnell Glacier are correlated with increased erosion of the Helena Formation. In addition to the constraint of CaO to the upper formations, geochemical analyses of the formations in the valley led to the discovery of three other potential tracers - TiO$_2$, Sr, and Sm. The Purcell Sill contains a uniquely high concentration of these elements, potentially providing other distinct tracers of previous erosion and subsequent deposition. Future work would
entail examining lake cores for TiO$_2$, Sr and Sm, to
determine if they are present in concentrations above
detection limits.

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