37th Annual

FIVE COLLEGE GEOLOGY
UNDERGRADUATE RESEARCH
POSTER SYMPOSIUM

APRIL 27, 2016
5:00 - 6:00 PM
BENESKI MUSEUM OF NATURAL HISTORY
AMHERST COLLEGE
The Yucatan peninsula is a relatively flat, low-elevation terrain made of Cenozoic limestone deposited on a broad carbonate platform/ramp of a gently sloping continental shelf. This project examines different types of limestone currently quarried on the Yucatan peninsula near the town of Mérida in order to establish criteria for identifying the stone used by the Pre-Columbian Maya people in artifacts and architecture at the Maya site of Mayapán around 1100 to 1450 AD (Masson and Peraza Lope, 2014). The examination of limestone includes gathering information on their geological descriptions and interpretations, which contribute towards interdisciplinary collaborative research with expert archaeologists from the University at Albany-SUNY

Ten samples of cut and polished limestone were obtained from two stone distributing companies. Each sample was described, photographed and turned into a thin section for petrographic analysis, which identified the following four groups of limestone: 1) the stones known commercially as Ostra and Sisal represent porous and friable coquina with large mollusk (pelecypod and gastropod) shells in a muddy matrix deposited on a shallow subtidal, low energy, relatively open carbonate ramp; 2) the stones called Macedonia and Nude are fine-grained, well-consolidated, light-colored, bioturbated peloidal-skeletal (echinoids, mollusks, algae and ostracods) packstone formed in a restricted, subtidal lagoonal environment; 3) the stones quarried under the name Uxmal are orange-brown, Fe-oxide impregnated skeletal (foraminifera, algae and mollusks) packstones to grainstones that formed by pedogenisis (terra rosa soil formation) of marine strata during subaerial exposure; and 4) the stone known as Venado is a limestone breccia with dark clasts that were impregnated with organic matter in coastal marshes and incorporated in lighter-colored marine skeletal deposits during sea-level rise. Review of published literature identified two additional types of limestone present in the region, but not currently represented in our samples: 5) calcrete or caliche is a well-indurated, hard surficial crust; and 6) sascab or sahcab is a very soft, unconsolidated, weathered limestone that commonly underlies caliche.

Limestone was the only locally available stone resource available to the Pre-Columbian Maya people who used the most resistant and durable rocks (e.g., Uxmal, Macedonia, Nube, caliche) for monumental buildings and roads. The more friable material (coquina and sascab) was used for lime production (Espinosa et al., 1998). Future field work (May 2016) will focus on documenting the relationship between geology and the history of limestone utilization on the Yucatan peninsula, with emphasis on different varieties of limestone, their weathering patterns, and the use of lime/concrete vs. natural stone.
Effects of Early Diagenesis on $\delta^{44/40}$Ca Records of Upper Ordovician Carbonates and Implications for $\delta^{13}$C Interpretations

Brothers, R. William and Jones, David S., Geology Department, Amherst College,

The end Ordovician (Katian and Hirnantian stages) was a time of continental ice sheet growth and sea-level fall, and it corresponds with the second largest mass extinction event in Earth history. A globally preserved positive excursion in carbon isotope ratios ($\delta^{13}$C) in sedimentary rocks has played an important role in constraining environmental changes that accompanied the mass extinction and glaciation. Calcium isotope ratios ($\delta^{44/40}$Ca), a relatively new tool for investigating earth history, can also preserve a record of environmental changes and diagenetic processes. Like $\delta^{44/40}$Ca, calcium isotope ratios are controlled by changes in ocean chemistry and subsequent diagenetic alteration, but the geochemical signatures of meteoric and seawater alteration are different for the carbon and calcium systems such that $\delta^{44/40}$Ca values can serve as an independent record of early diagenetic processes. As such, understanding $\delta^{44/40}$Ca has the potential to resolve outstanding issues in the interpretation of global and regional $\delta^{13}$C records.

We analyzed $\delta^{44/40}$Ca of three subtidal to peritidal dolostones and one deep water limestone from four upper Ordovician stratigraphic sections that transect a shallow carbonate shelf in the eastern Great Basin. Two of the dolostone sections, Pancake Range and Barn Hills, were located in the Ibex Basin, while Silver Island Range was deposited in the Tristate Basin. Monitor Range, a deep water limestone, was deposited in the Ibex Basin. Mean $\delta^{44/40}$Ca values differ between these three dolostone sections; they range from -1.3‰ to -0.5‰, which is significantly more enriched in $\delta^{44/40}$Ca than the Monitor Range which ranges from -1.9‰ to -1.1‰. Because seawater is enriched in $\delta^{44/40}$Ca relative to meteoric fluids and carbonates that precipitated from seawater, the elevated calcium isotope ratio in the dolostones can be attributed to early seawater alteration coincident with dolomitization. The differences between $\Delta \delta^{44/40}$Ca in each of the dolostone sections indicates that paleogeographic location influenced the magnitude of seawater alteration in the dolostone sections and likely caused the Monitor Range to undergo the least seawater alteration. Differences in temperature driven seawater convection patterns (known as Kohout convection) can explain the variable patterns of geochemical alteration in the dolostones. These convection patterns can also explain why caused the deeper Monitor Range is less altered by seawater. Variations in $\delta^{44/40}$Ca exceed what could have been caused by fluctuations in temperature alone, and the magnitude of the differences within each section suggest that dolomitization did not entirely overprint the original calcium isotope ratio. While $\delta^{44/40}$Ca and $\delta^{13}$C are uncorrelated in the dolostone sections, $\delta^{44/40}$Ca values in the Monitor Range—a limestone section—are correlated with $\delta^{13}$C, providing additional evidence that Monitor Range contains a more pristine geochemical record. Potential explanations for coupling between $\delta^{44/40}$Ca and $\delta^{13}$C in the Monitor Range include changes in original minerology and temperature related controls on fractionation.

Separately, the relationship between isotopic depletion and stratigraphic distance below sequence boundaries in Silver Island Range and Barn Hills indicates that meteoric flushing played a role in the early diagenetic history of these sections. Meteoric diagenesis partially overprinted the geochemical signal of seawater alteration, constraining the timing of seawater diagenesis. This is evidence that the fluxes of seawater associated with resetting $\delta^{44/40}$Ca
occurred very early in the diagenetic history of these strata, likely within ~50 m of deposition. Knowing that each section underwent different magnitudes of seawater alteration elucidates the degree to which δ¹³C values were reset by seawater during diagenesis. Particularly, these results show that Monitor Range has the best preserved δ¹³C signal (including a +7 ‰ Hirnantian excursion), while seawater alteration played a major role in altering the δ¹³C values of the dolostone sections. This indicates that the Hirnantian δ¹³C excursion may have been larger than the 3-4‰ change recorded in the dolostone sections. Determining the true magnitude of the δ¹³C excursion has important implications for reconstructing climactic changes during the end Ordovician ice age. Together, these data show the utility of calcium isotope measurements for constraining both the diagenetic history of carbonate strata and the impact that diagenesis may have had on carbon isotope records.
East and Paulina Lakes are located side-by-side in the Newberry Caldera separated only by a volcanic ridge of rhyolite approximately 2000 m wide. Despite their proximity to each other, these two lakes have vastly different water and sediment chemistries, suggesting a disparate hydrologic sourcing. This is highlighted by the concentrations of two very toxic metals in the sediments, mercury and arsenic. Paulina Lake has ~15 ppb Hg and up to 250 ppm As whilst East Lake has up to 3500 ppb Hg and only ~25 ppm As. Previous studies propose that these lakes are fed by one volcanic input that branches off to deliver a Hg-rich gaseous phase to East Lake and a As-rich hydrothermal input to Paulina Lake (Lefkowitz 2015). As part of a larger KECK study, this past summer we sampled each lake for water and sediment in addition to the hot springs surrounding each lake to further constrain their geochemical evolution. Early results indicate differences in organic input to each lake, with East Lake having on average 3 times the amount of TOC (~6%) with a carbon isotopic value of -20‰, while Paulina Lake’s organic input is lower (2%) with a more terrestrial isotopic signal (~ -26‰). The sediment’s pore waters also vary from lake to lake: Paulina Lake has ~4.5 ppm and ~40 ppm Cl and SO4, respectively, while East Lake has concentrations that are approximately half that. Finally, East Lake has been previously reported to have two isotopically distinct methane pools in its waters: a 13C-enriched end member (~30‰) in its deep water (likely a thermogenic source), and a pool nearer to the surface with δ13C of ~50‰ that may suggest a biogenic component (Varekamp 2015). We are examining the microbial populations in the water column via RNA analysis to further identify possible sources.
Relative Flow Intensity Analysis of Modern and Historical Tropical Atlantic Hurricanes

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University of Massachusetts, Amherst

Hurricanes and tropical storms can cause devastating fatalities and expensive structural damage within coastal communities. In our warming climate, we do not yet understand how climate change will affect hurricane frequency or intensity, making accurate climate and storm proxies necessary to protect against hazardous storms. This study aims to better understand relative tropical Atlantic hurricane intensity by relating grain size to settling velocity. Our core, taken from a blue hole basin off the southern coast of South Andros, Bahamas, preserves a 600 year record of tropical cyclone activity. We determined coarse fraction every centimeter of our core which revealed a period of frequent storm events depositing very coarse material into the basin. To further assess relative hurricane flood intensity, we ran samples >15 percent coarse on the Camsizer for grain size analysis. We also ran settling tube velocity tests for different grain size increments to produce a relationship between grain size and settling velocity. Our results show that the settling velocity for grains >710 um deviates greatly from the theoretical model, and grains >1500 um reaches a maximum setting velocity of 0.08 m/s. We account for this deviation and asymptotic maximum by the flattened shape of the carbonate grains. Theoretically, all grains >1500 um deposited in this blue hole could have been moved by the same intensity event, suggesting that settling velocity may be a more significant indicator of storm magnitude than grain size when studying carbonate basins.
Reconstructing Pleistocene Climate Variability in the Terrestrial Arctic: An Organic Geochemical Paleoclimate Record from Lake El’gygytgyn, Russia

Julie Chessia, Geoffery Small, M. Helen Habricht, and Isla Castañeda
Department of Geosciences, UMass-Amherst

Lake El’gygytgyn, Chukotka, NE Russia is a meteorite impact crater located 100 km north of the Arctic Circle. The crater was created 3.6 million years ago (Ma) and has remained unglaciated since its formation, thus providing the longest and most continuous record of Arctic paleoclimate. The Pleistocene is a period of Earth’s history, which lasted from 2.58 Ma to 11.7 ka, which is characterized by strong fluctuations between cold glacial periods and warm interglacial periods. This study utilizes organic biomarkers in Lake El’gygytgyn sediments from 200-800 thousand years ago (ka) to reconstruct climate variability in the terrestrial Arctic across the mid- to late-Pleistocene. Branched glycerol dialkyl glycerol tetraethers (brGDGTs) are used to reconstruct temperature variability and plant leaf waxes (n-alkanes) are examined to determine vegetation and hydrologic changes throughout the study interval. BrGDGT temperature reconstructions indicate the terrestrial Arctic experienced both warm interglacials and mild glacial periods during the mid-Pleistocene, and transitioned to more extreme temperature fluctuations later in the study interval. The average chain length of n--alkanes indicates that glacial intervals were especially arid, while interglacial periods were wetter at Lake El’gygytgyn.
Implications of Quartz Crystallographic Preferred Orientations in Granitic Orthogneiss and Quartzite in the Core of the East Humboldt Range Metamorphic Core Complex

Gabriel Chevalier: Mount Holyoke College
Advisors: Michelle Markley, Allen McGrew, Jeffrey Rahl

The Ruby Mountains - East Humboldt Range (RM-EHR) metamorphic core complex in Northeastern Nevada exposes deep crustal levels associated with Tertiary extension (~23 - 30 Ma) in the modern Basin and Range tectonic regime. This study focuses on one spectacular locality, Angel Lake Cirque, that exposes a significant transition from intensely deformed mylonites at shallower structural levels to a higher temperature but more diffuse deformational regime below. At least 700 m of exposures beneath the mylonitic shear zone offer a unique opportunity to study changes in fabrics, structures and deformation with depth. Most C-axis fabrics in the quartzites show strong central Y-axis maximum (parallel to foliation, perpendicular to lineation) but some less pronounced maxima are expressed at a high angle to foliation and lineation. Top to the WNW sense of shear predominates in these samples. The results from 2 monzogranite orthogneiss samples are consistent with, but weaker than, the results from the 7 quartzite samples. The measured quartz CPOs indicate mostly high temperature deformation that was accommodated on multiple slip systems. Peak pressures and temperatures of up to >750°C and 10 Mpa were achieved during Late Cretaceous emplacement of Winchell Lake fold-nappe which was subsequently overprinted by Cenozoic extensional mylonitic deformation at continued high T (>600°C) but declining P. The quartz CPOs at this locality document the transition from the mylonitic detachment down to deeper levels. They show that the temperature of deformation increases with depth, as does symmetry. The agreement between the CPOs of the quartzites and the late Oligocene monzogranitic orthogneiss confirms the late Oligocene to earliest Miocene timing of the extensional deformation.
Classification of Four Moroccan Chondritic Meteorites

Kayla Cox, Will Kopaciewicz, Josh Ostrow, Derek Trussell, and Sheila Seaman
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Four chondritic meteorites, each from falls in Morocco, and purchased on eBay, were classified on the basis of texture and olivine and orthopyroxene composition, and were evaluated as hosts of volatile compounds. Chondrites are generally undifferentiated primordial matter that has remained nearly unchanged for the past 4.5 billion years. Chondrules are spherical crystalline droplets in the chondritic meteorites. They are small droplets of olivine and pyroxene that are thought to have condensed and crystallized in the solar nebula in the form of small spheres. There are different kinds of chondrites because different asteroids that were the chondritic meteorite parent bodies formed in various regions of the primordial solar nebula under different conditions. Each chondrite is given a number from 1 to 7 based on the degree of alteration by water and/or metamorphism. A classification of 3 is a pristine chondritic meteorite. Numbers decreasing from 3 indicate increasing intensity of aqueous alteration, which is thought to have occurred on the meteorite parent body. Numbers increasing from 3 indicate increasing intensity of thermal metamorphism. Chondritic meteorites are classified as ordinary chondrites, enstatite chondrites, and carbonaceous chondrites. All of the meteorites studied here are ordinary chondrites. Ordinary chondrites are further classified as H Group (olivine-bronzite chondrites), L Group (olivine-hypersthene chondrites) or LL Group (iron-poor) chondrites. The four meteorites were thus classified on the basis of degree of alteration (1 to 7) and mineral assemblage (H, L, or LL Group). One of the meteorites studied here has been classified as an L5 meteorite, two as H5 meteorites, and one as an H4 meteorite. Olivine and pyroxene crystals in all of the meteorites host water. Water has been identified in chondritic meteorites by other workers (e.g., Doyle et al., 2015), who have shown with H isotopic analysis that hydrous alteration did not happen in the terrestrial environment. This has been taken as evidence that the asteroid(s) from which the hydrous meteorites were derived hosted water.
CHARACTERISTIC FEATURES OF PRODELTA TO DELTA FRONT SANDSTONES FROM THE CRETACEOUS NANUSHUK AND TOROK FORMATIONS, SLOPE MOUNTAIN, NORTH SLOPE, ALASKA

Sarah Dickson, Smith College
Keck Geology Consortium Advisors: Grant Shimer (Whitman College) and Paul McCarthy (University of Alaska, Fairbanks); Smith College Advisor: Bosiljka Glumac

The Torok and overlying Nanushuk Formations were deposited within the Colville Basin in northern Alaska during the Albian to Cenomanian (Mull et al., 2003). These interfingering formations illustrate an important environmental transition from fine-grained, muddy deposits to overlying coarser sand deposits. Data was compiled from field and hand sample descriptions, and petrographic analyses of thin sections from four different outcrops at Slope Mountain.

The documented upward-coarsening succession represents delta progradation from muddy prodelta deposits in the upper Torok Formation to sand-dominated delta front deposits in the Nanushuk Formation. Bioturbation, trace fossils, and soft-sediment deformation are features common to prodeltaic deposits, and are found abundantly in the lower part of the succession. The overlying sandstone-dominated delta front deposits have more current-generated structures such as crossbedding and ripple marks. Compositionally, these sandstones are mainly lithic wackes, with some lithic arenites in the uppermost sections, dominated by monocrystalline quartz and volcanic and metamorphic lithic fragments.

The textural and compositional characteristics of these rocks indicate that the Nanushuk and Torok Formations at Slope Mountain were deposited by the Umiat Delta, a lobate river-dominated delta which deposited sediment into the Colville Basin (Huffman et al., 1988). The Umiat delta deposits have been described as lithic arenites dominated by volcanic and metamorphic fragments with abundant bioturbation (Bartsch-Winkler 1985, Huffman et al. 1988). The deposits at Slope Mountain differ from other descriptions of the Nanushuk Formation in that bioturbation is less prolific, which may suggest lower oxygen levels or more rapid sedimentation in this particular area of the Colville Basin (Bartsch-Winkler, 1985, Huffman et al., 1988). This study complements previous work in the area with a more complete description of the prodelta to delta front environmental transition between the Torok and Nanushuk Formations (Johnson and Sokol, 1998).

Investigations of Lead (Pb) Solubility derived from Pipes and Peat: Experiments by Students in Aqueous Geochemistry (GEO 301) at Smith College

Sarah Dickson, Hannah Francis, Marina Howarth, Claudia Mazur, Emma Schlam, Seulgi Son, Courcelle Stark, Elizabeth Sturtevant, Meghan Sullivan

Department of Geosciences, Smith College, Northampton, MA

Dissolution of lead (Pb) from either water pipes or from soils into solution is both a health and environmental concern. Recently in Flint, Michigan, extremely high concentrations of lead in household drinking water, which resulted in acute health problems of many residents drinking this water, has been attributed to a change in the water source that supplies the Flint municipal water system and a lack of water treatment by the municipality. The new water source, the Flint River, is considered more corrosive because of high concentrations of chloride due to road-salt contamination. The chloride to sulfate mass ratio (CSMR) increased from 0.45 (low corrosivity) to 1.6 (high corrosivity) following the change in water supply. Additionally, anti-corrosive agents containing orthophosphate were not added to the water, and this more corrosive water leached lead from municipal water pipes. In sum, measured lead levels in many households in Flint exceeded the maximum contaminant level of 15 µg/L for drinking water established by the E.P.A. One news report cited levels for one household that were as high as 13,200 µg/L, exceeding federal standards by ~1000 times.

Inspired by these events, students in Aqueous Geochemistry at Smith College (GEO301) have been performing their own-designed experiments investigating the solubility of lead in solutions having varying pH and chloride concentrations. The experiments, performed over the past 4 weeks, are as follows:

Team Pipes (Dickson, Francis, and Stark): “Team Pipes” wanted to see whether the solubility of lead varied with chloride concentration, and whether ultra pure water (UPW) from the lab was more or less corrosive than tap water, which has been treated with the anti-corrosive agent zinc orthophosphate by the city of Northampton. Copper pipes (n=12) were first soldered using a 60/40 lead/tin solder. The pipes were reacted with solutions having chloride concentrations ranging between 0 - 250 mg/L; the pH of the UPW and tap water were not modified, and ranged from ~6 – 7.5. After reacting for one week, unfiltered samples were measured for Pb by Atomic Adsorption Graphite Furnace and for Pb and P by ICP-OES. Several reactions formed a white precipitate, and all solutions yielded high lead concentrations, ranging from ~ 10 – 95 mg/L. The lowest lead concentrations occurred in solutions having the highest chloride concentrations. Based on the low solubility of the mineral cotunnite (PbCl₂), it is believed the higher Cl facilitated precipitation PbCl₂ after Pb was leached from the soldered pipe joints, decreasing the concentration of Pb in the water.

Teams Peat Digest (Howarth, Schlam, Son, and Sullivan) and Peat Extract (Mazur and Sturtevant): This study investigated whether peat collected from an alkaline fen retained Pb, which presumably originated from air pollution when cars were fueled by leaded gasoline. If Pb was preserved, what solution chemistry could leach the Pb from the peat, and by how much?
The study site is Kampoosa Bog (Stockbridge, MA), which is a calcareous fen impacted by road-salt pollution by an adjacent highway. Peat was collected from the peat mat of the fen using a Russian Peat Corer from depths ranging from 0 – 2.5m. Collected at 2 cm intervals, subsamples of peat were digested with HNO$_3$ in a heated microwave digester. The extracts were then filtered and analyzed for Pb by an Atomic Adsorption Graphite Furnace. For the leaching experiments, peat was reacted with fen groundwater (field pH ~ 7) having varying chloride levels from the road-salt pollution (Cl $\approx$ 60-277 mg/L). To simulate an acidification event, half of the fen-water reagents were acidified with concentrated nitric acid to a pH $\approx$ 3. To simulate different climatic conditions, half of the samples were reacted in a refrigerator (4ºC), and half were reacted in an oven (30ºC). All reactions occurred over one week, and filtered samples were analyzed for Pb by Atomic Adsorption Graphite Furnace.

The digest results revealed high concentrations of Pb (almost 10 mg/kg) retained by peat at a depth of 1m, below which levels declined to a mean of approximately 2 mg/kg. No detectable Pb could be leached from the peat under alkaline conditions (pH ~ 7), even at high concentrations of chloride. However, all acidified reagents produced dissolved Pb (up to 2.8 mg/kg peat). Highest concentrations were leached from acidic reagents that had higher Cl concentrations, and the heated samples yielded slightly more Pb than the refrigerated samples. These findings demonstrate that this peatland has retained Pb, that Pb can be leached from organic soils under more acidic conditions, and more saline groundwater further facilitates leaching of Pb from the soil.
Experiments Investigating Retention of Sodium in Peatlands Affected by Road-Salt Pollution

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Road-salt contamination has the potential to alter the geochemistry of calcareous wetlands. Sodium from road salt adsorbs to organic material, causing it to accumulate and be retained by wetlands. Increasing salinity of soil water from road salt contamination can change the adsorption capacity and the energetic preference for calcium vs. sodium on exchange sites of soil organic matter. The level of sodium adsorption should vary with the concentration of Na\(^+\) and other cations in groundwater, as has been demonstrated for clay minerals. However, the equilibrium constants for these cation exchange reactions on peat, which define the thresholds to which sodium can adsorb to peat surfaces by removing a previously adsorbed cation, are not constrained. Experiments using different ratios of sodium to calcium in solution can test the limits of sodium adsorption on exchange sites on peat.

In this study, peat was reacted with solutions at various ionic strengths (I=1mM, 10mM, and 100mM) and with various ratios of sodium to calcium in solution (SAR= 1, 2.5, 5, 7, 10, 20, 40, 60). Values obtained from these experiments were used to calculate selectivity coefficients to determine energetic preference for sodium vs. calcium on the exchange sites. Peat for the exchange reactions was collected from a floating sphagnum moss peat mat at Hawley Bog (Hawley, MA) because it is remote from roads and should have low concentrations of sodium and divalent cations. Results inform reactions occurring in Kampoosa Bog, a calcareous fen that receives road-salt runoff from the Massachusetts Turnpike and where the dominant cation exchange reaction occurs between sodium and calcium, where sodium in solution replaces calcium on the exchange sites.

The experimental results suggest that sodium preferentially exchanges with calcium at higher ionic strengths, however to a limit. Sodium appears to be the preferential cation on the exchange sites until it is 60% (I=10mM) to 80% (I=100mM) saturated, above which calcium then becomes energetically favored. The maximum sodium adsorption occurs when the SAR solutions have exchange coefficients less than 1. These findings suggest that Kampoosa Bog (I=8mM) has not reached a threshold for sodium retention, at only 6.2%, in the wetland system. Given persistent use of road salt that increases sodium in the wetland due to runoff from current salting practices, sodium would also be expected to increase on exchange sites, potentially threatening the integrity of the peat mat and the viability of wetland species.
Borehole temperature profiles constrain groundwater flow, evaporation rates, and discharge to the Salar de Atacama, Chile

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The Salar de Atacama (SdA) in northern Chile provides a unique opportunity to study regional hydrogeologic processes in a hyperarid environment. The endorheic basin acts as a local and regional discharge zone for groundwater recharge off the Altiplano-Puna Plateau. The area is characterized by active modern (Late Miocene-Pliocene to present) volcanism and stratovolcanoes including Socompa (~6600 m) and Pular (~6200 m). The basin has been receiving groundwater discharge since ~ 7 Ma resulting in the accumulation of massive evaporite deposits in the halite nucleus (>1500 km³). Modern discharge of water along a 90km long flowpath evolves from fresh water to brine over an 8 km long transition zone. This study uses groundwater temperature profiles to constrain rates and hydrogeochemical processes impacting groundwater discharge in the southern transition zone of SdA.

Temperature profiles are analyzed for 13 wells along a 31 km hydrogeologic transect. The wells range in depth from 30m to 100 m with land surface elevations of 2450m at the most upgradient well and 2300m for wells in the heart of the halite nucleus. Wells were profiled seasonally so that we may observe seasonal temperature variations in the shallow subsurface. All wells are drilled into the southern transition zone aquifer and constrain the properties of the aquifer as fluids transition from the freshwater residing in the up-gradient alluvial aquifer to the brine found in the halite body to the north.

A general cooling trend along the discharge zone has been observed in the vicinity of ephemeral lagoons. Temperature profiles generated from boreholes spanning the hydrologic transition zone reveal a drop of approximately 10°C within the geothermal, discharge zone. Local volcanism, noble gas signatures, and upward flow of warm water seen in up gradient boreholes suggest a shallow magma body impacts available heat within the aquifer. We hypothesize that the enthalpy of vaporization of the brackish water found in the aquifer is one mechanism responsible for heat loss across the transect.
QUANTIFYING THE PENETRATIVE DEFORMATION OF A LIMESTONE PEBBLE CONGLOMERATE FROM THE KOOTENAY ARC, NE WASHINGTON

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This study applies $R_\phi$ analysis to high resolution (1200dpi) scans of three mutually perpendicular cuts from an oriented sample of deformed limestone pebble conglomerate, with the ultimate goal of producing a strain ellipsoid approximation. Similar analysis was previously performed on the same sample, where ellipses were measured by taking the longest dimension of the pebble as the long axis, and its perpendicular bisector as the short axis (Stewart 1996). A different protocol for ellipse measurement (largest internal-fit ellipse) was used in this study to determine the extent to which the protocol for fitting ellipses to irregular pebble shapes may affect the results. Statistical analysis using the $\chi^2$ goodness-of-fit test (assuming random initial distribution of long-axes; Chew, 2003) was chosen to determine the range of most probable aspect ratios of the strain ellipse for the study plane, instead of the graphical approach of using the best-fit initial-axial-ratio envelope (Lisle, 1985). Comparison of results from the same cuts indicate that the difference in protocol does not make a significant difference in outcome. Homogenous deformation was initially assumed because both pebbles and matrix are calcitic, suggesting negligible ductility contrast. However, new high resolution scans allow the measurement of very small pebbles (<2.5 mm$^2$), a different population than either outcrop pebble data (the sizes of which are not constrained by the size of the sample) or previous measurement of the same cuts using lower resolution scans, which raises the question of a size-dependent variation in deformation behavior. Important questions under consideration include the soundness of the assumption that the pebbles deformed passively and the extent to which the analysis can produce robust results applicable on a regional scale.

Part of the Windermere supergroup, this deformed conglomerate originated during the late Proterozoic in a prograding passive margin that subsequently became shortened and deformed during Mesozoic Cordilleran orogenesis. This study contributes to research aimed at quantifying penetrative deformation in the hinterland of the Canadian Cordilleran thrust belt, which can be compared to shortening estimated from palinspastic reconstructions of balanced cross-sections (Price, 1981; 1986).
Coprolites, despite their mundane origins, are among the most informative and useful specimens in paleontology. They sometimes contain the harder, bonier remains of prey that have been preserved through digestion, allowing paleontologists to draw trophic connections between animals in the same formation if the creator of the coprolite can be identified, aiding in the larger effort to map paleoecological trophic webs. First described by William Buckland in 1829, they have revolutionized our ability to reconstruct and comprehend ecosystems of the distant past, helping fit individual specimens into a larger picture.

I present here an analysis of the structure, contents, and significance of the oldest-known ichthyosaur coprolite. Recovered from the Luning Formation in Berlin-Ichthyosaurus State Park, Nevada during a Mount Holyoke expedition in May of 2014, it provides us with an intimate glimpse into the life history of the *Shonisaurus popularis* ichthyosaurs in the late Triassic.
STORM-DEPOSITED COASTAL BOULDER RIDGES ON SAN SALVADOR ISLAND, BAHAMAS IN THE AFTERMATH OF HURRICANE JOAQUIN

Naomi Jahan, Smith College
Advisors: Bosiljka Glumac and H. Allen Curran

Hurricane Joaquin was Category 4 at its strongest and high Category 3, with winds of 120-130 mph, when it passed over the Bahamian island of San Salvador on October 1-3, 2015. This research is part of a larger-scale study to assess the impact of the storm on San Salvador and to compare the effects of Hurricanes Sandy (October 2012) and Joaquin. This particular study focuses on storm-deposited boulder ridges in two localities on San Salvador and how specific boulders have been moved or modified by Hurricane Joaquin. Fifteen large boulders from the Singer Bar Point site along the north coast, and twelve large boulders from The Gulf site on the south shore of the island were catalogued in January 2012. Cataloguing included photographing the boulders and documenting their GPS location, size and composition. All but two of the boulders from The Gulf were relocated in 2013, post-Hurricane Sandy. In January 2016 we catalogued these boulders again, after Hurricane Joaquin, and aerial photos taken from a drone were used for comparative analysis of overall erosional impact. All of the large boulders at Singer Bar Point were relocated at or near their former positions although the surrounding sand and smaller clasts were moved by storm waves. In contrast, only five of the large boulders at The Gulf were relocated with certainty. Two of those, weighing ~2 tons, were carried as much as 20 m and 26 m inland to the NNW. The southern edge of the boulder ridge migrated landward by 4-5 m exposing the underlying Pleistocene/Holocene boundary terra rosa paleosol, which stands out in aerial images and can be used to map the extent of storm erosion. The formerly sharp-crested boulder ridge was modified by the storm into a larger, broad boulder field, stripped of vegetation, and partially covering the main coast road. Results indicate that Hurricane Joaquin had much larger impact than Hurricane Sandy on San Salvador because the island was directly in the path of Joaquin. The eye of the storm went over San Salvador, and storm-generated winds and waves pounded the island from multiple directions over several days. The northern coast of the island is more protected and underwent less boulder movement than the high-energy southern coast where the storm resulted in a localized pattern of erosion, preferentially eroding certain areas, related to the direction, angle and height of the waves, with some control from the shape of the coast. Distribution and morphology of boulder ridges and the information about the dynamics of their modification are indicators of storm patterns and activity and should be used to inform any future coastal development on San Salvador and elsewhere in the Bahamas.
Studying Anthropocene Sedimentation behind a 19th-20th century dam in Western Connecticut

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18th to early 20th century dams are a common occurrence in New England. Made from compacted earth and rock, and later with stone and brick masonry and concrete, these river impoundments served a variety of functions from powering mills to cooling iron furnaces. Over time, the reservoirs behind these dams become infilled with a sedimentary and geochemical archive of the contributing watershed that potentially preserves land use changes such as the clearing and regrowth of forest as well as recording historic flood events. With dam removal becoming more common, the possibility of releasing contaminated sediment is also a growing concern in the region. Our study reconstructs and analyzes sedimentation behind the Hollenbeck dam in Canaan Connecticut, which was used to cool the Buena Vista iron furnace from ~1847-1893. We assess the volume, sedimentology and geochemistry of 19th-20th century sediment preserved at this site. We collected three vibracore cores (HPSC1, HPSC2 and HPSC3) behind the Hollenbeck dam, recovering 237 cm, 203 cm and 390 cm of compacted sediment, respectively. Intercalated wood at the bottom of our deepest core (HPSC3) yields a $^{14}$C age of 12,327+/-184 ka. We will use Cs-137 and Pb-210 dating to constrain the age of post-dam sediment in the upper portions of our cores and core samples will be analyzed for Hg and grain size. 30 probe-depth measurements were also collected from river and floodplain locations behind the dam. At each point, we measured depths of the first, second and third impenetrable sandy layer, which are hypothesized to reflect historic floods. Field data will be combined with a 2010 1m LIDAR DEM and air photos from 1934-present to analyze the extent of the upstream reservoir. Our objective is to use the cores, probe, LiDAR and sediment chemistry data to correlate layers and reconstruct the Hollenbeck Dam’s history of infilling associated with Anthropocene activities and land-use change.
River restoration is a growing industry that uses expertise in hydrology, geomorphology, and ecology. However, its practices vary in objectives and projects do not necessarily follow uniform guidelines. River restoration is often performed in response to floods, as was case in New England following Hurricane Irene. The Chickley River in the MA Deerfield River Watershed underwent 5.1 miles of channelization in 2011 and subsequent restoration in 2012. The channelization, somewhat of a return to conditions when the USACE channelized the river 50 years ago, was found by the MassDEP to have caused extensive habitat destruction. In 2012, the Chickley River underwent restoration with a focus on natural river design, including planting trees, filling channelized locations, and placing large woody debris (LWD). This study examines the Chickley River’s geomorphic and habitat at post-Irene (2011), post-channelization (2011), post-restoration (2012), three years post-restoration (2015) conditions. Channel stability was computed at three cross sections. After channelization, the Shields parameter exceeded 0.05, indicating channel instability. After restoration, the Shields parameter was approximately 0.05 at all cross sections, suggesting channel stability. Changes (<15 cm of erosion/deposition) were observed in channel dimensions. GIS analysis of vegetation indicated the average width of canopy opening above the channel was 5.8 m in 2009 (pre-Irene), 12.3 m in 2011 (post-Irene/pre-channelization), and 17.5 m 2014 (post-channelization). This demonstrates notable reductions in riparian cover due to Irene and channelization, and that restoration planting has so far had little effect on riparian cover. Aerial photo analysis shows that LWD increased due to Irene in the form of large log jams of >50 logs spaced at ~1 per km. Channelization removed nearly all LWD and restoration replaced LWD with log jams of 3-5 logs. These observations show that channelization reduced channel stability, riparian cover, and LWD. Restoration improved channel stability relative to the channelized conditions, but did not restore LWD or riparian vegetation to pre-channelization conditions. This study can be applied to better understand a recent shift in river management to consider ecological and geomorphic conditions.
A Crystal Size Distribution Study of a Plagioclase Megacryst-Bearing Basaltic Dike, Rafe’s Chasm, Cape Ann Plutonic Suite, Massachusetts

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The Silurian (Thompson and Ramezani, 2008) Cape Ann Plutonic Suite of northeastern Massachusetts appears to represent a layered magma chamber with less silicic magma near the base and more silicic magma towards the top. Abundant mafic pillows on Salem Neck (Cat Cove) are consistent with mafic injections at the base of a mafic and silicic layered intrusion (MASLI of Wiebe and Collins, 1998), and granite and syenite dominated outcrops exposed throughout Gloucester are consistent with the upper reaches of such complexes. A wide variety of compositional and textural features indicative of magma mingling are exposed in the outcrops of Cape Ann. The present study focuses on a 2-3-meter-wide basaltic dike with outstandingly large and white plagioclase crystals located in Rafe’s Chasm in Gloucester. Plagioclase phenocrysts range from ~1 mm to 240 mm long. Phenocrysts are commonly deeply embayed, indicating either solution during depressurization or dissolution in a melt with which the phenocrysts were not in equilibrium. The dike was the subject of a crystal size distribution (CSD) study. In hand specimen it is apparent that the dike hosts several size populations of plagioclase phenocrysts, with smaller phenocrysts images collected of the slabs. Slabs were analyzed using Image J software, and the data obtained, including long axis crystal lengths, were used to create plots relating the number of phenocrysts in specific length groupings to the natural logarithm of long axis dimensions. The slope of the resulting line (or the slopes of line segments) is the negative inverse of the growth rate of that crystal population multiplied by crystallization time. Variations in slopes of the plots of ln (length of crystal) vs number of crystals indicate that phenocryst growth in the Rafe’s Chasm dike was sporadic, with growth rates of larger crystals faster than that of smaller crystals.
Deformation mechanisms and quartz crystallographic preferred orientations at varying structural levels in a crustal-scale extensional mylonitic shear zone, East Humboldt Range, Clover Hill, and Wood Hills, Elko County Nevada

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The Ruby Mountains-East Humboldt Range-Wood Hills metamorphic core complex in northeastern Nevada offers an unusual opportunity to trace the evolution and development of a 1km thick crustal-scale extensional mylonitic shear zone. An east-to-west transect from the Wood Hills through Clover Hill to the East Humboldt Range exposes progressively deeper structural levels of the mylonitic lower-plate of the Oligocene to earliest Miocene Ruby Mountain detachment fault.

Quartz deformation mechanisms have been inferred from the crystallographic-preferred orientations (CPOs) determined by electron backscatter diffraction (EBSD) for eight quartz-rich samples mylonitized within the shear zone. All of the samples have strong quartz crystallographic preferred orientations consistent with previously published reports. C-axis maxima range from 5-6 times uniform distribution in granitoid samples to 19-24 times uniform distribution in mylonitic quartzite. Though somewhat weaker, quartz CPOs from the mylonitic orthogneisses are consistent with those from nearby quartzites; they also serve to bracket the age of deformation between the early Oligocene age of the granitoids and earliest Miocene ⁴⁰Ar/³⁹Ar biotite cooling ages. The nature of the quartz CPOs changes systematically down the dip of the Ruby Mountain detachment. The structurally highest Wood Hills mylonites have quartz CPOs with c-axes distributed about an asymmetric girdle. This CPO is interpreted to be the result of quartz deformation with a significant contribution by basal <a> slip. Mylonites from structurally deeper Clover Hill outcrops have a quartz CPO with quartz c-axes forming an asymmetric girdle centered on Y, a fabric interpreted to have formed by a combination of rhomb <a> and prism <a> slip. Mylonites from the structurally deepest outcrops from the East Humboldt Range have quartz CPOs characterized by c-axis maxima parallel to Y, suggesting deformation dominated by prism <a> slip. This transition from basal <a> to rhomb <a> to prism <a> slip results from deformation at progressively higher temperatures towards the structurally deeper parts of the shear zone.
ITRAX Stratigraphy of the Deglacial Section of Ware Pond Core, Marblehead, MA

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I analyzed the geochemistry of a sediment core taken from Ware Pond in Marblehead, Massachusetts. My goal is to determine if the basal sediments are marine in origin using ITRAX data. The total length of the recovered sediment core is 1242 centimeters; however, I focus on the lower section of the core (1000-1242cm). This range shows significant grain size variations, indicative of abruptly changing environmental conditions. The age of these sediments correlate with the overall retreat of the Laurentide Ice Sheet, during deglaciation. Ware Pond is a kettle pond located approximately 0.5 km from the ocean, and lies the late glacial marine limit. Therefore, it is reasonable to suggest that the area flooded with marine waters after the glacial retreat. I created graphs displaying elements and element ratios commonly present in marine sediments. Previous studies have shown that marine sediment often displays elevated levels of titanium and strontium, while showing equal and elevated amounts of Calcium and Potassium. In addition, increasing Magnetic Susceptibility (MS) suggests the inflow of inorganic materials. Organic matter content also decreases, which is shown by the decrease of Loss on Ignition (LOI) values. This suggests the changing environmental conditions within this depth range are inorganic in origin and produced high energy transport of sediments. Combined with the glacial history, time of deposition and geographic location, the sediments in the lower section of Ware Pond show compelling evidence of a marine origin. This evidence would suggest that Ware Pond may be a continuation of the Presumpscot Formation in Maine and Southern New Hampshire and the blue clay described in the Boston basin.

Citations
Precambrian metamorphism of the Wyoming Province: a petrological and geochemical study of amphibolites from the Highland Mountains in southwestern, Montana

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Hornblende – plagioclase – quartz ± garnet ± clinopyroxene ± sphene ± ilmenite ± biotite ± epidote ± sericite ± chlorite comprise amphibolites from the Highland Mountains that occur in 1-5 m, laterally continuous, concordant layers and are intercalated within more abundant biotite – sillimanite – garnet schist. The bulk composition of these rocks is dominated by hornblende, which typically makes up at least 40% of the mode, and quartzofeldspathic material that is present in variable amounts between 15-45%. Where it is present, garnet does not exceed 15% of the bulk rock composition. Analyses of geothermobarometry are based on the mineral systems, Grt-Cpx-Pl-Qt and Grt-Opx-Pl-Qt and yield metamorphic temperatures and pressures that range from 600-750° C and 7-8 kbars. Garnet grains, which are locally rimmed and/or replaced by plagioclase, are, in many cases, chemically zoned, with an increase in pyrope content from core to rim. These characteristics document retrograde reactions that occurred within these rocks, implying a period of decompression. Bulk rock geochemistry from this suite indicates that amphibolites metamorphosed from a basaltic protolith, allowing for the application of basalt discrimination diagrams in this study. A range in trace element signatures suggests that these rocks record the evolution of a subalkaline, tholeiitic magma chamber within a back arc basin.

The metamorphic conditions of amphibolites derived from this study overlap with the P-T path interpreted by Klein (2010) from the suite of Bt – Sil – Grt schist in which amphibolites occur. Furthermore, the results of geothermobarometry are analogous to those in the Tobacco Root Mountains according to Cheney and others (2004) for the same collisional event. The comparable, coeval metamorphic histories of these two mountain ranges constrain the metamorphism of the Big Sky orogeny to the upper amphibolite to lower granulite facies. The interpretation of these rocks having derived from a back arc basin brings into question the polarity of a subduction zone believed to have been involved in the collision that amalgamated the Wyoming province with other Archean cratons to the north. Contextualizing the origin and metamorphism of amphibolites builds on the understanding of both the geometry and P-T history of the 1.77 Ga Big Sky orogeny.
SEDIMENTOLOGICAL SIGNATURES OF REGIONAL SEISMICITY IN WESTERN SHIKOKU, JAPAN

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The Nankai Trough in southwestern Japan causes great intraplate earthquakes every 100-150 years. Although historical documents are unreliable regarding the magnitude of the resulting tsunamis, sediments preserved in back-barrier lakes allow past storm events to be reconstructed. In these sediments tsunamis are characterized by anomalously coarse deposits with elemental signatures similar to those observed along the site's barrier beach, with chronologies obtained from Cesium-137, heavy metal and Carbon-14 ages. The event of record is believed to be the 1707 Hoei tsunami which has been observed in several back-barrier lakes in Shikoku. Lake Sunokawa which is also located on Shikoku, as well as Lake Ryujin, a lake across the Bungo Channel in Kyushu, both exhibit the 1707 event in their sediments, providing a lateral extent of the tsunami. In addition, lithological changes at other sites in the Bungo Channel at around 1000 years ago suggest that they were caused by a tsunami derived from the Median Tectonic Line. Lagoonal sediments and in turn the barrier beach at Lake Sunokawa in its current form date to 1000 years BP and show a major environmental change at this time. However, Lake Sunokawa is closer to the mouth of the Bungo Channel and to the Nankai Trough, indicating that the event at 1000 years BP was less regional than earlier thought.
This study investigates the geochemical evolution of surface and ground waters of Tobago to understand timing of recharge, nature flow paths, and rates of solute flux. Tobago is a developing island in the Caribbean, whose aquifers are highly heterogeneous and anisotropic, composed of metamorphic and crystalline rock with structural controls on permeability. Hydrogeologic analyses of the water budget suggest that despite the low matrix permeability of the host rocks, the island is underlain by a prolific fractured rock aquifer system, the characteristics of which allow groundwater to bypass major topographic boundaries. Understanding the hydrogeology of small islands is critical to evaluating groundwater resources, especially in the Caribbean which experiences strong seasonality in precipitation.

In March and December 2014, we sampled 32 groundwater wells, 36 surface water sites (with discharge measurements), 5 springs, and ocean water. Eight months of precipitation data (June 2014 – January 2015) from 16 meteoric stations on the island were also collected. All samples are analyzed for stable isotopes of oxygen and hydrogen of the water molecule, major and minor elements, and $^{87}$Sr/$^{86}$Sr isotopes. This extensive collection of samples and robust geochemical data is uncommon among coupled hydrologic and weathering studies.

Initial findings constrain temporal controls on recharge, and what appears to be seawater signatures in groundwater wells. Stable isotope signatures of groundwater are uniform spatially and seasonally, and similar to the signature of wet season rains. This data supports conceptualization that wet season precipitation dominates recharge and groundwater chemistry, despite the fact that dry season precipitation contributes significantly to total precipitation amounts. Interpretation of major elements and $^{87}$Sr/$^{86}$Sr isotopes indicate seawater mixing in groundwater wells, some of which are screened below a brackish water bearing confining unit. We distinguish the source of the seawater signature from saltwater intrusion, or from downward leaching of brackish water. The location of significant fresh potable groundwater less than 1km to the coast with screens below sea-level confounds the interpretation of the fresh water/salt water interface in aquifers dominated by fracture flow.
Style and timing of folding in the Whitehall Quadrangle, Eastern Adirondacks: implications for the tectonic history of the Adirondack Highlands

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Large NW-oriented folds and later E-plunging folds have been recognized in the Eastern Adirondack Mountains, but the nature, timing and P-T conditions of folding events are not yet constrained. At least four tectono-metamorphic events are recognized in the region: the 1.2-1.16 Ga Shawinigan Orogeny, 1.16-1.14 Ga emplacement of the AMCG igneous suite, the 1.09-1.05 Ga Ottawan Orogeny and post-Ottawan tectonism. Field mapping and structural/petrographic analysis has been carried out in the western portion of the Whitehall quadrangle, where a kilometer-scale southeast-plunging synform has been hypothesized. Major rock units include: quartzofeldspathic gneisses with varying amounts of pyroxene, hornblende and/or mica, massive to weakly foliated gabbro, and local khondalite (Grt-Sil-Qtz-Fspar, interpreted to be restite), especially near gabbro. It is unclear whether the sequence contains multiple gabbro units or one unit repeated by isoclinal folding. The region can be separated into a western domain that displays a dominant NNE-striking foliation and continuous layering, and an eastern structural domain characterized by complex folding on several scales. Outcrop-scale folds are isoclinal and recumbent with gently East-plunging axes (10° → 105°). The presence of folded gabbro layers that cut an earlier gneiss foliation, folded inclusion trails in garnet that is wrapped by a strong foliation, and recumbent style isoclinal folding of khondalite, indicate that the region underwent at least two periods of deformation. Structures and fabrics in both domains suggest that the second deformation event involved intense east-west-directed shearing. Current work involves detailed microstructural analysis, petrologic analysis, geothermobarometry and timing of folding and metamorphism using monazite geochronology.
The Petrographic Analysis of Late Bronze Age “Canaanite Jars”

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Until recently, the anthropological study of trade networks in the Late Bronze Age Mediterranean relied primarily on an art historical perspective. But, with Late Bronze Age trade routes being as extensive as they were, judging the source of an object based solely on artistic characteristics can be misleading due to stylistic imitations. The growing use of petrographic analysis on traded objects, such as jars and other commodities made of anthropogenic sediments, can be used to help further bridge the gap on the connections being made between material culture and human behavior. Provenance studies based on the geological analyses of material (i.e. sand, metals, stone, etc.) can help determine where an artifact was made compared to where it ended up. The pottery samples used in this research were collected from two sites on the SE coast of Cyprus in the Mediterranean and date to the period between 1550 and 1150 B.C. The thin sections made from these samples were studied using a petrographic microscope to identify mineral assemblages and fabrics within the samples. These descriptions accompanied by a collection of full color photomicrographs will serve to build a database that will be published in an open-access format to provide comparative material for future research. The dispersal of this material allows for the future grouping of anthropogenic sediment fabrics to be more cohesive, leading to a better understanding of the manufacturing of human artifacts.
A study of the geochemical and geomorphologic evidence for prehistoric floods from Paulina Lake in Newberry Crater, Central Oregon

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Abandoned waterfalls and dramatic knickpoints line Paulina Creek showing evidence for catastrophic prehistoric floods of unknown origin. In addition to erosional features, there is a large flood apron (4.5 km$^2$) that formed just upstream of the confluence of Paulina Creek and the Little Deschutes River. Paulina Creek originates in Paulina Lake (620 ha) which lies within the western part of the crater of Newberry Volcano. Newberry Volcano is a Holocene shield-type volcano composed of dominantly basaltic flow, with some flows ranging to rhyolitic composition. Ash flows, cinder cones and pyroclastic deposits also compose the flanks of the volcano. Origin of the floods could range from landslides and volcanic eruptions displacing water from Paulina lake, to a catastrophic collapse of the outlet associated with the upstream migration of a knickpoint.

Flood waters exaggerated knickpoints throughout the canyon, originally a result of the stratigraphy of the flanks, and created waterfalls up to 40m high. Chitwood and Jensen, in their paper on the prehistoric floods, propose a flood discharge of 110-280 m$^3$/s at peak flow, drastically different from normal peak flow (1.5 m$^3$/s). There was no significant change in discharge moving downstream (0.34 m$^3$/s-0.33 m$^3$/s), implying that groundwater influence is low and the majority of the water comes from Paulina Lake. Paulina Lake has high concentrations of arsenic (As), just above EPA drinking water limits in the water column and much more concentrated in the sediment (0.014 ppm and 250 ppm respectively). Amount of As in the sediment is dependent on proximity to the lake; Paulina Creek sediments contain more As than the flood plain (6 ppm versus 1 ppm).

Paulina Creek has a cemented bed, which negates the knickpoint migration theory as the creek water is clear and there is not enough energy to erode cement. The best hypothesis for flood origin is a volcanic event. Arsenic from Paulina Lake was characterized for use as a tracer in flood deposits and if such a volcanic event led to displacement of water and sediment from the lake, flood plain sediments would contain high As concentrations. Otherwise, it would have just been displacement of water, which would have also created the features seen in the canyon today.
EVIDENCE OF SUBSURFACE WARMING AS A TRIGGER FOR 
HEINRICH EVENTS: A HIGH-RESOLUTION LABRADOR SEA 
SURFACE AND SUBSURFACE WATER FORAMINIFERAL $\delta^{18}$O 
RECORD

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Heinrich events are characterized by episodic iceberg discharge events from the 
Laurentide ice sheet via the Hudson Strait Ice Stream (HSIS) and into the North Atlantic. Although their occurrence throughout late Pleistocene glaciations has been well documented in the oceanic sediment record, the triggering mechanism for Heinrich events is still poorly understood. Recent work (Marcott et al., 2011) has shown that subsurface ocean (~1200 m) warming in response to a shutdown of the Atlantic Meridional Overturning Circulation (AMOC) could lead to accelerated melting and destabilization of an ice shelf fronting the Laurentide Ice Sheet and subsequently trigger Heinrich events. However, evidence for this subsurface warming remains restricted to one core site. Here I use Labrador Sea core HU2006040-006pc from the Hamilton Spur to assess spatial and depth coverage of this signal. I infer surface and subsurface temperature variability using $\delta^{18}$O in planktic and benthic foraminifera, respectively. I also develop a corresponding suite of other sediment proxies, including XRF and XRD, in order to identify Heinrich layers, so as to pinpoint source regions for the Heinrich layers. My results indicate that subsurface temperatures increased systematically 500-1000 years prior to each Heinrich event at core site HU2006040-006PC in response to a reduction in the AMOC, with subsurface temperatures increasing between 7.7°C – 2.1°C over the course of an event, but until other analyses are carried out (e.g., Mg/Ca on the same species), these results should be viewed as preliminary. The benthic $\delta^{13}$C record substantiates existing proxy records that show a decrease in the AMOC strength 1-2 ka prior to Heinrich events (Marcott et al., 2011; Zahn et al., 1997; McManus et al., 2004; Bond and Lotti, 1995; Clark et al., 2007). Heinrich events did not occur until the AMOC was at its weakest and subsurface temperatures were near their maximum values. These results thus support climate modeling results, which suggest that a weakened or collapsed ice-shelf would trigger an ice-stream surge, producing a Heinrich event (Shaffer et al., 2004; Alvarez-Solas et al., 2010).