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Lisa M. Smith, Amherst College
Advisors: Peter D. Crowley, Lisa A. Gilbert

A variety of eruptive morphologies, including pillowed, massive, and hyaloclastite flows occur in the submarine volcanic rocks of the Blake River Group in Rouyn-Noranda, Quebec. Among all these styles of eruption, differing styles of vesiculation can be observed. This study examines the vesicle distributions in individual pillows and massive flows within this suite of rocks.

The Blake River Group is in the Abitibi Subprovince of the Superior Province of Canada. The rocks in this group are greenschist facies (chlorite-actinolite-clinozoisite assemblage) metavolcanic rocks of ages 2759-2670 Ma. Because of the relatively low grade of metamorphism, primary igneous textures, such as glassy pillow chill margins and rounded vesicles, can be easily observed. This study investigates three areas (one ~2 m^2, another ~50 m^2, and the third ~100 m^2) of pillow basalts and massive flows in the town of Rouyn-Noranda, Quebec. Facing indicators, including pillow morphology and drainback features were present at all three exposures.

North-south shortening has produced minor folds and subvertical dips. The three exposures examined here cross a syncline – one from each limb of the fold and one near the hinge surface of the fold. Eighteen 1-2 m^2 areas of pillows were mapped in detail, with vesicle sizes and densities measured from 3 to 17 1 cm^2 regions on individual pillows. Vesicles are filled with calcite, but appear in the field as open porosity where the calcite has weathered away. Deformation of vesicles has transformed them into slight elliptical strain ellipses that are elongate subparallel to bedding on the limb of the fold where bedding is oriented approximately E-W. Vesicle orientations on the opposite limb of the fold are more chaotic.

Many pillows, especially those containing drainback features, exhibit a characteristic vesicle pattern: a near radial symmetry and a high density of vesicles in the center of the pillow. This is surrounded by a region of decreased vesicle density, a ring ~10 cm. away from the pillow rim of high vesicle density and a vesicle-poor chill margin. Vesicle distribution and orientation will be used to investigate models of magma devolatilization and fold formation.

FLIP, ROLL, RIP: QUANTIFYING FORMATION OF MICROBIAL SEDIMENTARY STRUCTURES IN A UNIDIRECTIONAL FLOW

Conor McDowell, Amherst College
Advisor: James W. Hagadorn

Life, especially microbes that can coat and mesh grains, is present in all modern and ancient aqueous systems. These microbes, principally cyanobacteria and algae, strongly influence the cohesiveness and behavior of sediment by colonizing and forming microbial mats. These colonies bind particles together by using filaments and sugary extracellular polymeric substances. Once these colonies mature, they form a highly erosion resistant surface layer that prevents sand from eroding and inhibits formation of primary structures such as plane bed lamination, ripples, and dunes. The rock record contains abundant evidence of cohesive effects on sand grains, such as sand chips and sand roll-ups, which together with other microbial sedimentary structures suggests that microbial colonies were present in ancient environments. Although sand chips and related microbial structures are known from modern settings, little is known about how they form. Quantifying the conditions of formation for these structures has the potential to offer insights into processes active in ancient environments.

In order to examine what processes govern formation of these structures, experiments were performed by growing mats of freshwater blue-green algae on Plexiglas trays of medium grained quartz sand. Mats were exposed to a range of flow velocities at 17-20 cm depth in a laboratory flume, while observing the conditions under which sedimentary structures began to form or be eroded.

For thicker biofilms, higher velocity flow regimes are required to cause grain movement. In these mats, initial grain mobilization occurs at very high velocities and results in structures not seen in sterile sand. Once grains are mobilized, a suite of mat-destruction features is created, which begins with the flipping-over of mat edges and ends with the erosion of cohesive mat sections that resemble mud rip-up clasts and sand chips. Older mats also form intermediary “roll-ups” where the mat curls up on itself, similar to the rolling of a carpet. These findings suggest that the presence of microbes changes the erosion-resistance of sand grains in a unidirectional flow and offers insight into the flow conditions that lead to the formation of microbial sedimentary structures seen in the rock record.

THE PETM IN ALASKA?

SEDIMENTOLOGY, GEOCHEMISTRY AND GEOCHRONOLOGY OF THE PALEOCENE-EOCENE CHICKALOON FORMATION

John Linden Neff
Amherst College
Advisor: James W. Hagadorn

The Paleocene-Eocene Chickaloon Formation of southern Alaska was deposited at high-latitudes, contains abundant fossil flora, and spans the Paleocene-Eocene Thermal Maximum (PETM). Facies analysis, U-Pb geochronology, sedimentary petrology, and carbon isotope stratigraphic analyses were conducted on exposures of the Chickaloon Formation at the Evan Jones Coal Mine near Sutton, AK in order to provide a contextual framework for understanding vegetated terrestrial depositional environments in a greenhouse climate and to identify the PETM.

The studied strata represent an alluvial sequence dominated by floodplain, channel sandstone, crevasse lobe, and mire deposition. Floodplain environments are represented by medium-gray, commonly nodular, shaly siltstone and cm-scale sheet-sandstone interbeds. The majority of the channel sandstone deposits are crevasse channels; they are generally small (2-5 m in thickness), rarely coarser than medium-grained, and sand grains are commonly coated with Fe-oxides. Carbonaceous shale and coal are localized and indicate a high-rate of organic carbon accumulation in the area. Fossil floral material is very common and includes broad-leaf angiosperms, conifers, wood, and *in situ* tree trunks; these suggest a highly vegetated or forested environment. Considered together, lithologic and paleontologic data suggest that locally these strata represent a floodbasin environment; the observed crevasse channels probably originate from a main channel located within several km of the depocenter.

$\delta^{13}C_{ORG}$ analyses of 55 bulk organic carbon samples exhibit values ranging from -21.7‰ to -28.5‰ and a mean value of -25.4 ± 1.1‰ (1 σ). A major negative isotopic shift (5.8‰) was documented and is associated with a regionally extensive lithologic change. This excursion may reflect a regional event, influx of isotopically light carbon, and/or may be a short-lived signature associated with the PETM event.

One interbedded ash layer was sampled for U-Pb geochronology. Two potential air-fall zircons were separated; they yielded mean ages of 66.4 Ma and 100 Ma. Because fossil floras are Tertiary, these zircons must have been recycled.

P-T PATHS OF BIOTITE SILLIMANITE GARNET GNEISS FROM THE HIGHLAND MOUNTAINS SW MONTANA

Matt Herman, Amherst College
Advisor: Jack Cheney

The Tobacco Root and Highland Mountains in southwestern Montana are Laramide uplifts containing Precambrian rocks which record a 1.78-1.71 Ga metamorphic and deformational event known as the Big Sky orogeny. Previous work in the Tobacco Root Mountains (TRM) yielded a clockwise P-T evolution where the highest pressures and temperatures were followed by isobaric cooling and isothermal decompression.

The Highland Mountains, west of the TRM, are cored by a quartzofeldspathic gneiss unit cut by metamorphosed mafic dikes and sills. A thin and diverse unit (designated Xg) partially rims the core and is mostly garnet rich gneiss with marble, quartzite, iron formation, and amphibolite. These two units are similar to suites found in the TRM. The core is mantled by a unit containing biotite-sillimanite-garnet gneiss which is unlike any in the TRM. The core and mantle are juxtaposed across a zone of mylonitization and leucocratic melt.

The mantle gneiss and the Xg unit each contain rocks with the essential mineral assemblage sillimanite + garnet + K-spar + biotite with different textures. Samples from Camp Creek on the northwestern edge of the mantle contain no kyanite, sillimanite pseudomorphs after kyanite, cordierite or orthopyroxene, whereas abundant muscovite laths cut across the fabric, indicating nearly isobaric heating and cooling at P between 4 and 8 kbar and T between 650ºC and 800ºC. Samples from between Camp Creek and the Xg unit also have no evidence of kyanite but have less abundant and more skeletal back-reacted muscovite. Samples from the Xg unit have sillimanite pseudomorphs after kyanite and contain cordierite but have no retrograde muscovite, which indicates a clockwise P-T path with heating at $P>8.0$ kbar and cooling at $P<3.5$ kbar. The absence of orthopyroxene requires $T<850$ºC at $P=6.5$ kbars. 207Pb/206Pb spot ages on monazites from Camp Creek and the Xg unit were obtained from the ion microprobe at WHOI (Brown (2008) and Pearson (2008)). The majority of the Camp Creek rocks yielded an age range from 1870-1770 Ma and most of the Xg rocks yielded an age range of 1860-1760 Ma. The younger ages overlap with the Big Sky orogeny in the TRM while the older ages indicate the Highland Mountains were experiencing metamorphism necessary to grow monazites before the TRM.

SPONGIFORM TEXTURE IN BAHAMIAN CARBONATE ROCKS: ORIGIN BY TRAPPING AND CEMENTATION OF CARBONATE SAND AROUND DUNE VEGETATION

Madeline Weigner and Sarah Motti, Department of Geosciences, Smith College

Advisors: H. Allen Curran, Bosiljka Glumac, and Sara Pruss

The islands of the Bahamas are capped by carbonate rocks most commonly originating from wind-blown sands that build dunes. When lithified, these sands form rock called eolianite. In most cases, these rocks are thinly bedded with fine, well-sorted grains. However, some layers have a porous and disorganized structure that we term spongiform texture. This texture is found throughout the coasts of the Bahamas and is believed to be an indicator of wind deposits. This project focuses on the formation of spongiform texture observed in Holocene eolianites (less than 6,000 years old) on Cat Island, Bahamas.

Field observations and samples were collected from prominent spongiform layers on Alligator Point and the South Coast of Cat Island. Thin sections were made for detailed microscopic examination of grain types, cement, internal microstructures, and porosity of the samples. The primary objective of this project was to characterize spongiform texture in more detail in order to better understand its origins.

The samples examined have a variety of different carbonate sand grains that range in shapes, sizes, and sorting. With no visible internal microstructures, obvious dissolution, or deformation observed in individual samples, spongiform texture is characterized by well-defined holes and poorly cemented ooid and skeletal sand grains with thin rims of meteoric calcite cement. Vegetation in coastal zones is most likely responsible for the formation of this texture. Baffled wind-blown sand is deposited around plant roots, stems, and trunks. After lithification of this sediment, the organic material decomposes creating molds, and producing this unique spongiform texture in Bahamian carbonate rocks. Understanding the origin and distribution of porosity in carbonate rocks with spongiform texture is important for characterizing the potential of these rocks as freshwater aquifers and petroleum reservoirs.

THE RISE OF ANIMAL SKELETONS

A QUANTITATIVE ANALYSIS OF THE ORDOVICIAN RADIATION

Alexandra Breus, Smith College

Sara Pruss, Advisor

The Ordovician Radiation is considered one of the most important and rapid bio-diversification events, marked by a three- to four-fold increase in generic diversity. Between 486-460 million years ago, there was a significant increase in ecosystem complexity, faunal size and skeletal thickness (Knoll 2003). The dominant Paleozoic fauna, biomineralizing animals (Droser and Finnegan, 2003), became established at this time, and brought about a potentially significant change in the carbon cycle (Ridgwell and Zeebe, 2005).

Middle Upper Cambrian through the Middle Ordovician samples were collected from the Port au Port Peninsula, western Newfoundland, Canada for this study. Six carbonate facies were analyzed in thin section to quantify the contribution of fossil skeletal material to overall carbonate production. Changes in biodiversity, as well as relationships between fossil distributions and facies, were also examined. Skeletal abundance was low in the Cambrian and Lower Early Ordovician, around ~4%, but rose to ~16% by the Middle Ordovician. Biodiversity also increased in the Middle Ordovician, with the appearance of a new phylum, and visible changes in the mollusc phylum as observed in the field. Future analysis on a greater distribution of Middle Ordovician facies would provide further insight into the relationship between environment and organism evolution during this critical biodiversification event.

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Knoll, A. H., 2003. Biomineralization and Evolutionary History, Reviews in Mineralogy and Geochemistry, v. 54, pp. 329-356.

Ridgwell, A. and Zeebe, R., 2005. The role of the global carbonate cycle in the regulation and evolution of the Earth system, Earth and Planetary Science Letters, v. 234, pp. 299-315.

SNOWBALL EARTH: WHAT'S WRAPPED UP IN NAMIBIAN ROLL-UP STRUCTURES?

Katie Castagno, Smith College
Sara Pruss

"Snowball Earth" is a hypothesis that the earth was entirely covered in ice during parts of the Cryogenian Period (790-630 million years ago) (Hoffman et al., 1998; Hoffman and Schrag, 2002). Cap carbonates, sedimentary deposits that overlie Neoproterozoic glacial deposits, present significant evidence for "Snowball Earth" because the appearance of carbonates atop glacial deposits at low latitudes suggests a distinct change in climate and environments. The melting of "Snowball Earth," the hypothesis suggests, resulted in the formation of these caps.

The Ongongo subgroup in Namibia, southern Africa, is part of the Otavi fold belt. The Rasthof cap-carbonate sequence forms a knife-sharp depositional contact with the Chuos Formation (glacial strata beneath it). Of the several facies present in the Rasthof Formation, one of the most interesting is the 80-meter thick sublittoral microbialite, approximately 40 meters above the base of the section. Thick, rubbery microbial mats characterize sediment deposited at significant depths and formed millimeter-sized microbial laminations. Distinct roll-up structures suggest the pliability of these microbial mats; however, it is unknown what mechanism caused these layers to fold on themselves. To shed light on these unique features, a three-dimensional model was constructed to determine the structure of the roll-ups within the rock. Acid dissolution was also performed to potentially determine chemical composition and to characterize organic matter.

FORMATION OF POLYGONAL FRACTURES IN OOID-RICH CARBONATE SAND

Sarah Motti and Madeline Weigner, Department of Geosciences, Smith College

Advisers: Bosiljka Glumac, H. Allen Curran, and Sara Pruss

Polygonal fractures are common on Cat Island, Bahamas in Holocene to Recent eolian and backshore beach carbonate grainstone deposits. The polygonal fractures resemble mudcracks, but are produced in ooid-rich carbonate sand with little or no mud present. In the field we documented the size and shape of polygons and collected samples of polygonally fractured deposits for subsequent petrographic analysis. The polygons are 4-6 sided and up to 75 cm in diameter. The fractures are jagged and tightly fitting, and their maximum observed depth is about 80 cm. Occasionally the polygons are displaced and the resulting fractures are filled with sediment. Polygonally fractured deposits are composed of well sorted, fine gained, and well rounded spherical to elliptical ooid grains. Recent deposits are poorly cemented with thin rim or meniscus and pendant carbonate cements. Older Holocene deposits are more firmly lithified with fibrous, bladed, and equant carbonate cements. To further characterize the texture and composition of ooid-rich sediment, and to conduct experiments to determine the possible causes of fracturing we collected sand from the beach at Pigeon Cay, Cat Island. Drying of this sand in the lab resulted in polygonal fracturing of the sand surface similar to that observed in the field. To reproduce this result, we moistened the sand and placed it in clear glass containers as layers 1, 3, and 5 cm thick. The dried sand fractured in the same manner and the polygon sizes were measured to document their relationship to the layer thickness. Our laboratory observations suggest that the fractures form by stresses generated by the reduction of interparticle porosity and re-packing of grains due to the loss of cohesion between grains during drying. These polygonal cracks can then be preserved in the rock record because of the rapid lithification of carbonate sand. It is therefore somewhat surprising that such features are rarely documented in the geologic record. This may be because they could easily be mistaken for mudcracks. It also seems that the formation of polygonal fractures in mud-free sand may require sediment of very specific composition and texture such as that present on Cat Island. Future laboratory experiments may involve sand-size particles of different texture or composition, and may further explore the relationships between polygonal fracturing of sand and its pore water chemistry, the presence vs. absence of mud, moisture content, layer thickness and other parameters. Future fieldwork will aim at documenting additional ancient and modern examples of this unique sedimentary structure.

ATMOSPHERIC MERCURY DEPOSITION IN AN ISOLATED ENVIRONMENT: A 150-YEAR RECORD AT BLOCK ISLAND, RHODE ISLAND

Rachel Neurath, Smith College

Advisor: Robert Newton

Block Island, located 20 km off the Rhode Island coast, is isolated from local point sources of mercury, providing a record of atmospheric mercury deposition in southern New England over the last 150 years. Sediment cores were taken from the four prevalent aquatic environments found on Block Island: salt marsh, freshwater bog, salt pond, and seepage pond. Total mercury analysis was performed using a Milestone DMA-80 Direct Mercury Analyzer. Cores were dated using Lead-210 and Cesium-137, as well as pollen data. An elemental analysis of the cores was performed using X-ray Fluorescence (XRF). Total mercury data was converted to mercury accumulation rates and compared with atmospheric records. Total mercury data showed background levels of 30-40 ppb prior to the onset of an anthropogenic signal that reached a maximum of 322 ppb. Most sites showed a decline in mercury over the past 20 years. Mercury concentrations vary with depositional environment. Mercury concentrations were highest in freshwater cores (peak at 322 ppb), and lowest in the Great Salt Pond of Block Island (peak at 190 ppb). Differences in grainsize and sediment focusing in ponds with larger watersheds could account for these variations, however the ponds studied on Block Island appear to be seepage lakes, which would minimize sediment focusing. Peaks in mercury concentrations are thought to correspond to times of maximum mercury input into the atmosphere, and may also be associated with periods of unusually high precipitation.

COMPOSITION AND TEXTURE OF OOID-RICH CARBONATE SEDIMENT ALONG A BEACH-TO-OFFSHORE TRANSECT AT PIGEON CAY, CAT ISLAND, BAHAMAS

Sarah Motti and Madeline Weigner, Department of Geosciences, Smith College

Advisers: Bosiljka Glumac, H. Allen Curran, and Sara Pruss

Ooids are round carbonate grains formed by the precipitation of calcium carbonate around a nucleus suspended in water by tidal and wave currents. Ooids are a common component of ancient carbonate rocks, but their origin and distribution in Holocene deposits and modern carbonate sand are still relatively poorly understood. Even though ooids are well documented from Andros Island and several other regions in the Bahamas, only recently have they been described as a major sediment component on Cat Island, Bahamas. To better understand the origin and distribution of these grains, this study compares the composition and texture of beach sand to six sediment samples collected from the sea floor at every 50 meters along a 300m long transect at Pigeon Cay, Cat Island. Although the water along the transect was shallow (<4m deep), the water was murky and the poor visibility (<2m) precluded making detailed underwater observations. Barren sand on the sea floor was shaped in symmetrical wave ripples with the crests parallel to the beach. Sediment samples were collected using a rigid plastic container in one sweep across several ripples perpendicular to their crests. Within the sampled material, we found substantial variation in the sediment texture and composition. The beach sand was dominated by fine-grained and very well sorted ooids of spherical to elliptical shape. About 300m offshore, the sand was coarse grained, poorly sorted, contained more skeletal fragments, and was dominated by angular and irregular grapestone grains, which are aggregates of ooids and skeletal fragments in micritic matrix. In the middle of the transect, about 100-150m offshore in approximately 2m deep water, there is a distinct change in sediment composition from poorly sorted aggregates to more rounded and sorted ooids. This suggests that at Pigeon Cay ooids form within a relatively narrow, high-energy, wave-swept shallow environment. Storms and waves transport ooids on shore where they are further sorted and lithified into beach rock or eolianite. Ooids are also transported further offshore, where in deeper and less energetic water they are deposited together with skeletal fragments and carbonate mud, and lithified into micritic aggregate grains or grapestones. The results of this study provide important new information about the origin and distribution of ooids in modern carbonate depositional environments on Cat Island. Future work might include extending the transect further offshore, or conducting similar studies elsewhere on Cat Island and on other Bahamian islands.

CARBON ISOTOPE ANALYSIS OF THE ST. GEORGE FORMATION, WESTERN NEWFOUNDLAND

Emily Bush, Department of Geosciences, Smith College

Advisor: Sara Pruss

The Cambrian explosion (552 Ma) introduced multi-cellular, skeleton organisms, but an extinction event at the end of the end of the Early Ordovician killed off some of the new fauna. For 40 million years after this extinction, abundance remained low until the Lower to Middle Ordovician radiation of marine invertebrates (480 Ma). What caused this long gap of non-abundance? Based on previous work, we speculate that anaerobic conditions may have persisted at this time and limited abundance. Our work on the carbon isotopes of the Early Ordovician will show if isotopic perturbations were prevalent in this period of low biodiversity. We cut and drilled limestone and dolomitic rocks from the St. George Formation in western Newfoundland, and sent the powder samples to the University of Massachusetts to be analyzed for carbonate composition in a mass spectrometer by Stephen Burns. By creating and examining the negative and positive excursions on the carbon isotope profile, we will be able to correlate the carbon cycle to environmental conditions which might have delayed the recovery of faunal abundance.

GEOCHEMICAL INVESTIGATION OF WEATHERING IN A HIGH ARCTIC WATERSHED AND PROVENANCE OF SEDIMENTS IN KONGRESSVATNET, SVALBARD, NORWAY

Maya Wei-Haas, Department of Geosciences, Smith College

Advisors: Robert Newton (Smith College), Al Werner (Mt Holyoke College),

and Mike Retelle (Bates College)

This study uses changes in the chemistry and mineralogy of lake and surface sediments in a small lake in Kongress Valley to interpret Late Holocene climate change in Western Spitsbergen, Svalbard. Changes in clay mineralogy across an inactive outwash fan (Black Fan) in the valley reflect weathering since the fan's formation during the Little Ice Age (LIA) (1550-1920). X-Ray Diffraction of clay samples across the fan reveal a strong 10 Å peak, unaffected by ethylene glycol solvation or heating (550 °C), indicative of illite. Samples collected from vegetated lobes between the meltwater channels reveal a diminished 10 Å phase and a 14 Å peak, unaffected by Mg and glycerol saturation, indicative of vermiculite. This inverse relationship reflects weathering of illite to vermiculite, suggesting an early period glacial deposition eroded by glacial meltwater during the LIA.

Lake sediment chemistry should reflect changing sources of sediment inflow as meltwater from advancing ice activated the Black Fan. X-Ray Fluorescence (XRF) of the White and Black Fan, the only sources of sediment inflow, reveal distinctly different chemistries. Chemical composition of sediment cores from the lake resembles only that of the White Fan, indicating provenance cannot be used in Lake Kongress to constrain the LIA. Despite this dominant signature, ITRAX Scanning XRF of the core reveals ~2cm calcium-rich layers in the upper 200 mm. The correlation of these laminations using MS to cores dated to the LIA (Guilizzoni et al., 2006), suggest cryogenic calcite formation during cold periods due to lake ice formation. MS correlations indicate anomalous peaks in iron and sulfur of the lower core (300-400 mm) correspond to the Medieval Warm Period. Increases in organic inflow during this period spurs sulfur reducing bacteria activity, resulting in the precipitation of iron sulfides.

Reference:

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GEOCHEMICAL AND MINERALOGICAL COMPARISON BETWEEN CLAYS AND CERAMICS FROM THE ETRUSCAN ARCHAEOLOGICAL SITES OF POGGIO COLLA AND THE PODERE FUNGHI, TUSCANY, ITALY

Jane Didaleusky, Department of Geosciences, Smith College

Advisors: Bosiljka Glumac and Robert Newton

In archaeological geology, provenance studies are aimed at discovering the source of raw materials used in the production of an artifact. My research focuses on chemical and mineralogical comparison of clays and ceramic material. The purpose was to determine a possible provenance for the clay used by the Etruscan potters in ceramic production. The study was conducted using x-ray fluorescence, x-ray diffraction and thin-section petrography. The clay and ceramic samples were collected at the Poggio Colla, the Podere Funghi, and the Northwest Trench sites within the Mugello Valley in Tuscany, Italy. The sites are located on the western edge of the northern Apennines Mountain belt on the edge of known Etruscan territory. X-ray diffraction patterns were obtained for clay samples, and the majority has a mineral composition of montmorillonite/illite, kaolinite, and quartz. The thin-section petrographic results show that the majority of the ceramic samples contain quartz, plagioclase, mica and Fe-oxides. The statistical tests of the x-ray fluorescence results seem to support the conclusion that there is a correlation between the clays at the Podere Funghi and the ceramics found at Poggio Colla. The clay samples collected are statistically similar to each other. The differences found between the clay samples and the ceramics could be due to the archaeological sites being a combination of forested area and agricultural land, thus adding organic matter to the clay. The differences can also be due to post-depositional changes to the ceramics.

SEDIMENTOLOGY AND PALEONTOLOGY OF THE NASH DINOLAND QUARRY (EARLY JURASSIC PORTLAND FM), GRANBY, MA

SIME, Timothy S., Geology, University of Massachusetts Amherst, 611 North Pleasant Street, 233 Morrill Science Center, Amherst, MA 01003, tsime@student.umass.edu and GETTY, Patrick Ryan, Center for Integrative Geosciences, University of Connecticut, 354 Mansfield Road U-2045, Storrs, CT 06269

Dr. Margery Coombs, Advisor

Nash Dinoland is a privately owned and operated quarry that has sold dinosaur footprints for 70 years. The quarry is located in Granby, Massachusetts and exposes 1.3m of rock of the Early Jurassic (ca. 200MA) Portland Formation. Although footprints have been sold worldwide, Nash Dinoland has never been scientifically examined in depth. Thus, the paleontology and sedimentology of the site are poorly constrained. A preliminary examination has been conducted to better constrain these aspects of the site.

Various lines of evidence indicate that the depositional environment was a hypoxic lake bed. The rock, which is primarily siltstone to fine-grained, oscillation-ripple-marked sandstone, has a dark gray to black color on fresh surfaces, which is indicative of hypoxic aqueous environments. Furthermore, no invertebrate bioturbation has been observed and fossilized fish, when found, are rare and fragmentary. The paucity of fish and invertebrate burrows indicates low dissolved oxygen content for aqueous macroorganisms. Large concentrations of poorly preserved, water-transported plant material occur on bedding planes, and suggest a cause for the hypoxia. No subaerially-produced sedimentary structures, such as desiccation cracks or raindrop impressions were observed, indicating that subaerial exposure did not occur.

There are four dinosaur ichnotaxa present at the site, including the theropod prints *Anchisauripus*, *Eubrontes*, *Grallator* and the ornithischian print *Anomoepus*. Theropod ichnotaxa comprise the vast majority of footprints, with only a few ornithischian footprints being present. Despite the fact that aqueous conditions predominated, no swim tracks were observed. Thus the animals must have waded through water shallower than their hips, or they would have become buoyed up and produced tracks with the characteristic swim track morphology seen at other sites. Estimates of maximum water depth were obtained by using equations for dinosaur hip height, which was calculated from the lengths of the smallest footprints (ca. 9.6 cm). Based on these calculations the water depth probably did not exceed ca. 38 cm.

BIOMECHANICS OF THE MOUTH APPARATUS OF *ANOMALOCARIS*: COULD IT HAVE EATEN TRILOBITES?

Mariel Schottenfeld
University of Massachusetts Amherst
James Hagadorn (Advisor)
Amherst College

The Cambrian animal *Anomalocaris* is hypothesized to have eaten trilobites and other biomineralized prey. The lack of broken or abraded teeth on the plates of the mouth apparatus of *Anomalocaris* suggests that it may not have had the ability to break the exoskeletons of any hard-shelled animal. Worn teeth, as would be expected, would indicate *Anomalocaris* was wearing its teeth down biting hard-shelled prey. SEM – EDS of the mouth apparatus from the Burgess Shale specimens indicate that the 32 plates are composed of organic carbon, suggesting they were originally unmineralized cuticle.

Mechanical properties of these plates were analyzed using CAD modeling and Finite Element Analysis. Poisson's ratio and Young's modulus of potential *Anomalocaris* plates, as well as density and fracture strength used for FEA analyses, were estimated using a range of modern-day arthropods. Two end-member values were used both to approximate the range of strengths exhibited by *Anomalocaris*' cuticle, and also to encompass the range of exoskeleton strengths likely exhibited by trilobites. The hardest skeletal values are from wet lobster (*Homarus americanus*) crusher claw cuticle; these are the most likely to deform in a brittle manner. The softest are from shrimp (*Pandalus* sp.) carapaces. In order to bite and successfully break the calcified cuticle of a trilobite, *Anomalocaris'* mouth plates would have needed to withstand forces that are greater than those required to fracture a trilobite exoskeleton. Results demonstrate that the teeth-like structures of the mouth plates should have deformed or broken when less than or equal to 13 N of force was applied perpendicular to the plates. 13 N would be the amount of force needed to break a plate comprised of lobster claw material, whereas 6.2 N would be needed to break a plate of shrimp carapace material.

NATURE AND TIMING OF THE EARLIEST DEFORMATION STRUCTURES IN TUSAS MOUNTAINS, NEW MEXICO: IMPLICATIONS FOR THE PRECAMBRIAN HISTORY OF NORTH AMERICAN CONTINENTAL CRUST

Emerald K. Shirley, University of Massachusetts Amherst
Michael L. Williams

The continental crust of North America (Laurentia) grew southward during the Palaeoproterozoic. The crust that underlies much of the USA was added and stabilized as continental lithosphere during the Yavapai and Mazatzal orogenies (1.75-1.65 Ga). Many of the details of the crustal assembly of Southern Luarentia have remained uncertain due to questions about the nature and timing of the Yavapai and Mazatzal events in the southwestern United States. Specifically, it is unclear what type of tectonic events these orogenies represent, continental collision, back-arc closure, or reheating. This study aids in clarifying the evolution of Laurentian continental crust by constraining the deformational and metamorphic history of the Mazatzal Group in northern New Mexico. The Mazatzal Group is a 1-2 km thick sequence of clastic and volcaniclasitc sediments deposited syntectonically during the Yavapai orogeny and metamorphosed rhyolites. A large fold has been identified in the immature sedimentary and volcanic rocks of the Tusas Mountains of northern New Mexico that represents one of the oldest structural features of the Southwestern crustal assembly yet recognized. The goal of this study is to characterize the history of this fold generation, especially the timing of the fold and the depth in the crust (i.e. amount of burial) at the time of folding. Through a petrographic and microstructural investigation of the fold, we have found that the fold is indeed the first ductile, penetrative deformational event affecting the rocks of the Tusas Mountains, and that deformation took place at shallow mid-crustal levels. In the sedimentary rocks, metamorphic muscovite anastomoses around fractured quartz and feldspar grains to create a fabric aligned with the axial plane of the fold. High abundances of epidote and garnet indicate a greenschist to an amphibolite facies metamorphic event, corresponding to temperatures and pressures of the mid-crust. It seems likely that this large fold reflects a period of continental collision and tectonic burial of the juvenile crust and may correspond to the stabilization of true continental crust in the area. Future dating of monazite and xenotime crystals in the sedimentary rocks will help to constrain the timing of the folding, and thus will indicate if this thickening and stabilization occurred during the ca 1.6 Mazatzal orogeny or later during a regional heating of the crust at ca. 1.4 Ga.

UNIFYING ARCHITECTURAL DESIGN WITH STORM WATER MANAGEMENT
A CASE STUDY OF THE LONGSWORTH ARTS VILLAGE, HAMPSHIRE COLLEGE

Maryette Haggerty Perrault
Hampshire College

Collaborators: Christina Cianfrani,
Assistant Professor of Hydrogeology
Hampshire College
Thomas Long
Five College Assistant Professor of Architectural Studies
Hampshire College

The Charles & Polly Longsworth Arts Village on the Hampshire College Campus was redesigned to incorporate experiential education, artistic expression and low-impact stormwater management. The seventeen acre site, consisting of four large structures and a 15,000 square foot steel truss canopy roof, has been plagued with inadequate drainage and excessive runoff due to over 60,000 square feet of impervious surfaces. During the wetter months, it is not uncommon for people to intentionally avoid the area because of constant puddling and dripping from the canopy roof. After studying the area's climate conditions and average precipitation data, acceptable types, sizes and quantities of mitigation elements were determined in order to make the site independent of the public drainage system. To alleviate these issues the redesign for the outdoor space includes several different types of stormwater mitigation elements including rain gardens, filter berms, and vegetated swales in addition to pervious pavement, green roofs and solar powered lighting. With theses improvements to the site, a realistic low-impact design that improves the social, academic and environmental conditions of the site was devised. The site is intended to function as an outdoor classroom to exhibit ecosystem-friendly sustainable design practices while also serving as precedent for the community. Lastly the area is designed to foster a pedestrian-based campus while also maximizing accessibility to public transportation as it draws the academic learning of the preexisting structures outdoors. The project attempts to seamlessly unite architectural and landscape design with environmental engineering and storm water management. If the ecosystems being built within are considered as a positive environmental aspect of the design process rather than a bothersome building constraint, the entire system benefits: designer, builder, inhabitant, and of course, nature.

WETLANDS AS A REMEDIATION TECHNIQUE FOR GROUNDWATER PERCHLORATE CONTAMINATION.

Jen Greenberg
Hampshire College

Wetlands are an ideal *in situ* treatment method for the removal of perchlorate (ClO_4) because they already posses the necessary characteristics for its bioremediation. In addition, wetlands are easier and less expensive to monitor and maintain than other more traditional methods, especially for sites with low concentrations of perchlorate. This makes them more environmentally appropriate and economically feasible. Constructed or natural wetlands can provide a low-cost treatment option that does not require much maintenance. Recent studies have found that perchlorate is a potential health risk because it acts to inhibit iodide uptake by the thyroid gland. Perchlorate is a unique contaminant because it is used as an oxidizer in many different products, from rocket fuel to air bag inflators and fireworks, which use various concentrations and result in diverse contamination sites. There is currently no enforceable national regulation for perchlorate, though an interim health advisory of 15 μg/L was passed by the US Environmental Protection Agency in January 2009. In order to create a Maximum Contaminant Level that would be nationally enforceable, more research is necessary to determine the health effects and remediation techniques for low concentrations of perchlorate in drinking water and the environment. Specific bacteria mediate the reduction of perchlorate, and therefore wetland remediation efforts focus on creating the ideal characteristics for their growth. The ideal conditions include an anoxic environment and sufficient organic material to act as an electron donor. If not already present, the conditions necessary for perchlorate reduction can easily be created in a wetland environment, making it a superior remediation method over more traditional practices.

RECONSTRUCTING LATE HOLOCENE CLIMATE THROUGH TREE-RING ANALYSIS OF SIBERIAN LARCH: ALTAI MOUNTAINS, WESTERN MONGOLIA

Brittany Gaudette
Department of Geology and Geography, Mount Holyoke College
Advisor: Al Werner

Dendroclimatology utilizes tree-rings to reconstruct past climate. Tree-ring growth is related to limiting growth factors, which can be either internal (biologic) or external (environmental or climatic). A good tree ring record for climate reconstructions is one that is sensitive to its external surroundings, one that records annual changes in climatic parameters such as temperature and precipitation within its annual growth rings. Siberian larches (*Larix siberica*) in the Altai Mountains of Western Mongolia are examples of such stressed trees. Larch forests are not ubiquitous in the region, suggesting that they are at the limit of their environmental extent and are sensitive to changes to climate patterns and periodicities.

This study attempts to extend paleoclimate records beyond geographically and temporally limited meteorological data for the Altai Mountains, a NNW-SSE trending mountain range along the western border of Mongolia. Studying the climatic patterns of Mongolia prior to instrumental data puts recently observed changes in a broader climatic context. Tree cores were collected from two small larch forests, both occurring on north-facing slopes and at elevations of 2400 to 2900 m. A total of 34 cores were recovered, yielding a 425-year chronology (A.D. 1584). Based on positive correlations with summer temperatures (June through August), this chronology was determined to be a summer temperature paleoclimate proxy for Mongolia's Altai Mountains.

ANALYSIS OF RECENT PALEOCLIMATOLOGICAL RECONSTRUCTIONS: A RE-EVALUATION OF THE IMPACT OF CLIMATE CHANGE ON THE NORSE WESTERN SETTLEMENTS, WESTERN GREENLAND

Advisor: Laura C. Carlson

Understanding climate change in all its aspects is crucial to the survival of humankind, and knowing how to adapt is essential. We can only learn how to evolve with changes by examining and learning from the past experiences of civilizations and analyzing their respective successes and failures. The Western Settlement of Greenland is one example of an attempt at establishing a colony in an extreme environment. The Norse colony was founded in the year 985 and stably endured nearly five centuries of harsh weather conditions; however, it is thought that due to a combination of climate change and its impacts on related factors like trade and farming, the colony eventually failed.

Through analysis of climate data from the ECHO-G global climate model and NARR reanalysis data, and an application of them in a statistical regression equation to calculate an estimation of snow days during the years that the colony was doing well and during years that they were in their decline, I analyzed how the Greenlanders' farming abilities were being affected by a changing climate. Distinguishing how many days the colonists had without snow determined how often they were able to send their livestock, the main source of their food supply as trade worsened, outside to graze. Snow days and the length of seasons also determined how much hay they could grow in one season to sustain the livestock during overwintering, when they needed to keep cows indoors.

Model results show that the Western Settlement in Greenland actually had warmer weather, less sea ice in the nearby coastal area, more days without snow over its period of decline, and in fact, was experiencing a milder climate compared to the rest of continental Europe and Iceland at the onset of the Little Ice Age. This evidence of warming on the western coast of Greenland suggests a larger impact of the crippling trade situation with ruling Norway and poor food and farming choices on behalf of the Western Settlement.

CALCITE-GRAPHITE ISOTOPE THERMOMETRY NEAR THE BLACK LAKE SHEAR ZONE, ADIRONDACK LOWLANDS, NY

Celina N. Will, Mount Holyoke College
Advisor: Steven R. Dunn

The Grenville Province of Ontario and New York is comprised of distinct lithotectonic belts separated by shear zones. The Adirondack Lowlands of New York are considered part of the Frontenac terrane of the Central Metasedimentary Belt. The Black Lake Shear Zone (BLSZ) in the northwest Adirondack Lowlands may be an important yet overlooked structure separating the Lowlands from the rest of the Canadian Frontenac terrane to the west.

I have analyzed 20 samples of graphitic calcite marble from 14 outcrops near the BLSZ for carbon isotope thermometry. Samples are typically coarse-grained with <2% graphite and common minerals include quartz, phlogopite, potassium and plagioclase feldspars, titanite and diopside. With the exception of one outlier, the $\delta^{13}C$ range from -2.8‰ to 5.0‰ in calcite and from -6.5‰ to 1.2‰ in graphite. The $\delta^{13}C$ of the analyzed calcite in the outlier is -10.4‰ and -15.2‰ in analyzed graphite. The $\Delta_{(cal\text{-}gr)}$ for all samples are between 3.2‰ and 4.8‰, corresponding to approximately 780-590ºC. For the 6 outcrops I sampled twice, the difference in $\Delta_{(cal\text{-}gr)}$ for each pair is 0.3‰ or better at 4 outcrops. In 2 of the 3 locations previously analyzed by Kitchen & Valley (1995), my $\Delta_{(cal\text{-}gr)}$ are within 0.2‰ of the previous data. The data from this study alter a 675ºC isotherm proposed by Kitchen & Valley (1995) by curving it to the west. The revised isotherm continues to separate a hotter zone in the west from a slightly cooler zone in the east, and is broadly parallel to the NE-SW trending BLSZ.