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Amherst Students on an early collecting expedition led by F.B. Loomis

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PETROGENETIC HISTORY AND GEOTHERMAL POTENTIAL OF THE ANDOVER GRANITE, NORTHEASTERN MASSACHUSETTS

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Northeastern Massachusetts can be described as a series of fault-bounded, northeast-striking accretionary terranes associated with the Acadian orogeny. One of these, the Nashoba Terrane, is located northwest of the Clinton-Newbury fault zone and southeast of the Bloody Bluff fault zone and includes the felsic, heterogeneous Andover granite. The Andover granite exhibits a variable gneissic fabric and localized pegmatites and aplitic dikes. Initial geochemical studies of samples from the Andover granite classify it is a peraluminous granite. Plots of Rb and Y compared to Nb suggest a syn-tectonic/volcanic arc affinity, in agreement with previous interpretations. This study has two aims: 1) obtain petrographic and geochemical data to understand the petrogenesis of the Andover granite in the context of Acadian orogenesis; and 2) evaluate the geothermal potential of the Andover granite. The second goal is part of a larger, statewide project focused on evaluating the geothermal potential of granitoids in Massachusetts. Geochemical analyses include the heat producing elements U, Th, and K. Heat source candidacy requires temperatures that significantly exceed those of the average continental geotherm. A simplified heat production equation, including geologic constraints, has been applied to geochemical data from the Andover granite. Modeling parameters assume uniform 2.65 kg/m^3density, thermal conductivity of 2.9 W/m°C and that sample compositions represent the granite at depth. Sample analyses obtained to date indicate variable U, Th, and K_2O concentrations of 0.4 to 20.1 ppm, 0.3 to12.1 ppm and 0.73 to 8.03 Wt. %, respectively. Preliminary temperature modeling calculations indicate that Andover granite lacks required elemental abundances for local energy source production. However, one sample yields a maximum temperature of 129.5 °C at depths of 7.5km (123.9°C ≈ geotherm) and minimum temperature of 20.1°C at 0.5km depths (19.1°C ≈ geotherm). This sample, located in the pegmatitic phase of the granitoid, indicates a possible presence of local hot phases, in the Andover granite. Future work will focus on petrographic studies and additional whole-rock geochemistry to refine the current understanding of the emplacement and development of the Andover granite and the geothermal potential of this granite body.

ANALYZING THE HYDRAULIC PROPERTIES OF SOIL IN THE ASSABET RIVER WATERSHED, EASTERN MASSACHUSETTS

Shakib AHMED, University of Massachusetts

During the late Pleistocene continental glaciations, two widely known tills were deposited in southern New England (Melvin et al, 1992). The objective of this study is to identify the hydraulic properties of the mineral soil content above the till. This includes calculating the grain distribution, porosity, bulk density, and specific yield of the soil and come up with a model for the water flux across the overburden-bedrock interface under ambient and stressed conditions. These studies will be done in three hydrogeologic locations in the glaciated terrain of the Assabet River watershed, located in Eastern Massachusetts. This location is the main water source for the local cities in the vicinity which creates an interest (and a concern) about the abundance of groundwater in the area. The study will help the general public understand the abundance of groundwater near the Assabet River and potentially assist in comprehending the positive and negative effects of removing groundwater resources from this landscape.

CHARACTERIZATION AND CLASSIFICATION OF TWO MOROCCAN CHONDRITIC METEORITES

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Two Moroccan chondritic meteorites were characterized on the basis of texture, mineral assemblage and composition, and volatile species and concentrations. Both meteorites consist of chondrules, although the size range of chondrules differs. Meteorite 1 has chondrules to ~0.8 mm, and Meteorite 2 has chondrules to ~2.0 mm diameter. Most chondrules are coarsely crystalline and consist mostly of olivine. However, olivine concentration differs, with Meteorite 1 olivine ranging from Fo_{85-86} and Meteorite 2 olivine ranging from Fo_{73-76}. A few chondrules in both meteorites have barred texture. In both meteorites, barred crystals are orthopyroxene (En_{83} in Meteorite 1). Olivine and pyroxene crystals in both meteorites contain water in concentrations to several hundred ppm. Meteorite 1 also hosts measureable carbon dioxide, apparently in the structure of olivine crystals. On the basis of the mineral assemblage and textural characteristics, both meteorites are classified as Type 4 L chondrites.

SHIFTING SANDS: STORM IMPACTS ON PLUM ISLAND, MASSACHUSETTS

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Adviser: Robert Newton

The track of storm centers relative to the New England coast strongly affects directions of longshore currents. Storms track either west or east of New England's coastline, producing southern or northeastern winds, respectively. This project evaluates storm track dominance, the role of storms in shaping the New England coastline, and climate change effects on storm tracks.

Using Plum Island, Massachusetts, as a study area, storm impacts were analyzed using historical aerial photography coupled with a geographic information system (ArcGIS). The Great Hurricane of September 1938 and the Blizzard of February 1978 serve as illustrative examples of the two types of storm tracks. These were also two of the strongest storms of the twentieth century. Wind speeds during the Hurricane of 1938 reached 195 km/h (121 mph) winds with gusts of 298 km/h (186 mph) at Blue Hill Observatory in Milton, Massachusetts. Storm surge rolled in at 4 m (13 ft) with a storm high tide 4.5 m (15 ft) above mean high tide. The Blizzard of 1978 produced winds up to 100 mph on Plum Island and high tides 20 feet above mean high tide levels (Page, 2007). Strong winds and high waves produced drastic change in beach morphology.

Morphological change to the spit after the Great Hurricane of 1938 and the Blizzard of 1978 shows significant northward shoreline recession. Northward erosion of about 71,700±100 m^2 after the storm in 1978 contradicts expected erosion from the north and deposition to the south as a result of south-trending currents produced by this Northeaster. Anomalous results from 1978 aerial photos suggest that factors other than wind velocity shape Plum Island. For example, terrestrial and submarine topography affect wave refraction and tidal currents. Larger-scale chronological analysis may exhibit non-storm controls on morphology as well as storm-based change. On a centennial scale, results so far point to a distinction between morphology and sand volume change: while sand volume appears to fluctuate around a mean, the traceable shape of the shoreline has shifted significantly in the past century. Future work includes more extensive beach area mapping (using geographic information systems) and quantitative analyses based on volume change estimates from other New England beach profiles (FitzGerald et al., 2000).

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FRESH LUNAR CRATER EJECTA AS REVEALED BY MINI-RF

Sam BELL, Amherst College Geology and Astronomy

Micrometeorite, solar wind ion, and cosmic ray bombardment gradually erode the ejecta blankets that form around small lunar impact craters on timescales of tens to hundreds of millions of years. Sensitive to surface roughness on the scale of its 12.6 cm wavelength, the 30 m/pixel Mini-RF instrument provides detailed imagery of the ejecta blankets of small lunar craters at an unprecedented resolution and quality allowing us to examine large numbers of ejecta blankets with a higher degree of precision than possible beforehand (Thompson et al., 1981; Nozette et al., 2010; Neish et al., 2011). Using well-established crater-counting techniques (Arvidson et al., 1979; Michael and Neukum, 2010), we have characterized the lifetime of the discontinuous portion of the ejecta blanket as a function of the crater diameter, finding that the discontinuous ejecta lifetime is proportional to the square of the crater diameter. Combining our empirically derived function for discontinuous halo lifetime with an estimate of what fraction of its lifetime the discontinuous ejecta blanket has lived through, we are able to estimate absolute dates of individual craters. Cosmic ray exposure ages of craters visited by the Apollo missions provide confirmation of our results: Our lifetime model predicts that the discontinuous ejecta blanket around the 25-30 Ma (Turner et al., 1971) Cone Crater will have vanished after 8.7(+1.5/-1.7) Ma, and the discontinuous ejecta blanket is indeed absent. Our method produces an age estimate of 54(+39/-29) Ma North Ray Crater, consistent with the known age of 50.0±1.4 Ma (Arvidson et al., 1975).

SANDCRACKS AND SANDCHIPS: EXPERIMENTALLY PRODUCED SEDIMENTARY FEATURES IN OOID SAND AND GLASS BEADS

Sarah BRISSON, Smith College
Advisor: Bosiljka Glumac

Every builder of sand castles is aware of a major difference in physical properties between dry and wet sand. Addition of a small amount of moisture turns cohesionless sand into a cohesive material that can aggregate easily due to adhesive capillary forces caused by the presence of liquid bridges between grains. In laboratory experiments with ooid sand and glass beads we aim to evaluate the role of composition and texture in the formation of unusual sedimentary features in moist sand.

We experimented with mud-free beach sand from Cat Island, Bahamas that is fairly well sorted and composed mainly of well rounded, fine to medium sand size (100-400 μm), spherical to elliptical ooids. Layers made of cohesive, moist ooid sand had abundant large irregular pores, similar to that common in beach deposits. When left to dry at room temperature, the porosity was reduced due to loss of cohesion, gravitational collapse and repacking of grains. During this process the sand surface cracked and the resulting polygonal sandcracks resembled desiccation mudcracks. We also produced sandchips, similar in origin and morphology to muddy intraclasts or clay chips, by disturbing the surface of moist or cracked sand. Similar results were obtained in experiments with glass beads of the same texture as ooid sand.

Although polygonal desiccation cracks and intraclasts are usually associated with muddy deposits, our experiments demonstrate that such features can be produced in homogenous, mud-free, relatively fine-grained, well-sorted, round, spherical to elliptical sand of various compositions. Uniform size and regular shape of such sand appear to provide homogenous distribution of liquid bridges between grains so that sand can contract and crack polygonally due to stresses generated by surface tension when continuous films of interstitial water break into isolated capillary films during desiccation. While texture seems to control the formation of sandcracks and sandchips, the composition of sand and interstitial fluids influence their preservation by rapid lithification. The presence of salt and carbonate cements favors preservation in eolian and beach carbonate sand as supported by field examples on Cat Island. The apparent paucity of these features in the geological record suggests that generally they are not easily produced and/or preserved.

CORING A 12KYR OMBROTROPHIC *SPHAGNUM* PEAT BOG: A HISTORY OF ATMOSPHERIC MERCURY

Erin CAMP, Amherst College

This project cored a subalpine ombrotrophic *Sphagnum* peat bog in the Front Range of Colorado in order to test for mercury concentration. The extracted core was compacted to a length of 1.8m and began accumulating at approximately 9,000 years BP, according to radiocarbon data.

The mercury data illustrate a distinct boundary between natural and anthropogenic inputs of mercury through time at 75 cm depth, interpreted as the onset of silver mining in North and South America. Mercury concentrations along the core have been correlated to large volcanic events, Holocene climatic shifts, local mining and processing of the Colorado Mineral Belt ores, and other recent anthropogenic influences. A natural background rate of mercury deposition for this location was calculated at 23.2 ppb. Radiocarbon data yield a peat accumulation rate of 0.36 mm per year for the bulk of the core, while Cs-137 data yield a rate of 0.14 mm per year for the top 11 cm of the core, where there is much less compaction.

Additionally, ArcGIS was used during this project to create a visual representation of the bog bathymetry and to quantify the volume of material in the bog. Spatial analysis of the bog determined a volume of 9355 m^3 of peat and other organic material and a peat accumulation rate of 0.78 m^3 per year.

GEOCHEMICAL ANALYSIS OF THE CAMBRO-ORDOVICIAN COW HEAD GROUP, WESTERN NEWFOUNDLAND

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The Cambro-Ordovician marks a time period of extreme change in Earth's life and environment. The Cambrian explosion saw rapid diversification of many complex forms of life, but the diversity and abundance of organisms remained low for ~40 million years after the early Cambrian extinction. Following this depauperate interval, the Ordovician biodiversification event was a time of adaptive radiation during which skeletal groups flourished and took over as dominant carbonate producers. The driving force behind this delayed diversification remains poorly understood. Carbonates of the Cambro-Ordovician Cow Head Group in western Newfoundland, Canada, span this interval of time and record the appearance of complex skeletal life present in deep water environments of the Ordovician. Here, we report new data from the later Cambrian through Middle Ordovician portion of the Cow Head Group, Cow Head Peninsula, northern Newfoundland. The Cow Head Group is ~225 m-thick at Cow Head and consists of conglomerates, shale and limestone. Carbon isotopes were measured from the matrix of conglomerates and fine-grained limestones. The $^{13}C_{carb}$ profilerevealed a significant positive isotope excursion (from -5‰ to +1‰) in a Furongian Cambrian to Lower Ordovician 18-m thick conglomerate and overlying 5-m fine-grained dolomitic carbonate. This excursion may be related to the large positive excursion reported at the Cambro-Ordovician boundary in other places, but future work will determine if this is a globally correlative excursion.

A MICROFOSSIL ASSEMBLAGE FROM POST-STURTIAN CAP CARBONATE OF THE RASTHOF FORMATION, NORTHERN NAMIBIA

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Formation of northern Namibia hosts a Sturtian cap carbonate (~716 Ma) that directly overlies glacial deposits of the Chuos Formation. The basal 170 m of the Rasthof Formation is characterized by thinly (<1 mm) and thickly (1-4 mm) laminated microbialaminites, which preserve the first microfossil evidence for life that was present in the immediate aftermath of the Sturtian low-latitude glaciation. Here, we describe the microfossils present in the microbialaminites of the lower Rasthof Formation at the Okaaru locality (18°45’15”S, 13°42’37”E).

At Okaaru, the basal 40 m of the Rasthof Formation alternates between allodapic carbonates and thickly laminated microbialaminite. Lamination size decreases up-section, and at ~60 m, thinly laminated microbialaminite becomes prevalent. Samples from both thin and thickly laminated facies were collected and thin-sectioned. Oval-shaped walled organic structures (69—358 µm long) were abundant in 7 out of 15 thin sections. More than 150 oval, elongate organic structures were also identified in the acid macerates of thinly laminated microbialaminite, but were rarer in the thickly laminated microbialaminite (<50 specimens). Most of these structures are globular with a blunt end, but < 10 % are vase-shaped with distinct necks. All of these contain agglutinated phyllosilicate grains, and some are hollow. These forms are consistent with shells constructed by Arcellinid testate amoebae. Both facies also contain flat, ~ 10 µm wide and >100 µm long filaments that may be the remnants of fossils algae or cyanobacteria. Rare organic-rich agglutinated tubes (N=12) with variable lengths (250-890 µm) and widths (26 – 123 µm) are also present in both facies. The common types of microfossils found in both facies, fossil testate amoebae and agglutinated tubes, are similar. The prevalence of fossil testate amoebae in the thinly laminated microbialaminites and apparent paucity in thickly laminated microbialaminites may be due both to ecological and taphonomic variations between these two morphologically distinct deep water facies. Overall, the preservation of abundant testate amoebae and other shell-building organisms in both facies demonstrates the importance of diverse agglutinated organisms in deep-water microbial ecosystems after the Sturtian glaciation.

EXPLOSIVE VOLCANISM AND THE ABRUPT GROWTH OF THE ANTARCTIC ICE SHEET

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Thirty-four million years ago, there was an abrupt shift from a warm climate with little ice in the Eocene epoch, to a cooler climate in the Oligocene epoch coinciding with the rapid glaciation of Antarctica. The two principal hypotheses to explain the global cooling and glaciations of Antarctica are: 1) the opening of tectonic gateways and isolation of Antarctica, and 2) falling atmospheric CO_2. Scientific ocean drilling in the Caribbean revealed extensive explosive volcanism in Central America, with a peak in ash accumulation near the E-O boundary. The purpose of this research is to test the hypothesis that explosive volcanism could have been a trigger or contributor to this global cooling event. Similar to observations following the eruption of Mt. Pinatubo, explosive volcanism could have caused cooling of sea surface temperatures and other feedbacks in the ocean-climate system. Stable oxygen isotope data from the calcium carbonate shells of planktic and benthic foraminifera from Ocean Drilling Program Site 998 on the Cayman Ridge are analyzed to test for evidence of sea surface temperature change and the global signal of ice volume increase before, during, and after four explosive volcanism events. Planktic foraminiferal oxygen isotope data suggest that tropical sea surface temperatures cooled by as much as 2.5 degrees C in 3 out of 4 ash intervals studied. Sparse benthic foraminiferal data from Core 4R-3 (multiple taxa) do not allow us to say one way or another whether the 1st Oi1 oxygen isotope excursion had occurred before or during the ash intervals. Sparse benthic foraminiferal data from Core 3R-5 (*Cibicidoides*) suggest that the 2nd Oi1 oxygen isotope excursion had occurred prior to the volcanic events implying that explosive volcanism was not the primary trigger of Antarctic glaciations in the earliest Oligocene.

PETROGRAPHIC AND GEOTHERMOBAROMETRIC ANALYSES OF METASEDIMENTARY ROCKS IN THE HENRYS LAKE MOUNTAINS, IDAHO AND MONTANA

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Several different types of metasedimentary rocks occur in the Henrys Lake Montains in southwest Montana, each with a complex and unique metamorphic history. In the Henrys Lake village area, at least three stages of progressive metamorphism can be seen; the first as aligned inclusions in garnets, the second as garnet porphyroblasts, and the third as a new matrix wrapping the garnets. Schoolhouse Canyon, a nearby suite with a similar mineral assemblage, has signs of two stages of porgressive metamorphism; the growth of the matrix and the growth of garnet and staurolite porphyroblasts.

Two other important rock types occur at Divide Creek Road and Deer Mountain. The Divide Creek Road Suite is amphibole rich and has crenulation cleavage, as well as at least two stages of amphibole growth.

The Deer Mountain suite is highly retrograded to chlorite, with porphyroblasts of amphibole as well as possible lithic fragments.

Samples from four other sites were also studied, they are all low grade schists with mineral assemblages dominated by chlorite and biotite.

Thermobarometry calculations for Grt-Bt and Grt-Bt-Pl-Qz reactions in the Schoolhouse Canyon suite indicate that the pressure of the most recent metamorphic event was 5.5-6.5 Kbar at 550-575^{O}C. In the Henrys Lake village rocks, the temperature was 575-650^{O}C at 6.5-8 Kbar. Some anomolously low and high pressures were found, indicating that alteration or late reactions have occurred in the mineral grains.

Since the schists found in the Henrys Lake Mountains are likely outside of the area affected by the Big Sky orogeny, this complex metamorphic history may preserve information about pre-Big Sky orogeny events. The rocks clearly preserve signs of a multi-part geologic history that is highly variable even across the relatively small study area.

THE SEP 4, 2010 AND FEB 22, 2011 EARTHQUAKES NEAR CHRISTCHURCH, NEW ZEALAND

Lizzie GILLIS and **Ayla Heinze FRY**, University of Massachusetts

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Two major earthquakes in New Zealand over the past year have received significant global notice. On September 4, 2010, the first earthquake, M=7.1, occurred approximately 40 km west of Christchurch. It slipped about 3 m horizontally, with some vertical thrust generally less than a meter. On February 22, 2011, almost 6 months after the magnitude 7.1 earthquake, a 6.3 magnitude earthquake struck 9 km from the center of Christchurch on a previously inactive segment of the Greendale fault. This oblique reverse fault earthquake caused approximately 1.5 m of horizontal slip and 0.40 m of vertical slip. Our project models the coulomb stress change caused by the September 4th earthquake, and whether the Coulomb stress increase could have contributed to triggering of the February 22nd earthquake.

DEEP GEOTHERMAL POTENTIAL OF NEW ENGLAND GRANITOIDS: THE FALL RIVER PLUTON, SOUTHEASTERN MASSACHUSETTS

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Devonian-aged plutonic rocks that are interpreted to be part of the Fall River pluton, along the southern edge of the Narragansett Basin, appear to have potential as a source of deep geothermal energy. The Narragansett Basin covers a ~1500 Km^2 area in southern Massachusetts and is dominated by complexly deformed and metamorphosed, Pennsylvanian-aged, fluvial and alluvial deposits. A northeast-striking series of brittle faults and discrete shear zones define the southern margin of the basin. Preliminary modeling of igneous and gneissic fabrics from outcrops along the southern edge of the basin show that the granite dips predominantly north, northeast. This pattern suggests that granitoids along the southern edge of the basin continue beneath the Narragansett Basin and correlate with granitoids exposed to the north. Regional joint sets in the Fall River pluton can be grouped into three dominant clusters at 350°, 90°, and 250° based upon 86 field measurements. Low-angle sheeting joints are also common and suggest interconnected fracture networks at depth. Preliminary geochemistry from the Fall River pluton suggests that feldspars and accessory minerals contain the appropriate concentrations of heat producing elements, primarily U, Th, and K, to be a reasonable geothermal resource. K_2O values range from 2.4 to 5.0 weight percent. U and Th values (in ppm) range from 0.9 to 6.2 and 2.9 to 30.1 respectively. Assuming a relatively consistent composition at depth, a density of 2.6 kg/m^3, and a thermal conductivity of 2.9 W/m°C, initial temperature modeling suggests average temperatures of 81°C at depths of 5 kilometers and 93°C at depths of 6 kilometers. Temperature estimates increase to ~150°C and ~170°C respectively when a two kilometer thick sediment package is modeled overlying the granitoids. The goal of current and future work is to improve assumptions about compositional uniformity as well as the regional position of granitoids at depth. At the conclusion of this work we hope to develop a protocol for studying geothermal potential of buried granitoids in New England in the absence of reliable drill-hole data. Preliminary estimates from this project suggest that basins underlain by granitoids of compositions similar to that of the Fall River pluton have reasonable potential as a deep geothermal resource.

ICE COVER TRENDS IN AN ARCTIC LAKE (SVALBARD, NORWAY)

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Lake Linné is being used to monitor environmental impacts on lake temperature and duration of ice cover. Lake Linné is a glacial lake located in the Linné Valley of western Spitsbergen, Svalbard, Norway (78˚N, 12˚E). The lake is 4.6 km long, 1.2 km wide, and up to 45 meters deep, and fed by glacial meltwater from the Linné glacier and snowmelt from the watershed. Since 2003, Svalbard Research Experience for Undergraduates (REU) faculty and students have monitored environmental conditions around the Linné glacier and lake, and have collected lake water temperature, turbidity, and sedimentation data. For this project, temperature loggers were located at five points throughout Lake Linné. At each mooring site, loggers were placed at regular depth intervals, approximately every 5 to 10 m from surface to bottom. In addition, meteorological station weather records and automated cameras recorded daily lake conditions. An overall average lake temperature was calculated. Temperature baselines of 0.5ºC and 1.0ºC were used to determine break up and freeze up timings as well as the duration of ice free time. The 0.5ºC baseline identified break up earlier, freeze up later, and a longer ice free duration than the 1.0ºC baseline. Preliminary air temperature analyses indicate a relationship between increased air temperature and later freeze up timing.

A CASE STUDY FOR SEDIMENT AND CONTAMINANT STORAGE IN FLOOD PLAIN TIDAL PONDS: SELDEN COVE, CONNECTICUT RIVER

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The Lower Connecticut River has inherited a legacy of contamination since the onset of industrialization. Tidal ponds and coves along the river provide ample storage space for the deposition of fine-grained sediment and likely serve as a primary depocenter for contaminants introduced to the river over the last few centuries. Here we present sedimentological and geophysical data from Selden Cove, a fresh water tidal pond located along the floodplain of the Connecticut River, in order to assess the inventories of sediment and heavy metal contaminants. Using ground-penetrating radar surveys, we are able to determine patterns and spatial distributions of depositional units within the sub-bottom. Cesium-137 is used to evaluate decadal rates of deposition as well as define temporal stratigraphic horizons. The onset of heavy metal pollution in sediments marks material deposited since industrialization and provides an additional chronological constraint for evaluating centennial rates of deposition. Historical documents reveal that the primary tidal channel that connects Selden Cove to the river was opened during a flood in 1854, allowing rapid infilling of the pond. Using these tools, we are able to determine that the total volume of contaminated sediment stored within the cove is approximately xx as well as an inventory for the total amount of mercury, 16kg, which has accumulated in the pond since 1854. These inventories are then compared to previous published results for neighboring marsh locations in order to assess the relative role floodplain tidal ponds play in the storage of contaminated sediment.

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INSIGHTS INTO THE ORIGIN OF THE SOUTH FORK FAULT, WYOMING, USING CALCITE STRAIN ANALYSIS

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The origin of the South Fork fault, a 10km by 40 km rootless detachment fault, has been in question for over 90 years. In order to better understand its emplacement history, this project used calcite twinning analysis to calculate stress and strain associated with the South Fork detachment. Oriented samples of the Jurassic Sundance Formation were collected within both the upper and lower plate of the South Fork detachment. Calcite twinning analysis, using a universal stage, was conducted to calculate the strain ellipsoid, the principal stress axes and the differential stress preserved within the South Fork detachment. The twinning present within the upper and lower plates show compression and shortening axes oriented to the NW-SE with shallow plunges. Because transport of the allochthon was to the southeast, the stress and strain calculated from the calcite twins are likely due to emplacement of the allochthon itself. Samples within the lower plate also have steeply dipping compression and shortening axes representative of loading by the upper plate, providing further evidence for South Fork detachment-related twinning strain. The average differential stress calculated is ~20 MPa, which agrees with this interpretation of the calculated stress and strain ellipsoid orientations. The calcite twins within the Jurassic Sundance Formation of the South Fork fault indicate a localized, detachment related deformation. There is no sign of regional stress or strain induced by the proximal and temporal orogenic events, which is seen in many carbonates throughout the area.

PETROGENESIS AND DEFORMATION OF PRECAMBRIAN QTZ-DOL MARBLE UNITS IN THE GRAVELLY RANGE AND REYNOLDS PASS, HENRYS LAKE MTNS, SW MT AND ID

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Marble is one of the most extensive units making up the study area (Fig. 1). By studying structural data assembled from marble outcrops, the petrography of marble samples, calcite-dolomite thermometry, as well as carbon and oxygen isotope data for selected marble samples, we may better understand the Big Sky orogeny and the marble protolith. I studied selected marble samples using the Scanning Electron Microscope (SEM) as well as petrographic analysis to establish the mineral assemblages and textures. The majority consists of rather fine-grained dolomite and quartz with minor calcite and muscovite or phlogopite. Calcite-dolomite geothermometry was applied to samples that contained both calcite and dolomite. Also, carbon and oxygen stable isotope compositions were obtained from samples that contained one or more minerals, including dolomite, calcite, quartz, and tremolite. Structural data were collected in the field wherever folds were visible. Tremolite-bearing samples are relatively rare, while dolomite-quartz assemblages are common. Metamorphic temperature is higher east of Henry's Lake and lower to the west. Tremolite occurrences are associated with higher temperatures. Carbon isotope values in dolomite marble regions show little to no alteration, but oxygen isotope values suggest some kind of alteration event. The tremolite-forming reaction has caused an alteration in carbon and oxygen isotope values explained by the removal of CO_2.

CHARACTERIZATION OF TRACE METAL CONCENTRATIONS AND MINING LEGACY IN SOILS, BOULDER COUNTY, COLORADO

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Keck Advisors: David Dethier, Will Ouimet

Smelting processes contribute to the emission of trace metals through ore deposit burning. Heavy metals are unstable in the atmosphere, and surface soils serve as a major metal sink in the environment. Therefore in regions of smelting activity, soils are thought to be enriched in metals associated with ore processing (Pb, Hg, Cd).

The purpose of this investigation is to characterize metal concentrations in soils across a historic mining region of the Colorado Mineral Belt in southwestern Boulder County, Colorado. Fieldwork was conducted through the Keck Geology Consortium Colorado Front Range project in association with the NSF-funded Boulder Creek Critical Zone Observatory (CZO) project. The approach is to determine (1) whether the geochemical signal thought to be associated with mining is present in surface soils across the region, (2) what the controls on accumulation in the soil profile are, and (3) how the soil geochemistry compares with other soils in the state. This project focused on laboratory analysis to characterize soils in terms of metal concentrations (Al, As, Ba, Cd, Cr, Cu, Fe, Hg, Mn, Pb), acidity (pH), loss on ignition (LOI, approximate % organic content), and grain-size (% fine-grained content). Interpretation of geochemical data included spatial analysis of trace metal soil chemistry (MAS/MILS U.S. Bureau of Mines dataset in ArcGIS) and a comparison of results with statewide soil geochemistry from the 2006 USGS Colorado soil survey (Smith et al., 2010).

Trace metal concentrations in southwestern Boulder County soils are enriched in Pb, Cr, Cd, and Hg relative to other Colorado surface soils. Results show that Pb, As, Cd, Mn, and Ba are enriched in surface soils (O and A horizons) with respect to parent material. Mn and Ba enrichment is not likely from anthropogenic sources, and the correlation between these metals in the soil profile suggests that the source of enrichment for Mn and Ba in surface soils may be bioaccumulation. Surface soil enrichment of Pb, As, Cd, and Hg suggests a common source: atmospheric deposition from an anthropogenic source. Correlation between concentrations of these elements supports the original hypothesis, that surface soils are enriched in metals associated with mining activity.

Additionally, Pb, As, Cd, Hg, Mn, and Ba are correlated with LOI % (approximate organic content); there is no relationship between (1) fine-grained percent content of soils and trace metal concentrations or (2) proximity to former mining or smelting sites and trace metal concentrations. This indicates that the present-day concentrations of surface soil-enriched metals across the region are a function of soil organic content, not of location or of clay content.

THERMOMETRY OF LEUCOGNEISS IN LAMOILLE CANYON, NV

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In the Ruby Mountains of Nevada, the Lamoille Canyon area contains schists and gneisses that experienced pervasive metamorphism and deformation during Cenozoic extensional faulting. The extensional fault system is associated with the Ruby Mountains Metamorphic Core Complex (RM^2C^2), and Lamoille Canyon contains metasedimentary strata from the core complex's lower plate.[1] Peak temperature data for these rocks have never been collected. Therefore, a temperature estimates from these rocks will give further insight into the thermal dynamics of the RM^2C^2 lower plate.

This study will enable me to compare the thermal dynamics of the RM^2C^2 with other core complexes. In addition, I will compare these data with results from a parallel study using the developing titanium (Ti) in quartz thermometry method. Research methods consist of analyzing field samples from Lamoille Canyon, which shows a transition from migmatite to mylonite over only a few hundred meters of section. I have completed petrographic and electron backscatter diffraction analyses to characterize the types of recystallization involved and the crystallographic preferred orientation of quartz in the quartzites of Lamoille Canyon. Recrystallization microstructures do not vary significantly throughout the detachment zone, despite the work of others, who have argued for significant temperature gradients in detachment zones.[2]

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[1] MacCready T. 1997. Mid-crustal flow during tertiary extension in the ruby mountains core complex, nevada. Geological Society of America Bulletin 109(12; 12):1576-94.

[2] Gottardi et al. Geology (accepted March 2011).

ASSESSING HYDROCLIMATOLOGICAL SENSITIVITY TO CLIMATE CHANGE ACROSS NORTHERN EURASIA

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By understanding the spatial variability of areas at high latitudes that are most sensitive to climate change, we can begin to focus on those regions in which the human populations will be more or less vulnerable to change. Using multiple variables to describe the human-biophysical system combined together, we get a single snapshot of the "hot spots" of sensitivity.

We used a broad-scale index approach, adapted from the Giorgi (2006) Regional Climate Change Index (RCCI), using temperature and precipitation data from the IPCC AR4 simulation runs for the pan-Arctic drainage region of Eurasia gridded to Northern Hemisphere EASE grids. The adapted index, or Arctic Climate Change Index (ACCI), considers the change between 1960-1999 and 2080-2099 for four variables: surface air temperature, precipitation, temperature interannual variability, and precipitation interannual variability. An ACCI value layer was calculated independently for eight CMIP3 models and two IPCC emissions scenarios. To provide a measure of certainty/uncertainty in the region's responsiveness to climate change, standard deviation was calculated across the 16 subsequent ACCI layers.

The ACCI identified several areas of high and low sensitivity to climate change. Areas of high sensitivity tended to have higher certainty levels across the broad range of future climate predictions. Applying the regional sensitivity and certainty measures to the human population, we found the areas of the Eurasian pan-Arctic that are most sensitive to future climate change are also areas having less uncertainty and with greater population. This indicates that a large portion of the population in pan-Arctic Eurasia has relatively greater vulnerability to projected future climate change.

ANCESTRY OF THE LEGS LAKE SHEAR ZONE, SASKATCHEWAN: EVIDENCE FOR MULTIPLE STAGES OF TECTONISM IN THE SNOWBIRD TECTONIC ZONE

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The Snowbird tectonic zone forms the boundary between the Rae and Hearne domains of the Canadian Shield. There have been many hypotheses for the timing and significance of this enigmatic lineament. The Snowbird tectonic zone is well exposed in the Athabasca granulite terrain (AGT), in Saskatchewan, where it coincides with the Legs Lake shear zone, an oblique thrust-sense shear zone that served to uplift the AGT, over the mid-crustal Hearne domain to the east. The Legs Lake shear zone was active at 1.85 Ga, and was possibly localized in an area that was thermally weakened by the 1.9 Ga Chipman mafic dike swarm. One major tectonic question is whether the Chipman dike swarm and Legs Lake shear zone are the only expression of the Snowbird tectonic zone or whether the zone had an earlier, possibly Archean, history. This question has been investigated in the southern part of the Legs Lake shear zone, where it juxtaposes the 2.6 Ga Fehr granite in the west with the Hearne domain in the east. Field mapping suggests that the Fehr granite may already have contained NE-striking, possibly tectonic, contacts before it was tectonized by the Legs Lake shear zone, i.e. a previous Snowbird-related tectonic fabric. The Fehr granite is a megacrystic granite with both non-mylonitic and intense mylonitic domains. Microstructural analysis, petrologic analysis, and insitu geochronology are currently being used to investigate whether boundaries and strain gradients within the mylonite reflect earlier tectonic contacts or strain localization within a homogeneous granite. If early tectonic contacts are present, these may reflect an early event (possibly Archean juxtaposition) along the Snowbird tectonic zone.

MOLLUSK DRILLING PREDATION FREQUENCY AT DUCK CREEK BEACH, CAPE COD, MA

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Advisor: Sara Pruss

Since the Cambrian, evolution has been continually influenced by the existence of predator-prey relationships. By studying predation in the fossil record, paleontologists can better understand how predator-prey relationships influence morphological and behavioral changes as organisms attempt to satisfy various frustrated needs. Predation intensity and frequency of predation are best measured in the fossil record by quantifying direct traces of predation, such as drill holes. Here we report new results from an assemblage of mollusks collected at Duck Creek Beach in Cape Cod, MA during March 2008.

A subset of 200 intact shells was assembled using blind selection from an existing collected made by S. Pruss at Duck Creek Beach. All shells were identified to the genus and species level, where possible. Shells were also examined for drill holes or incomplete drill holes. The diameters of each shell and drill hole (where present) was measured with electronic calipers and recorded. This data was then used to determine the total predation frequency, drilling frequencies for each genus, and predator selectivity.

There is a relatively low amount of biodiversity in the shell assemblage when compared with other assemblages analyzed from nearby Plum Island and the Bahamas, both of which have more than 10 genera present. Only 7 genera are present and a clear dominant genus, *Crepidula*, comprises 53.5% of the assemblage. The overall predation frequency for the assemblage is 16.5%, and this is generally constant among the different genera with drill hole traces (+/- 2%). There are two distinct borehole morphologies present, indicating the presence of both naticid and muricid predators in the ecosystem, although each prey genus only has one type of borehole on the shells where drill holes are present. These two predators have distinctly different life modes and do not interfere with one another's predation patterns; As a result, they have a non-emergent effect on the prey. Initial quantification of drill holes in this assemblage indicates that predator-prey dynamics in the area of Duck Creek Beach differ from other areas in New England. The 16.5% predation rate is high in comparison to other local beaches – Plum Island to the north has a rate of only 6.5%, which is more typical for the area. This, paired with the absence of failed drill holes, indicates that competition in the area is low. These features may result from the location of Duck Creek Beach, which is sheltered on the bay side of the Cape Cod peninsula.

GEOCHEMICAL GROUNDWATER ANALYSIS OF HORIZONTAL HYDRAULIC FRACTURING IN THE MARCELLUS SHALE BED, FIDDLE LAKE PENN, U.S.A.

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Amy Rhodes, advisor

Hydrofracturing has become more prevalent in the US, as a method for natural gas extraction from shale beds. This energy source is controversial, due to the use of toxic chemicals and the possibility of ground water contamination. The Marcellus Shale Bed lies within New York, Pennsylvania, Ohio, Maryland, New Jersey, Virginia, Kentucky, Tennessee, parts of Canada and underneath Lake Erie. Fracking the Marcellus Shale Bed may alter the groundwater, and/or the surface water chemistry. Since the 2005 energy bill passed, provisioning the Halliburton Loophole, fracking companies are exempt from abiding to the standards set by the Clean Air and Clean Water Acts. This loophole strips the Environmental Protection Agency (EPA) of authority to regulate the fracking process. Testing drinking water, so as to prove changes in court, now lies on homeowners.

The goal of this project is to establish a water quality monitoring program for residents near Fiddle lake, PA, where natural gas leases have recently been established. In March 2011, samples were collected from residents wells, surface waters surrounding the lake and snow and were analyzed for elements that might alter with fracking within the watershed. We measured samples for SC, pH, ANC, Ca, Mg, Na, K, SiO2, F, Cl, NO3, SO4, Br, and found the ion balance, and percent error. Future analyses will test for Ba, Sr, As, Fe, Mn, and other trace elements.

The aim of this work is to set up a base line, of regional water chemistry so that when/if fracking occurs, potential changes can be recorded. Improperly disposed flowback water from the hydrofracking process will add high TDS, including Cl, Br, Ba and potential trace metals. The monitoring program aims to document seasonal changes in water chemistry. Seasonal changes will occur, and need to be mapped out, hence the importance of starting this study before fracking occurs.

STRUCTURAL ANALYSIS OF PRECAMBRIAN MYLONITE ZONES, HENRY'S LAKE MOUNTAINS, SOUTHWEST MONTANA AND IDAHO

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As part of the 2011 Montana, Big Sky Keck Projects, mylonites, protomylonites, and cataclasites were documented in thin, widely spaced, NE trending, NW dipping (Fig. 1), SE verging (Fig. 2, 4) shear zones. Differences in protolith composition are interpreted to control position of shear zones and textural differences between mylonites, protomylonites, and cataclasites. Cataclasites likely have the highest concentrations of retrograde minerals because their highly fractured texture provided a conduit for water flow. Symplectite grew during shear, potentially as a means for volume reduction (Simpson and Wintsch, 1989). Mineral assemblages typical of greenschist facies and phengite equilibrium with k-feldspar, quartz and phlogopite suggests a minimum pressure during shear of 5 kb (0.5 GPa). As shear zones in the Henrys Lake Mountains are found to be the along strike equivalents of the 1.8 Ga Madison mylonite zone in the Southern Madison Range (Erslev and Sutter, 1990), it is believed that they are the result of shearing as part of a foreland thrust zone inboard of a major compressional orogen at 1.8 Ga (Erslev and Sutter, 1990). It is suggested that this event was the Big Sky Orogeny.

METEORIC ^{10}BE IN GORDON GULCH, COLORADO SOILS: IMPLICATIONS FOR HILLSLOPE PROCESSES AND DEVELOPMENT

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The dramatic relief of the Colorado Front Range was produced by post-Eocene uplift and fluvial erosion into the uplifted range (Gregory and Chase, 1992; Chapin and Kelley, 1997; Steven et al., 1997; Anderson et al., 2006; McMillan et al., 2006; Wobus et al., 2010). Modern incision began with some agent of tectonic uplift and/or isostatic responses to increased erosion driven by climate change.

This research contributes to research done by the Boulder Creek Critical Zone Observatory (BC-CZO), within the extents of its Gordon Gulch focus area, a focus areas of the BC-CZO and is situated between the downslope limit of Pinedale glaciation and the upslope limit of the mountain front. This project uses LiDAR analysis and presents meteoric ^{10}Be data as a tracer of modern hillslope evolution to look at soil development on hillslopes in Gordon Gulch, a 2.75 km^2 catchment within the Boulder Creek drainage basin.

Nine soil pits on two ridge to stream transects in Gordon Gulch were examined, five on the north-facing hillslope and four on the south-facing hillslope. Across both hillslopes, soils in the sampled pits ranged from 32 to 188 cm thick. A-, C-, and Cr-soil horizons are present in nearly all soil pits. O- and B-horizons are common on the north-facing hillslope but are largely absent on the south-facing hillslope. Meteoric ^{10}Be concentrations range from 2.85×10^8 to 8.06×10^8 atoms/cm^2 at the surface and generally decrease with depth, with some small bulges toward the tops of the profiles. Inventories of ^{10}Be range from 9.42×10^9 atoms/cm^2 to 3.53×10^{10} to. Soil ages calculated from inventory values range from 8,950 to 33,700 years with minimum annual precipitation and 10,900 to 41,300 years with maximum annual precipitation. ^{10}Be inventories and ages are generally significantly greater on the north-facing hillslope than on the south-facing hillslope.

Meteoric ^{10}Be soil ages based upon inventories throughout the Gordon Gulch catchment show that these soils are young (middle Pleistocene to Holocene in age). These data suggest that the opposing hillslopes of the lower Gordon Gulch catchment have evolved differently and suggest that the south-facing hillslope of the lower catchment is eroding faster than the north-facing hillslope. The north-facing hillslope is characterized by generally downslope thickening soils and more clearly defined soil horizons, many Ponderosa pine trees, a larger meteoric ^{10}Be inventory, and an overall ~10º slope. The south-facing hillslope is characterized by variable soil thicknesses downslope and less clearly defined soil horizons, shrubs, grasses, and some trees, a smaller meteoric ^{10}Be inventory, an overall ~12º slope, and a relative abundance of bedrock outcrops compared to the north-facing hillslope.

Had erosion on the south-facing hillslope been faster than on the north-facing hillslope from the Laramide orogeny to present, like it is today, the south-facing hillslope would have evolved to be shorter than the north-facing hillslope overall. The hillslopes in the Gordon Gulch catchment today, however, are the opposite, suggesting that faster erosion on the south-facing hillslope is a more recent occurrence.