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FIVE COLLEGE GEOLOGY

UNDERGRADUATE RESEARCH SYMPOSIUM

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MUSEUM of NATURAL HISTORY

Amherst College

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Daniel R. Arnost, University of Massachusetts
Advisor: G. Christopher Koteas

The Flander's Bay greenstone (Gilman and Lash, 1988) is an isolated ~11km^2 metavolcanic body of unknown age within the central coastal Maine magmatic province. This body is intruded by the bimodal ~420 Ma Gouldsboro pluton in the south and the ~366 Ma Tunk Lake pluton in the north. Along Flander's Bay, the greenstone is unconformably overlain by the Siluro-Devonian Bar Harbor formation. Field relations show that the greenstone pre-dates the Bar Harbor formation as well as all surrounding intrusive bodies. These observations suggest that the latest possible age of emplacement is Ordovician. Plots of total alkalis vs. quartz imply a basaltic-andesite protolith.

The greenstone body records varying degrees of metamorphism and deformation. The actinolite+chlorite+feldspar+hornblende±quartz±epidote assemblage restricts the grade from greenschist facies in the south to epidote-amphibolite facies in the north. A pervasive lineation is best displayed by elongate qtz+ep pods that plunge consistently gently southeast. Thin (<1-2cm thick) but abundant quartz veins define pervasive cm-scale asymmetric, tight folds that typically verge southwest and rarely north. A top-to-the-northwest shear sense is indicated by sigmoidal quartz veins. The primary metamorphic foliation is commonly sub-parallel to veining. The overall fabric is warped into a series of broad open folds in the southern portion of the greenstone. No metamorphic fabric is present in the eastern-most portion of the body. In the northwest, near the intrusion of the granitic Tunk Lake pluton, there is a pervasive, consistent south dipping foliation along with isolated localities that display gneissic banding. Bands defined by alternating chl+act+hbl vs. qtz are characteristic of more strongly deformed zones subparallel with the Tunk Lake contact. Grain shape preferred orientation of act+chl+feldspar define the foliation where banding is not present. Evidence of multiple phases of deformation present in the south are overprinted in the north by contact metamorphism and deformation related to the intrusion of the Tunk Lake pluton.

Future textural analysis and detailed geochemical and isotopic studies will focus on improving correlation with other regional metavolcanic units such as the Castine, North Haven, or Ammonoosuc volcanic successions.

Petrography and Geochemistry of the ArnesCentral Volcano, Northwestern Iceland: The case for Fractional Crystallization in Rhyolite Petrogenesis

Michael Bernstein, Amherst College
Advisor: John T. Cheney

Basalt is the dominant product of Icelandic volcanism. Approximately 12% of Icelandic volcanism is silicic (Sigurdsson and Sparks 1981). To further the study of Icelandic rhyolites, the 2007 KECK Iceland project explored a transitional volcanic center along the abandoned Skagi-Snaefellsnes rift in the Westfjords of northwest Iceland. Integrating mapping, petrography and geochemistry, this project seeks to constrain mechanisms of rhyolite petrogenesis in Iceland's volcanic environment.

Fieldwork was conducted over a four-week period during the summer of 2007. Samples were collected and initially used to characterize the volcanic stratigraphy and delineate distinct units. At Amherst, thin sections were prepared for petrographic and SEM/EDS analyses. Billets were sent to Washington State University's Geo Analytical Labs for complete geochemical analysis by XRF and ICP-MS.

Geochemical data were plotted graphically for study. The progression in Mg number across samples supported a genetic relationship among the units. Harker and Fenner variation diagrams yielded curvilinear trends consistent with fractionation. Log-Log incompatible element plots show that the incompatible elements in these lavas behave perfectly incompatibly. Incompatible trace element plots show that the ratios between incompaible elements remain the same while their concentrations increase, a trend consistent with fractional crystallization. REE diagrams and spider diagrams reveal that the rocks share similar patterns and are consistent with genetic linkages among the units in the Krossnesfjall field area. The data were next considered in the context of Iceland array data and mechanisms of rhyolite petrogenesis.

A model by Brophy (2008) was employed as a means of descriminating between partial melting of hydrothermally altered MOR gabbros and extended fractional crstallization of MORB. The comparison shows that REE versus liquid SiO_2 variation in the present lavas is consistent with extended fractional crystallization of MORB under moderate pH2O conditions. Considering the results of the comparison to Brophy (Submitted March 2008) in conjunction with the co-linear variation of the Rb/Hf ratio that is inconsistent with a partial melting model of hydrothermally altered basalt crust, we conclude that the basaltic andesites through rhyolites in this study are related by fractional crystallization. The data do not preclude a more complex relationship of hybridization of silicic and basaltic magmas with subsequent fractional crystallization producing the more evolved lavas in the Krossnesfjall lava series.

These data are consistent with a model of ~65% fractionation, calculated using the Rayleigh model of fractional crystallization, from the most primitive samples present to the most evolved. Fractionating minerals are clinopyroxene, plagioclase and Ti-mgt as indicated by Sc trends, a negative Eu anomaly in dacite and rhyolite samples, and SiO_2 enrichment and associated TiO_2 and V trends.

P-T PATHS OF GARNET-BIOTITE-SILLIMANITE MIGMATITES AT CAMP CREEK , HIGHLAND MOUNTAINS OF SOUTHWEST MONTANA

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Advisor: John T. Cheney

Massive to well-foliated aluminous garnet-biotite-sillimanite gneiss and migmatite, overlying a NE-trending antiform of crystalline basement rock in the Highland Mountains of southwest Montana, outcrop extensively at Camp Creek. The rocks at Camp Creek were deformed by partial melting followed by back-reaction during an event that predated, then overlapped an orogenic event in the adjacent Tobacco Root Mountains during the Middle Proterozoic (1.78 – 1.71 Ga) called the Big Sky orogeny.

Based on mineral assemblages, reaction textures and chemical zoning, a possible P-T path was predicted within the context of the NaKFMASH system to provide an understanding of metamorphism at Camp Creek, and to provide insight as to the extent to which the Big Sky orogeny affected western Montana beyond the Tobacco Root Mountains. The presence of sillimanite, relative absence of k-feldspar and total absence of kyanite limits pressures to a range of 3.5 – 8 kbar during retrograde metamorphism; the presence of sillimanite, and lack of kyanite and cordierite limits retrograde temperatures to 650 – 800 º C. Back-reaction and later chloritization obliterated most evidence for prograde mineral assemblages, which makes constraining the prograde path very difficult. The absence of kyanite and cordierite suggests that the P-T path at Camp Creek was either isobaric or else followed a very narrow clockwise path within the upper sillimanite region on the NaKFMASH petrogenetic grid.

Ages obtained from monazites in samples at Camp Creek with an electron microprobe at Rensselaer Polytechnic Institute suggest timing between 1807±16.7 Ma and 1636±14.6 Ma. These ages correspond to a slightly broader range of spot ages from Camp Creek samples previously obtained by John T. Cheney in 2005.

CARBON- ISOTOPE STRATIGRAPHY OF UPPER CRETACEOUS DEPOSITS OF THE DALMATIAN ISLAND OF BRAC, CROATIA

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This study focuses on the carbon-isotope stratigraphy of two successions of marine carbonate deposits from the Island of Brač in Dalmatia, Croatia to improve their age determination and local to global stratigraphic correlation. These successions were deposited during the Late Cretaceous on the Adriatic-Dinaric carbonate platform within the Tethys region. The carbon-isotope records from both successions reveal a shift towards positive $\delta^{13}C$ values reaching +4 to +5‰ VPDB. Limited biostratigraphic data suggest Late Cenomanian age for fossils present in the lower part of the successions, and the documented stratigraphic variations in carbon-isotope composition are compared to standard reference $\delta^{13}C$ curves for this time interval derived from fossiliferous successions elsewhere. Such chemostratigraphic correlation allows for the recognition of the start, plateau, and possibly the end of the secular positive carbon-isotope excursion across the Cenomanian-Turonian boundary in the successions examined.

The start of the excursion is documented stratigraphically above the lithostratigraphic boundary between the Milna and Sveti Duh Formations. The Milna Formation is characterized by alterations of various skeletal lithofacies, laminated mudstones, and slumped beds with breccia, interpreted as deposited in a shallow, restricted marine environment. With a sharp contact between the two formations, the overlying Sveti Duh consists of pelagic deposits rich in calcispheres (planktonic microfossils), interpreted as deposited in a low energy, drowned carbonate platform. Thus, the onset of the Cenomanian-Turonian isotopic excursion coincides with a transgressive trend worldwide, observed on Brač as a change to pelagic sedimentation in the Sveti Duh Formation.

This chemostratigraphic study indicates that this part of the Adriatic-Dinaric carbonate platform was affected by the onset of global sea-level rise and oceanic anoxic event corresponding with the interval across the Cenomanian-Turonian boundary. The results of this study confirm Late Cenomanian age for the Milna Formation and Late Cenomanian-Early Turonian age for the Sveti Duh Formation in the study area. Ongoing biostratigraphic studies are expected to further refine the placement of the Cenomanian-Turonian boundary in this important stratigraphic interval associated with large perturbations in global carbon cycle and palaeoceanographic circulation patterns.

URBAN GEOLOGY: GIANT FOSSIL SPONGES RULE IN THE CANALS OF MIAMI, FLORIDA.

Andrea L. Gohl, Smith College
Advisor: H. Allen Curran

Late Pleistocene demosponge biostromes were recently discovered in paleotidal channels of Miami Limestone in southeastern Dale County of metropolitan Miami, Florida. The abundance, size, and extent of sponge biostromes, reaching a height of 2 meters and extending laterally for distances up to 3.5 km, indicate a once successful community. This is an interesting occurrence because instead of being located in a low-energy environment, these sponges occurred between ooid shoals in high-energy tidal channels. The unique morphology and occurrence of sponges have lead to their classification as a new genus and species, Miamiamplia vasiforma. Understanding this not so typical community brings new questions to be answered about shallow marine environments and sponge dominated communities.

SEASONAL GROUNDWATER LEVELS PROVIDE EVIDENCE OF RECENT CLIMATE WARMING IN THE NORTHEASTERN US

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Advisor: Prof. David Boutt

Groundwater levels provide a rough analog of regional climate by reacting to temperature, precipitation and snowmelt. The combination of these elements produces a sinusoidal annual cycle with predictable highs and lows. This study examines the seasonal groundwater and precipitation cycles for Ft. Kent, ME and Haverhill, MA. Regional climate warming is already disrupting the historic seasonality of the region by causing spring to occur earlier (Schwartz, 2006) and decreasing the snow-to-rain ratio (Huntington et al., 2004). Groundwater levels record these changes as a forward shift in the annual cycle. At Ft. Kent, where there have been great changes in precipitation patterns since the late 1970's, the groundwater cycle shift is already obvious, and is easily distinguishable from a simple increase in annually averaged levels. The change corresponds well with the coupled precipitation record from the site. There is a declining snow-to-rain ratio at Ft. Kent in addition to a strongly linear increase in annual precipitation. Both of these trends have been observed at other northern New England locations. Haverhill, while showing a similar, but weaker increase in annual groundwater levels does not show the same pronounced cycle shift, indicating a minimal change in seasonality. As expected, the site has a weakly correlated increase in precipitation, and no noticeable decrease in the snow-to-rain ratio. Current model projections for the northeast call for average temperature increases of 2.7C -5.7C by the end of the century in addition to dramatic increases in precipitation (Hayhoe et al., 2007). This study provides a scale for the shift in seasonality associated with the temperature and precipitation increases. Additionally, the use of groundwater levels to track climate change driven seasonality changes may be extremely useful in areas with long groundwater records.

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DENDOCHRONOLOGICAL STUDIES OF HISTORICAL WEATHER AND EXTREME STORMS, CAPE COD

Ryan Mann, University of Massachusetts
Advisor: Paul Krusic, Lamont Doherty Earth Observatory, Columbia University

The Waquiot Bay National Estuarine Research Reserve (WBNERR) preserves and provides access to visitors and researchers to the Waquoit Bay estuary and its contributing waterways in Falmouth, Massachusetts. The reserve is part of the National Estuarine Research Reserve system of reserves administered by the National Oceanic and Atmospheric Administration (NOAA). NOAA is partnered with the State of Massachusetts Department Of Conservation and Recreation (formerly the Department of Environmental Management) in managing the reserve. Various coastal systems encompass the reserve including barrier islands, estuarine characteristics, dune and inter-dunal environments as well as coastal pitch pine/Scrub oak forest characteristic of Cape Cod.

Due to the periodic but regular occurrence of storms, the area is known to be adapted to disturbances. Although the reserve presently keeps climate data records, the records of the past 50 to 100 years are sporadic and have large gaps in observations. This project aims to correlate known weather occurrences with data collected through dendrochronology from Pitch Pine (*Pinus rigida*) and Juniper (*Juniperus communis*) in various locations near the barrier beaches of Vineyard Sound. By comparing growth patterns in the trees with records of precipitation, temperature and storms, juniper growth rings can be used as a proxy of climate and extreme weather events.

More than twenty trees were cored using an increment borer at heights of one foot and diameter breast height (4.5 feet). The sampled trees are all known to be less than 70 yrs old due to historical uses and known hurricane events. Tree ring indices were delineated using Measure J2X on a magnified computer scanner at the Lamont Doherty's Tree Ring Laboratory; cross correlations were tested using the program "Cofecha". The results were more difficult to come by due to issues related to the cross correlation process with this difficult wood. Further analysis is being conducted to determine what environmental signals are being observed.

MYSTERIOUS MEANDERING MICROBIAL MATS: CLUES TO THE ENVIRONMENT POST-SNOWBALL EARTH 700MYA

Marie McLane, Smith College
Advisor: Sara Pruss

Roughly 800-550 Million years ago, during the Neoproterozoic, what is now the west coast of Namibia lay near the equator. Thick glacial deposits found in this region are evidence that widespread equatorial glaciers reached sea level during the Neoproterozoic, during what is hypothesized as Snowball earth events. This hypothesis suggests that at least twice during the Proterozoic the planet was completely covered with snow and ice. Carbonates, deposits known mostly from tropical settings in the Modern, immediately overlie these glacial deposits. This strange sequence repeats several times and is found around the world indicating significant and rapid global climate changes. Very little work has been done on these cap carbonates, which may hold integral clues to the rapidly changing environment during this time.

The goal of this project was to research many different aspects of the older of the two cap carbonates (the “Sturtian” Snowball Earth event), in an attempt to achieve a better understanding of the environment during this time after the glaciation of Snowball earth. The purpose of this project was to examine controversial roll-up structures that occur in some carbonate layers and were likely formed by microbial mats. Very little work has been done on these unique features, thus the formational processes and environments are poorly understood.

Serial sectioning of a sample containing roll-up features showed that the lateral extent varies slightly, but they usually extend only a few centimeters. This scale makes the previously hypothesized tectonic disruption or slumping unlikely as physical causes. We now favor the hypothesis that the development of gas bubbles under the elastic surface microbial mat may burst under sediment loading and disrupt surrounding layers.

Thin sections were made of all different facies preserved in the Rasthof Formation. This allowed for mineral identification as well as micro-structure analysis of the roll-up structures. In one sample found near the base of the sequence, possible fossilized microbes were found. Raman spectroscopy of this sample will be able to identify chemical bonds and thus determine whether or not organic material is present. This will allow us to determine whether or not these microfossils are biologic or merely a result of mineral recrystallization. Carbon isotope analysis of matrix sediment and void cements can be used as a proxy for the seawater alkalinity during crystal growth. This is useful as it may constrain the conditions surrounding gas bubble formation in the microbial layers, which are hypothesized as a possible cause for the roll-up features.

MODELING THE EFFECT OF LEACHATE TRANSPORT ON REGIONAL GROUNDWATER CHEMISTRY

Nicholas Newcomb, Hampshire College
Advisor: Robert M. Newton, Smith College

Three municipal landfills exist over the primary recharge area of the Barnes Aquifer which provides several towns in Hampshire and Hampden counties, Massachusetts with drinking water. Existing water chemistry data from wells in the vicinity of the Northampton landfill provide preliminary evidence suggesting that landfill leachate may produce reducing conditions capable of mobilizing iron, manganese, and arsenic constituents from aquifer sediments. The purpose of this study is to construct a groundwater flow model using MODFLOW in order to quantify the extent and concentration of dissolved organic carbon (DOC) present in leachate plumes generated from three landfills and assess the potential effects on municipal water sources. The study relies on leachate production results yielded from an EPA Hydrologic Evaluation of Landfill Performance (HELP) model coupled with a 3-dimensional reactive transport package (RT3DV2.5). The model was able to accurately predict groundwater head under steady state conditions. Contaminant transport results indicate that contaminant plume containing high biological oxygen demand (BOD) produces a plume of depleted dissolved oxygen (DO) which is transported to a high yield municipal well. Low background DO concentrations at this site suggest that small changes in geochemistry could have large impacts on iron, arsenic, and manganese concentrations.

THE ORIGIN OF POTASSIUM FELDSPAR MEGACRYSTS IN THE LEXINGTON BATHOLITH, WEST-CENTRAL MAINE

David Newton, University of Massachusetts
Advisor: Sheila Seaman

The Lexington batholith (~400 Ma) of western Maine can be divided into 3 lobes. The central lobe is a peraluminous granite consisting of a matrix of quartz, plagioclase, biotite, K-feldspar and muscovite hosting large (to 20 cm long), abundant K-feldspar megacrysts. These megacrysts are euhedral, tabular perthitic microcline crystals that contain abundant inclusions of biotite, plagioclase, quartz and muscovite.

The origin of potassium feldspar megacrysts in granites as phenocrysts or porphyroblasts has been largely settled over the past decades, with abundant textural evidence supporting their origin as phenocrysts. However, questions remain about the magmatic processes that lead to the growth of phenocrysts of such disparate size compared to groundmass crystals. Previous workers (e.g., Cox et al., Journal of the Geological Society of London, 1996) have suggested that influxes of mafic magma into the granitic magma chamber caused K-feldspar to remain on the liquidus over a long time span, during which they grew to megacryst size. In this study we explore the possibility that generation of a flux-enriched boundary layer around the growing crystals could promote the rapid growth of megacrysts in the absence of mafic magma influxes.

Mineral inclusions in the megacrysts occur in one to four concentric zones, as well as scattered in smaller numbers throughout the megacrysts. The concentric zones typically contain specific types of inclusions at specific locations. The two most abundant inclusion types, plagioclase and biotite, commonly alternate in abundance with distance from the core of the megacryst. As a specific type of mineral inclusion crystallizes, nucleating on or near the surface of a growing megacryst, it would consume the ions that it requires and thus deplete the boundary layer of those ions. The growth of this species would also cause the accumulation of those ions that it does not need, and thus create an environment that may be more hospitable for the growth of a new and different species. The boundary layer model was developed by Wang and Merino (Journal of Petrology, 1992) to explain orbicular granites. FTIR water concentration mapping of K-feldspar megacrysts also shows concentric water rich and water poor zones in megacrysts, supporting the model of repeated generation of a boundary layer surrounding megacrysts, which becomes enriched in water as a growing K-feldspar rejects it. The development of fluxed boundary layers enhances the growth of K-feldspar megacrysts because the fluxed ions cause rapid growth of K-feldspar crystals. This model seems more likely than that of mafic influxes that simultaneously affect K-feldspar megacryst growth throughout the entire volume of a large pluton.

IDENTIFICATION AND ANALYSIS OF DEEP CRUSTAL DEFORMATIONS FROM THE UPPER DECK OF THE EAST ATHABASCA MYLONITE TRIANGLE: NORTHERN SASKATCHEWAN, CANADA.

M. W. Novick, University of Massachusetts
Advisors: M.L. Williams and G. Dumond

The East Athabascia Mylonite Triangle (EAMT), located in northern Saskatchewan, Canada, is one of the best exposed examples of exhumed lower crustal terranes on Earth. The EAMT resided in the deep crust for at least 700 million years, and was subjected to two deformational episodes during that time. The first of these events occurred at 2.6 Ga, and the second shortly before exhumation at approximately 1.9Ga.

The EAMT consists of three sections, the structurally higher upper deck, and the northwestern and southeastern blocks, collectively known as the lower deck. Despite their deep crustal origins, the subdivisions of the EAMT possess markedly different characteristics and geologic histories. The upper deck is composed of garnet rich felsic gneiss, which was subject to extensive melting during very high temperature and pressure metamorphoc conditions that are unique to the terranes in the EAMT. In contrast, the northwestern and southeastern blocks, dominated by the Mary granite and Chipman tonalite respectively, were subject to lower, but still granulite facies, metamorphic conditions of roughly 725 - 825° C and 0.9 – 1.2 GPa.

Superimposed deformational events in the EAMT are often difficult to distinguish and characterize due to intense transposition during the later event(s). They can, however, be distinguished in a 10m scale fold near Curry Lake, in the northern upper deck domain. Mineral compositions, pressure and temperature conditions, and monazite dating will be used to characterize the sequence of events, at least two of which are believed to be the 2.6 and 1.9 Ga regional events. Monazite dating is ongoing, but two main deformational fabrics have been identified in the garnet rich, plagioclase feldspar and quartz dominated rocks. The earleir (folded) fabric may represent an early shallow Grt-migmatite, deep crustal flow event. Reactions between the above minerals as well as biotite, ortho and clinopyroxene, and hornblende present will allow for P-T analysis of their coinciding deformational events. Identifying and understanding these deformations allows for a better understanding of deep crustal processes on a whole, which will ultimately illuminate the formation and evolution of present day continental crust.

ION MICROPROBE $^{207}PB/^{206}PB$ MONAZITE AGES FROM PRECAMBRIAN METAMORPHIC ROCKS OF SW MONTANA

Bradley J. Pearson, Amherst College
Advisor: John T. Cheney

Southwestern Montana contains a series of mountain ranges made up largely of metamorphosed Precambrian basement rock constituting the northern extent of the Wyoming Province. Previous work (Harms et al., 2004) focused upon the Tobacco Root Mountains (TRM) established two different ages of metamorphism—the first at ~2450 Ma and a younger event, the Big Sky Orogeny, at 1720-1780 Ma (Cheney et al., 2004). Work is being done to extend results from the TRM to surrounding mountain ranges in an effort to establish geographic extensions of the Big Sky Orogeny and continuity for Precambrian tectonic processes.

Seventeen rocks, predominantly quartzo-feldspathic gneisses and micaceous schists, from the Highland, Gravelly, Greenhorn, and Madison Ranges were collected for monazite dating. One hundred twenty-four $^{207}Pb/^{206}Pb$ spot ages have been obtained from these 17 samples using the IMS 1280 at the Northeast National Ion Microprobe Facility at WHOI. These Monazites are from a variety of textures including those in the matrix as well as those occurring as inclusions within biotite, kyanite, staurolite, and garnet. Fifty-nine of these spot ages are between 1710 and 1790 Ma, initially indicating that, although the event at ~2450 Ma found in samples from the TRM is absent or masked in the surrounding mountain ranges, evidence of the Big Sky Orogeny is extensive. In addition, of the remaining 65 ages, 53 are between 1800 and 2000 Ma, suggesting a slightly older event preceding the Big Sky Orogeny. For comparison, monazite from four samples will also be dated on an electron microprobe, which provides more precise spatial resolution.

This work proposes possible parallels between the processes of formation of the TRM and its neighboring mountain ranges and continues the contextualization of the metamorphic history of the Wyoming Province as it was added to the North American craton.

AN EVALUATION OF QUARTZ C-AXIS PATTERNS FROM A SHEATH FOLD IN METAMORPHOSED PRECAMBRIAN ROCKS, TOBACCO ROOT MOUNTAINS, MT, USA

Derek Prill, Amherst College

Advisor: Tekla A. Harms

A well-exposed outcrop-scale sheath fold occurs in Precambrian metamorphic rocks in the Tobacco Root Mountains of MT. Created during upper amphibolite facies metamorphism of the Big Sky orogeny at 1.775 Ga, it folds five distinct lithologies: a quartz-biotite-plagioclase-garnet-sillimanite schist with migmatitic segregations, a garnet-quartz-plagioclase-biotite-sillimanite gneiss with compositional bands, a five centimeter thick quartz-biotite-plagioclase-garnet gneiss, and two amphibolites of varying plagioclase content, one containing garnet. The sheath fold has a cross-sectional ellipticity of 0.22 and a hinge angle of 64 degrees. The fold is 4.93 meters across at its widest. The average mineral lineation within the sheath fold is similar to that found in outcrops within a 50-meter radius and bisects the hinge angle of the fold.

Eight oriented samples were obtained from the quartz-rich gneisses in the sheath fold so as to represent all possible positions within the fold: three from the limbs and five from the nose and apex. Evidence for grain boundary migration and bulging recrystallization in quartz during deformation, followed by recovery, is observed in thin section. Approximately 10% of quartz grains include a small number of large subgrains that have mutually indenting but polygonal boundaries. Quartz lattice preferred orientations determined for the eight samples by petrographic microscope with a universal stage and by electron backscatter diffraction with a scanning electron microscope are compared. Patterns obtained indicate that high temperature slip systems were active during sheath fold formation and constrain the pattern of solid-state flow around the sheath fold.

EARLY BIOMINERALIZERS: STRANGE ECHINODERM PLATES FROM THE LOWER CAMBRIAN OF THE SOUTHWESTERN UNITED STATES AND MEXICO

Emily F. Smith, Amherst College
Advisor: J.W. Hagadorn

Among the first animals to begin building biomineralized skeletons were echinoderms. Whereas the first echinoderm species were widely distributed and abundant, their initial success was short-lived in the Series 2 Early Cambrian. The taxonomic affinity of these echinoderms is unknown because no articulated specimens have been found. They occur as disarticulated 1 - 4 mm diameter ovoid to circular plates in shell concentrations that are 10 cm-3 m thick and extend laterally for tens to thousands of meters. Plates occur in inter-bedded limestone and well-sorted sandstone packstones and wackstones. These echinoderm shell concentrations are unusual because they are mostly monotaxic accumulations of echinoderm plates, only rarely containing additional archeocyathid, *Salterella*, trilobite and debris.

The phenomena of the formation of echinoderm shell concentrations in the Early Cambrian is unusual for a few reasons: 1) they are discrete, thick, laterally continuous units, 2) they are almost always monotaxic despite the fact that other organisms lived concurrently with them and 3) their only occurrence in the fossil record is in a narrow window of time during the Early Cambrian. In order to better understand this phenomenon, the depositional environment and the ocean chemistry were examined before, during, and after the proliferation of the earliest echinoderms.

Echinoderm beds occur throughout the upper member Wood Canyon Formation in California and Nevada and the Buelna Formation in Sonora. Very dispersed individual plates occur throughout Units 2 - 4 of the Puerto Blanco Formation. Four stratigraphic sections of these formations were logged, and samples of both echinoderm beds and carbonates were collected for slab, petrographic, and geochemical analysis. These stratigraphic sections record the sequence of depositional environments and sedimentology in which the echinoderm beds occur. Three levels of analysis were conducted on echinoderm shell beds, including outcrop, polished-slab, and thin-section examination. The lithologies, grain sizes, grain types, packing, and fabric were noted at each scale. This three-tiered analysis allowed visualization of levels of alteration and identification of skeletal and non-skeletal grains in the samples.

Analyses of the shell concentrations suggest that the echinoderm shell concentrations are only preserved in high energy, sandy limestones and dolomites. Although the echinoderm shell concentrations are constrained to a specific lithofacies, dispersed echinoderm plates occurred in other depositional environments, as revealed in petrographic analyses.

The finest-grained, least-altered carbonates were petrographically screened and micro-drilled to assess the isotopic ($\delta^{18}O$, $\delta^{13}C$) and trace element (Mn, Sr, Ca, Mg, Fe) chemistry of seawater before, during, and after the proliferation of early echinoderms. The occurrences of the echinoderm shell concentrations did not coincide with changes in the tested isotopic and trace element values. Echinoderm plates were also micro-drilled to

assess their skeletal chemistry in relation to the surrounding matrix, but results were inconclusive due to lack of data and imprecision in drilling methods. Geochemical results suggest that occurrences of the echinoderm shell concentrations do not coincide with changes in ocean chemistry tested in this study. However, that does not necessarily mean that the onset of biomineralizing organisms was not triggered by chemical change. Lithostratigraphy, biostratigraphy, and chemostratigraphy correlations between the sections in the Mesquite Pass Hills, the Nopah Range, and the Cerro Rajón confirmed previously suggested correlations between the upper member Wood Canyon Formation and Units 2-4 of the Puerto Blanco. Because the echinoderm shell concentrations exist in the Buelna Formation and the upper member Wood Canyon, the echinoderm shell concentrations are not time correlative and likely thrived in a very specific environment.

TAPHONOMY AND CLASSIFICATION OF LATE CAMBRIAN MEDUSAE OF CENTRAL WISCONSIN AND NORTHEASTERN NEW YORK: PROBLEMS OF PRESERVATION

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In Wisconsin and New York tens of thousands of medusae occur in the Late Cambrian (Paibian) medium-grained orthoquartzites of the Elk Mound and Potsdam Groups. Medusae occur in intertidal and sand flat facies that contain abundant microbial sedimentary structures.

Over 90% of medusae-bearing bed surfaces contain individuals that are nearly evenly distributed across bed surfaces and are closely associated with sedimentary structures indicating extremely shallow marine to emergent conditions. One medusae-bearing surface exhibits direct evidence of subaerial exposure and the remaining medusa-bearing surfaces are intercalated between beds bearing polygonal mudcracks, raindrop imprints, and adhesion structures. The shallow to emergent conditions indicated by this facies suggest that many medusae may have been deposited as a result of stranding events. External concave bell pulsation rings are present in many individuals and suggest that both living and dead individuals were transported or swam into shallower settings and were stranded onshore. A small proportion (<10%; N = 2436) of the medusae occur in agglomeritic clusters on beds lacking surficially produced sedimentary structures and are preserved in full relief within the beds; this suggests possible entrainment and burial of medusae by sediment-laden fluids. Some medusa-bearing surfaces are characterized by burial veneers lacking sedimentary structures, suggesting the presence of a binding agent which may have prevented reworking of the underlying material. Pustular and stromatolitic textures are associated with at least seven out of 19 medusae horizons, suggesting that microbial biofilms or mats may have mediated preservation.

At least two distinct species of scyphomedusae can be recognized. One taxon, of probable semaeostomean affinity, is characterized by large diameter (commonly ~20-45 cm), high relief (commonly ~0.5-20 cm), tri- or quadriradial gastrovascular structures, trailing "tentacular" and "strand"-like oral arms interspersed with ovoid to spherical swellings and is commonly associated with an escape ring (≥35%; N = 2261). The second taxon, of probable rhizostomeaen affinity, is smaller (~ 7cm diameter), has very high relief relative to its size (~1.5 cm), a more circular bell shape, "packeted" or "bead"-like oral arms, and has less frequent evidence of escape (~5-10%; N = 175). Absence of any indication of a chitinous float suggests that medusae were not chondrophores; the presence of oral arms suggests a morphology closer to that of scyphozoans, rather than hydrozoans.

PROTOLITH CONSTRAINTS OF METAMORPHIC ROCKS FROM SYROS, GREECE

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Syros, a Cycladic island, has undergone at least two metamorphic events. The first was a subduction-related high-pressure, low-temperature blueschist to eclogite facies event that took place about 45 Ma, during the subduction of the Apulian microplate. The second was a medium-pressure, greenschist to amphibolite facies, regional metamorphic overprinting event about 20-25 Ma.

Syros contains N-NE dipping sequences of marbles and micaceous schists, with some quartzites, metabasites, metacomglomerates and calc-mica schists. There is ophiolite mélange, consisting of serpentinites, metatuffites and chloritic schists containing large blocks made of eclogites, metagabbros, glaucophanites, ultramafics and jadeite gneisses. Most rocks on Syros appear to have originated as either island arc volcanics interlayered with shallow carbonates or as ocean-floor igneous rocks, such as basalt or gabbro, including MORB and fault-bounded ophiolite sequences.

Earlier researchers have constrained protoliths using a variety of geochemical techniques. Mafic rocks of Syros have been determined to be some form of basalt or andesite. Coarse-grained rocks and eclogites have been interpreted as metamorphosed fractionally crystallized gabbros. Protoliths for associated felsic rocks have been interpreted as residual melts from the aforementioned gabbros, (Schumacher, 2004). Others have interpreted schists as having rhyolitic and dacitic as well as some andesitic and basaltic protoliths. Calc-alkaline (possibly subduction-related protoliths) have been identified for some schists of Syros. Schists depleted in Nb and Ti have been interpreted as having an arc protolith. Quartz-white mica schists and jadeite-bearing rocks have been interpreted as having arc-related protoliths. Glaucophane schists and eclogites have been shown to have arc to MORB affinities and thus to have possible back-arc basin protoliths, (Kepler, 2004). Still other investigators have obtained basalt-trachy basalt and MORB protoliths for the "Airport Ophiolite" sequence, (Walton, 2001). Yet others have interpreted the schists from Katergaki, in the southeast of Syros, and those from South Point, in southernmost Syros, as having MORB and terrigenous sedimentary protoliths that have been metamorphosed and altered by seawater, (Prinkey, 2001).

For this study, I am synthesizing whole rock analyses and analyses of REES that have been collected for many past theses, as well as adding some new data of my own, in order to better determine possible protoliths of many types of metamorphic rocks across Syros. These analyses indicate that most of these rocks (blueschists, greenschists, eclogites, Mg metagabbros, Fe-Ti metagabbros and undifferentiated metagabbros) are metabasalts.

The eclogites seem to be metamorphosed NMORBs. The greenschists are probably meta-arc basalts. The undifferentiated metagabbros seem to have an arc protolith. The Mg metagabbros are also likely meta-arc rocks. However, it is also possible that they are metamorphosed MORB rocks. The Fe-Ti metagabbros are probably either metamorphosed plume- or arc-related rocks, or possibly a combination of both. The protoliths of the blueschists could be NMORB, arc basalts, or a combination of the two. The quartz-white mica schists appear to be metamorphosed volcanoclastic rocks. It is unclear exactly what the protolith is for the jaditeites, although it is probably some type of metamorphic rock.

CHARACTERIZATION OF MICROBIAL COMMUNITIES IN THE BIOLUMINESCENT BAYS OF VIEQUES, PUERTO RICO

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Bioluminescent bays are spectacular wonders of nature and some of the brightest bays are found along the southern coast of the Puerto Rican island Vieques. The glow in these bays originates from an abundance of the planktonic dinoflagellate *Pyrodinium bahamense var. bahamense*, which releases light when it is agitated. This study is part of a larger research effort to understand the present and past environmental conditions that support these thriving bioluminescent ecosystems. Bay water residence times and current velocities will be used to quantify the modern relationship between dinoflagellate populations and the hydrodyamic regime. Since many of the important nutrient cycles are largely controlled by microbial degradation of organic matter in both bay water and shallow sediments, it is likely that sediment microbial ecology also has an impact on *Pyrodinium* populations in these bays. Examining the distribution of microbial populations in the sediment column may indicate which metabolic pathways are most influential in organic matter degradation.

In a typical marine sediment geochemical profile, $[SO4]^{2-}$ decreases and DIC (dissolved inorganic carbon) increases with depth. This profile is explained by sulfate reduction ($2CH_2O + SO_4^{2-} \rightarrow H_2S + HCO^{3-}$). Deep sites within the bays (>3 meters) follow this pattern, while shallow sites suggest more permeability, likely due to bioturbation, as the pore water sulfate and DIC concentrations do not change significantly throughout the core. It is assumed that the sediments are dominated by sulfate-reducing bacteria (SRB). This study focuses on the microbial activity (using oligonuceotide probes for eukarya, archaea and bacteria) that occurs at sediment faces changes indicated by TOC (total organic carbon) and TIC (total inorganic carbon) in the sediment column at approximate 1, 5 and 15cm depth. T-RFLP (terminal-restriction fragment length polymorphism) analyses and FISH (fluorescent in-situ hybridization) imaging were used to characterize the microbial populations and to gain an understanding of how those populations change with respect to sediment and pore water chemistry.

"DIGGING" FOR TRILOBITES AT THE SMITHSONIAN MUSEUM OF NATURAL HISTORY: THE RESOLUTION!

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Steptoean age (Late Cambrian or about 500 million years old) fossils are very rare in the northern U.S. Appalachians. The only two known occurrences of Steptoean fossils are trilobites from northwestern Vermont and southeastern New York. These fossils are stored at the Smithsonian Museum of Natural History in Washington, D.C. Globally, Steptoean carbonate rocks display unusually high carbon isotope signatures, which can be used to age date non- or poorly fossiliferous deposits. Field studies of the strata that yielded trilobites of presumable Steptoean age revealed no record of elevated carbon isotope values in Vermont, and inconclusive evidence in New York. To test the age of these trilobites, this study examines carbon isotope values of carbonate rock matrix surrounding the fossils. The results provide invaluable new information about Cambrian deposits from the northern Appalachians.

GRANITOID PETROGENESIS IN NEW HAMPSHIRE : SOURCE CHARACTERISTICS OF THE MESOZOIC WHITE MOUNTAIN MAGMA SERIES AND THE PALEOZOIC NEW HAMPSHIRE PLUTONIC SUITE

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The Devonian New Hampshire Plutonic Suite and Jurassic White Mountain Magma Series occupy much of central New Hampshire. This study addresses the question of the source rocks of the two series. Previous work (e.g., Eby et al., GSA Special Paper 268, 1992) showed that the White Mountain batholith was produced by a combination of crustal anatexis and assimilation, augmented by fractional crystallization. The origin of the New Hampshire Plutonic Suite has been more controversial, with some models (e.g., Chamberlain and Sonder, Science, 1990) suggesting an origin entirely from anatexis of Central Maine terrane metasedimentary rocks, and others (e.g., Dorais, American Journal of Science, 2003) suggesting that mantle heat and/or mass input was necessary to generate the series.

In the present study, samples have been collected from representative sites within both series, as well as from mafic rocks in and around granitic and syenitic plutons in both complexes. Major and trace element data collected in this study were compared to data collected by earlier workers. Trace element concentrations are consistent with the interpretation that rocks of the White Mountain Magma Series were products of crustal anatexis and assimilation, and later fractional crystallization. Anatexis occurred when basaltic magma intruded the crust at a shallow depth. Further research, utilizing samples from more sites within each pluton, will help constrain models of the petrogenesis of the New Hampshire Plutonic Suite.

GEOCHEMISTRY OF THE NORTHAMPTON LANDFILL: ARE THE SOILS AND WATER CONTAMINATED?

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During July of 2007, the presence of arsenic was reported in concentrations exceeding the Environmental Protection Agency's (EPA) recommended maximum contaminant level (MCL) of 0.01 mg/L in a private well located at 981 Park Hill Road, down gradient of the Northampton landfill. The landfill is located in an area of unconsolidated sands and gravel that were deposited by melt water streams from glaciers during the retreat of the last continental glaciers during the late Pleistocene. These deposits are about 30 m thick and are underlain by the Mesozoic New Haven Arkose, but the sediments themselves were derived from Paleozoic metamorphic and igneous rocks that lie to the northwest. Thick layers of iron precipitate were observed in a tributary to Hannum Brook immediately south of the landfill. Chemical data from geochemical reports of Gradient Corporation, Fuss O'Neill, and Stantec are analyzed to determine the source of arsenic detected in the contaminated private well. This study supports the hypothesis that arsenic is mobilized from the aquifer itself and is not directly released from the landfill. Elevated chloride concentrations down gradient of the landfill suggest the presence of a leachate plume, which may be responsible for the arsenic observed in the contaminated well. Elevated iron and manganese concentrations in the groundwater reflect reducing conditions, which may result from the decomposition of dissolved organic carbon in the plume. Since arsenic commonly forms complexes with iron and manganese oxides, hydroxides, and sulfides, the mobilization of these minerals results in the release of arsenic species. Equilibration of anoxic groundwater with atmospheric oxygen is responsible for the precipitation of extensive iron and manganese floc in seeps observed south of the landfill, in a tributary to Hannum Brook. Studies currently in progress include analysis of arsenic in floc deposits and water sampling during an extended pump test of the well located at 981 Park Hill Road.