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Committee members: Christina Cianfrani, Hampshire College
Tekla Harms, Amherst College

The Pioneer metamorphic core complex (PMCC) in south-central Idaho experienced a normal sense of shear along its low-angle detachment fault. Identification of microstructures and measurements of quartz crystallographic orientations in the mylonitic footwall of the fault define grain-scale conditions of deformation associated with extension-related detachment faulting and exhumation of lower ductile crust.

Samples were collected along a transect that is perpendicular to the detachment fault and parallel to vergence direction in order to observe strain gradients. Mineral lineations cluster around (20, 295) and foliations measure (220, 030) throughout the study area, indicating a northwest vergence that is consistent with trends in other northern Cordilleran core complexes. Deformation fabrics seen in outcrop and thin section include S-C fabrics, boudinage, isoclinal folds, ductile shear zones, asymmetric porphyroclasts, and lattice-preferred orientation associated with dislocation migration and recrystallization.

Quartz crystallographic orientations were measured with electron backscatter diffraction (EBSD) and combined with microstructural data in order to determine the sense of shear along the detachment fault. C-axis fabrics of the samples are indicative of non-coaxial strain that occurred at amphibolite facies metamorphism. Lattice preferred orientation is strongest nearest to the detachment and scattered farthest from the detachment. Prism and basal <a> slip were the dominant active slip systems in all samples, and prism [c] slip can be inferred from a high-temperature sample. The overall sense of shear determined with EBSD was opposite to that of microstructural observation. Domain choice, orientation of stereoplots, modal value and high-temperature deformation may all be factors in the generation of opposing patterns.

This study ultimately aims to examine the relationship between grain-scale deformation and tectonic movement. Microstructural and crystallographic fabrics allude to the crustal rheology of metamorphic core complex formation during ductile extension, while defining vergence direction along the fault.

VARIATIONS IN MAGMA COMPOSITION AT HEKLA VOLCANO, ICELAND, 1104-2000 A.D.

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Hekla volcano, in southern Iceland, is among the world's most active volcanoes, having erupted 14 times since 1104. The purpose of this paper is to explain the evolution of magma erupted from Hekla through interpretation of data collected from chemical analyses of flows dating from the first eruption in the historic record, in 1104, to the most recent, in 2000. The analyses include electron microprobe analyses of plagioclase feldspar phenocrysts and x-ray fluorescence analyses of whole rock samples for major and trace element concentrations. All analyses were done in the Department of Geosciences at the University of Massachusetts.

The samples were collected from Hekla during the summer 2006 field season and include flows from the 1104, 1300, 1389-90, 1554, 1766-68, 1878, 1913, 1947-48, 1970, 1980, 1991 and 2000 eruptions. The samples are all massive basaltic andesites with varying degrees of vesiculation. Phenocrysts are typically not visible in hand specimen. Major element analyses indicate that lavas have evolved to more felsic compositions (53.7 wt.% SiO_2 in the 1766-68 flow compared to 54.6 wt.% SiO_2 in the 1991 flow). The data show that the 1766-68 and 1878 flows are very similar in composition, but the 1947 flow is both more silicic and more alkalic than previous flows. The 1970 flow presents a drop in both SiO_2 and $Na_2O + K_2O$ concentrations, possibly indicating a new surge of basic magma into the chamber, or tapping of deeper less evolved magma in a zoned magma chamber. The 1991 flow has the highest SiO_2 concentration but records a major drop in $Na_2O + K_2O$ concentration, possibly indicating the fractionation of an alkalic phase. Plotting of trace element concentrations from more to less incompatible show that all of the flows are enriched in incompatible trace elements, and are about 10 times enriched relative to EMORB and NMORB ,suggesting that the Hekla magma source tapped an incompatible element-enriched source, possibly the deep mantle plume source, unavailable to MORBs. Most plagioclase phenocrysts are intermediate in composition Plagioclase phenocrysts in the 1766-68 flow have rims of lower anorthite percentage that the cores of the crystals indicating normal zoning in the crystals. Plagioclase crystals from the 1878 flow have lower anorthite concentration than those of the previous flows, possibly indicating the decrease in temperature of resident Hekla magma over time. The 1947-48 crystals show normal zoning with rims15-20 wt.% lower in An concentration than cores, indicating that the phenocrysts grew throughout an event that caused a major geochemical change in the magma Plagioclase phenocrysts from the following two eruptions (1970 and 1991) are again more anorthite-rich, with little zoning in the crystals.

The data indicate that over 900 years, the magma erupted from Hekla volcano has evolved significantly, on the basis of slightly elevated SiO2 concentrations, more alkaline magmas, and overgrowth of more albitic rims on anorthitic cores of recently-erupted plagioclase crystals.

GEOCHEMICAL AND MINERALOGICAL ANALYSIS OF MAGMA INTERACTION WITHIN THE VINALHAVEN MAFIC AND SILICIC LAYERED INTRUSION, VINALHAVEN ISLAND, MAINE

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The Vinalhaven Intrusive Complex, comprising the bulk of the bedrock of Vinalhaven, Maine and surrounding islands and tidal ledges, is a pluton formed by successive magma injections. Due to excellent coastal bedrock exposures, the Vinalhaven Intrusive Complex is an excellent place to study silicic magmatic processes. The complex is divided into a unit of coarse-grained granite in the center of Vinalhaven, and a smaller gabbro-diorite unit in the southeast; a small fine-grained granite intrudes both these units in the east. Layering in the gabbro-diorite unit dips approximately 20° to the NNW suggesting that the gabbro-diorite is at the base of the complex.

The rocks of the gabbro-diorite unit, on which this project focused, are rhythmically layered, showing wide variation in composition over relatively short distances (10s to 100s of meters). The ~1.5 km of coast examined in this study corresponded to ~200 m of plutonic stratigraphy and contained one complete macrorhythmic unit, as well as portions of both the underlying and overlying sheets. A similar gradational change is seen the stratigraphically lower two sheets. Olivine-bearing, clinopyroxene and plagioclase-rich gabbros (as mafic as 48 wt% SiO_2 and 7 wt% MgO) grade upward into diorites with rapakivi feldspar, clinopyroxene, and amphibole-rimmed quartz grains (formed by a reaction between the quartz and a mafic liquid) which, in turn, give way to granites (>73% wt% SiO_2) characterized by quartz, biotite, plagioclase and alkali feldspars. The stratigraphically highest sheet is dominated by plagioclase lathes and clinopyroxene, with little mineralogical change through ~50 m of stratigraphy.

These sheets formed when mafic magma ponded at a boundary between crystal-rich and crystal poor granite within the pluton and mixed with surrounding felsic magma. Fractional crystallization of the injected magma also played a role. Differences between the sheets indicate possibly different methods of sheet formation that may be attributable to the volume of the injected mafic magma or to the nature of the pluton at the time and location of injection.

SHORT-TERM SEDIMENT DEPOSITION IN TWO FRINGING SALT MARSHES OF BEAUFORT, NORTH CAROLINA

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As sea level rises it is important to understand how fringing marshes respond to the changes. While long-term deposition and erosion are being studied currently, little is known about short-term deposition. A 5-week study took place in two different marsh sites; site one is a marsh is behind a discontinuous anthropogenic granite boulder sill (sill site), whereas site two is a marsh is behind a natural oyster reef (natural site). Sediment accretion was measured for two tide cycles once a week. Along with measuring short-term accretion in the marshes, total accretion for the five-week duration was also measured in hopes of distinguishing between actual accretion and sediment resuspention. Factors such as, grain size, organic mater percentage, marsh elevation, bioturbation (fiddler crabs) and vegetation are also being considered.

Two permanent Sediment Erosion Tables (SETs), are in place at both the natural and sill study sites, at the 0 meter marks and in the upper marsh (about 10-12m inland). The SETs were measured in week-one and week-five to determine total accretion or erosion.

Short-term sediment accretion was measured once a week with sediment traps. Traps were made by drilling three holes into the bottom of a Petri dish, 9cm glass filter paper was placed on top of the dish; the filter paper was labeled and holes were punched into the paper in accordance to the Petri-dish holes, and the filter paper pre-weighed. Traps were placed in each marsh during a low tide cycle. Three replicate transects at five different sampling stations located at meter 0 (the beginning of vegetation), meters 2, 6, 10 and 12 in the natural marsh and meters 0, 2, 5, 8 and 10 in the sill marsh. Traps were collected the next day after two tide cycles. The traps were rinsed with DI water to prevent salt crystals from collecting and dried at 60°c for 24 hours. Traps were then weighed and total accretion found. The traps were then ashed at 500°c for 4 hours and weighed again for organic mater content.

Grain size and organic mater analysis was done at for three replicates at each sampling station in both marshes. Marsh vegetation analysis was completed for both sill and natural sites, looking at plant species, and heights of *Spartina alterniflora*.

A quick statistical analysis shows significant differences between the sill site and natural site sediment accumulation as well as significant differences in accretion between each of the sampling stations. There appears to correlations between grain size, organic mater content, vegetation and accretion, but this research is not yet completed and will be continued into the school year at Smith College.

This study was supported by the Anges Shedd Andreae 1932 Research Internship Fund.

PETROLOGICAL AND GEOCHEMICAL ANALYSES OF METASUPRACRUSTAL ROCKS IN THE CENTRAL GRAVELLY RANGE, SOUTHWEST MONTANA

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Multiple aluminosilicate polymorphs are present in metasupracrustal schists in the central Gravelly Range of southwest Montana, and the polymorphs' textures indicate a replacement order that provides evidence for a clockwise metamorphic pressure-temperature path. Andalusite was the first pseudomorph to form during contact metamorphism. The andalusite was completely replaced by kyanite during later metamorphism, and the kyanite was subsequently incompletely replaced by sillimanite. The schists are unusually Al-rich and Mg-poor, so the high-grade metamorphism did not reach high enough temperatures to form garnet in these rocks. The schists contain kyanite and amphibole growing in multiple directions, both with and against the foliation. This indicates that the high-grade metamorphism was a multi-phase process with periods of deformation and periods of mineral growth.

The phyllites and quartzites at the structurally higher northern end of the central Gravelly Range have been metamorphosed less extensively and the quartzites still contain cross-bedding. There is no indication of extensive faulting in the area, so it is proposed that the protoliths of the lower-grade rocks to the north were deposited unconformably on the southern rocks after the schists had already undergone amphibolite-facies metamorphism. The entire suite was then metamorphosed at a much lower grade, creating a consistent foliation throughout the central Gravelly Range.

The Big Sky orogeny (BSO) is a 1.78 to 1.71 Ga upper amphibolite facies metamorphic event that affected the Tobacco Root Mountains to the north of the current study area. The high-grade schists and associated rocks in the current study area reached their peak metamorphism before the BSO and constrain the greatest southern extent of high-grade metamorphism in the BSO. The low-grade metamorphism that formed the consistent fabric in the study area, however, could be an effect of the BSO. This low-grade metamorphism may mark the southern continuation of the BSO's influence.

DEFORMATION AND METAMORPHISM IN THE LOWER CONTINENTAL CRUST: NEW DATA FROM THE WILEY LAKE AREA, LAKE ATHABASCA GRANULITE TERRANE, CANADA.

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The East Lake Athabasca area in the Churchill Province of the western Canada is a large, high P-T granulite terrane. The terrane preserves the characteristics and a record of deformation processes in the lower continental crust. The region is dominated by plutonic rocks and metamorphosed plutonic rocks that were emplaced into the deep crust. The Mary Granite (Hamner et al 1994) is a large composite granitoid/gneiss, which was emplaced at ca. 2.62 Ga. Igneous assemblages consist of opx +/- hbl, pla, ksp, qtz; metamorphic assemblages contain grt, qtz, pla, opx, cpx [ilm]. Because later igneous intrusions crosscut deformed and metamorphosed bodies, regional emplacement is interpreted to be syn-tectonic. Evidence for two major deformational fabrics is preserved regionally and at Wiley Lake, corresponding with two major tectonic events. The first fabric has an easterly strike and typically a shallow dip. In-situ monazite analysis suggests that the first event was Archean (2.6 Ga) in age. It is interpreted to represent high-T, ductile flow of the deep crust. The second fabric has a north-east strike, a steep dip, and is Proterozoic in age (1.9 Ga). It seems to reflect a cooler and stronger deep crust in Proterozoic time. At Wiley Lake exposures of the Mary Granite occur in a transition zone between several tectonic blocks and structural domains. The location of the Wiley Lake area allows correlation of fabrics, metamorphism and tectonic events with other exposures in the East Lake Athabasca area. Microprobe analysis was used to acquire compositional maps and data from grt, cpx, opx and pla. The data were used to calculate peak pressures of ~10 kilobars and temperatures of ~850 C, using Grt-Pyx thermometry and Grt-Pyx-Pl-Qtz Barometry (Williams et al 2000). In contrast to much of the region, the early fabric at Wiley Lake is more steeply dipping, perhaps due to more intense second-stage deformation. However, the shear sense on the early fabric is top to the west, similar to that throughout the region. Granulites of the Wiley Lake area and East Athabasca in general, may be analogous to rocks in the deep crust under the Andes or Himalayas today. The Granulites at Wiley Lake may provide information about deformation and metamorphic processes and especially the rheology of the deep crust over time.

GARNET OF THE SOUTH MOUNTAIN BATHOLITH, NOVA SCOTIA

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The Devonian South Mountain Batholith (SMB) in southwestern Nova Scotia is the largest granitoid batholith of the Appalachian orogeny (MacDonald, 2001). The peraluminous granites of the SMB were emplaced above Avolonian rocks within the upper crust of Meguma Terrane in the Late Devonian (Benn, 1999). The SMB is believed to be a partial melt of the aluminous sedimentary rocks in the underlying Avolonian Basement (MacDonald, 2001). Garnet is a common mineral in the granodiorites, monzogranites and leucomonzogranites of the SMB (Allan and Clarke, 1981). Through the characterization of SMB garnets, this study considers how the granite melt interacted with country rocks.

Fieldwork in the southern mainland of Nova Scotia was conducted during the summer of 2006. Lab work consisted of petrographic analysis of thin sections and analysis of garnet compositions in epoxy mounts by scanning-electron microscopy with energy dispersive x-ray spectrometry (SEM/EDS). Experiments were performed in the piston-cylinder apparatus in the experimental petrology lab at Smith College to investigate the reactivity of xenocrystic garnets in the Peggy's Cove monzogranite.

Most of garnets observed occurred with biotite. Garnet and biotite "clots" are abundant in the Peggy's Cove Monzogranite and the Boot Lake Granodiorite. Small anhedhral garnets (< 2mm) are commonly found in clots ~2 cm diameter. The anhedral shape of the garnets suggests that they have interacted with the magma and possibly dissolved. SEM/EDS analyses show that SMB garnets are almandine- rich. Garnets from the Boot Lake and Halifax Plutons all have spessartine-enriched rims. The Mn rims around the garnets are evidence of a chemical interaction between xenocrystic garnets and a granite melt. The Mn may have diffused into the xenocrystic garnet from the peraluminous granite melt, as the garnet equilibrated with the magma. Another possibility is that the source of the Mn was not the granite melt, but the garnet itself; the Mn may have preferentially stayed behind and diffused into the remaining garnet as the crystal partially melted. A third hypothesis is that the garnets are Avalonian metamorphic garnets with Mn rims produced during the partial melting that produced the SMB.

Experiments were performed to investigate the origin of the Mn rims observed for garnets in the Peggy's Cove monzogranite. Results from two runs at 5 kb and 700°C and 800°C provide further evidence for a xenocrystic origin for the garnets. At 700°C, the garnet was clearly reacting with the melt to produce biotite. The source for the xenocrysts is still unknown.

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GLACIAL ABLATION DYNAMICS AND SEDIMENT FLUX AT LINNEBREEN, SPITSBERGEN

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Modern process studies, conducted on Arctic glaciers, provide valuable insight into the dynamic responses observed in the high latitudes due to global scale climate change, with telltale implications for environmental change in the lower latitude. This research was conducted on Spitsbergen, the largest island of Svalbard, as part of an NSF funded Research Experience for Undergraduates program. Svalbard, residing in the Norwegian High Arctic, is influenced by the northern extent of the Gulf Stream and its advection of warm air and moisture to the polar north. This creates highly variable climate conditions that influence all 2100 ice masses of the archipelago. A compilation of mass balance measurements, local meteorological data, stream gauge, and suspended sediment concentrations were taken at Linnèbreen, a high arctic cirque glacier, for four weeks during the summer 2006 melt season. High resolution data was collected in 30-minute increments and manual readings were taken at eight centerline stakes for analysis. Comparisons were made directly to concurrent meteorological fluctuations permitting an evaluation of the correlations between the local and regional weather data and the dynamic behavior of this glacier. Summer precipitation was found to be the main agent of surface lowering on Linnèbreen. Days of high precipitation correlate directly with days of greater surface lowering and peak suspended sediment concentrations. High rates of surface lowering are a result of latent heat release caused by meltwater and precipitation percolating down into and refreezing below the glaciers surface. This triggered the removal of overlying ice providing a glassy surface until such time that eolian debris and new sediment could accumulate and melt into the glacier surface differentially due to contrasts in albedo. Peaks in sediment discharge were observed to be the result of debris being liberated from ice-marginal channels during times of precipitation-induced high discharge. Sediment flux into Linnèelva is derived by fluvial means from prior glacially eroded sediment. Supply is dominated by active layer thawing, resultant of rising temperatures and precipitation induced high discharge. The rise and fall of discharge, allowing temporary storage in ice-marginal channels and braidplains, display a diurnal SSC trend. Linnèelva operates in a dominantly supply limited mode due to the lack of active glacial erosion, with signs of complete sediment exhaustion over the meltseason. Sedimentation rates are likely to rise as the active layer deepens due to rising temperatures, and proposed increases in the Arctic's precipitation budget allow for high discharge events. A net mass balance of -1.14m water equivalent was measured for Linnèbreen in 2006. 93.6% of Linnèbreen's mass now lies entirely below the modern ELA at 458m. The extensive loss of mass associated with ice margin retreat of ca. 1200 m from its maximum extent could signal a significant change in thermal regime to cold based ice. Further warming, changes in moisture advection, and a freshening of the Arctic Ocean will further degrade Svalbard's glaciers, resulting in accelerated deglaciation of this archipelago, a situation unprecedented during the Holocene.

USING GEOCHEMICAL PROXIES TO RECONSTRUCT ANCIENT DEEP SEA CIRCULATION THROUGH THE CARIBBEAN AND GULF OF MEXICO

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The opening and closing of tectonic gateways during the Neogene Period (past 23 million years) has controlled deep sea circulation through the Caribbean and Gulf of Mexico. These events include, but are not limited to, the closure of the Central American seaway, the partial foundering and subsidence of the shallow carbonate system along the Northern Nicaragua Rise, and the subsidence of the Aves Swell. Much of the water that flows through the Caribbean and Gulf of Mexico as part of the global conveyor exits through the narrow Straits of Florida. In this study, I analyzed samples from Ocean Drilling Program Site 626 in the Straits of Florida in order to test for possible changes in the source of the deep waters during the Neogene. Water mass source is monitored through the application of geochemical proxies. I analyzed benthic foraminifera for carbon isotopes ($\delta^{13}C$), which can vary as a function of water mass age and source. In addition, phosphatic material (fish bone, fish teeth, phosphatic pellets) were analyzed for Neodymium (Nd) isotopes, which is another proxy for the source of deep and intermediate waters.

Three possible water masses include Upper North Atlantic Deep Water, Antarctic Intermediate Water, and North Pacific Intermediate Water, with present day $\delta^{13}C$ values of ±1.0‰, ±0.5‰, and ±0.0‰, respectively. Single specimen benthic foraminifera and planktic foraminifera from the Straits of Florida site were analyzed to quantify the carbon isotope gradient between the benthic and planktic foraminifera and establish which specimens (and their values) represent the deepest parts of the Straits, and which specimens may have been reworked from shallower waters depths. The $\delta^{13}C$ data yield values too enriched, ranging from 1.0 to 1.6‰. This is either indicative of foraminifera living on the shelf or upper slope, or it could represent a mixture of deep water and upper water column signatures. Either way, this leaves the $\delta^{13}C$ data a questionable source for use in discriminating between water masses flowing through the Caribbean and Gulf of Mexico. It is hoped that data of Nd isotopes of phosphatic material (data analysis pending) will help in discriminating different water mass sources during the Neogene. These data will be interpreted in the context of tectonic events occurring at similar times that modified tectonic gateways into the Caribbean and Gulf of Mexico.

DAVIS MINE: ACID MINE DRAINAGE AND ITS EFFECTS ON TRACE METAL CONCENTRATIONS

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Acid Mine drainage is a phenomenon observed in the vicinity of surface mines where iron pyrite deposits are oxidized in the presence of water, leading to a decrease in the water's pH and the dissolution of high concentrations of metals (Al, Cu, Mn, and Zn). As a result, the environment in the area can be drastically altered with the downstream hydrological system becoming acidic, and a build up in the iron oxide precipitates observed. Davis Mine located in Rowe, Massachusetts opened in 1882 as a pyrite mine and closed in 1911 after the collapse of a mineshaft and has received little remediation. This makes it a prime site for the study of natural attenuation of acid mine drainage. Sediment samples were collected from stream draining the Davis Mine site in order to quantify the mechanisms for the uptake of dissolved heavy metals. By employing a sequential extraction technique the following fractions were separated:

1. Exchangeable fraction, which is loosely bound to particle surfaces.
2. Acetate Extractable fraction, which contains trace elements more tightly bound in some soluble mineral phases.
3. Fe-Mn Bound fraction, which contains trace elements as part of the Fe-hydroxide structure.
4. Organic fraction, which is tied to organic compounds.

Trace metal concentrations in the fractions were measured on the Inductively Coupled Plasma Spectrometer. The greatest concentrations of metals are in the exchangeable and Fe-Mn bound fractions, with lower concentrations in the organic fraction. Exchangeable ions are relatively easily remobilized accounting for the high concentrations.

PETROLOGIC CONSTRAINTS ON THE SOURCES OF GRANITES FROM THE HANGAY MOUNTAINS, CENTRAL MONGOLIA

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The Hangay Mountains of central Mongolia are the second largest mountain range in Mongolia, with mountains up to 4,000 meters in elevation. They are a domal uplift of Archean to Proterozoic granitic and gneissic basement overlain by Cambrian to Devonian metasediments. This block is intruded by a Permian batholith complex that is over 100,000 km² in area and by younger plutonic bodies. This study investigates a region in the southern portion of this batholith complex.

Mongolia is located in the Central Asian Orogenic Belt and its modern tectonic framework is influenced by both Himalayan crustal compression to the south and the Baikal rift to the north. The country has a complex geology formed during a series of subduction events, and is comprised of island arc, accretionary wedge, and other associated terranes. Twenty-six samples from two different granite units were analyzed to compare their geochemical and petrographic characteristics. These characteristics indicate that both granite units originated in a subduction zone environment, probably the subduction of the Siberian plate beneath the Hangay region from the Permian to the Jurassic. The composition of the younger granite reflects the decreasing influence of the oceanic slab in magma production over time.

The highest peaks of the Hangay Mountains preserve an uplifted pre-Oligocene erosion surface upon which Oligocene volcanic and sedimentary rocks are deposited. In the field, samples were collected along an elevation transect ranging from 3223 meters to 2473 meters. (U-Th)/He ages using four of the samples determined that the Hangay region experienced a significant episode of unroofing at approximately 110 Ma. This episode is linked to extension after the end of subduction of the Siberian plate.

DEVELOPMENTAL BASIS OF SIZE DECREASE IN *TURRITELLA* GASTROPODS DURING A REGIONAL MASS EXTINCTION IN THE PLIO-PLEISTOCENE OF FLORIDA

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Small body size is a common feature among survivors of mass extinctions, but it is unclear how and why this phenomenon occurs. Catastrophic declines in population size during the extinction event itself may select for an opportunistic (r-selected) life history strategy, in which individuals are short-lived and reproduce early. In contrast, small size could reflect the effects of a lower level environmental stress on metabolic rates. Testing these different models requires data on the developmental components on size (e.g., growth rate, age).

Here, we use stable isotope sclerochronology to reconstruct shell growth development in the gastropod genus *Turritella* during a regional mass extinction event in the Late Neogene of Florida. *Turritella* shells decreased from a maximum of around 800 mm in length (measured along the axis of spiral growth) in the middle of the Pliocene to around 500 mm in the Late Pliocene and no more than 150 mm in the Pleistocene to Recent. Our isotopic analyses bracket this step-wise decline by including representative shells from middle Pliocene, late Pliocene, and early Pleistocene shell beds of Florida.

Isotopic reconstructions of *Turritella* development suggests that size was due to a decrease in maximum age after the middle Pliocene followed by a dramatic decrease in growth rates at the Plio-Pleistocene boundary. The ‘dwarf’ nature of post-Pleistocene and modern *Turritella* therefore reflects two distinct phases of selection, with an early phase of catastrophic population decline followed by a low-level, by protracted environmental stress.

MAGNETIC PROPERTIES OF DEEP CRUSTAL ROCKS FROM THE SNOWBIRD TECTONIC ZONE, CANADIAN SHIELD

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Collecting magnetic data on deep crustal rocks is required for modeling and understanding the nature of long wave anomalies as well as aiding the interpretation of recently discovered large scale Martian magnetic anomalies and in preparing for upcoming international satellite missions. A study of the magnetic properties of deep crustal rocks from the Snowbird Tectonic zone in the Canadian Shield is in progress.

A detailed aeromagnetic map from the Geological Survey of Canada is available to study the relationship between aeromagnetic anomalies and the magnetic properties of 13 rock samples provided by Greg Dumond and Kevin Mahan of the Structure and Tectonics Research Group for the Canadian Shield led by Michael L. Williams at the University of Massachusetts Amherst. Samples include granulite facies gneiss and schist as well as mafic dikes and granites, each of which had 1-3 cores drilled and oriented in a sandbox to within 10°. Data for susceptibility, density, and natural remanent magnetization (NRM) were collected on the cores from which Koenigsberger ratios (Q) were calculated for each sample. Koenigsberger ratio (Q) is a measure of remanent magnetization to induced magnetization, providing information on the source of the observed anomalies. Susceptibilities ranged between 1.33×10^{-4} and 1.04 SI units, NRM ranged between 1.11×10^{-3} and 38.8 A/m, while Q values fell between 1.85×10^{-2} and 3.21 with 5 samples having Q values greater than one. A range of magnetic properties over several orders of magnitude is surprising for an area with large magnetic anomalies. Based on the Q values, some of the sampled units are dominated by induced anomalies (magnetic highs on the anomaly map) while others have a remanent component influencing the observed anomalies.

TECTONIC INVESTIGATION OF PRECAMBRIAN MAFIC METAMORPHIC ROCKS IN THE CENTRAL GRAVELLY RANGE, MONTANA

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Geothermobarometry estimates that two garnet amphibolites from a Precambrian metasupracrustal sequence on the east flank of the Gravelly Range in southwest Montana equilibrated at ~620° C and ~8-9 Kbar. Hornblende, garnet and plagioclase mineral assemblages occur in these rocks, in some cases with an epidote-group mineral, and spessartine decreases in zoned garnets from core to rim, suggesting prograde amphibolite facies metamorphism. Trace element geochemistry of metagabbros and some amphibolites is consistent with a volcanic arc related origin and may support a common magma source for their protoliths. Major and trace element concentrations of garnet chlorite phyllite in the north of the study area are richer in Fe and Si than typical metabasaltic rocks, and do not plot in the fields of some basalt discriminant diagrams. Zircons occur in this Fe-rich phyllite, suggesting a non-igneous protolith such as a tuff or epiclastic sediment.

The rocks outcrop in north-northwest-dipping homoclinal units. Mineral lineations in the study area cluster around a single orientation within the foliation plane, while fold axes and crenulations scatter in orientations parallel or subparallel with foliation. Fabrics in the Precambrian rocks of the Tobacco Root Mountains to the north that have been attributed to strain from the 1.78 to 1.71 Ga Big Sky orogeny are consistent with those of the study area, suggesting that rocks in the central Gravelly Range may have been deformed together during the Proterozoic.

Chlorite fabric appears to postdate hornblende growth in phyllites associated spatially with high-grade amphibolites, while garnet growth truncates the chlorite fabric in possibly low-grade garnet chlorite phyllite structurally higher and in the north of the area, suggesting a fundamental difference in metamorphic history. This may be due to a fundamental transition or boundary, such as a depositional unconformity, which can be constrained to the area between the garnet chlorite phyllite and the nearest amphibole-bearing rocks to the south. This transition may represent the depositional contact of Proterozoic Big Sky orogen foredeep sediments on Archean basement.

METAMORPHIC PETROLOGY AND STRUCTURE OF METAPELITES IN THE EASTERN AXIAL ZONE OF THE MONTAGNE NOIRE GNEISS DOME, MONTAGNE NOIRE, FRANCE

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The French Massif Central is the south-vergent orogenic wedge of the Southern European Variscides. The Montagne Noire Gneiss Dome comprises the Axial Zone of the Montagne Noire, which is the southernmost extent of the French Massif Central. Extensive studies of the deformational history of the Montagne Noire have been undertaken in recent years, however studies of the metamorphic history have not been as thorough. This study looks at the differences in the metamorphic histories of the various parts of the Montagne Noire Gneiss Dome.

The peak metamorphic grade in L'Espinouse, potentially as low as the biotite-chlorite zone, is lower than the peak grades in the Rosis Syncline and Le Caroux. The metamorphic grades of both the Rosis Syncline and Le Caroux increase from east to west, toward the core of the gneiss dome. Phyllitic rocks in L'Espinouse yielded peak temperatures of 500 ± 25 °C using the biotite-tourmaline thermometer and the abundance of chlorite and the lack of garnet, staurolite, and aluminosilicates suggest that peak metamorphism was in the chlorite-biotite zone. The metamorphic grade increases from east to west, toward the core of the dome, in the Rosis Syncline. Peak temperatures in the metasedimentary envelope reached at least 575 ± 50 °C while metatexites in the core with an assemblage biotite + fibrolite + cordierite(?) are up-grade from the muscovite-out isograd and indicate temperatures over 650 °C. The metamorphic grade also increases from east to west in Le Caroux. Unfortunately, the low-Al bulk composition of these rocks does not allow for mineral assemblages conducive to tightly constraining the succession of isograds across the subdome. However, the mineral assemblages combined with geothermobarometry show a transition from the kyanite zone to the sillimanite zone at the approach of the core. Monozites, enriched in Y from garnet breakdown, yield ages around 310 Ma. These same samples exhibit three distinctly orthogonal cleavages that represent at least two deformation pulses or events. Garnet breakdown in Le Caroux, possibly coincident with a shearing event (gravitational collapse?) in the metasedimentary envelope occurred around 310 Ma as recorded by monazite growth. This shearing event may have postdated a shortening event recorded in a cleavage orthogonal to the shearing cleavage.

ABSENCE OF LOWER PALEOZOIC STRATIGRAPHIC SECTION AS EVIDENCE FOR TERTIARY EXTENSION IN SOUTHWEST MONTANA

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On three hills in Alder Gulch, just south of Virginia City, MT, Madison limestone lies directly on top of Precambrian gneiss. Tertiary volcanic rock forms an abutment contact with the Madison limestone and overlies the Precambrian gneiss in the western part of the study area. Field relationships, three-point analyses and stereographic analyses of the limestone-gneiss contact indicates that this contact is shallowly anticlinal, and while it dips varying directions, the contact never dips more steeply than 30°, and in most places dips in the range of 10-15°.

Gneiss and limestone samples taken close to the contact contain cracks filled with fine-grained fragments, while samples taken farther away do not. Gneiss samples taken close to the contact also show evidence of hydrothermal alteration, with chlorite replacing biotite and clay minerals overprinting feldspar. This alteration is not common in samples far from the contact. Absence of normal lower Paleozoic stratigraphy (which appears complete only 3 km away), evidence of brittle deformation and evidence of hydrothermal alteration indicates that normal faulting is the most likely cause of the low-angle limestone-gneiss contact. Faulting most likely occurred between 65.5 Ma (the beginning of the Tertiary) and 51.1 Ma (the age of the Tertiary volcanic rock).

The upper and lower age limits for faulting along the gneiss-limestone contact correlate this activity to the earliest two Cenozoic extensional events that have affected southwestern Montana, and have been linked to metamorphic core complex formation. The appearance of a low-angle normal fault in an area to the south and east of these complexes could mean the expansion of the understanding of the effects of this extensional event into an area that has not previously been associated with substantial Eocene or Miocene extension.

THE PORE WATER CHEMISTRY, MICROBIAL PROCESSES, AND TRACE METAL MOBILITY OF BIOLUMINESCENT BAYS, VIEQUES, PUERTO RICO

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Three bioluminescent bays on the island of Vieques, Puerto Rico have spectacular nighttime displays produced by the dinoflagellate *Pyrodinium bahamense* var. *bahamense*. Concentrations of these dinoflagellates and thus the extent of bioluminescence vary greatly among the three bays. Puerto Mosquito exhibits particularly strong bioluminescence, while the other two bays, Bahía Tapón and Puerto Ferro, exhibit the phenomenon to lesser degrees. The population of dinoflagellates may be controlled by environmental parameters including nutrient and metal cycling, both of which are in turn controlled by microbial processes in the sediment column.

Analysis of organic matter decomposition pathways through pore water chemical analysis and flux and incubation experiments show no significant differences between the bays' total rate of carbon oxidation or dominant decomposition pathway in individual cores. Analysis of pore water uranium concentrations as a case study of heavy metal cycling shows increasing uranium concentrations with depth and with incubation. This indicates that uranium is more concentrated in deeper sediments and is actively being released into the pore water, possibly by decomposition of uranium-rich organic matter. $\delta^{13}C$ analysis of carbonate sediments, organic matter, and seawater DIC from the three bays all track the same trends of lower $\delta^{13}C$ values in Puerto Mosquito, indicating that isotope ratios in these bays is controlled by organic matter input rather than primary productivity. Puerto Mosquito's lower $\delta^{13}C$ values indicate greater terrestrial organic input from mangrove leaves and less water exchange between the bay and outside seawater, both factors that could contribute to the higher dinoflagellate concentrations in the bay.

USING MICROGRAVITY AND MICROMAGNETIC SURVEYS TO DETERMINE SUBSURFACE STRUCTURE OF EN ECHELON DIKE SEGEMENTS IN THE NORTHEAST DIKE OF SHIP ROCK, N.M.

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The northeast dike at Ship Rock, New Mexico is composed of en echelon segments whose offsets do not appear to be formed by post-emplacement deformation. Based on the surface expression of the dike, Delaney and Pollard (1981) modeled the subsurface structure of the northeast dike and concluded that the en echelon segments formed due to rotation of the maximum horizontal compressive stress direction as the dike propagated vertically. They proposed that a main dike was located at depth, connecting the en echelon segments.

The study presented here modeled the structure under the northeast dike based on gravity and magnetic field measurements over a pair of en echelon dike segments and used that modeling to constrain the emplacement mechanism. The gravity and magnetic field data were measured during the summer of 2006. The gravity data were drift-corrected and corrected for latitude and elevation (simple Bouguer and terrain corrections). Both the gravity and magnetic anomalies should follow the en echelon pattern of the dikes. Once the terrain correction is applied to the gravity data, however, the measured anomaly appears to be random. This suggests that the actual gravity anomaly is within the error of the Lacoste and Romberg Model-G gravimeter that was used for this study. For this reason, only the magnetic data were used to determine a best-fit model.

To constrain the subsurface structure, several models of the subsurface were developed and run using the University of British Columbia's Mag3D programs. This program produces the magnetic field data at the surface for a given model of the subsurface. Four initial models were developed that are based on Delaney and Pollard's 1981 model, and these models were used to determine the depth of connection between the dikes and the orientation of the dike segments with respect to the main dike. However, the four initial models produced anomalies that are both larger and wider than the anomalies in the measured field data. To produce a smaller and narrower anomaly, dike material must be removed from the model. In the best-fit model for the magnetic field data, the dike terminates at approximately six meters *below the surface*. This surprising result suggests that the northeast dike was originally emplaced *above* the present-day land surface and propagated both upwards and downwards. The remnants of the northeast dike appear to be the base, not the top, of the original dike, which has since been eroded away. The en echelon segments formed due to rotation of the maximum horizontal compressive stress direction at the bottom edge of the dike.

The results of this study have implications for the other dikes at Ship Rock. Ship Rock is surround by several smaller dikes with less surface expression than the northeast dike, but these dikes were likely more substantial and have since be eroded. Furthermore, the south and west dikes likely terminate in the shallow subsurface as well, but more data would need to be collected to determine the depth of the west and south dikes.

SPHENOTHALLUS-LIKE FOSSILS FROM THE UPPER MARTINSBURG FORMATION (UPPER ORDOVICIAN) IN NORTHEASTERN TENNESSEE

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The occurrence of rare *Sphenothallus*-like fossils is documented for the first time in the strata of the upper Martinsburg Formation (Shermanian Stage, Caradocian Epoch) at the Thorn Hill locality in northeastern Tennessee. These strata consist of skeletal limestones (with common brachiopods, bryozoans, and trilobites) interbedded with gray siltstone and shale and interpreted as tempestites or storm deposits of a shallow marine shelf environment. The *Sphenothallus*-like remains are black to dark gray carbonized tubes found in siltstone beds of the upper parts of the tempestite successions, oriented parallel to bedding and commonly subparallel to each other. The tubes are up to 60 mm long and 0.5-2 mm wide. They are unbranched, straight or slightly bent, occasionally twisted and wrinkled, and not significantly tapered. Many tubes exhibit straight fractures that are parallel to each other and perpendicular or at an angle to tube elongation. All observed tube terminations were formed by breaking along these and other irregular fractures during transport and deposition by storm waves and currents. The tube fracturing in part also reflects taphonomic modification during burial.

In cross section, the well-preserved tubes are elliptical (compressed) or circular (uncompressed) and filled with silty sediment, scattered organic material and calcite cement. SEM examination revealed bumpy and irregular to smooth tube surfaces and simple walls, 3-80 μm thick, with fine laminations parallel to the tube walls. These laminations and lack of other distinctive structure are similar to the characteristics of *Sphenothallus* (Hall, 1847), a relatively rare tube-dwelling marine worm of Cambrian to Permian age. The size and shape of the Martinsburg fossils resemble the remains of *Sphenothallus bicarinatus* (Girty, 1911). The Martinsburg fossils, however, show only limited evidence for longitudinal thickenings (producing two lateral ridges on opposite sides of the tube) and for lateral tube tapering or widening, which are common features of most *Sphenothallus* species. Future studies of these *Sphenothallus*-like fossils, including geochemical analyses of their carbonized remains, will attempt to further improve identification of these rather rare and mysterious fossils.

THREE-DIMENSIONAL GEOMETRY OF ACTIVE FAULTING ALONG THE SOUTHERN SAN ANDREAS FAULT, CALIFORNIA

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Investigating the three-dimensional geometry of acting faulting within the San Gorgonio region of the San Andreas fault in Southern California will help geologists predict how earthquakes might behave in this area. The San Gorgonio knot is made up of many faults with complex geometries and rates of slip. If the San Andreas through the San Gorgonio pass is complex (e.g. non-vertical, curving and discontinuous) earthquake ruptures may not be transferred through the knot thus future earthquakes in this area will have smaller magnitudes. On the other hand, if the geometry of the San Andreas is simple (e.g. vertical, relatively straight and continuous) then earthquakes may rupture through the knot resulting in slip on a greater area and thus the magnitudes of earthquakes would be greater. By comparing two numerical models one with simple vertical fault geometry and one with complex discontinuous fault geometry, I can assess the role of interpreted complexities along San Andreas fault on fault behavior. I compare the average slip rates, slip distribution and the uplift pattern from both models to each other and to the available geologic data. This comparison will show that the different geometries effect the movement around the San Gorgonio knot and will help to gain a greater understanding to how this area will be affected by earthquakes.