VIRGINIA TECH
DEPARTMENT OF GEOSCIENCES

25TH ANNUAL GEOSCIENCES STUDENT RESEARCH SYMPOSIUM

FEBRUARY 13-14, 2020
KELLY HALL ROOM 310

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GEOSCIENCES STUDENT RESEARCH SYMPOSIUM AT VT GEOS

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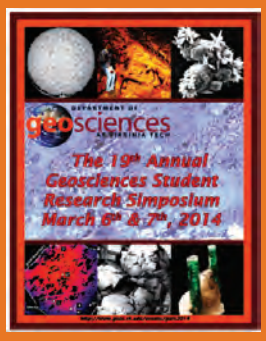
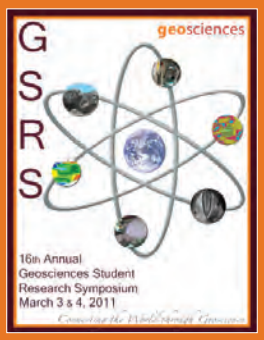
25th Annual GSRS

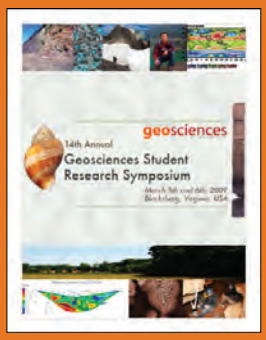
Welcome to the 2020 Geosciences Student Research Symposium. In 2020, we are celebrating the quadricentennial of GSRS, 25thGSRS. This event is entirely student-led and Fundraising and logistics are organized by a committee of graduate students. GSRS objectives are to help students gain experience in developing communication skills, event preparation, leadership, mentorship, and team-building. GSRS provides students a platform to communicate their research across the far-reaching disciplines of our department which promotes student growth as scientists in a collegial environment. Students also gain practice in communicating their research to a broad audience which offers a unique opportunity for students to prepare for future talks at national conferences. GSRS brings the geoscience family together through scientific talks, poster sessions, and discussions during Breakfasts, lunches, and department's favorite banquet!

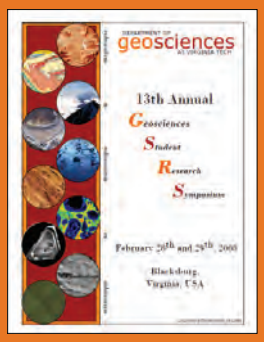
GSRS would not be possible without the help of our greater geoscience family and friends. Thank you very much to everyone who donated to GSRS through our Virginia Tech Crowdfunding Campaign last fall. This symposium would not be possible without your generosity. Thank you to Carol Lee Donuts, Blacksburg Bagels, Due South, Moe's, and Custom Catering for working with us through the catering process. Thank you to the VT Police Department and Rhino security for providing security at our banquet. Thank you very much to everyone in the Department of Geosciences (students, faculty, and staff) for helping to make GSRS possible. A special thank you goes out to members of Sigma Gamma Epsilon for volunteering for GSRS. Additionally, thank you to ICTAS at Virginia Tech for allowing us to use Kelly Hall for our symposium. We would also like to thank Dr. Holbrook and Dr. Spotila for their continuous support. Last but not least, thank you to our amazing alumni who are joining us to share their memories of how GSRS started back in 1996!

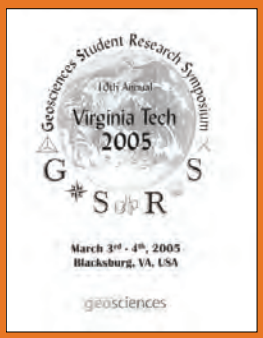
25 years of student research

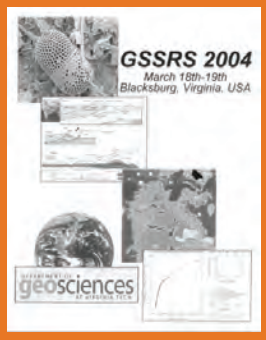


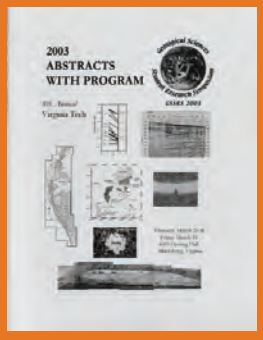


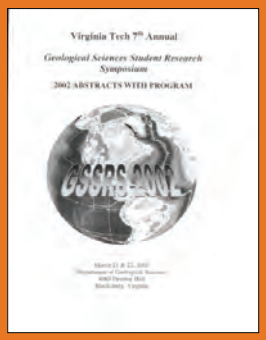


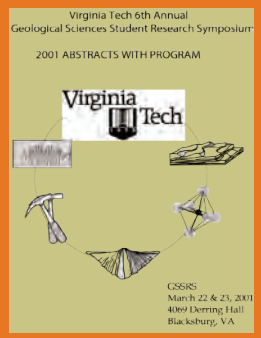


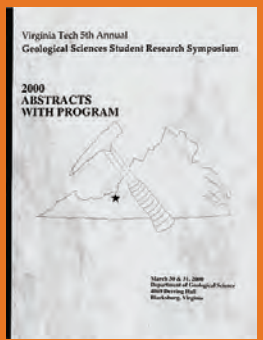


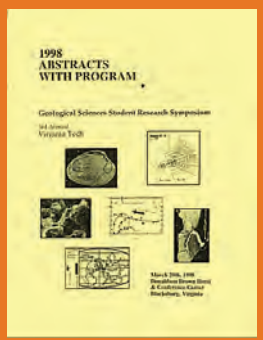


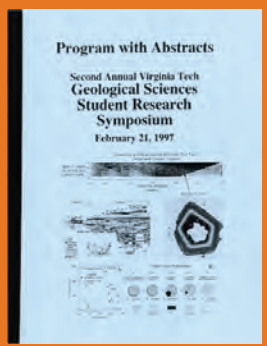


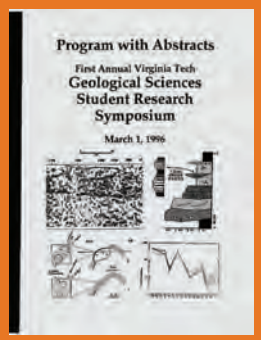










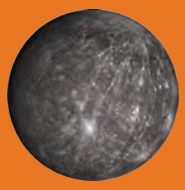


and more to come!

25 years of GSRS in FACTS

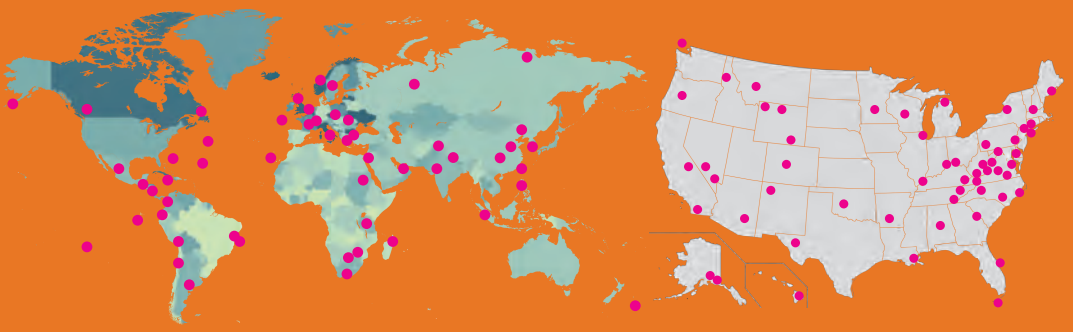
GSRS 2020
Geosciences Student Research Symposium

Where we have studied:

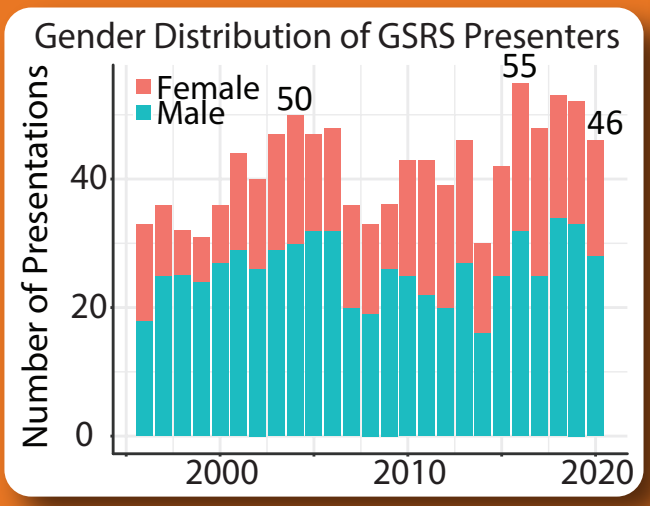

Mercury

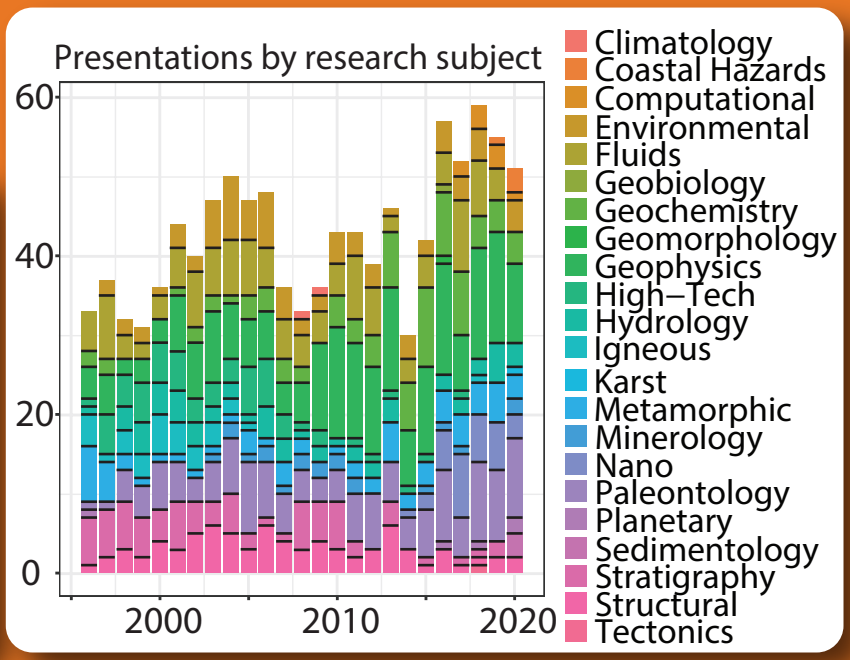

Mars

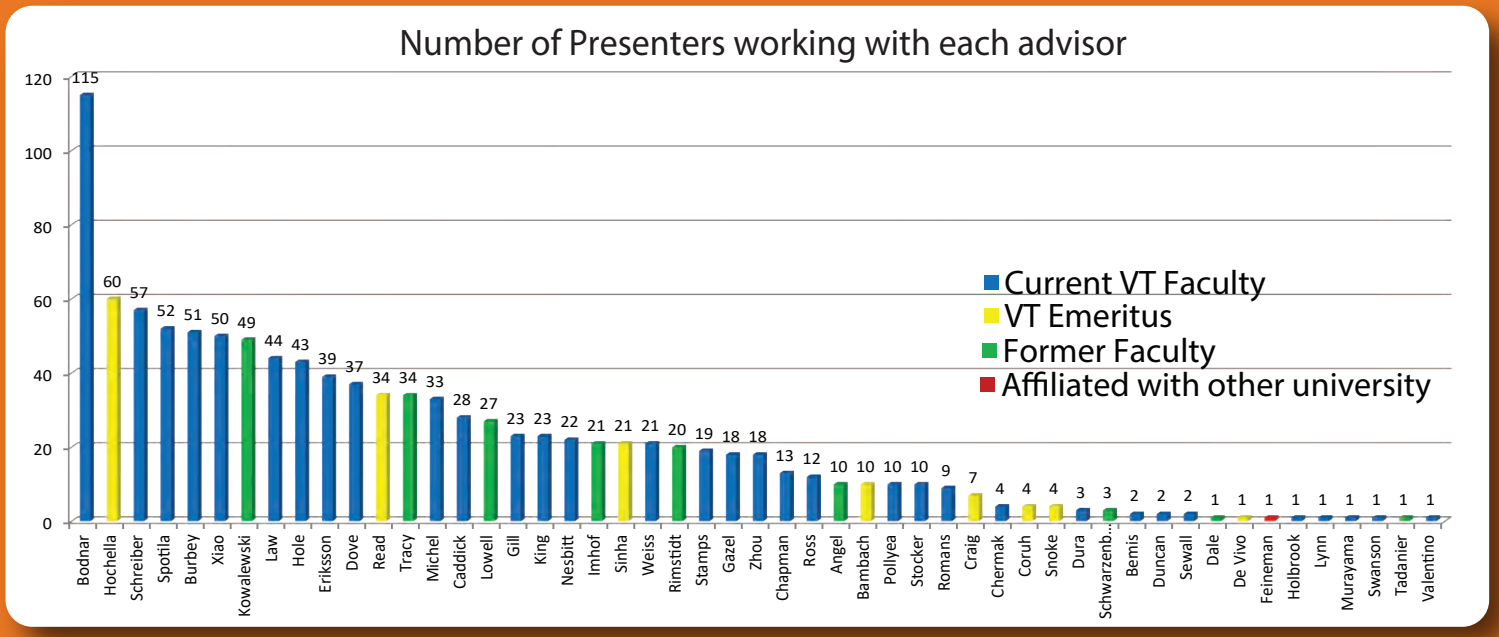

Earth



1046 Talks and Posters







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… and to all of our anonymous donors, thank you!

2020 GSRS Schedule

Thursday, Feburary 13th	
8:45-9:15	Breakfast
9:15-9:30	Opening Remarks
	Session 1
9:30-9:45	Nicholas Hammond
9:45-10:00	Emmanuel Njinju
10:00-10:15	Laura Szczyrba
10:15-10:30	Alexa Prater
10:30-10:45	Coffee Break
	Session 2
10:45-11:00	Christopher Griffin
11:00-11:15	Kristin Chilton
11:15-11:30	Selva Marroquin
11:30-11:45	Joshua Benton
11:45-12:00	Kirkland Broadwell
12:00-2:00	Lunch & Poster Session
	Session 3
2:00-2:15	Tahiry Rajaonarison
2:15-2:30	Morrison Nolan
2:30-2:45	Amin Abbasi Baghbadorani
2:45-3:00	Yezi Yang
3:00-3:15	Shuyang Sun
3:15-3:30	Coffee Break
	Session 4
3:30-3:45	Devin Hoffman
3:45-4:00	Andrew Parent
4:00-4:15	Alireza Namayandeh
4:15-4:30	Jessica DePaolis
4:30-4:45	Alumni Speaker
4:45-5:00	Closing Remarks

Friday, Feburary 14th	
8:45-9:15	Breakfast
9:15-9:30	Alumni Speaker
	Session 5
9:30-9:45	Allie Nagurney
9:45-10:00	Priyanka Bose
10:00-10:15	Cathleen Humm
10:15-10:30	Graydon Konzen
10:30-10:45	Coffee Break
	Session 6
10:45-11:00	Ben Kligman
11:00-11:15	Josh Murphy
11:15-11:30	Natalia Varela
11:30-12:00	Up-Goer 5
12:00-2:00	Lunch & Poster Session
	Session 7
2:00-2:15	Jonathan Prouty
2:15-2:30	Khanh To
2:30-2:45	Alix Ehlers
2:45-3:00	Junyao Kang
3:00-3:15	Fiona McGroarty
3:15-3:30	Coffee Break
	Session 8
3:30-3:45	Nathan Roethlisberger
3:45-4:00	Max Garvue
4:00-4:15	Dalton Anderson
4:15-4:30	Nigel Groce-Wright
4:30-4:45	Alumni Speaker
4:45-5:00	Alumni/Closing Remarks
5:30 Onwards	GSRS Banquet *Museum of Geosciences*

Undergraduate Poster Presenter

1 Omar Ghamedi
2 Roberto Gorjon-Andujar
3 Camille Do
4 Shelly Worek
5 Cameron Chambers

Undergraduate Poster Presenter

6 Michael Mellett
7 Ryan Farris & Steven Watson
8 Ryan Roane
9 Hannah-Marie Eddins
10 Emily Patellos
11 Mason McCabe

GRADUATE

STUDENT

ABSTRACTS

RADAR IMAGING OF FRACTURES AND VOIDS BEHIND THE WALLS OF AN UNDERGROUND MINE

ABBASI BAGHBADORANI, Amin, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

Undetected voids and fractures in underground mining can pose significant operating challenges and safety issues such as flooding and structural collapse. Probe drilling is one of the main methods of detecting fractures and voids in the underground mining industry. However, given the complexity of these structures, they are often not detected or fully understood through drilling. Radar electromagnetic waves can propagate tens of meters into most rocks, and can be reflected by contrasts within the rock. Rock-penetrating radar was used to detect and image naturally occurring fractures and karst voids within limestone. 2D and 3D rock-penetrating radar data were acquired in a lime mine on the wall of a pillar with exposed karst and fractures along its walls. Shielded antennae eliminate reflections from the tunnel walls, resulting in higher image quality. Strong radar reflections in the raw field data correlate with exposed fractures and karst. Reflections were observed from the far wall of the pillar and from karst and fractures exposed on the pillar walls. Migration was used to create reflection images through the pillar interior. The Kirchhoff migration algorithm properly migrates steep dips from true topography. The resulting images penetrate >25 m distance behind the pillar wall, with a spatial resolution of <0.5 m. Higher frequency radar improved the image resolution, but comes at the cost of less depth of penetration and considerable extra data acquisition effort. Most of the exposed fractures have apertures much thinner than a radar wavelength, but produce strong reflections due to the strong contrast in physical properties between rock and pore fluids. Thin-layer synthetic data indicate that fractures containing a millimeter of water or a centimeter of air can produce easily detectable radar reflections. A dominant reflection at the intersection of two fractures is interpreted do be a void at least 2.7 cm wide. Absent reflectivity along the fracture planes probably indicates where they are locally closed, whereas moderate reflector/scatterer strength indicates mm to cm scale fracture aperture. The irregular open fracture geometry could be caused by minor irregularities in the fracture's original quasi-planar geometry, the modern stress direction, and subsequent dissolution by water flow and karst formation. This research demonstrates the effectiveness of radar in detection of fractures and voids prior to excavation that could cause significant operating challenges and safety issues. It could guide future practical radar applications to detect fractures and voids in hard rock underground mining.

Advisor: Dr. J. A. Hole

ECONOMIC POTENTIAL OF RARE EARTH ELEMENTS WITHIN APATITE IN QUARTZ MINE TAILINGS

ANDERSON, Dalton, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

Rare Earth elements (RREs) are of crucial economic importance due to their critical applications within multiple different industries such as: electronics, magnets, lasers, sonar systems, and nuclear control rods. Rare Earths can be detected within over 200 different minerals, but economic exaction of rare earths is limited to several key minerals. Apatite is a prime target for the economic extraction of RREs due to its ability to incorporate a wide variety of RREs within its crystalline structure as well as providing an economic resource for phosphate. This study investigates the Spruce Pine district of North Carolina. Spruce Pine is home to several different on-going quartz and feldspar mining operations. The local geology is granitic pegmatites of late Ordovician age with the major mineral components of 40% oligoclase, 25% quartz, 20% microcline, and 15% muscovite. Apatite is noted as a key accessory mineral, but generally does not exceed more than 5 weight percent. Apatite within the region is considered to contain up to 3 weight percent RREs. This study seeks to investigate the waste tailings of 2 on-going quartz mining operations to constrain the potential economic resource of rare earth elements within apatite left over from the initial separation process utilizing LA-ICPMS and XRF data. X-ray fluoresce data will help to constrain bulk composition of the tailings while LA-ICPMS will seek to specifically pinpoint the rare earth content of apatite within the tailings. The results of this investigation could potentially be of economic benefit and could provide information on an untapped resource from what is now considered to be a waste product.

Advisor: Dr. M. J. Caddick

MODELING COUPLED MAGMA-HYDROTHERMAL PROCESSES AT YELLOWSTONE NATIONAL PARK

BOSE, Priyanka, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

America's first national park, Yellowstone, has mesmerized the public with colorful acid pools, and thrilling geyser eruptions. Many studies have found the hydrothermal system in Yellowstone National Park has maintained a quasi-steady heat output since the last glaciation, about 10,000 years ago. However, how the hydrothermal system interacts with the magma lenses below it is still poorly understood. For example, Fournier et al (1976) used a simple heat balance argument to show the hydrothermal heat output can be derived from the latent heat & cooling of a 0.6 - 1.2 km thick magmatic sill underlying the park's 2500 km^2. But this estimate does not consider magmatic replenishment in the magma lenses or the presence of a crystallizing conductive thermal boundary layer at the top of each lens. The goal of this research is to understand how the heat output of the hydrothermal system is affected by both magmatic recharge and the crystallization of a conductive thermal boundary layer in the magma lenses. We created a model that assumes the two crystallizing and cooling magma lenses under the caldera are the main heat source for the park's hydrothermal system. Given that the lenses are cooling and crystallizing, the heat resulting from this state change is transferred to the hydrothermal system but is buffered by a conductive thermal boundary layer at the top of each lens. This model studies the effects of a crystallizing conductive thermal boundary layer and a constant magmatic recharge rate for the magma lenses. The constant recharge rate was based on the averaged heat flow estimate of the entire park from the chloride inventory data: 5.3 GW. Based on the preliminary research completed, magmatic recharge has to occur within the magma lenses for the hydrothermal heat flow output to maintain a quasi-steady state. Without recharge, the magma lenses solidify relatively quickly within the simulation timeline, and thus cannot provide enough heat transfer for the hydrothermal system to maintain its quasi-steady heat flow value over the past 10,000 years. With a constant rate of recharge, the magma bodies are able to provide enough heat to maintain the quasi-steady state of the hydrothermal system over the past 10,000 years. More research is needed to understand the sensitivity of the magmatic recharge rate in order to better constrain the magmatic recharge rate, in order to advance the understanding of the Yellowstone hydrothermal system.

Advisor: Dr. M. S. Duncan and Dr. S. D. King

DISSOLUTION-REPRECIPITATION REACTIONS DECOUPLE AGES FROM CHEMISTRY IN MONAZITE AND ALLANITE: OBSERVATIONS AND IMPLICATIONS FOR PETROCHRONOLGY

BROADWELL, Kirkland, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

Monazite, zircon, and allanite are commonly used mineral chronometers, increasingly tied to petrologically important minerals (e.g. garnet, feldspars, micas) to constrain rates and durations of tectonic processes and provide key information on the overall tectonic and thermal evolution of the crust. However, a variety of processes can both erase and alter petrologic and geochronologic information in these minerals, generating uncertainty in the linkage between ages and conditions. Natural case studies provide invaluable information on the diversity of behavior in these systems, informing both experiments and tectonic interpretations. Here, we report on monazite from the central Appalachians that preserve complex chemical zoning surrounded by a double corona of apatite + allanite, interpreted to represent poly-metamorphic monazite that has been variably altered during a fluid-induced dissolution-reprecipitation reaction. Fluid-altered monazite exhibits a strong depletion in Y+HREE that correlates with cuspate and lobate BSE zoning, but not with age. This decoupling of chemistry and age produces significant scatter in monazite age vs. chemistry plots and inhibits the use of monazite trace element thermometers. Mixing models are used to deconvolve 3 separate age populations that correlate with well-known tectonic events in the central Appalachians – Taconic regional metamorphism (~470 Ma), arc magmatism (~450 Ma), and post-collision slab break-off (~430 Ma). Allanite ages are interpreted to record the timing of early Alleghanian (~300 Ma) tectonism and are texturally linked to a garnet-forming reaction. While the formation of apatite and allanite from monazite requires external input of major elements (Fe, Si, Ca, H_2O), trace elements patterns suggest significantly limited mobility. Overall, these data suggest a decoupling between 1) ages and chemistry in fluid-altered monazite and 2) major and trace element chemical equilibrium between monazite-apatite-allanite corona structures and major silicate phases in the rock (garnet, biotite, plagioclase). The application of commonly used trace element thermobarometers and "chemical signatures" between accessary and major minerals must be applied with great caution in these settings, as indiscriminate application can lead to erroneous interpretations.

Advisor: Dr. M.J. Caddick

EXAMINING THE INFLUENCE OF BEDROCK DISCONTINUITY ORIENTATION ON KNICKPOINT FORM AND EVOLUTION VIA BEDROCK CHANNEL FLUME EXPERIMENTS

CHILTON, Kristin, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

Knickpoints, which are convexities along the longitudinal profile of a stream, can indicate a change in erodibility of the underlying bedrock or mark the leading edge of an upstream-propagating incision wave, initiated by a change in downstream boundary conditions (e.g., a drop in base level due to sea level change, drainage network reorganization, tectonic or isostatic uplift, or active fault displacement). The latter type can serve as a record of perturbation events within a given landscape, and are therefore commonly used as valuable interpretive tools that can help unravel complex climatic and tectonic histories. The morphology of such knickpoints is often used to infer the nature of the initiating event (e.g., magnitude, rate of change), and knickpoint migration rate is used within numerical models to infer landscape response times. However, the use of knickpoint morphology and migration rate to make interpretations about initiating events and landscape sensitivity is problematic without a thoughtful investigation of other factors which may impact knickpoint form and evolution, such as bedrock discontinuity orientation (e.g., bedding dip angle). Limited field evidence from fluvial, glacial, and coastal geomorphic realms suggests discontinuity orientation may exert an important control on knickpoint morphology and behavior, and it is therefore necessary to clarify the nature and significance of this relationship in order to more appropriately use knickpoints as interpretive tools. Because this problem is difficult to address in the field due to the presence of many other influencing factors, we plan to investigate the role of discontinuity orientation in determining knickpoint form and evolution via flume experimentation. This will allow the effects of discontinuity orientation to be isolated and permit testing across a well-distributed range of orientations. We will use unglazed porcelain tiles, stacked and supported at various orientations using 3D printed plastic trays, to simulate dipping sedimentary bedrock with two perpendicular joint sets. A knickpoint will be initiated at the downstream end of the flume, and each experiment will be run at a constant discharge constrained by the Froude number and threshold velocity for block entrainment. We will test eight different orientations of bedding dip angle relative to flow direction, and continually monitor knickpoint morphology, migration rate, and block plucking events using time-lapse photography, videography, and structure-from-motion photogrammetry. The results of these experiments will have implications for the interpretation of bedrock channel knickpoints, numerical landscape evolution modeling, fluvial erodibility, and ultimately further our basic understanding of bedrock channel morphodynamics.

Advisor: Dr. J.A. Spotila

THE APPLICATION OF DIATOM ANALYSIS TO RECONSTRUCT COSEISMIC UPLIFT ON MONTAGUE ISLAND, ALASKA

DEPAOLIS, Jessica, Department of Geosciences, Virginia Tech, Blacksburg, VA 24061

The 1964 M_w 9.2 Great Alaska Earthquake ruptured >800 km of the eastern segment of the Alaska-Aleutian megathrust, and remains the second largest earthquake ever recorded. Earthquake-induced faulting along the Patton Bay Splay-Fault System (PBFS), contributed to local tsunami generation and vertically displaced shorelines on Montague Island, Prince William Sound by as much as 10 m. The sudden uplift of the island resulted in significant changes to coastal environments, such as the seaward shift of shorelines and the gradual draining of coastal lagoons. Field mapping, detailed lithologic descriptions, and computer tomography (CT) scans of sediments underlying a series of drained lagoons on the western coast of Montague Island reveal distinct and laterally continuous lithologic contacts between sand/silt and peat, potentially signaling prior instances of abrupt coastal uplift over the last 4.2 ka. Here, we investigate the microfossil signature across potential coseismic uplift contacts in order to characterize how environments shifted (e.g., tidal flat to freshwater peat) and quantify uplift. Microfossils, such as diatoms, contained in coastal sediments can indicate sudden changes in relative sea level along the coast and provide an independent test of earthquake-related deformation inferred from coastal stratigraphy. Preliminary diatom results across the penultimate earthquake contact (0.8 ka) reflect an environmental shift from a brackish lagoon to a freshwater peat, consistent with the draining of a coastal lagoon. Our diatom results, in combination with geomorphic and stratigraphic observations, will help assess the rupture history of the PBFS and improve our understanding of earthquake and tsunami hazards in Prince William Sound.

Advisor: Dr. T. Dura

HIGH-PRESSURE STUDY OF ZIRCONS WITH VARYING DEGREES OF AMORPHIZATION

EHLERS, Alix, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

Zircon ($ZrSiO_4$) is an important accessory mineral in the Earth's crust and is widely used to date geological events by measuring the uranium and thorium (U/Th) incorporated in the structure (e.g. Wilde et al., Nature, 2001). The radioactive decay of U to Th damages the crystallinity of the zircon structure, causing changes in its physical properties and chemical resistance, and potentially resulting in an amorphous, or a "metamict" form (e.g. Ewing et al., Reviews in Mineralogy and Geochemistry, 2003). Although previous studies have measured the equation of state (EoS) of zircon, there are discrepancies in the reported data. To date, there has not been a comprehensive analysis exploring the effect of amorphization on the EoS of zircon. My objective is to determine how amorphization affects the elastic properties of zircon of natural zircons with varying degrees of amorphization and synthetic zircons using single-crystal X-ray diffraction and Raman spectroscopy. Natural samples including zircons from the Mud Tank carbonatite complex in central Australia, Pacoima Canyon in California, Tambani Area in Malawi, and from aegirine syenites in central Brazil, have been collected for high-pressure EoS experiments. They will also be characterized using Raman spectroscopy to determine the degree of radiation damage in the samples (Nasdala et al., Physics and Chemistry of Minerals, 2008). Synthetic zircons have been provided by Professor John Hanchar (University of Newfoundland) for comparison with the natural samples. A natural, crystalline zircon from the Mud Tank carbonatite, characterized by low U/Th substitution (Valley et al., Contributions to Mineralogy and Petrology, 1998), has been screened and loaded in a diamond anvil cell for *in situ* high-pressure X-ray diffraction experiments. Unit cell parameters and structural changes were analyzed from 1 bar to 8.505 GPa. The unit cell volumes were fit to a 2^{nd}-order Birch-Murnaghan EoS resulting in an isothermal bulk modulus $K_0 = 229(1)$ GPa. High-pressure X-ray diffraction experiments are in progress on the synthetic and metamict zircons. This will be the first study to provide a comprehensive range of equations of state that will strengthen our understanding of how zircon behaves in geological systems. This information will also provide critical insight into the effects that radiation damage and metamictization have on the structural and elastic properties of materials at high pressures.

Advisor: Dr. N. L. Ross

GEOLOGICAL SLIP-RATE DETERMINATION OF THE SOUTHERN CALICO FAULT SYSTEM AND IMPLICATIONS FOR THE EASTERN CALIFORNIA SHEAR ZONE

GARVUE, Max, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

The Eastern California shear zone (ECSZ) is a system of dextral strike-slip faults that stretch from the southern Mojave Desert through Owens Valley, east of the Sierra Nevada. Approximately 25% of the motion along the transform plate boundary between the Pacific and North American plates is accommodated by the ECSZ, yet slip rates on individual faults are not fully known and a discrepancy exists between geologically and geodetically determined rates. Geological studies document longer term rates from 10^2 to 10^5 yr, while geodesy reveals shorter term rates spanning over recent decades. Thus far, the geologically determined cumulative dextral slip-rate in the ECSZ is 6.2 mm/yr, whereas the geodetically determined rate is 11-18 mm/yr (Savage et al., 1990; Dixon et al., 2000; Meade and Hager, 2005; Oskin et al., 2008; Herbert et al., 2014). The Calico fault system in the southern Mojave section of the ECSZ has the highest estimated slip-rate and the largest individual disparity between geologic and geodetic methods. The Calico fault is also the longest and most continuous fault strand within the ECSZ. Of the Calico fault's 90-km length, existing geologic rates have only been measured along a 15 km stretch on the north-central portion (Oskin et al., 2007; McGill et al., 2015; Selander, 2015; Evans et al., 2016; Wetmore et al., 2017). More geologic slip-rate determinations are needed to provide a robust comparison between rates measured over different timescales using independent techniques. We have mapped offset alluvial fans and deformed features along a 20-km long stretch of the fault and a neighboring strand, the Hidalgo fault, in the US Marine Corps base at Twentynine Palms (MCAGCC). Offsets are evident in satellite imagery, high-resolution topography using structure from motion analysis via unmanned aerial surveys, and from ground-based neotectonic mapping. We observe numerous offset features along this stretch of the Calico fault, suggesting a high rate of activity and relatively recent rupture. We have collected alluvial samples from a range of offset features to be dated using Optically Stimulated Luminescence (OSL) and Terrestrial Cosmogenic Nuclides (TCN) and thus will eventually provide the first geologically determined slip rates from a range of timescales for this section of the Calico fault. These rates should help resolve the discrepancy in slip-rate determinations using different techniques for the Calico fault and southern ECSZ, as well as contribute to the understanding of seismogenesis, hazards, and fault behavior in the shear zone.

Advisor: Dr. J. A. Spotila

THE BIRD PELVIS POSSESSES ANCESTRAL DINOSAURIAN ANATOMY AT EARLY EMBRYOLOGICAL STAGES

GRIFFIN, Christopher, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

Because an organism's anatomy is controlled by how it grows and develops, untangling the relationship between development and the evolution of animal form is a central goal of evolutionary biology. However, incorporation of developmental data from embryos of living animals with data from the fossil record has been challenging. The origin of the bird body plan provides an excellent system to tackle this knowledge gap because birds possess a distinct body plan relative to all other reptiles, with the anatomical changes that occurred during this transition constrained by an excellent dinosaurian fossil record. The bird pelvis is particularly distinct: unlike ancestral dinosaurian anatomy, with a short ilium, a long tail, and a forward-facing pubis, the avian pelvis has an expanded ilium, a short tail, and a backward-facing pubis. To examine the origin of the bird pelvis in both a deep-time and developmental context, I integrated data from *Alligator* and non-bird dinosaur (i.e., *Coelophysis*, *Tyrannosaurus*, *Velociraptor*, *Archaeopteryx*) pelves that track the transition from the ancestral dinosaurian anatomy to those of living birds with embryological data. Specifically, I used a novel embryological technique conducted on *Alligator* and quail embryos to show the embryonic pelvis more clearly and at earlier developmental stages than was previously possible. I found that many ancestral dinosaurian features are present in early-stage bird embryos, which only transition to the 'typical' bird anatomy at later embryonic stages: the bird ilium during early stages is short, the tail is long, and the pubis is forward-facing. Geometric morphometric analysis—a method of quantifying and comparing complex shapes—supports the qualitative observation that the developmental order of these transitions mirrors the evolutionary changes that occurred during the transition from early dinosaurs to living birds recorded in the fossil record. The 100-million-year transition from the dinosaurian pelvis to that of living birds can be observed across two days of pre-hatching bird development. Extinct groups known from the fossil record are critical to correctly identifying the origin of ancestral and novel features that appear during evolution.

Advisor: Dr. S. J. Nesbitt

ANALYZING TIME-SERIES DATA OF CAVE DRIPS AND STREAM DISCHARGE IN JAMES CAVE, VIRGINIA: STORAGE AND RECHARGE IMPLICATIONS FOR APPALACHIAN KARST

GROCE-WRIGHT, Nigel, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

Karst aquifers, characterized by soluble rocks such as limestone and dolostone, provide drinking water to 20-25% of the world's population. Despite the importance of these systems, recent work suggests that rapid alteration of karst aquifers is occurring because of the impact of climate change on precipitation patterns. The impact of these altered precipitation patterns on recharge to karst systems is one change that is of critical concern for drinking water supply. Karst aquifers present a challenge to researchers because of their heterogeneity, including extensive fracture and conduit networks. Much of the research on karst hydrology has relied on using patterns of karst spring discharge, as springs are easy to access and monitor. However, because springs can integrate multiple flowpaths, it is difficult to rely on spring discharge patterns to get information on where and how karst aquifers are receiving recharge. Monitoring closer to the source of recharge in a karst watershed (i.e., caves, sinkholes, soil) allows for a more accurate analysis of recharge timing and mechanisms. This study aims to expand knowledge of how karst aquifers respond to changes in precipitation and recharge. Using a 12-year record (2007-2019) of precipitation, cave drips and cave stream discharge in James Cave (Pulaski Co., VA), I will conduct time-series analyses, including analysis of lag times and recession characteristics, to 1) quantify the hydrologic connections between precipitation, cave drips and the cave stream; and 2) examine daily, seasonal and annual trends in the datasets. These results can be used to aid forecasting of response of karst aquifers to differences in precipitation regimes.

Advisor: Dr. M. Schreiber

EFFECT OF DISSOLVED OXYGEN FLUCTUATIONS ON IRON AND MANGANESE CYCLING IN A DRINKING WATER RESERVOIR

HAMMOND, Nicholas, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

The cycles of iron (Fe) and manganese (Mn) in seasonally stratified freshwater bodies play an important role in biogeochemical processes that govern carbon processing, ecosystem productivity, and other elemental cycles. In addition, Fe and Mn have the potential to create water quality issues when they accumulate at high concentrations in drinking-water reservoirs. Therefore, evaluating the processes that drive Fe and Mn cycling would improve predictions of when and where these metals could pose water quality problems. The behavior of Fe and Mn in natural waters is largely governed by the redox conditions in the water; both metals are highly insoluble under oxidizing conditions but are soluble under reducing conditions. Therefore, the dissolved oxygen (DO) dynamics of the water body are considered a dominant control over Fe and Mn cycling. DO concentrations in lakes and reservoirs are highly variable over different time scales, ranging from daily fluctuations caused by wind-driven mixing to seasonal, climate-driven trends. My research aims to investigate how Fe and Mn cycles in a drinking water reservoir are affected by DO dynamics over time scales ranging from multiple years to sub-hourly. To do this, I will be conducting ecosystem-scale oxygenation experiments, facilitated by an engineered oxygenation system at a study reservoir, to assess how Fe and Mn respond to these changes in DO. A long-term water quality monitoring program has been collecting data on Fe and Mn, in addition to a suite of other water quality parameters, for more than five years. I will leverage this robust data set to discern how fluxes of Fe and Mn respond to a variety of oxygenation scenarios over multiple years. In order to study short-term fluctuations in Fe and Mn concentrations throughout the water column, I plan to employ novel sensor technology that can analyze Fe and Mn concentrations in-situ from a range of depths at a high frequency. Previous work on the short-term cycling of Fe and Mn in lakes is limited, but I hypothesize that these periods of high reactivity will make significant contributions to the metal cycles. The high-frequency data will be combined with the long-term data to calibrate a model of Fe and Mn dynamics in the reservoir, which will be integrated with an empirical forecasting model to predict future concentrations of Fe and Mn in the reservoir. This would be a novel, valuable tool for reservoir managers.

Advisor: Dr. M. E. Schreiber

VARIABLE EVOLUTIONARY RATES IN THE MORPHOLOGY OF THE EXTINCT CLADE AETOSAURIA (REPTILIA:ARCHOSAURIA)

HOFFMAN, Devin, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

Though evolutionary rates of living organisms can be estimated using molecular data, paleontological studies must rely solely upon morphology which has be hindered by a reliance on parsimony models that cannot account for variable evolutionary rates. One such parsimony-based study used the Aetosauria, a clade of armored, crocodylian-line archosaurs, whose osteoderms are debated to evolve faster than the rest of the skeleton, and may be too homoplastic for reconstructing deeper clade relationships. One previous attempt to resolve the debate was limited to sub-setting data by the parsimony framework used. We use this same dataset (26 taxa, 83 characters) and implement partitioning, then a phylogenetic reconstruction in a ML framework to better address the debate. Using PartionFinder 2.0 we found osteoderms (= 33 characters) evolve at a different rate than the endoskeleton (= 50 characters). When we used this dataset to reconstruct the phylogeny of aetosaurs, with variable gamma distributed rates, we found osteoderm characters had a lower global evolutionary rate than endoskeletal characters. We conclude that though osteoderms evolve slower on average, the different gamma shapes show osteoderms are more variable in their evolutionary rates than endoskeletal features. Although the phylogeny we generated is identical in topology to the parsimony hypothesis, when using the same support measures, only by phylogenetic comparative methods (PCMs) can we address the debate in evolutionary rates. By determining which characters evolve faster and with more heterogeneity, we can better resolve aetosaur and other taxa phylogenetic hypotheses. With these refined hypotheses and using PCMs we can trace evolutionary rate shifts for these extinct clades to reconstruct macroevolutionary processes surrounding faunal turnovers, mass extinctions, and radiations.

Advisor: Dr. S. J. Nesbitt

EFFECTS OF REGIONAL GEOLOGY AND REGULATION ON GROUNDWATER AQUIFERS IN BRITTANY, FRANCE AND WEST-CENTRAL TAIWAN

HUMM, Cathleen, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

As the second largest source of freshwater, groundwater plays an imperative role in ecosystems worldwide. Aquifer systems are dependent on regional climate and geology and are commonly pumped year-round to meet local water demands. Typically, aquifers are made up of permeable, fine and coarse-grained sediments. However, the Ploemeur aquifer in Brittany, France is a confined aquifer composed of fractured crystalline granite and mica schist. Faults and the contact zone between granite and schist serve as groundwater flow paths throughout the crystalline aquifer. Using recharge estimates, MODFLOW6, and ModelMuse, we develop a groundwater model of the Ploemeur aquifer to understand recharge infiltrates and travels through this complex system during pumping conditions. The crystalline Ploemeur aquifer provides a stable water supply to 20,000 people without significant or continuous drawdown or deformation. In contrast, a multi-layer aquifer system consisting of alluvial sediments in west-central Taiwan experiences notable land subsidence due to pumping. Unlike the French, the Taiwanese are not required to report the amount of groundwater extracted from the aquifer, only the amount of electricity used. Due to the lack of regulations, Taiwan's groundwater users are overexploiting the underlying aquifers for farming and domestic uses. Subsidence compromises infrastructure, including the Taiwan High Speed Rail (THSR). Previous authors derived a methodology to calculate the amount of groundwater extracted from the aquifers from the reported electricity usage from pumping. We will model the pumping data from 2007 to 2017 using MODFLOW-2005, the SUB (subsidence) package, and ModelMuse to understand and predict the effects of groundwater pumping. Furthermore, the model can investigate the impacts of a proposed plan to use an artificial recharge program in Taiwan to both mitigate land subsidence and determine if uplift in certain regions can lessen the continuous subsidence. This study is integral to the land subsidence crisis in Taiwan and will contribute to the continuously growing knowledge of the effects of overexploited aquifers in the region and worldwide. The aquifers in both Brittany, France and west-central Taiwan represent the difference in the effects of location and regulations on groundwater extraction. Both of the studies discussed can be applied to various aquifers globally and show the importance of knowledge and regulation on vital natural resources.

Advisor: Dr. T. J. Burbey

RECONSTRUCTING REDOX CONDITIONS OF TONIAN (CA. 1,000–720 MA) OCEANS

KANG, Junyao, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

The Tonian Period (1000–720 Ma) marks a critical transition in Earth history as it bridges the "Boring Billion" (stability in global carbon cycles during 1600–1000 Ma) and the Cryogenian Snowball Earth glaciations. Recent paleobiological data have shown a significant increase in biodiversity, an expansion in morphological range, and critical eukaryotic innovations in the Tonian Period (Xiao and Tang, 2018). Furthermore, molecular clock analyses show that animals may have diverged in the Tonian Period (Dos Reis et al., 2015). However, the environmental context and drivers of these evolutionary events remain ambiguous, mainly because paleoenvironmental conditions, particularly oceanic redox architectures, are poorly understood for the Tonian Period. To improve our knowledge of the Tonian paleoenvironments and their impact on the early evolution of eukaryotes, I propose a geobiological investigation of the Huaibei Group in North China to test the hypothesis that changes in mid-depth oceanic redox conditions are correlated with eukaryotic diversification in the Tonian Period. Previous studies have shown that a global transition from euxinic (anoxic, with dissolved H_2S) to ferruginous (anoxic, with Fe^{2+}) mid-depth ocean waters occurred in the Tonian Period (Guilbaud et al., 2015). This transition may have set the environmental stage for the diversification of eukaryote in the Tonian Period. To investigate this possibility, I propose to collect geochemical data from the Tonian Huaibei Group in North China. Carbonate samples have been systematically collected and prepared for iron speciation analysis (Poulton and Canfield, 2005), in order to quantify the different forms of Fe present in the sediment. A ratio of highly reactive iron [$Fe_{HR,}$ including pyrite iron (Fe_{py}), carbonate iron (Fe_{carb}), iron oxides (Fe_{ox}), and magnetite (Fe_{mag})] versus total iron (Fe_T) will be evaluated to determine oxic vs. anoxic conditions. Additionally, the ratio of Fe_{py} vs. Fe_{HR} will be assessed to distinguish the two forms of anoxic conditions (i.e., euxinic vs. ferruginous conditions). The primary data of Jiayuan, Zhaowei, Niyuan formations (the middle-upper Huaibei Group) shows $Fe_{HR}/Fe_T > 0.4$, $Fe_{py}/Fe_{HR} < 0.3$, which indicates ferruginous conditions. The Fe speciation data will be integrated with existing paleontological and biostratigraphic data to evaluate the correlation between paleoenvironmental transitions and biodiversity changes or evolutionary innovations.

Advisor: Dr. S. Xiao

GEOLOGIC AND PALEONTOLOGICAL SURVEY OF A NOVEL TRIASSIC BASIN IN COLORADO, AND A NEW SPECIES OF TUSKED REPTILE

KLIGMAN, Ben, Department of Geosciences; MCCLURE, Warren, Otero Junior College, La Junta Colorado; KORBITZ, Mark, Otero Junior College, La Junta Colorado; SCHUMACHER, Bruce, USDA Forest Service, PNW Research Station.

The stratigraphy and fossil biota of Upper Triassic rocks from southeast Colorado are poorly known because of limited exposures and complex stratigraphy, complicated by difficult access caused by shifting ownership of various ranchland. Our recent joint field efforts revealed a previously unknown basin of Upper Triassic terrestrial sedimentary rocks preserved on land in trust with The Nature Conservancy. Starting with only a few fossil finds that indicated a Late Triassic age, we did an intensive field survey in summer 2019 to get a better understanding of the basin's depositional setting, paleoenvironment, age, and biota prior to its transfer to private ownership. Our efforts revealed a basin that preserves a unique Triassic environment compared to coeval strata in North America, characterized by a high energy fluvial depositional setting, a novel species of extinct reptile, and other fossils of reptiles, amphibians, and plants which allow for biostratigraphic age constraints. Specifically, we recovered a new fossil of a small-bodied reptile with tusk-like dentition. This reptile is a close relative of species known from Triassic rocks in South America and Europe, all of which have tooth and jaw structures inferred to be for processing plant material. The presence of tusks on this Colorado taxon is unique amongst its close relatives and we suggest they may have been used for rooting and digging up plant material based on comparisons to living animals with similar morphology. The shifting public-private land ownership of the area in which these rocks are exposed facilitated the discovery of this basin while at the same time may limit the amount of future research possible. Our study serves as a model for how university researchers, local community college professors, public land managers, and private landowners can collaborate to successfully conduct geologic research and add to knowledge of past biodiversity.

Advisor: Dr. M. R. Stocker

REGIONAL IMPACTS OF HIGH-DENSITY OILFIELD WASTEWATER INJECTION DISPOSAL

KONZEN, Graydon, Dept. of Geosciences, Blacksburg, VA 24061

The increase in earthquake occurrence rates in Oklahoma and Kansas is linked to oilfield wastewater injection disposal, particularly into the regionally underpressured Arbuckle Group. The Arbuckle is hydraulically connected to Precambrian basement through an extensive fracture system, which transmits pressure perturbations from high-density wastewater injections to seismogenic depths. The hydrogeologic principle of superposition indicates that the cumulative effects from closely-spaced injection wells are additive, pushing pore pressure transients to distances of 70 km or greater. Even after injection stops, pressure plumes sink as high-density wastewater displaces lower-density, Precambrian formation waters. This process is modeled in a variable density numerical simulation comprising parts of the Anadarko and Ardmore Basins, the Anadarko Shelf, and the Cherokee Platform as well as injection data from 2006-2018. Preliminary results suggest that the gravitational influence of dipping strata forces pressure transients across the Nemaha Fault Zone.

Advisor: Dr. R. M. Pollyea

EXPANDED ANOXIA WITHIN THE EUROPEAN EPICONTINENTAL SEAWAY ACROSS THE TOARCIAN OCEANIC ANOXIC EVENT

MARROQUÍN, Selva, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

Modern oceans have been experiencing a drastic decline in dissolved oxygen over the past several decades as a result of climatic warming. Models predict this trend to continue, making this widespread deoxygenation a pressing concern for the future habitability of the oceans. Deoxygenation events, in particular, can result in changes in the carbon, sulfur and iron cycles on our planet, in addition to a suite of various other elements that are sensitive to the presence or absence of oxygen (i.e. considered redox-sensitive). The changes in these elemental cycles lead to distinctive variation in the chemical composition of seawater that is recorded in marine sediments that are preserved into the geologic record. We can look to the rock record of similar deoxygenation events (Oceanic Anoxic Events, OAEs) to improve our predictions for future climate scenarios. For this study we have focused on an event in the Early Jurassic known as the Toarcian Oceanic Anoxic Event, T-OAE (~183 Ma). The T-OAE, is defined by a distinctive negative excursion in the $\delta^{13}C$ record associated with an increase in total organic carbon (TOC) content that is thought to reflect the climatic feedbacks associated with eruptions of the Karoo-Ferrar Large Igneous Province. However, $\delta^{13}C$ and TOC are not direct measurements of anoxia therefore this study aims to address the geographic and temporal extent of deoxygenation during the T-OAE by utilizing a local redox proxy. Here, we present iron speciation data in addition to existing $\delta^{13}C$ and TOC content data from the event as recorded within three basins of the seaway: the Cleveland Basin (UK), the Paris Basin (Luxembourg), and the Southern German Basin (Switzerland and Germany). The generated data show evidence for the development of local anoxia as early as the Pliensbachian-Toarcian boundary in the Cleveland and South German Basins. Both anoxic and euxinic conditions become more persistent within the interval attributed to the T-OAE (e.g. negative $\delta^{13}C$ excursion), however all three basins have evidence for anoxia persisting well after this interval. This presents a greater temporal extent of anoxic conditions and suggests a greater sensitivity of marine oxygen levels to climatic change than previously considered for this event. Our improved temporal understanding of anoxia for this event may be a useful analog to understanding future deoxygenation associated with present climate warming.

Advisor: Dr. B. C. Gill

THERMAL EVOLUTION OF THE MARTIAN CRUST THROUGH TIME

MCGROARTY, Fíona, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

Despite the critical role of the thermal evolution of Mars in its tectonic and volcanic history, there is currently little constraint on Mars' specific thermal history. The current constraints arise from observed volcanics, which range from the ~4 Byr old highlands to the young crater-count ages of Olympus Mons, indicating that Mars has an interior that allows for melt generation throughout its history. While the surface of Mars can be indirectly determined from orbit and directly sampled by rovers, it is more difficult to determine the specific internal processes that lead to the formation of the crust and how the crust and lithosphere evolved. From gravity measurements and derived models the crust is inferred to be ~50 km thick on and of basaltic composition (Taylor, S. R. and McLennan, S. 2009, Neumann, G. A. et al., 2004). We will be using these parameters to calculate areotherms and crustal structures for the martian crust over the past 4 Gyr. In order to constrain the planetary-scale thermal evolution at the crustal-scale geochemical level, we model crustal evolution by first calculating a range of modern day areotherms. Using the thickness, heat production, heat flow, thermal conductivity, and density for the present-day crust, we are constructing the areotherms as a function of temperature over depth. We begin with a reference case of a homogenous HPE distribution within the crust and an undepleted lithospheric mantle, using the average thickness of 50 km today and average modern heat flow of 25 mW/m2 (e.g., Schatz, J. F. and Simmons, G., 1972). Because heat production in the crust is related to the abundance of HPEs, we can calculate areotherms through time. The areotherms are used with previously calculated adiabats (Duncan, M. S. et al., 2018) and a mantle solidus (Plesa, A. C. et al. 2016) to determine melt fraction (F) and potential crustal compositions. With these areotherms and surface compositions, we will be able to model the composition of the crust and lithosphere.

Advisor: Dr. M. S. Duncan

SMALL-SCALE CONVECTION AND THE GEODYNAMIC ORIGINS OF MARTIAN VOLCANISM

MURPHY, Josh, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

Mars has two major centers of volcanic activity. The largest is the Tharsis Rise, a broad dome centered in the equatorial western hemisphere containing several large volcanoes. The origin of Tharsis is generally ascribed to one or more long-lived mantle plumes (e.g. Harder and Christensen, 1993; Sramek and Zhong, 2012). While the rise itself was emplaced by 3.7 Ga, the region has remained active for most of the planet's history (Phillips et al., 2001; Richardson, 2017). Another major volcanic province, Elysium, is centered ~105 degrees to the west-northwest of Tharsis and is also marked by a broad dome and volcanoes of similar age. However, while both regions are large by Earth standards, geodynamicists have typically focused on the much larger Tharsis. Our goal is to explain the volcanism in both provinces and the difference in magnitude between them. Tharsis straddles the boundary between the thicker crust of the southern highlands and the thinner crust of the northern lowlands. This contrast, the Martian dichotomy, predates Tharsis, and the boundary passes south of Elysium. The dichotomy may be related to the development of Tharsis (e.g. Wenzel et al., 2004; Zhong, 2009). One proposed mechanism for this link is that Tharsis is the result of small-scale convection at the dichotomy boundary, which could also explain Elysium (King and Redmond, 2005). We look for two different small-scale convection scenarios: (1) conventional edge-driven convection and (2) upwelling from beneath a thicker, insulating southern hemisphere. To do this we analyze 3D mantle convection models using a modified version of the finite element code CitcomS (Zhong et al., 2000; Tan et al., 2006; Zhong et al., 2008). The largest modification is the calculation of melt production. Others include a cooling core boundary condition and decaying internal heating. The dichotomy boundary, first modeled as purely hemispherical, is later derived from elevation and gravity data. Variations from an equatorial, uniform step may cause melting to be concentrated near specific parts of the boundary. Our models so far indicate that of the two small-scale convection scenarios described above, the latter is most likely. Even with an unrealistically large root at the dichotomy boundary, edge-driven convection does not develop. However, warm material trapped beneath the southern hemisphere upwells from beneath the boundary, concentrating melting in the northern hemisphere, particularly the area along the dichotomy boundary.

Advisor: Dr. S. D. King

CRYSTALLOGRAPHICALLY CONTROLLED VOID SPACE AT GRAIN BOUNDARIES IN EXHUMED QUARTZITES

NAGURNEY, Allie, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

Grain boundaries, the interfaces between minerals, are pathways for material transfer in metamorphic rocks. They facilitate reactions, act as pathways for the migration of elemental complexes, and control the rheological and petrophysical properties of rocks. Understanding the structure of grain boundaries is important, but it is unclear if this structure is locked in at peak pressure (*P*) and temperature (*T*) conditions, and how it changes during exhumation. We present an example from the Harkless Quartzite in the contact aureole of the Papoose Flat Pluton, eastern California where there is a heterogeneous but non-random distribution of void space at certain mineral interfaces. The Harkless Quartzite is a Precambrian-Cambrian quartzite that was plastically deformed and dynamically recrystallized during the intrusion of the Papoose Flat Pluton during the mid-Cretaceous (Sylvester et al. 1978; Law et al. 1992).

We combine Electron Back Scatter Diffraction analysis to determine the orientation of quartz grains with Scanning Electron Microscopy to image of void spaces at grain boundaries. Our results reveal that some quartz-quartz grain boundaries contain ~300 nm wide void spaces. The distribution of grain boundary void spaces correlates with the crystallographic orientation of neighboring quartz grains relative to the grain boundary. There is a statistically significant relationship in which void spaces are more prevalent at grain boundaries in which the a axis of quartz is normal to the grain boundary than any other orientation.

We then link the distribution of void spaces at grain boundaries to the elastic properties (thermal expansion and bulk moduli) of quartz. During exhumation from low *P*-medium *T* settings (550ºC and 3.5 kbar), the molar volume of quartz will decrease anisotropically, in which the length of the a axis decreases by more than that of the c axis.

We conclude that this anisotropic volume change in quartz during exhumation results in void space preferentially forming at grain boundaries neighbored by quartz with the a axis normal to the grain boundary. The preferred orientation of the void spaces thus matches the preferred crystal orientation of quartz in the samples, suggesting that the preexisting rock microstructure and crystal fabric plays an important role in controlling porosity structure during exhumation.

Advisor: Dr. M.J. Caddick & Dr. F.M. Michel

THE EFFECT OF OXYANION SURFACE COMPLEX TYPE ON THE RATE AND PATHWAY OF FERRIHYDRITE TRANSFORMATION

NAMAYANDEH, Alireza, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

Transformation of nanosized ferrihydrite (Fh) to crystalline iron (hydr)oxides causes desorption of pre-adsorbed metal and metalloid oxyanions to solution. This process impacts environmental water quality by affecting contaminant transport and fate, as well as how synthetic ferrihydrite can be used to remove potential pollutants from municipal and industrial waste streams. The effects of different types of surface complexes (outer-sphere, inner-sphere, monodentate, bidentate, etc.) on the rate and pathway of Fh transformation to goethite (Gt) and hematite (Ht) remain only partly understood. We investigated the impacts of adsorbed nitrate, sulfate, and arsenate on the kinetics and pathways of Fh transformation. The oxyanion surface complexes range from weak electrostatic outer-sphere for NO_3^-, to a mix of outer-sphere and inner-sphere for SO_4^{2-}, to predominantly strong bidentate inner-sphere for $H_2AsO_4^-$. Pure and adsorbed ferrihydrite samples were buffered at pH 5.5, aged for up to 50 days at 70 °C, and then characterized by powder x-ray diffraction (pXRD) and synchrotron pair distribution function (PDF) analysis. Results showed a significant decrease in the rate of Fh transformation with increasing strength of the oxyanions bonding on the surface such that pure Fh was almost entirely transformed to Gt and Ht (~ 90%) after 25 days, while As-adsorbed samples were still stable (untransformed) after 50 days. The rate of nitrate-adsorbed sample was almost close to the pure Fh, whereas sulfate-adsorbed samples showed a slower rate of transformation. The primary and secondary products for all the transformed samples was Gt and Ht, respectively, but the pathway of Fh transformation was influenced by the surface complex type. The Gt fraction was the highest (~ 74%) in the nitrate adsorbed sample, whereas sulfate-adsorbed sample favors forming more Ht (~ 37%) as a secondary phase. Solution chemical analysis results showed that with more Fh transformation, nitrate and sulfate were progressively desorbed from the surface, whereas As remained fully adsorbed to the Fh. This study shows that the rate and pathway of adsorbed Fh transformation that affects the fate and transport of toxic elements in natural environment are controlled by the type and strength of complexation on the surface.

Advisor: Dr. Marc Michel

LITHOSPHERIC CONTROL OF MELT GENERATION BENEATH THE MALAWI RIFT AND RUNGWE VOLCANIC PROVINCE, EAST AFRICA

NJINJU, Emmanuel, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

Models of continental rifting highlight the importance of magma in strain accommodation. However, there are competing hypotheses about the source of magma for the Rungwe Volcanic Province (RVP) in the northern Malawi Rift (NMR), East Africa, which may also migrate beneath the entire Malawi Rift. Some studies suggest the melt beneath the RVP is sourced from the African superplume SW of the volcanic province, while others propose the melt is from the Kenyan plume coming from the NE. Another option is decompression melting from lithospheric modulated convection (LMC) where there is thin lithosphere. In this work, we test the hypothesis that part of the melt feeding the Rungwe Volcanic Province is due to LMC-derived melt generation. Our preliminary results suggest decompression melting from LMC occurs at a maximum depth of ~200 km beneath the axis of the Malawi and at shallower depths (~100 km) beneath the northern and southern segments of the Malawi Rift. We therefore propose that the melt beneath the RVP and the entire Malawi Rift can be generated by LMC without necessitating any plume at the base of the lithosphere.

Advisor: Dr. D. S. Stamps

REFINING STRATIGRAPHIC CORRELATION OF EDIACARAN BLACK SHALES USING MERCURY CONTENT: A CASE STUDY OF THE DOUSHANTUO FORMATION IN SOUTH CHINA

NOLAN, Morrison, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

The Ediacaran Period represents a critical transition in Earth and life history, and it witnessed key environmental changes and evolutionary events that set the stage for the Cambrian explosion (e.g., Marshall, 2006). In South China, the Doushantuo Formation hosts an important record of fossils and geochemical data pertinent to these events (e.g., McFadden, et al., 2009). Relating the Doushantuo record of life and environment to these evolutionary and environmental changes requires stratigraphic correlation among sections of the Doushantuo Formation, especially correlations among black shale units in the formation (e.g., Member IV, Miaohe Member, and Lower Black Shale). Conventionally, the Member IV is correlated with the Miaohe Member or with the combination of the Lower Black Shale, Upper Dolostone, and Miaohe Member. However, some $\delta^{13}C_{carb}$ data suggest that only the Lower Black Shale correlates to the Member IV, while the Miaohe Member and Upper Dolostone correlate to the overlying Dengying Formation (An et al., 2015). These correlations have significant consequences for interpreting the age and duration of key geochemical events (Zhou et al., 2017). Building on lithostratigraphic and carbon isotope chemostratigraphic correlations, we use mercury (Hg) concentration data to test these correlations. Organo- and siderophilic mercury is often enriched in black shales, and it can record environmental signals related to volcanism, erosion, and redox conditions (e.g., Selin, 2009; Grasby et al., 2019) that are useful in regional stratigraphic correlation. We collected samples from six sections of the Doushantuo Formation, focusing on black shale units. In each of the six sections, there is at least one horizon with elevated Hg concentration in either the Miaohe Member or the upper Member IV, and another horizon with even greater Hg enrichment in the Lower Black Shale or the lower Member IV. This pattern persists when the Hg concentration is normalized by total organic carbon content to account for differential sedimentation rates. The pattern of Hg enrichment is consistent with the conventional correlation of these units, with the Lower Black Shale, Upper Dolostone, and Miaohe Member equivalent to Member IV black shales. The source of the Hg enrichement can be explored via comparison of mass-independent and mass dependent Hg isotope fractionation and with comparison to redox proxy data from the intervals of enrichment to determine if the Hg enrichment is driven by redox conditons or increased Hg input.

Advisor: Dr. S. Xiao

DRAINING THE EARLY EASTERN NORTH AMERICAN MARGIN: IMPLICATIONS FROM DETRITAL ZIRCON GEOCHRONOLOGY OF EARLY CRETACEOUS SANDSTONES

PARENT, Andrew, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

Passive continental margins provide geoscientists temporally extensive and spatially widespread stratigraphic records of hinterland tectonics, landscape evolution, and climate. These basins also hold societal relevance, in that many passive margins contain significant volumes of petroleum. As such, these systems have been rigorously studied and modeled to interpret typical styles of stratigraphic and structural evolution. Compared to adjacent and conjugate margins, the Eastern North American Margin (ENAM) remains understudied. With the exception of early reconnaissance seismic mapping, little effort has been made to fully understand the geologic evolution of ENAM. I present detrital zircon U-Pb geochronology from Early Cretaceous sandstones from the U.S. mid-Atlantic margin to 1) assess sediment source areas delivering sediment to the margin, and 2) investigate source-to-sink evolution and linkage between onshore and offshore deposystems. Core samples were collected from two wells: DOE Crisfield Airport #1 in Somerset County, MD, and DSDP Leg 93 Site 603B, ~550 km basinward of the modern coastline, located on the Hatteras abyssal plain. These wells capture Berriasian-Albian strata, providing a unique, continuous record of Early Cretaceous sedimentation. The Crisfield Airport well recovered fluvial strata of the Potomac Gp. (Berriasian-Hauterivian Waste Gate Fm., Aptian-Albian Patuxent Fm.), and site 603B recovered turbidite sandstones of the Valanginian-Albian Blake-Bahama Fm. Detrital zircon U-Pb ages of the fluvial, heterolithic Waste Gate Fm. exhibit a unimodal age peak centered on ~600 Ma, consistent with local, adjacent crystalline rocks of the Pan-African (~500-710 Ma) Carolina Terrane. Coeval turbidites of the Blake-Bahama Fm. feature a cosmopolitan U-Pb age spectra, dominated by Grenvillian (920-1300 Ma) zircons with secondary modes attributable to Alleghenian (260-325 Ma), Taconic/Acadian (325-500 Ma), and Pan-African heritage. Three samples overlying this basal turbidite sand (~Hauterivian-Albian) contain a similar detrital age signature. The fluvial Aptian-Albian Patuxent Fm. expresses a similar, widespread age distribution as the Blake-Bahama turbidites, greatly contrasting the underlying Waste Gate Fm. These data suggest that the Early Cretaceous mid-Atlantic featured small, segmented onshore basins draining singular source terranes (e.g. Waste Gate Fm. derived from Carolina Terrane), whereas the coeval basal Blake-Bahama Fm. received zircons from several distinct Appalachian tectonomagmatic provinces. By Aptian-Albian time, coastal plain rivers had apparently accessed the regionally-extensive drainage system and, potentially, were incorporated into the offshore sediment transfer system. Additional samples from southern onshore sites, along with (U-Th)/He cooling ages of detrital zircons, will further refine interpretations of drainage basin configuration and evolution during the early drift phase of ENAM.

Advisor: Dr. B.W. Romans

STRATIGRAPHIC AND MICROFOSSIL EVIDENCE OF REPEATED LATE HOLOCENE TSUNAMI INUNDATION AT SITKALIDAK ISLAND, AK

PRATER, Alexa, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

Despite a remarkable series of >M_w8 ruptures and accompanying tsunamis during the 20th century, little is known about prehistoric earthquakes and tsunamis along the Alaska-Aleutian subduction zone. Recent studies west of Kodiak Island and the western margin of the 1964 M_w9.2 rupture have used tidal marsh stratigraphy and seismic reflection data to establish the potential of this region to generate tsunamis directed at far-field sites such as the west coast of the United States and Hawaii. Here, we present stratigraphic and microfossil evidence of repeated tsunami inundation over the last ~500 years at Sitkalidak Island, located 0.5 km off the coast of south-central Kodiak Island. Peat cores collected from an estuary in southern Sitkalidak Island reveal three anomalous, laterally continuous sand beds with sharp upper and lower contacts preserved within a coastal peat sequence. The sediment properties and preliminary diatom characteristics of the sand beds—for example, the upward fining sand sequences, the presence of anomalous marine planktonic diatoms, and the high fragmentation of diatoms within the beds—indicate high-energy deposition from a marine sediment source with tsunami inundation. Radiocarbon dating constrains the deposition of the sand beds to 1964 CE, 1788 CE, and ~400 cal yr B.P. These dates are consistent with records observed at sites ~90 km to the west at Sitkinak Island, and ~80 km to the east at Middle Bay, Kodiak Island. Despite the lack of significant lithologic changes between the peat under- and overlying the sand beds, preliminary foraminifera and diatom results suggest decimeter-scale subsidence concurrent with the deposition of the 1964 CE sand bed. Deformation concurrent with the 1964 CE rupture and the presence of sand beds associated with the 1788 CE and ~400 cal yr BP ruptures at Sitkalidak help better define the western (1964 CE and ~400 cal yr BP) and eastern (1788 CE) rupture limits, and thus the permissible maximum magnitudes, of past Alaska-Aleutian subduction zone ruptures.

Advisor: Dr. Dura, Tina

VIRGINIA'S RECORD OF MESOZOIC RIFTING: IMPLICATIONS FOR DISRUPTIONS TO THE SULFUR AND CARBON CYCLES

PROUTY, Jonathan, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

Virginia's Culpeper Basin is one of dozens of Mesozoic rift basins found along the length of the Atlantic margin. In many areas basin geometry follows the relict convergent margin boundary, as an early Triassic tensile stress regime commonly led to normal movement along preexisting faults. Extension along these normal fault systems led to widespread thinning and subsidence of Pangean crust, with deposition in many of these new depressions beginning in the Triassic. Basin depths exceeded 3000 m by the late Triassic (e.g. Newark Basin). In these basins, the Triassic/Jurassic boundary (TJB) boundary is associated with the seemingly instantaneous intrusion of mafic material along the length of the nascent Pangean rift system. These intrusions are known today as the Central Atlantic Magmatic Province (CAMP), a name which underplays their true extent, as CAMP-associated rocks extend from offshore Argentina in the south to southwestern Europe in the north. The TJB is associated with a major extinction of marine fauna, an event not recognized as easily in the terrestrial record. This research utilizes existing data from the Luck Stone Quarry in Fairfax, Virginia, collected along a traverse crossing a metamorphic contact aureole adjacent to a large CAMP-associated dike. Previously collected reconnaissance energy-dispersive specroscopy (EDS), bulk rock chemistry, and sulfur and carbon isotope composition determinations have been complemented with focused EDS characterization and detailed petrography. These data will be further supplemented with electron microprobe determination of chemical zonation and in situ SIMS determination of isotopic fractionation within individual crystals. These data will be used to constrain reactive transport models designed to investigate the behavior of sulfur and carbon species in the metamorphic aureole. The ultimate goal of this research is to characterize the effects of CAMP activity on the sulfur and carbon systems.

Advisor: Drs. B. C. Gill and M. J. Caddick

THE ROLE OF VARIATIONS IN LITHOSPHERIC BUOYANCY FORCES IN DRIVING DEFORMATION AT THE EASTERN BRANCH OF THE EAST AFRICAN RIFT SYSTEM

RAJAONARISON, Tahiry, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

Understanding the balance of forces that drive continental rifting is a long-standing problem of geodynamics. The East African Rift System (EARS) is diverging the Nubian and Somalian plates with approximately E-W extension, generally thought to be driven by variations in lithospheric buoyancy. However, whether the rift is mainly driven by variations in lithospheric buoyancy forces is unclear because GNSS velocities show anomalous along-rift motion within the Western Branch, the Main Ethiopian Rift, and the Eastern Branch. These along rift motions are inconsistent with expected E-W extension, but consistent with coupling to northward mantle flow that is inferred from azimuthal anisotropy. Here, we focus on the Eastern Branch of the EARS and test if lithospheric buoyancy forces, in the absence of mantle flow, drive the present-day deformation. To do so we use instantaneous 3D numerical modeling with the open source code ASPECT. Using ASPECT, we calculate surface deformation induced by lithospheric buoyancy induced stresses that are derived from topography (ETOPO1) and internal variations of density (CRUST1.0) for the Eastern Branch and surroundings. The lithospheric temperature structure is derived from estimates of regional lithospheric thickness and surface heat flow, which are used to calculate a steady-state conductive geotherm characteristic of the continental lithosphere. The rheological model combines non-linear viscous flow with plastic failure in the crust. Our result suggests that variations in lithospheric buoyancy forces mainly drive the E-W extension, which is consistent with previous studies, but do not explain northward along-rift motions. Additional forces, such as coupling to asthenospheric flow, must be acting on the EARS.

Advisor: Dr. D. S. Stamps

ONE-DIMENSIONAL VERTICAL MODELING ANALYSIS OF SUBSIDENCE IN THE SOUTHERN COASTAL PLAIN OF VIRGINIA BY AQUIFER/AQUITARD COMPACTION FROM GROUNDWATER PUMPING

ROETHLISBERGER, Nathan, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

The Coastal Plain in the southern Chesapeake Bay area is becoming increasingly susceptible to nuisance flooding as a result of the combination of sea-level rise and land subsidence associated with aquifer compaction from excessive groundwater pumping. Detailed time-series of cumulative compaction data (land subsidence) from the three USGS deployed extensometers in the region, along with cyclical piezometer data, reflect the nature of the this complex multi aquifer/aquitard system in the Coastal Plain. The Franklin, Virginia and Suffolk, Virginia, extensometers, which were deactivated in 1995, and have been reactivated in 2016. In addition, along with the addition of aa new high-sensitivity bore-hole extensometer has been added in Nansemond, Virginia, in collaboration with the Hampton Roads Sanitation District as a part of the Sustainable Water Initiative For Tomorrow (SWIFT). Yearly compaction rates estimated from the Franklin, Suffolk, and Nansemond reactivated extensometers are 0.5 mm/year, 6.486 mm/year, and -0.86 mm/year, in Franklin, Suffolk, and Nansemond, Virginia respectively. One-dimensional vertical compaction modeling is utilized to estimate the total compaction and differentiate which fine-grained confining units or aquifer interbeds are contributing most to total compaction being measured by each extensometer. Additionally, properties of the system can be estimated including the elastic specific storage of the aquitards and aquifers and the inelastic storage of the aquitards. The total cumulative change in aquifer system thickness estimated by the MODFLOW subsidence package can be compared to the observed total cumulative change in aquifer system thickness at each site for validation. Subsidence rates and aquifer/aquitard properties can be useful for managing and modeling the groundwater system and evaluating the potential impacts from future groundwater injection associated with the SWIFT project in the Virginia Coastal Plain of Virginia.

Advisor: Dr. T. J. Burbey

IMAGING THE GLOBAL STRUCTURE OF THE LITHOSPHERE-ASTHENOSPHERE BOUNDARY

SUN, Shuyang, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

The lithosphere-asthenosphere boundary (LAB) divides the cold, rigid shell from the underlying weaker mantle and is of great significance in understanding plate tectonics and mantle convection. However, its depth and defining mechanism are currently poorly understood. It has been suggested that the LAB is probably a sharp discontinuity (over<30 km) which cannot solely be explained by temperature but might be associated with the presence of partial melting, volatiles, or a change in seismic anisotropy. In this study, we compare seismograms generated in 1-D reference earth models with varying discontinuity sharpness to investigate seismic signals that are sensitive to the LAB structure. At 5 to 100 seconds periods, travel times of SS precursors show negligible differences when a first-order discontinuity is replaced by a gradient zone over 50 km, as long as the average S wave speed over the depth range remains the same. It shows that surface wave overtones at those periods are most sensitive to the sharpness of the discontinuity and can be potentially used to better constrain the LAB. We build a global dataset of finite-frequency traveltime measurements using SS precursors and higher-mode surface waves and invert for global depth perturbations of the LAB based on boundary sensitivity calculated in the framework of traveling-wave mode summation. Despite their distinct geometry in finite-frequency sensitivity, both SS precursor and surface wave overtone data back-projections are consistent with a shallower LAB in oceanic regions. In the Pacific Ocean, inversions from the two independent datasets agree on small-scale structures extending in the northwest direction, possibly associated with secondary convections in the Pacific mantle.

Advisor: Dr. Ying Zhou

QUANTIFYING THE ROLE OF VULNERABILITY IN HURRICANE DAMAGE VIA A MACHINE LEARNING CASE STUDY

SZCZYRBA, Laura, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

Hurricane María (2017) left over 300,000 structures damaged in Puerto Rico and became the third costliest storm in U.S. history. Pre-disaster damage predictions and post-disaster damage assessments are challenging to quantify since they result from complicated interactions between multiple drivers, including the exposure to various hazards, structural resiliency, and demographic characteristics. Each factor may exhibit complex, nonlinear relationships with damage. Socioeconomic characteristics, in particular, can greatly magnify the impact of a natural hazard, however they are frequently ignored in disaster management. In order to more accurately identify areas of greatest need in the wake of a disaster, both the hazards and the socioeconomic conditions need to be carefully assessed since they have been shown to be positively correlated with damage patterns. This study evaluates the contribution of eight drivers of structural damage from Hurricane María in Puerto Rico, leveraging machine learning algorithms to determine the role that human factors played. Ensemble decision tree algorithms can inform both damage prediction, disaster response, and damage assessment efforts because they are readily interpretable, can accommodate large datasets from a variety of different sources and formats, and provide quantifiable measures of feature importance. In this study, Random Forest and Stochastic Gradient Descent algorithms analyzed a rich set of publicly available data with full coverage of Puerto Rico. Predictive features included wind, flooding, landslides, and vulnerability while a damage index representing structural impact normalized by exposure was the target variable. Geospatial processing aggregated all data to a consistent unit of analysis – the census tract, then randomized splitting techniques created representative training and evaluation data subsets to be fed into the algorithms. Automated optimization techniques, including grid search cross validation, tuned the model hyperparameters using error measures to optimize performance. Variable importances and dependencies were then extracted from the top-performing models. Preliminary results demonstrate that societal-driven vulnerabilities play critical roles in damage pattern analysis and the partial dependencies of each predictive variable exhibit unique, often nonlinear, relationships with damage. The findings of this study may indicate that targeted, pre-disaster mitigation efforts should be enacted to reinforce household resiliency in socioeconomically vulnerable areas. Furthermore, recovery programs may need to be reworked to focus on the highly impacted vulnerable populations to avoid the persistence, or potential enhancement, of preexisting inequalities in the wake of a disaster.

Advisor: Dr. R. Weiss

RHAMPHOTHECA: UNDERSTANDING THE EXTANT ANALOG AND FOSSIL RECORD

TO, Khanh, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

The development of teeth was revolutionary in vertebrate feeding evolution and changed the way that they process food, expanding how animals interacted with food both ecologically and biomechanically. However, in several distantly related lineages across synapsids and sauropsids, teeth were then either partially or completely lost (partial edentulism and edentulism, respectively). In at least two lineages, birds and turtles, a rhamphotheca appeared when teeth were lost. The rhamphotheca is a complex keratinous sheath covering the upper and lower jaw bones consisting of different materials and architecture which we do not have fully understood. Within the fossil record, several extinct lineages (including pterosaurs, Permian mammal-relatives, and theropods dinosaurs) have been inferred to have had rhamphotheca. Unless the rhamphotheca is preserved intact with the fossil, there are few bony or chemical signatures known that directly correspond to the presence of a rhamphotheca. Several of the bony correlates that have been used to identify rhamphotheca in the fossil record include the presence or increased presence of pitting for neurovasculature on the jaw bones and edentulism. However, the increased presence of pitting for neurovasculature has also been linked to increased sensitivity in that part of the skull, and some edentulous and partially edentulous taxa do not develop a rhamphotheca. Part of my dissertation work will address two questions: 1) what osteological correlates exist on the macro- and microscale for confirming the presence of rhamphotheca in living and extinct animals?; and 2) what is the microstructural composition and architecture of rhamphotheca across a range of avian species? I will use a combination of histology, contrast-enhanced CT data, and microindentation to characterize rhamphotheca in living birds in order to build a foundation for interpretation of beaks and rhamphothecae in the fossil record. This will provide an understanding for how a key innovation in feeding transformed avian dinosaurs into the most successful and diverse group of tetrapods alive today.

Advisor: Dr. M. R. Stocker

TURBIDITES AS A PROXY OF BOTTOM-WATER OUTFLOW: HILLARY CANYON, ROSS SEA, ANTARCTICA (IODP SITE U1524)

VARELA, Natalia, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

Oceanographic processes that are unique of polar environments, such as sea ice and polynya formation, can trigger gravity flows that transport and deposit sediment down the continental slope, therefore leaving behind a record of the interaction between the climate, ocean, and surface processes. International Ocean Discovery Program (IODP) Site U1524 is located on the levee adjacent to Hillary Canyon, a 500 m deep and 40 km wide submarine canyon-channel system, ~120 km north of the Ross Sea Ice Shelf, West Antarctica, and one of the largest conduits of modern Antarctic Bottom Water (AAWB) outflow. The ~280 m thick sedimentary section recovered at this drill site is an almost continuous record of the turbidity currents that we interpret to have been produced by dense shelf water cascading, and therefore, documenting AAWB outflow history from the late Pliocene (~3.3 Ma) to recent. The use of high-resolution core photographs allowed us to recognize >3,300 thin (1.5 mm average thickness) turbidite beds whose frequency systematically declines up section. To estimate current magnitude, we subsampled 100 of these thin turbidite beds and its directly overlying mud, and performed grain-size analysis using laser diffraction and x-ray particle sizing, respectively. The median grain size of the turbidite beds varies between very fine to medium silt (5-30 μm) with the upper end of the distribution (D90) between medium silt to very fine sand (19 to >100 μm). Mud deposits directly overlying the turbidite beds have an average silt: clay ratio of 23% and show no systematic variability up-section in the grain size distribution. Sediment composition data from cm-scale XRF scanning of the core suggests that the turbidite beds contain a mixture of biogenic (diatom fragments) and terrigenous material. Smear slide analysis of a representative subset of the sampled beds reveals an up-section trend of decreasing biogenic content. The sedimentary record on the Hillary Canyon will enhance our understanding of deep-water turbidity current processes along the Antarctic margin, and by estimating turbidity current properties and the biogenic/terrigenous distribution in the context of the ocean–ice sheet interactions during the Plio- Pleistocene climatic conditions, we can assess the role of the globally important AABW formation.

Advisor: Dr. B. W. Romans

INVESTIGATING THE CARBON ISOTOPE RECORD OF THE END-BOTOMIAN MASS EXTINCTION: PRELIMINARY RESULTS FROM THE SHADY DOLOMITE FORMATION OF SOUTHWESTERN VIRGINIA

YANG, Yezi, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

The end-Botomian mass extinction in the late Early Cambrian (513 – 509 Ma) is the first major animal extinction event in the Phanerozoic, and severely affected reef builders such as archaeocyathids, small shelly fossils and some trilobites. An abrupt, negative $\delta^{13}C$ excursion found in northern Siberian successions slightly predated this extinction event, and may record a perturbation to the carbon cycle related to the biotic crisis. Studies have linked this negative $\delta^{13}C$ excursion to ^{13}C-depleted CO_2 emission from the emplacement of the Kalkarindji Large Igneous Province in Australia. An alternative hypothesis suggests that this excursion is a local signal driven by higher rates of remineralization in the water column. However, since the global expression of the $\delta^{13}C$ excursion is not known, the driver of this perturbation remains uncertain. Here I present carbon isotopic data from the Shady Dolomite Formation of southwestern Virginia as a Laurentian equivalent to the Siberian strata. The Shady Dolomite Formation represents a unique opportunity to assess the global versus local nature of this mid-Botomian negative $\delta^{13}C$ excursion because 1) it is a relatively thick and temporally continuous carbonate succession through the Early to Middle Cambrian 2) our preliminary data are within the same range as the northern Siberian record 3) our preliminary results show that dolomitization does not have outstanding impact on the carbon isotopic record, allowing for primary seawater signatures. This record will assess the extent of the mid-Botomian $\delta^{13}C$ excursion, and help evaluate the environmental drivers behind this excursion and the end-Botomian extinction event.

Advisor: Dr. B. C. Gill

UNDERGRADUATE

STUDENT

ABSTRACTS

GEOSPATIAL ANALYSIS OF OKLAHOMA EARTHQUAKES: 2011 – 2018

CHAMBERS, Cameron, Department of Geosciences, Virginia Tech, Blacksburg, VA 24061

Recent research by our group presented a geospatial analysis of earthquake occurrence and SWD volume within a 68,420 km^2 area in north-central Oklahoma between 2011 and 2016. During this study, several important conclusions were made: Arbuckle SWD well centroids predict the location of the M3+ earthquake centroids, 2014 – 2016 show a strong positive correlation between SWD volume and earthquake occurrence, and earthquake mitigation strategies affect the joint variability of SWD volume and small magnitude earthquakes. This project is a continuation of the study in which we *i.)* focus solely on the seismic area of interest delimited by the Oklahoma Geologic Survey, *ii.)* include years 2017 and 2018 which provide information on the effects of the mitigation efforts set in late 2015 and 2016, and *iii.)* provide an explanation for the spatial correlation of SWD volume and earthquake occurrence using pressure propagation models.

Advisor: Dr. R. M. Pollyea

GEOCHEMICAL CONTROLS ON LITHIUM AND BORON DISTRIBUTIONS IN MINERALS AT THE RHYOLITE RIDGE DEPOSIT

DO, Camille, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

To sustainably power the future, the world will need to begin using more renewable "clean" energy and make the transition away from fossil fuels. Resource demand is outpacing supplies to support this transition and is one of our technological challenges. The United States (US) is heavily dependent on other countries for many strategic elements/minerals. One of these elements is lithium which is needed to power this clean energy transition as it is used in lithium-ion batteries in electric vehicles.

To help build a stronger domestic market for batteries in the US, the strategic mineral program and industry are partnering to identify and evaluate potential opportunities to extract lithium-rich deposits in the US. Numerous lithium-rich deposits have been identified in Nevada, but their distribution, geochemical controls, and mineralogy are poorly understood. In this investigation, we are evaluating the geochemistry and mineralogy at Rhyolite Ridge, Nevada to better understand the distribution of lithium and boron.

Within the lake sediments of the Cave Springs formation at Rhyolite Ridge, there are two major mineralized zones: the upper zone, which has high lithium concentrations, and the lower zone, which has both high lithium and boron concentrations. Lithium, in the upper zone, is primarily found in hectorite (lithium-rich smectite) and, in the lower zone, is found primarily in lithium- rich illite (associated with boron). The observed distribution of lithium and boron and the associated mineralization may have occurred as a result of hot spring fluids impacting the lacustrine sediments, which are then preserved within the claystones, but controls on these processes continue to be analyzed.

Rhyolite Ridge is a lithium-boron rich deposit in Nevada that may potentially provide the US some internal supplies of lithium. By understanding and identifying the connections between these elements and minerals and other deposits, the United States may be able to further expand our domestic production of lithium.

Advisor: Dr. J. Chermak

INVESTIGATION OF AUTOPODIA OF PHYTOSAURIA AND THE ANCESTRAL CONDITION IN ARCHOSAURIA

EDDINS, Hannah-Marie S., Dept. of Animal and Poultry Sciences, Virginia Tech, Blacksburg, VA, 24061

Hand and foot morphology includes key features for understanding archosaur phylogeny, evolution of anatomical systems, and biomechanical transitions. Whereas the ankle and foot received much attention, the hand has not, largely because it is poorly represented in earlier relatives. Moreover, of the few archosaur species that have a hand preserved, few have both the foot and the hand preserved in the same individual. Within Phytosauria there is a complete absence of diagnostic cranial material associated with nearly any hands and feet, which affects our knowledge of the ancestral condition for Archosauria. Here we describe the right hand and foot of the well-preserved phytosaur *Machaeroprosopus pristinus* (UCMP 27235) in order to aid in resolving details of some of the postcranial anatomy within Phytosauria and across archosaurs. UCMP 27235 is a nearly complete articulated skeleton, and material includes all of the metatarsals with many associated phalanges as well as the astragalus. The astralagus has a shallow anterior hollow, and the 5th metatarsal is hooked; these characteristics are shared across the phytosaurs *Smilosuchus*, *Parasuchus*, and *Diandongosuchus*, demonstrating conserved morphology of the foot of Phytosauria. Of the five metacarpals present, metacarpal three is longest, then the fourth, second, first, and the fifth is the shortest. Metacarpal three as the longest implies a possible upright posture. This specimen lacks carpals, and the only other manus of a phytosaur described in detail, that of *Parasuchus hislopi*, also lacks carpals, meaning it is possible that these structures never ossified in phytosaurs. Additionally, the absence of ossified carpals and tarsals in UCMP 27235 appears to be shared by all phytosaurs and may indicate that cartilage was a critical factor in the morphology and functionality of the hand and foot in this clade. Furthermore, it may be a signal of semiaquatic ecology. Additionally, comparing the hand and foot material to that of trackways that have been previously assigned to phytosaurs, we may be able to tie ichnotaxa to specific track-makers. Phytosaurs appear to modify the carpals through clade evolution, but the overall architecture of the hand appears to reflect the ancestral condition for Archosauria.

Advisor: Dr. M. R. Stocker

BENCH-SCALE EXPERIMENTATION WITH FERRIC HYDROXIDE COATINGS ON CALCITE FORMED DURING THE REMEDIATION OF ACID MINE DRAINAGE

FARIS, Ryan, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061
WATSON, Steven, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

Acid mine drainage (AMD) results from mining operations that disturb Earth's surface, facilitating the oxidation of metallic sulfides, such as pyrite. This process impacts environmental water quality by releasing metallic cations, sulfate anions, and hydrogen ions into the surrounding environment. The negative impact can be mitigated by passing polluted water through a trench filled with crushed limestone to neutralize the acidity with carbonate. However, this "passive" remediation process progressively precipitates large quantities of iron hydroxide as pH rises, coating the limestone and inhibiting surface reactions with H+.

In this project, a mixed flow reactor (MFR) simulates the AMD system to closely examine the neutralization rate and better understand the parameters controlling the development of ferric hydroxide coatings on carbonates. A known amount of crushed calcite (~ 2 to 5g) was inserted into the MFR, then iron sulfate solution containing 0.2 to 2 mM Fe with adjusted pH was injected into the reactor's base at a rate of 1-1.25 ml/min until |d(pH)/d(t)| was less than .01 pH/5 min. Changes in pH were monitored using an in situ pH flow cell and effluent samples were collected at a rate of 1 sample/10 min to analyze Fe, SO4-2, and Ca using ICP-OS. After experiment completion, precipitated iron was recovered from the calcite surface to determine mineralogical phases and particle size using Powder X-ray Diffraction and small angle scattering, respectively.

Results showed that once the solution enters the MFR, dissolution of calcite consumes the free H+ ions to produce carbonic acid, sharply raising the effluent pH to ~ 6. However, while pH > 4, neutralization decreases as ion transport is impaired by Fe(III) precipitating and coating the calcite as Fe(OH)3. After only three to four hours, the effluent's acidity approaches that of the source until steadying at 3 pH. This pattern of rising and falling pH is consistent amongst the four concentrations tested, all of which were prepared at pH 2. The effluent's ICP-OS shows a decrease in Ca dissolution, while Fe and SO4-2 both increase in presence as precipitation decreases. The effluent exhibiting that d(Fe)/d(t) > d(SO4-2)/d(t) hints that Schwertmannite ($Fe_8O_8(OH)_6(SO_4)$) is primarily produced over Goethite (α-FeO(OH)). The XRD may confirm this assumption later in the project. This research is providing important information for improving the effectiveness of passive AMD drains by better understanding how Fe(OH)3 precipitation influences the rate at which calcite neutralizes pH.

Advisor: Dr. F. M. Michel

ESTIMATION OF GRAIN SIZE OF SAND FRACTION FROM DEEP-SEA MUD DEPOSITS USING IMAGE-ANALYSIS TECHNIQUES, IODP SITE U1525A (PLIOCENE-PLEISTOCENE), ROSS SEA, ANTARCTICA

GHAMEDI, Omar, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

Grain-size analysis of a sedimentary material is a fundamental tool in the reconstruction of depositional environments, by recording the dynamic processes involving transportation and deposition. Characterization of sand size is especially important in glacio-marine deposits because of the variable processes (e.g., bottom currents vs. ice rafting). However, this is time-consuming because it involves assessment on the microscope of several samples to define grain characteristics and distribution. Thus, in order to facilitate this analysis, Buscombe (2013) developed the Digital Grain Size (DGS) algorithm, an image-analysis software that determines grain-size distribution based on the dispersal of light intensity within a photographic image of the sample. To test this method, a series of images were acquired of a set of ten coarse-fraction samples from International Ocean Discovery Program (IODP) Site U1525A from the Antarctic continental margin, and the results were compared to determine if the color and/or brightness of the images had any impact on grain-size distribution.

Two identical images of each sample were processed in standard color and greyscale. In nearly all sample images a distinct lighting pattern was observable. After running the images through DGS, the Normalized Frequency vs. Grain size (mm) plots were nearly identical. However, samples with larger, brighter grains had drastically different results for standard color and greyscale. This suggests that the image format may have an impact on grain-size distribution results when applying DGS to digital images. This subtle brightness variation likely impacted the final distribution graph, and eventually, could affect the sedimentological interpretation.

Advisor: Dr. B. Romans

ANALYSIS OF GPS MONUMENTATION FOR THE EAST AFRICAN RIFT SYSTEM

GORJON-ANDUJAR, Roberto, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

Poor GPS monumentation can result in non-tectonic signals being observed at the station. In this work, we aim to analyze the monumentation of GPS instruments in East Africa, an area both seismically and volcanically active. This investigation potentially allows data that has been affected by non-geologic mechanisms to be isolated when calculating tectonic displacements. Types of monumentation were organized into 6 groups: (1) instruments positioned in bedrock, (2) instruments positioned on boulders, (3) instruments braced in sediments, (4) instruments placed on building rooftops, (5) instruments placed on concrete slabs and pillars, and (6) sites with unknown monumentation due to availability of documentation. Additionally, position data is either collected continuously at a station left in the field, or a measurement is episodic such that a marker is left behind and data is collected repeatedly over a period of years. The region of study spans longitudes 22° to 56° and latitudes -52° to 20° - The East African Rift System. At this stage in the project, sites have been sorted based on monumentation, and velocities have been correspondingly visualized onto 6 maps. In the next steps of this research a statistical approach will be used to quantify deviations of individual groups and sites when compared to an existing model. This approach requires comparing the velocities of individual sites, to calculated velocities based on modeled Euler pole and rotation definitions of pertinent tectonic plates.

Advisor: Dr. D. S. Stamps

THE FIRST PECTORAL AND FORELIMB MATERIAL ASSIGNED TO THE LAGERPETID *LAGERPETON CHANARENSIS*: COMPARING TO OTHER LAGERPETIDS AND OTHER AVEMETATARSALIANS

MCCABE, Mason, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

The posture of the earliest dinosaurs is thought to be bipedal whereas their crocodilian relatives and stem archosaurs are thought to be typically quadrupedal. Therefore, the transition from quadrupedality to bipedality lies somewhere between the origin of bird-line archosaurs and Dinosaurs. However, studying this transition is hampered by the lack of forelimb fossils from many of the close relatives of dinosaurs and it is not clear if the morphology of the dinosaur relatives had forelimb morphology that was unique or represent the ancestral condition leading to dinosaurs. Here I present the first pectoral (left scapulocoracoid) and forelimb (left humerus) bones of the important early dinosaur relative, *Lagerpeton chanarensis*. The bones were prepared from a concretion that only consisted of *Lagerpeton* bones and from an early mammal relative called *Massetognathus*. We identify the bones as belonging to *Lagerpeton* because the end of the femur possesses an inflated condyle that is unique to lagerpetids, and the newly recognized pectoral and forelimb bones are generally similar to those of other lagerpetids such as *Dromomeron romeri* and *Ixalerpeton*. The length of humerus and the proportions of the proximal and distal end in *Lagerpeton* is most similar to that of *Dromomeron romeri*. Overall, the scapulocoracoids and humeri of lagerpetids are similar in proportion across the group, but comparing the length of the forelimbs to the hindlimbs is hampered by the lack of articulated or unambiguously associated individuals of any member of the group. Currently, it is still not clear if the anatomy of the pectoral girdle and forelimb of lagerpetids, and thus posture, is unique for lagerpetids or represents the ancestral condition for dinosauromorphs.

Advisor: Dr. M.R. Stocker

DENTAL MICROWEAR ANALYSIS OF TWO NEW SPECIES OF TRILOPHOSAURID FROM THE CHINLE FORMATION (AZ)

MELLETT, Michael P., Dept. of Biological Sciences, Virginia Tech, Blacksburg, VA 24061

Determining the specific diets of Triassic animals is crucial to understanding the stability of ecosystems during concurrent changes in the Earth system including climate change and bolide impacts in the post-Permian extinction recovery period. Herbivores, specifically, can inform on the ecosystem and trophic structure of a paleocommunity. Trilophosaurids are a group of Late Triassic reptiles found in what is now North America and Europe and are named for their three-cusped teeth. Beyond suggestions of herbivory for that group, little research has been done on their diets. In many herbivores the teeth wear against each other and their food as they chew, making diet a major influence on the patterning of wear surfaces on teeth. Measuring the patterning of scratches and pits on the teeth (known as microwear analysis) is an effective way to clarify diets of both extinct and extant species with burgeoning applicability for reptiles. Here we used a Scanning Electron Microscope to quantify microwear from two specimens of trilophosaurids, PEFO 43837 (lower jaw with teeth) and PEFO 42082 (isolated tooth), representing two new species of trilophosaurids collected from the Late Triassic Chinle Formation in Petrified Forest National Park, Arizona. PEFO 43837 is unique for having more bulbous teeth than those of other trilophosaurids, whereas PEFO 42082 is unique for possessing two, as opposed to three, cusps on each tooth. Relative abundance of scratches to pits was analyzed to determine approximate diet, taken at a magnification of 1200x for PEFO 43837 and 600x for PEFO 42082. Microwear structures are nested within their visible range, making results comparable despite different scales of image. Our analysis found PEFO 43837 to have a high proportion of pits to scratches, indicating a diet of tough plants, such as cycads. PEFO 42082 was found to have a high proportion of scratches to pits and indicates a diet of softer plants, such as ferns. Ferns and cycads are common in plant-bearing horizons stratigraphically equivalent to the trilophosaurid-bearing sites, suggesting resource partitioning of trilophosaurid diets in Chinle ecosystems. This is one of the first times that herbivore resource partitioning has been suggested in Late Triassic communities. This shows that herbivore diversity and ecology in the Chinle is more complex and diverse than previously suggested.

Advisor: Dr. M. R. Stocker

A NEW REPTILE FROM THE MIDDLE TRIASSIC OF MADAGASCAR MAY INDICATE THE PRESENCE OF OSTEODERMS IN THE EARLIEST-DIVERGING AVEMETATARSALIANS (ARCHOSAURIA)

PATELLOS, Emily, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

The fossil record is key to understanding the evolution, systematics, and biodiversity of species in the past. Understanding the morphology of the hypothetical common ancestor of Archosauria has been hampered by a poor fossil record largely because the earliest diverging avemetatarsalians (bird-line archosaurs) known, such as *Teleocrater*, are separated from the earliest pseudosuchian (crocodilian-line) archosaurs and the closest outgroups of Archosauria by a clear morphological gap. Here, we describe a new taxon that appears to bridge the morphological gap between avemetatarsalians and pseudosuchians. The potential early-diverging avemetatarsalian from the "Basal Islao II" beds of Madagascar (?Middle Triassic, ~230 Ma) is represented by a partial skeleton including articulated cervical vertebrae with articulated dorsal osteoderms; a scapulocoracoid; a partial femur; an ilium; and isolated trunk, sacral, and caudal vertebrae. Noteworthy features of the neck region include: anteroposteriorly elongated vertebrae with laterally expanded dorsal ends of the neural spines, and an articulated set of osteoderms dorsal to the vertebrae. The cervical osteoderms, three pairs per vertebra, arranged in paramedian row, and bear tapering anterior processes. Potential synapomorphies of this specimen with avemetatarsalians include: femur with an incipient anterior trochanter, 1st sacral vertebra with a dorsoventrally expanded sacral rib, and ilium possessing a notch on the articulation surface with the ischium. These features place the new taxon represented by this specimen at the base of Avemetatarsalia, outside aphanosaurs (*Teleocrater)* + dinosaurs. This position is poorly supported due to the incomplete skeleton and generally plesiomorphic morphology of the new taxon. However, the taxa being placed within Avemetatarsalia indicates that osteoderms were present in the earliest bird-line archosaurs. Furthermore, the presence of an early diverging avemetatarsalian along with a lagerpetid and silesaurid in the "Basal Isalo II" beds of Madagascar documents cooccurrence of multiple subgroups of avemetatarsalian in Gondwana during the Triassic.

Advisor: Dr. S. Nesbitt

TESTING THE ASPECT-BALTO PLUG-IN BY MODELING LITHOSPHERIC MODULATED CONVECTION BENEATH THE MALAWI RIFT

ROANE, Ryan, Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

In this project, we test the open-source ASPECT-BALTO plug-in (Advanced Solver for Problems in Earth's Convection - Brokered Alignment of Long-Tail Observations). The ASPECT-BALTO plug-in is cyberinfrastructure that allows for seamless access and readability of data from the remote BALTO server. The approach involves the implementation of OPeNDaP's Hyrax open-source software. We test the reliability and usability of the ASPECT-BALTO plug-in by modeling Lithospheric Modulated Convection (LMC) in the Malawi Rift. To do so, we broker a lithospheric thickness model of the Malawi Rift from the BALTO server and use it as input for a computational model designed to calculated LMC. The model involves solving the incompressible Stokes Flow Equation for LMC in the asthenosphere. In our testing, we find that using the ASPECT-BALTO plug-in provides a solution that is consistent with LMC modeled using an alternative approach, hence the new cyberinfrastructure is validated.

Advisor: Dr. D. S. Stamps

CRYSTAL FORMATION ONTO AN ORGANIC MATRIX: EFFECT OF PH ON NUCLEATION RATE AND POLYMORPHS OF CALCIUM CARBONATE

WOREK, Michelle M., Dept. of Geosciences, Virginia Tech, Blacksburg, VA 24061

Organisms synthesize skeletal structures as mineral-organic composites in a process known as biomineralization. Calcium carbonate ($CaCO_3$) is the most abundant biomineral in the ocean and typically occurs as the three most common polymorphs – aragonite, calcite, or vaterite. Progressive acidification of world oceans raises the question of how decreasing pH will impact the rate and types of $CaCO_3$ polymorphs that form.

We tested the hypothesis that environmental pH influences the type of polymorph that initially precipitates onto an organic matrix and the nucleation rate. A series of experiments were conducted, with triplicate replications, using Type B gelatin as a simple model for an organic matrix. The gelatin was mounted in a flow-through cell using $CaCl_2$ and Na-HCO_3 solutions; and with the pH of each bicarbonate solution adjusted to 8.98, 9.32, or 9.90. The formation of crystallites was recorded with an optical microscope equipped with Leica Application Suite software using previous methods to determine the nucleation rate (Giuffre et al., *PNAS*; Hamm et al., 2014, *PNAS*). SEM and XRD were used to characterize the resulting polymorphs.

For the control system, vaterite formation is predominant at all pH conditions, with variable amounts of aragonite and calcite. The rate of nucleation decreases with solution pH where rates at pH = 8.98 are approximately 50% of rates at pH = 9.90. With the introduction of magnesium chloride ($MgCl_2$) at a Mg:Ca ratio = 3:1, aragonite is the only polymorph to form. There is no evidence of calcite or vaterite for any solution pH. The rate of aragonite nucleation is approximately 2X faster than the control experiments for all pH conditions; the rate is pH dependent with slowest rates at the lowest pH (8.98). Additional experiments will determine the pH influence on chitosan as an organic matrix.

The rate of $CaCO_3$ formation in oceans, and the resulting polymorphs, may be compromised or inhibited due to lowering pH levels in marine environments.

Advisor: Dr. P. M. Dove

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