51st Annual Graduate Student Colloquium

Eastfjords, Iceland. Photograph by Collin Oborn

Sponsored by Shell

Hosted by the Department of Geosciences

March 28th – 29th, 2019

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The Graduate Student Colloquium is a student-organized annual event that celebrates the research accomplishments of our graduate student community. This event is hosted by the Department of Geosciences and is open to all graduate students involved in geosciences related research. The Graduate Student Colloquium provides all of us with an opportunity to present our research to the department, receive feedback from faculty judges and peers, and compete for monetary prizes. The colloquium format also stimulates research discussion, and helps students improve their communication skills and think about the broader implications of their work

The Graduate Colloquium Committee wishes to thank in advance the students and faculty for their participation. The Committee also wishes to thank the Shell People Services Division of Shell Oil Company; the Department of Geosciences for their donations of prize money and their generous financial support; and Dave Cannon and his family for their generous donation towards the graduate colloquium awards.

Graduate Student Colloquium Committee Members:

Erica Pitcavage (chair), Jonas Kintner (chair), Srisharan Shreedharan, Kalle Jahn, Rebecca Payne, Heather Jones, Guangchi Xing, Josh Woda, Kirsten Stephens

Event Schedule

Thursday, March 28

Kick Off Lunch – 11:45 to 12:45 pm – 5th Floor

Poster Session 1 – 12:30 to 1:45 pm – 5th Floor

Coffee – 1:45 to 2:00 pm – 5th Floor

Oral Session 1 – 2:00 to 3:15 pm – Deike 541

Oral Session 2 – 3:30 to 4:45 pm – Deike 541

Friday, March 29

Breakfast – 8:30 to 9:00 am – 2nd Floor

Oral Session 3 – 9:00 to 10:15 am – Pulse of the Earth (Deike 240)

Coffee – 10:15 to 10:30 am – 2nd Floor

Oral Session 4 – 10:30 to 11:30 am – Pulse of the Earth (Deike 240)

Lunch – 11:45 to 12:45 pm – 5th Floor

Poster Session 2 – 12:30 to 1:45 pm – 5th Floor

Oral Session 5 – 2:00 to 3:00 pm – Pulse of the Earth (Deike 240)

Coffee – 3:00 to 3:15 pm – 2nd Floor

Oral Session 6 – 3:15 to 4:15 pm – Pulse of the Earth (Deike 240)

Reception – 4:30 to 6:00 pm – 5th Floor

The Peter Deines Lectureship

The first place award for an oral presentation by a post-comprehensive Ph.D. student is designated the Peter Deines Lectureship for the following academic year.

This award was started in 2004 to represent the tremendous amount of respect and admiration the graduate students in the Department of Geosciences had for Dr. Peter Deines, who that year was stepping down from the position of Graduate Program Chairman. Recipients of the honor are invited to give a departmental colloquium talk during the proceeding academic year.

The department and the world lost a great man and wonderful person when Peter passed away on February 2, 2009. It is with great pride that the Graduate Student Colloquium continues the tradition born in 2004.

Past Recipients:

2018-2019: Beth Hoagland

2017-2018: Matthew Herman

2016-2017: Rosie Oakes

2015-2016: John Leeman

2014-2015: Ashlee Dere

2013-2014: Jonathan Schueth

2012-2013: Elizabeth Herndon

2011-2012: Bryan Kaproth

2010-2011: Tim Fischer

2009-2010: Aaron Diefendorf and Bryn Kimball

2008-2009: Daniel Hummer

2007-2008: Gavin Hayes

2006-2007: Christina Lopano

2005-2006: Shawn Goldman and Courtney Turich

2004-2005: Margaret Benoit

The Peter Deines Lectureship

Peter Deines (4/02/36 - 2/02/09) earned a Geologen Vordiplom at the Rheinsche Friedrich Wilhelms Universitaet, Bonn, Germany in 1959, an M.S. (1964) and a Ph.D. (1967) in Geochemistry and Mineralogy from Penn State University. Since 1967, and after 2004, as an Emeritus Professor, he was a member of the Geological Science Faculty of the Pennsylvania State University. He earned an international reputation for his geochemical research, teaching, and science administration. Recognition came in teaching awards, election to the University Senate, in which he served for 24 years, and election especially to Treasurer of the International Geochemical Society. In that office, he was so effective that he was awarded a unique Honorary Life Membership for his financial management of the society. He was a principal organizer of that Society's primary international meetings, the famous Goldschmidt Conferences.

With his gift for organization, he also served the Department of Geosciences on most of its committees and he served as its Graduate Program Chairman, while also administering committees for the College of Earth and Mineral Sciences, primarily for Scholarships. Most important was his commitment to the University Academic Senate, in which he served in 28 committee posts, including its Chair for 1990-91; and to the University, on 34 committees and commissions, including University Ombudsman since 2006. He also was elected President of the Faculty-Staff Club. Dr. Deines' research centered on precise explanations of natural variations in stable isotope abundances as means of understanding geologic processes. Results were presented in lectures throughout the world and in over 60 published papers. His illustrated book, "Solved Problems in Geochemistry," was polished by his teaching of eight graduate courses and is available on the web especially for graduate students.

A 40-year member of the Nittany Valley Symphony, Peter will be missed for his finesse with violin and viola.

Thursday, March 28th

12:30 – 1:45 PM **Poster Session 1**

2:00 – 3:15 PM **Oral Session 1**

3:30 – 4:45 PM **Oral Session 2**

Friday, March 29th

9:00 – 10:15 AM **Oral Session 3**

10:30 - 11:30 AM **Oral Session 4**

12:30 – 1:45 PM **Poster Session 2**

2:00 – 3:00 PM **Oral Session 5**

3:15 – 4:15 PM **Oral Session 6**

Poster Session 1

Thursday, March 28th 12:30 - 1:45 PM

Field investigations of bio-induced calcium-carbonate precipitation mechanisms at the origin of whiting events

Chloe Stanton
Master's Student, 2nd year

Advisor: Julie Cosmidis & Lee Kump

Whiting events – the episodic precipitation of fine-grained $CaCO_3$ minerals suspended in the water column – have been documented across a variety of environments, including both marine and lacustrine settings. Whitings could be a predominant source of carbonate muds, especially in the Precambrian, before the rise of green algae, a major source in the Phanerozoic, and are important archives for geochemical proxies of Earth history. While several biological hypotheses have been proposed to explain the onset of these precipitations, no consensus has been reached so far, and it is still unclear which process dominates in which environments. Our understanding of these mechanisms is however crucial to our understanding of the geological record.

We are performing both field and laboratory tests of different proposed models for biological $CaCO_3$ precipitation involving cyanobacteria, diatoms, and viruses, as possible mechanisms for whiting events. Time-series field studies were initiated this year at Green Lake in Fayetteville (NY), which experiences a whiting every year initiated in the spring and persisting through the summer. Relevant geochemical parameters were analyzed in the water column, while suspended minerals, cells, and extracellular materials were collected and visualized using scanning electron microscopy and scanning transmission X-ray microscopy. Laboratory experiments aiming at reproducing different proposed (bio)mineralization mechanisms at the lake, including the novel hypothesis of viral lysis involvement, as well as investigations into the impact of interactions with biological materials on the Ca isotopic composition of carbonate minerals, are forthcoming.

Preliminary results suggest that two groups of plankton are involved in whiting events at Green Lake. As previously reported, Synechococcus cells are associated with large calcite grains. A new finding is the role of diatoms: small carbonate grains are ornamenting their siliceous tests, and larger grains are associated with diatom-exuded EPS. Monthly sampling reveals the evolution of the whiting in terms of water depth, water chemistry, biotic mediation, and crystal growth.

Dynamic Time Warping as a technique for identifying gaps and distortions in proxy climate records: Application to the Paleocene-Eocene Thermal Maximum

Seyi Ajayi
Ph.D. Student, 3rd year, Pre-Comps

Advisor: Lee Kump

Variations in sedimentation rate, bioturbation, and dissolution create gaps and distortions in the sedimentary record, establishing a convoluted relationship between depth and time of a geochemical proxy. Dynamic time warping (DTW), a signal processing method used in speech recognition, can be used to align two time series with similar patterns and is used in this study in one of its first applications to chemostratigraphic alignment. DTW helps us better understand convoluted records by aligning these records with more complete records spanning the same time period at different locations. In this application of the methodology, we align bulk sediment carbonate isotope records ($\delta^{13}C$) from various records spanning the Paleocene-Eocene Thermal Maximum, a large global warming event 55.8 Ma, that records a globally synchronous negative carbonate isotope excursion (Kennett & Stott, 1991; McInerney & Wing, 2011). $\delta^{13}C$ records for Walvis Ridge sites 1262 and 1265 were first aligned to the more complete site 1263 record. The $\delta^{13}C$ alignments were found to be similar to existing published alignments based on correlating breaks and inflections in the isotope record by hand. The $\delta^{13}C$ record from Maud Rise Site 690 was then aligned to Site 1263. This alignment creates a previously unidentified hiatus in Site 690, which would indicate that the carbon isotope excursion did not record its minimum value at this site. These preliminary results indicate that DTW may provide a more objective way to align climate proxy records, identify gaps and distortions, and together with astrochronology and geochronology, lead to a more complete understanding of the geologic record of biospheric events in deep time.

Coupled Heat and Fluid Flow model for the Hikurangi subduction margin

Dorivaldo Alexandre Santos
Ph.D. Student, 2nd year, Pre-Comps

Advisor: Demian Saffer

Rob Harris, Oregon State University

Preliminary analyzes of heat flow data obtained across the northern Hikurangi margin, New Zealand, indicates an average background heat flow of 56 mW/m2 for the subduction margin. However, short wavelength variations from this mean are observed within 15 km of the deformation front (landward) which could be explained by the existence discharge of warm fluids through one or more of the several splay faults that intersect the seafloor in the area. The modeling of this heat flow data presents an opportunity to gain further insight into the accretionary prism's heat and fluid flow regime, distribution of fluid pressures, as well as the hydrologic and mechanical properties of its sediments and faults. In addition, the interplay between these processes and properties is thought to exert a first order control in the location and timing of earthquake occurrence in the region. We present a two-dimensional numerical model of coupled fluid flow and heat transport to test the hypothesis that fluid discharge through one of the splay faults at the Hikurangi accretionary prism can be used to explain the heat flow observations across it.

Temperature variation in tectonic mélanges of the Shimanto Belt, SW Japan

Tsai-Wei Chen
Ph.D. Student, 1st year, Pre-Comps

Advisor: Donald Fisher

Andrew Smye, Penn State University
Yoshitaka Hashimoto, Kochi University

Silica redistribution along plate interfaces is a fault zone aging process likely to affect the slip behavior of subduction interfaces. Numerical modeling for slip according to the rate law based on silica kinetics reproduces the characteristics of real-world subduction zones, such as an updip limit to the seismogenic zone, earthquake clustering, and a power-law size distribution of earthquake magnitudes. In the field, the structure of subduction fault zones is typically marked by veined sandstone blocks within mudstones with scaly fabric, with mudstones providing a local source of silica and other elements that precipitate as minerals veins, which act as a sink for mobile elements. The silica kinetics related to diffusion from shearing mudstones to cracking sandstone blocks in mélange provides a temperature dependent mechanism for fault zone aging whereby the contact area across the fault zone increases in the time between slip instabilities. In the Shimanto belt of Japan, scaly fabric and vein microstructures show textural variability as a function of temperature. There is a gradient in the age of paleosubducting oceanic crust from north to south within the inner Shimanto belt, from the Yokonami mélange, with a thick pelagic chert section and older basalt and younger mélanges in the south (Okitsu, Hyuga, and Mugi) with little or no chert section, suggesting younger subducting crust. Thus, the mélanges of the Shimanto belt were accreted at different temperatures and depths along the interface, and there also may have been differences in the subduction geotherm. We suggest that these variations in temperature are likely to lead to different silica kinetics and rates of mineral redistribution, recorded in microstructural variations that may reflect different frictional properties along the plate interface. The slip behavior of the plate interface depends on temperature as evidenced by down dip variations in slip mode and differences in earthquake size distributions for subduction zones with different age crust. We therefore have undertaken a study of oxygen isotope thermometry using coexisting mineral pairs of quartz-albite-calcite observed in the tectonic mélanges from the Shimanto belt at a variety of estimated temperatures. This data provides an independent method for evaluating the temperature during mineral redistribution that can be compared with current estimates based on vitrinite reflectance and fluid inclusion analyses.

Seismic attenuation improves the understanding of hydrate saturation and the gas hydrate morphology in south Hydrate Ridge

Aoshuang Ji
Ph.D. Student, 2nd year, Pre-Comps

Advisor: Tieyuan Zhu

Gas hydrate as a promising energy resource is widely distributed in the continental margins. Further quantitative assessment of the gas hydrate will be critical for exploitation. It is well documented that seismic methods can identify gas hydrate as the bottom simulated reflectors in seismic images. However, the relationship between seismic properties and gas hydrate remains poorly understood, which prevents using seismic methods from quantitative assessment of gas hydrate. Recent studies demonstrate that the seismic attenuation is sensitive to hydrate saturation but the relationship between them is still controversial. Here we analyze the seismic attenuation data estimated from the vertical seismic profile (30 – 150 Hz), and sonic logging data (10 k – 15 kHz) collected by ODP leg204 in the Hydrae Ridge. Our study aims to understand how hydrate saturation and the morphology of the hydrate (i.e. pore-filling hydrate and cementing hydrate) influence the attenuation. First, we compare our attenuation data with data from three other hydrate sites (Canada, India, and Nankai). Although four geologic settings would be very different, we found that seismic attenuation is relatively high in Canada and India where hydrates saturation is high (60% - 80%) and small in Nankai and Hydrate Ridge which have low hydrate saturation (<40%). To quantify our interpretation, we employ a rock physic model considering the microscopic phase. Our results indicate that the cementing hydrate can cause the similar seismic attenuation at lower frequency range (30 – 150 Hz) and sonic range (10 k – 15 kHz) in hydrate-bearing sediments, which is the case of the Hydrate Ridge with 80% - 95% cementing gas hydrate. Our findings also suggest that both saturation and morphology of the hydrate should be taken into consideration.

Seismicity in central West Antarctica revealed by POLENET seismic stations

Erica Lucas
Ph.D. Student, 1st year, Pre-Comps

Advisor: Andrew Nyblade

Richard Aster, Colorado State University
Douglas Wiens, Washington University in St. Louis
Terry Wilson, The Ohio State University
Audrey Huerta, Central Washington University
Jeremy Paul Winberry, Central Washington University

In this project, the occurrence of small earthquakes within the central portion of West Antarctica is being investigated using broadband seismic data from POLENET stations. The study area encompasses the central and eastern portions of the West Antarctic Rift System (WARS) and the Ellsworth-Whitmore Mountains. We analyze continuous data from the POLENET mini-array, comprised of 10 seismic stations deployed from 2015-2016 in the eastern WARS, along with data from 14 POLENET backbone stations distributed throughout the study area. Using the Antelope software package, continuous data are manually scanned to detect and associate events. For events with P and/or S waves clearly picked on 4 or more stations, preliminary locations and magnitude estimates are obtained using the Antelope location algorithm and the IAPSI 1D velocity model. So far 50+ events have been located using 6 months of data. The events occur mainly in two clusters, one located near the front of Thwaites Glacier, which flows into the Amundsen Sea, and another located in the northern Whitmore Mountains. Preliminary magnitudes range from 0.31 to 3.16. Ongoing work is focused on refining event locations, including source depths, to differentiate sources that are tectonic in origin from those associated with glacial movements and calving at the front of the Thwaites glacier.

A kinetic study of the transformation of ferrihydrite to goethite and hematite as a function of pH and temperature

Xiaoni Hu
Ph.D. Student, 2nd year, Pre-Comps

Advisor: Liz Hajek

Sedimentary records in rift basins are regarded as important source to interpret interacting climate and tectonic processes in Earth history. Generally, tectonic and climate events control the sedimentary record with the following main factors: the sediment flux and grain size distribution from the upstream erosional systems, the diffusivity of sediment transport systems and the accommodation creation rate of the depositional systems. Recent studies have presented that transport systems can blur part of these external signals due to their self-adjustments. Here we build a 1D numerical model to analyze that to what extent could climate and tectonic signals with different magnitude and periods be preserved in the sediment records. We input sinusoidal signals of sediment flux imitating climate changes as well as pulsed signals of subsidence imitating periodic tectonic events. Then key parameters of sediment profiles, including the thickness of depositions, the stacking patterns of sedimentary packages and the downstream fining rate of grain size, are recorded from the model outputs to evaluate the persistence of these external signals. The results show that signals with lower frequency and larger magnitude have higher possibility to be preserved in sedimentary records than signals with higher frequency and smaller magnitude. Signals with periods longer than tens of thousand years (e.g. precessions in astronomical cycles) are normally capable to propagate throughout the whole systems. In addition, tectonic and climate signals are possible to smear out the variations of depositions induced by each other when they have comparable periods and magnitude.

Chaos and renewal: paleoceanography and the emergence of *Emiliania* in the Cariaco Basin, Marine Isotope Stages 7-8

Adriana Rizzo
Master's Student, 2nd year

Advisor: Timothy Bralower & Katherine Freeman

Emiliania huxleyi is a cosmopolitan coccolithophore that is highly abundant (and biogeochemically important) in the modern ocean. The evolutionary dynamics leading to the origin of this, the youngest coccolithophore species (or speciation in phytoplankton in general) are poorly understood. Here we use nannofossil assemblages, sterol and alkenone biomarkers, and other geochemical data from ODP site 1002 to reconstruct productivity and phytoplankton ecology of the Cariaco Basin during MIS 7-9 (late Pleistocene). We demonstrate that *Emiliania* first became ecologically significant during a period of warming at the end of the MIS 8 stadial. This period was characterized by instability in the sources and quantities of nutrients that resulted in rapid ecological disruption in the phytoplankton, allowing *Emiliania* to gain a foothold.

Carbon monoxide as a source of electrons in photosynthetic microbes

Gregory Wong
Ph.D. Student, 4^{th} year, Post-Comps

Advisor: Christopher House

Carbon monoxide (CO) is an abundant gas in many planetary atmospheres and can be readily used by certain microbes for energy during its oxidation to CO_2. The oxidation of CO is mediated by an enzyme known as carbon monoxide dehydrogenase (CODH). Interestingly, CODH is present in several anoxygenic photosynthetic microbes, which leads to the question of whether CO can act as an electron donor in photosynthesis. While other inorganic electron donors (e.g. ferrous iron, hydrogen sulfide, and molecular hydrogen) have been documented as external electron donors in anoxygenic photosynthesis, it remains unknown whether CO can serve this purpose. Previous studies have demonstrated that a purple non-sulfur bacterial species, *Rubrivivax gelatinosus*, can grow in light with CO as the sole carbon source, but not necessarily as the source of photosynthetic reducing power. Here, we have begun investigations into whether CO can act as an external electron donor during photosynthesis in *R. gelatinosus*. We have grown *R. gelatinosus* in light or dark conditions with nitrogen or CO headspace. We have been removing potential electron donors from the media one-by-one and measured growth of cultures over time with a spectrophotometer. So far, in both complete media and media lacking the primary external electron donor (succinate) both nitrogen and CO headspace cultures have grown in light, but not in dark. The data suggest that cultures are not growing significantly differently with either gas headspace. However, there are other electron donors in the media that can contribute to photosynthetic growth, such as organic compounds in yeast extract. Future research will remove remaining potential electron donors. This work will increase our understanding of microbial metabolic diversity and be telling of new extraterrestrial environments in which microbes could possibly survive, such as Mars.

Carbon monoxide as a source of electrons in photosynthetic microbes

Abby Kenigsberg
Ph.D. Student, 5th year, Post-Comps

Advisor: Demian Saffer

Chris Marone, Penn State University
Jacques Rivière, Penn State University

The elastic and mechanical properties of fault zones control fault zone stiffness, fault slip, damage and healing. The role of gouge characteristics including frictional strength, density, porosity evolution, and fabric formation in modulating these properties remains unclear. Ultrasonic waves have been used to investigate fault zone properties in nature and laboratory experiments. Porosity loss and compaction are most often cited as dominant factors controlling elastic and mechanical properties throughout shear. However, the role of shear localization and fabric development is poorly resolved. In this study, we investigate the effects of composition and shear fabric evolution on fault zone properties. We report on a suite of synthetic (0-100% smectite/quartz) and natural (input sediment samples from the Sumatra subduction zone) fault gouge shear experiments at an effective normal stress of 25 MPa, a shear velocity of ~20 μm/s, and shear strains of ~30. We monitored compressional and shear wave velocities (Vp, Vs) through shearing, while concurrently measuring evolution of friction and porosity and computed shear and bulk moduli.

We find that the evolution of elastic moduli are controlled by the interplay of porosity loss, shear fabric development, and force chain evolution. In general, Vp, Vs, transmitted amplitude and elastic moduli all increase as a function of shear strain and are accompanied by gradual densification and porosity loss. At intermediate shear strains (g = ~2-7) a decrease in wave velocities and elastic moduli is superimposed on this overall trend. Porosity decreases by ~3%and Vp and Vs decrease by 15-20% and 7-10%, respectively over these strains. The coefficient of friction also decreases from peak values of 0.45 - 0.48 to residual values of 0.38 -0.4. SEM images show that shear bands develop parallel to the direction of shear (perpendicular to wave propagation) over these strains. This suggests, at these shear strains, fabric development leads to a reduction in fault stiffness and is more important than porosity loss in controlling elastic properties. Determining the relationships and impacts that fabric and force chain development can have on elastic and mechanical properties allows us to investigate how these micromechanical processes more broadly control fault elastic properties.

Oral Session 1

Thursday, March 28th 2:00 - 3:15 PM

Araucarian conifer fossils of Eocene Patagonia reveal an Australasian rainforest connection

Gabriella Rossetto Harris
Master's Student, 2nd year

Advisor: Peter Wilf

Ignacio Escapa, Museo Paleontológico Egidio Feruglio (Argentina)

The iconic conifer genus *Araucaria* is commonly known as the monkey puzzle tree in South America because its umbrella-like branching structure and sharp leaves would be a challenge to climb. The fossil record shows that *Araucaria* was prolific worldwide during the Mesozoic. However, since the end-Cretaceous the genus has been entirely restricted to the Southern Hemisphere. During the early Cenozoic, globally warm climate and a close connection between South America, Antarctica, and Australia allowed for *Araucaria* to flourish in trans-Antarctic rainforests. Biotic interchange through this southern corridor continued until complete Antarctic separation and cooling began in the mid-late Eocene, causing large shifts in the genus' distribution, which are still apparent in the modern biogeography. Of the 20 living species of *Araucaria*, 14 of them belong to a group called Section *Eutacta* and are restricted to the islands of New Caledonia. The remaining species are divided between Australia, Papua New Guinea, and South America. It remains unclear what the evolutionary age of Eutacta is and whether it was really present in Gondwanan South America due to unconvincing fossils of isolated elements, often of only a single organ type. New fossil data from Patagonia will greatly clarify Eutacta's evolutionary timeline. Rio Pichileufu, Argentina (RP; 47.8 Ma), and a second locality in the neighboring province, Laguna del Hunco (LH; 52.2 Ma) are two exceptionally diverse and well-dated Eocene mesothermal rainforest floras recovered from fossil caldera lake deposits in the modern-day steppe of Patagonia. The RP and LH fossil floras represent ecosystems in Patagonia present before complete opening of the Drake Passage and thus provide evidence for the lineages that must have evolved prior to Gondwanan break up. The fossil *Araucaria pichileufensis*, described from type locality RP 80 years ago, appears more closely related to living Australasian Eutacta species than the South American *Araucaria* species growing in the Andes just 100 km northwest of where the fossils were found. Large new collections of *A. pichileufensis* including pollen cones, leafy branches, and cone scale organs represent the most complete fossil preservation and the first strong fossil evidence that Sec. Eutacta, which is now completely concentrated in Australasia, actually have histories in South America. The objectives of this research are to use systematics and phylogenetics to test for the evolutionary relationships of the fossils with living *Araucaria* and to examine how a Gondwanan connection, and subsequent Antarctic isolation, may have been critical in shaping the modern distributions of the genus.

Quantifying plant extinction and morphological change across the K-Pg boundary in Argentine Patagonia

Elena Stiles
Master's Student, 2^{nd} year

Advisor: Peter Wilf

Maria Alejandra Gandolfo, Cornell University
Néstor Rubén Cuneo, Museo Paleontológico Egidio Feruglio (Argentina)

The Cretaceous-Paleogene (K-Pg) bolide impact and subsequent mass extinction permanently reshaped global ecosystems. However, the extent of the extinction in Southern Hemisphere floras is poorly understood because very few plant-bearing K-Pg localities are reported outside the Western Interior of North America (WINA). Southern Hemisphere sites have been previously restricted to New Zealand and Antarctica, but recent studies on K-Pg palynological and insect damage records in Argentine Patagonia show much lower extinction rates and faster recovery times than in WINA, suggesting a muted extinction compared to the Northern Hemisphere. However, macrofloral extinction rates have not been calculated. New localities from Chubut, Argentine Patagonia, have yielded the first temporally and stratigraphically constrained K-Pg macrofloral collections in the Southern Hemisphere, offering unique insight into the paleofloras of two coastal lowland sites along the Paleo Atlantic coastline during a period of global biotic turnover. The latest Cretaceous (latest Maastrichtian) section of the boundary-spanning Lefipán Formation and the earliest Paleocene (early and late Danian, respectively) Salamanca and Peñas Coloradas formations have yielded over 4,000 leaf specimens temporally constrained by a suite of biostratigraphic, magnetostratigraphic and absolute dating techniques. In this study, I used a four-step approach to compare the diverse Maastrichtian and Danian leaf assemblages of the Lefipán, Salamanca and Peñas Coloradas formations to test for survivorship and extinction across the boundary. First, a species-level search for K-Pg survivors based on shared leaf architecture was performed by comparing the 63 Maastrichtian morphotypes and 57 Danian morphotypes. Second, to detect assemblage-level changes in leaf morphological diversity, a morphospace was constructed using discrete leaf architectural characters. Third, the published pollen taxa reported for the Lefipán and Salamanca fms. were compared to detect floral geographical heterogeneity between the two formations, separated by ca. 400 km along the Paleo Atlantic coastline. Finally, using published pollen and macrofloral records, higher taxonomic levels (families, genera) present before and after the boundary were documented as indicators of survivorship of major plant groups across the K-Pg in the region. There are several biases against observing survivorship in these collections, including geographic separation of the samples, the uncertain placement of the Maastrichtian floras within the last million years before the K-Pg, and changes in facies where floras are found. Nevertheless, about 20% of Maastrichtian leaf morphotypes occur in Danian floras. Morphospace analysis of Maastrichtian and Danian leaves shows overlap of assemblage-level morphospace occupation, related to similar environmental conditions and taxonomic groups recorded in both floral assemblages. The comparison of pollen taxa in the Lefipán and Salamanca formations showed distinctive floral compositions, in which only about 30% of Maastrichtian Lefipán species were found both in the Danian Lefipán and Salamanca sections. Lastly, documentation of higher taxa in the Lefipán, Salamanca and Peñas Coloradas formations based on micro and macrofloral records shows that identifiable taxa persist across the boundary, with members from the Cunoniaceae, Araucariaceae and Proteaceae families, among several others. Continuity of higher taxonomic levels, diversity and survival of morphotypes and continued occupation of similar morphospace corroborates a muted extinction observed in other Southern Hemisphere sites. These results indicate geographical heterogeneity of global extinction patterns for plants across the K-Pg boundary.

Ultrasonic Monitoring of Laboratory Scale Hydraulic Fracturing

Tim Witham
Master's Student, 2nd year

Advisor: Chris Marone

Parisa Shokouhi, Penn State University

Hydraulic fracturing is a proven method to enhance the recovery of hydrocarbons from tight reservoirs and source-rock plays. Larger, more complex fractures have greater surface area, which is thought to help maximize recovery. However, measuring the degree of complexity and interconnectedness of fractures is still a challenging problem, even with microseismic data.

Here, we use laboratory-scale hydraulic fracturing experiments in conjunction with active and passive ultrasonic monitoring to evaluate how stress wave responses can be used to better constrain fracture development. An array of piezoelectric sensors transmits compressional stress waves through isotropic acrylic samples during hydrofracture. This allows for determination of the fracture's behavior over time throughout different regions of the sample. Fracking fluids are delivered to the sample at a constant stress rate in all cases.

The waveforms display amplitude changes during and immediately after fracturing occurs before returning to a new steady state. Relative attenuation and time of flight changes are used to determine the response of the fracture at different locations in the sample during an experiment. Specifically, the wave attenuation increases along the ray paths passing through fracture planes while the attenuation through intact regions remains unchanged. These laboratory methods could be upscaled using borehole seismic testing.

A Record of Rift Evolution and Ultra-High Temperature Metamorphism from Lower Crustal Xenoliths in the Southern Rio Grande Rift

Jacob Cipar
Master's Student, 1st year

Advisor: Andrew Smye

Joshua Garber, Penn State University

The thermal evolution of the lower crust in continental rift systems exerts a primary control on (1) the style of rift deformation, and (2) chemical stratification of continental crust. Remarkably few empirical constraints exist on the thermal evolution of lower crust during active extension. This is because interpreting geophysical observations in active rifts can be complicated by non-unique combinations of temperature, melt fraction, and lithology, and petrologic approaches applied to exhumed metamorphic terranes are complicated by ambiguous structural relations and overprinting. Here, we apply U-Pb isotope geochronology, thermochronology, and thermobarometry to lower crustal xenoliths from Kilbourne Hole, NM to reconstruct a lower crustal geotherm in an archetypal active rift system - the Rio Grande Rift (RGR). The young age of these xenoliths (<80 ka) implies that they sample ambient conditions at the base of the crust, providing a rare opportunity to integrate P-T constraints with geophysical monitoring of an active continental rift system.

Initial results show: (1) rutile that has 'zero-age' U-Pb isotopic compositions and Zr contents ~6000-9000 ppm (960-1030 °C, ref. 1); (2) ternary feldspar in equilibrium with high temperatures (e.g. $An_{42}Or_7$, ~920 °C, ref. 2); (3) zircon U-Pb ages that span ~45-5Ma coupled to calculated Ti-in-zircon temperatures of 800-950 °C, with distinct temperature-time regimes that correspond to episodes of magmatism and extension along the RGR.

We propose that this petrologic record is a direct measurement of RGR crustal conditions during rifting; equilibrium thermobarometry corresponds to the modern RGR geotherm, and T-t information from zircon is a record of crustal thermal history – a unique archive of crustal evolution during extension. In addition to being the youngest (U)HT crustal rocks discovered to date, the presence of similar-grade metapelites at several sites 1000's of km away in the Mexico Basin and Range (Hayob et al. 1989) suggests that conditions at Kilbourne Hole may be representative of large spatial area.

1. Ferry, J. M. & Watson, E. B. New thermodynamic models and revised calibrations for the Ti-in-zircon and Zr-in-rutile thermometers. Contrib. to Mineral. Petrol. 154, 429–437 (2007).
2. Benisek, A., Dachs, E. & Kroll, H. A ternary feldspar-mixing model based on calorimetric data: Development and application. Contrib. to Mineral. Petrol. 160, 327–337 (2010).
3. Hayob, J. L., Essene, E. J., Ruiz, J., Ortega-Gutierrez, F. & Aranda-Gomez, J. J. Young high-temperature granulites from the base of the crust in central Mexico. Nature 342, 189–92 (1989).

How are sediments incorporated into lower continental crust? A monazite-based P-T-t investigation of the Ivrea Zone

Damaris 'Marit' Wyatt
Master's Student, 2nd year

Advisor: Andrew Smye

The Ivrea-Verbano Zone (IVZ) in northwest Italy is an archetypal section of lower continental crust. However, contrary to geochemical, seismic wavespeed-, and heat flow-based estimates for lower continental crustal composition, the IVZ is dominated by metasedimentary rocks that equilibrated at depths between 15 and 28 km [1]. This poses the question: how are sediments incorporated into lower continental crust?

This investigation evaluates several tectonic mechanisms for incorporating metasediments into the lower crust through field observations and geochemical analyses of two sampling transects. Here, I present the results of laser ablation split stream (LASS) ICP-MS measurements of monazite grains found in amphibolite to granulite facies metapelitic rocks from Val Strona di Omegna, IVZ. Trace-element data and Th-corrected U/Pb dates from two suites of amphibolite-facies metapelites record the Permian to Jurassic metamorphic history of the region. We focus on the pre-300 Ma monazite population, which likely records the prograde metamorphic evolution of the IVZ and is characterized by higher Y and HREE concentrations than the <295 Ma monazite population. Monazite dates are quantitatively linked to P-T conditions by combining trace-element partitioning with phase equilibria calculations. Combined with detrital zircon geochronology to determine oldest possible sedimentation ages for the metasediments. This approach constrains the prograde P-T-t evolution of the Ivrea Zone and enables testing of competing models of its assembly.

[1] Redler et al. (2011) Journal of Metamorphic Geology 30(3) 235–254.

Oral Session 2

Thursday, March 28th 3:30 - 4:45 PM

Controls on calcareous nannoplankton 'boom-bust successions' following the Cretaceous-Paleogene (K-Pg) mass extinction event

Heather Jones
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Advisor: Timothy Bralower

Christopher Lowery, University of Texas at Austin

Calcareous nannoplankton have been one of the most dominant primary producers since the late Triassic and reached their maximum diversity at the end of the Cretaceous. The bolide impact at the Cretaceous-Paleogene (K-Pg) boundary 66 million years ago (Ma), wiped out over 90% of calcareous nannoplankton species, and was the biggest mass extinction event in their history. The recovery of this group following the K-Pg boundary was hemispherically asynchronous, with Southern Hemisphere assemblages dominated by previously rare Cretaceous survivors which became regionally incumbent. In contrast, Northern Hemisphere recovery assemblages are characterized by a series of low diversity, high-abundance acmes, each of which are short-lived (<100,000 years). Although these "boom-bust" successions have been well-documented at several Northern Hemisphere K-Pg sites, the mechanisms driving the taxonomic switchovers between acmes is unknown. In addition, most of our high-resolution data comes from deep, open-ocean environments, which may not be reflective of recovery dynamics in shallower settings. Here I present nannoplankton relative abundance data from the Chicxulub impact crater to identify the environmental variables and associated causal mechanisms that drove boom-bust successions.

Microscale geochemical analysis of primitive lavas from Bufumbira, Uganda: implications for rift magmatism

Erica Pitcavage
Ph.D. Student, 5th year, Post-Comps

Advisor: Tanya Furman

Wendy Nelson, Towson University
Peggy Kalegga, Makerere University, Kampala (Uganda)
Erasmus Barifaijo, Makerere University, Kampala (Uganda)

Magmatism in the Western Branch of the East African Rift System is characterized by low volume, alkaline melts, which differ from much of the rest of the rift system and provide an opportunity to explore tectonic and geochemical controls on rift-related magmatism. In the Western Branch, magma compositions lack evidence for asthenospheric mantle plume input—rather, most show evidence for metasomatized lithospheric mantle sources. We focus on the Bufumbira (Uganda) cinder cones in the Virunga Volcanic Province, where bulk geochemistry suggests that primitive mafic lavas are derived from garnet ± phlogopite-bearing pyroxenite, indicating a deep metasomatized SCLM source. Source isotopic and mineralogical compositions vary on a short spatial scale in all portions of the Western Rift, suggesting heterogeneity driven by metasomatism in the regional lithospheric mantle. We explore the mechanisms that produce this heterogeneity and the implications it has for promoting rifting and magmatism in the EARS Western Rift.

We utilize mineralogical composition data (olivine and clinopyroxene) to provide additional constraints on melting depth, source characteristics, and magma evolution. Multiple generations of clinopyroxene crystallization are apparent petrographically and geochemically, and thermobarometric constraints require crystallization at a range of depths and temperatures throughout the lithosphere. Pyroxene and olivine trace element systematics are consistent with derivation from melting of lithospheric mantle, and along with bulk rock characteristics, argue against a mantle plume origin for Virunga magmatism. Comparison of xenolith mineral chemistry to minerals found in Bufumbira lavas reveals that some lava pyroxenes are xenocrysts, and that the xenoliths may be consistent with a cumulate origin.

Radiolysis Products of Macromolecular Organic Matter in Mars-relevant Matrices

Allison Fox
Ph.D. Student, 3rd year, Post-Comps

Advisor: Katherine Freeman

Jennifer Eigenbrode, NASA Goddard Space Flight Center

The fate of organic material on Mars after deposition is crucial to interpreting the source of these molecules and understanding Mars' ability to host life throughout time. The detection of organic material on the surface of Mars is complicated by oxidizing soil conditions due to high doses of ionizing radiation. However, the recent detection of small hydrocarbons at two locations at Gale crater, Mars suggest that organic material can survive this harsh radiation environment. These small hydrocarbons are thought to be derived from larger macromolecular structures, which may aid in their survival. Previous work has addressed how various organic compounds respond to UV radiation, but has not addressed how higher energy radiation, such as solar or gamma radiation, interacts with macromolecular organic material. UV radiation can only penetrate the first couple of millimeters of Martian soil, but solar and gamma radiation are expected to penetrate up to 2 meters. As a result, little is understood about the effects of ionizing radiation on organic material buried at the depths that current and future missions are sampling (2 cm -2 m).

Here, we report radiolysis products of macromolecular organic material in different mineral matrices exposed to high energy protons and the metastability of organic acids at high radiation exposure. We found that formate and oxalate are produced from a variety of organic starting materials and mineral matrices. Unlike UV-driven reactions which invoke Fenton-like chemistry to explain organic acids production, our work suggests that irradiation of semi-conductor surfaces forms oxygen and hydroxyl radical species which can breakdown macromolecular organics into organic acids. We also found that these organic acids can resist degradation from ionizing radiation at high levels of exposure. Benzoate was added to samples prior to irradiation and persisted up to 500 kGys of exposure. Our findings suggest that organic acids are likely a major component of organic material on Mars that can survive exposure to high energy radiation for millions of years.

Fire distinguishers: A molecular isotopic approach to constrain C_4 grassland burning in the late Miocene

Allison Karp
Ph.D. Student, 4th year, Post-Comps

Advisor: Katherine Freeman

Kevin Uno, Lamont-Doherty Earth Observatory
Pratigya Polissar, Lamont-Doherty Earth Observatory

The importance of fire feedbacks in explaining regional differences in the expansion of C_4 grasslands in the Mio-Pliocene has long been suspected but is poorly constrained. Here, we apply molecular proxies for fire, alongside records of vegetation change and paleohydrology, in samples from Bengal fan sediments (ODP Leg 116) to examine this feedback on a continental scale. We utilize abundances of polycyclic aromatic hydrocarbons (PAHs) to reconstruct fire occurrence, along with novel $\delta^{13}C$ measurements of these deep time pyrogenic PAHs. This allowed us to explicitly test both parts of the fire feedback hypothesis 1) as trigger for the expansion of grassland ecosystems, and 2) for the continued maintenance of these systems. A major challenge to quantifying paleo-fire inputs in sediments is that PAHs can be sourced from weathered fossil carbon (i.e., a petrogenic source) as well as from aerosols and particles derived from burned terrestrial biomass (i.e., a pyrogenic source). We overcome this obstacle through multivariate methods to distinguish between predominately pyrogenic and petrogenic derived samples and to identify PAHs associated with pyrogenic inputs. Increased abundances of pyrogenic PAHs synchronized with enrichments in δD of n-alkanes and $\delta^{13}C$ of n-alkanes at 7 Ma support a seasonality driven increase in fire occurrence triggering the expansion of C_4 ecosystems on the Indian Subcontinent. Concurrent C_4-enrichments in $\delta^{13}C$ of n-alkanes, $\delta^{13}C$ of PAHs, correlated to increased abundances of PAHs indicate the burning of C_4 grasslands maintained these open systems. Our results link fire to the opening of grassy landscapes on a continental scale, and support disturbance as a critical mechanism of terrestrial biome transitions that can and should be quantified in deep time.

Oxidized micrometeorites provide a lower limit on Archean atmospheric CO_2

Rebecca Payne
Ph.D. Student, 4th year, Pre-Comps

Advisor: James Kasting

Don Brownlee, University of Washington

Recently, Tomkins et al. (2016) suggested that the iron oxides contained in 2.7 Ga iron micrometeorites could be used to determine the concentration of O_2 in the upper atmosphere during the Archean. Specifically, they argued that the presence of magnetite in these micrometeorites meant that O_2 must have been near present day levels (~21%) in the upper atmosphere within the altitude range where the micrometeorites were melted during entry. To explain the discrepancy with inferred low O_2 at Earth's surface during the Archean, they suggested that vertical atmospheric mixing was inhibited, potentially by a stratospheric organic haze absorbing incoming sunlight.

Here, we use a 1-D photochemical model to test their hypotheses. We find that atomic oxygen is the most abundant oxygen species in the upper atmosphere (rather than O_2, as Tomkins et al. assumed) and exceeds CO near the top of the atmosphere. CO_2 itself may also serve as a potential oxidant. Therefore, while the presence of multiple abundant oxygen species makes it difficult to determine O_2 concentrations during the Archean based on these micrometeorites, it is possible to use these micrometeorites to place a lower constraint on Archean CO_2. This is because essentially all of the oxygen in the Archean atmosphere is the byproduct of CO_2 photolysis. CO_2 and its photochemical byproducts are able to oxidize all of the Tomkins et al. micrometeorites when CO_2 is relatively high (~0.3 mixing ratio or higher). These iron micrometeorites may represent a new proxy of Archean CO_2 which will benefit from further study.

Oral Session 3

Friday, March 29th 9:00 – 10:15 AM

Slow Slip Event Constraints on Subduction Zone Kinematics

Kirsty McKenzie
Ph.D. Student, 3rd year, Pre-Comps

Advisor: Kevin Furlong

Subduction zone environments are host to some of Earth's most damaging natural hazards, including megathrust earthquakes and earthquake-induced tsunamis. A major control on the generation of subduction megathrust earthquakes is how the locked or coupled zone along the subduction interface is loaded between events. We present new results from surface observations of slow slip earthquakes, that occur down-dip of the locked patch, that suggest that the orientation of loading of the locked patch can vary with depth. Across its upper limit, forces derived from current plate motions dominate. However, deeper on the plate interface, below the locked patch, gravity (e.g. slab pull) becomes the dominant force acting on the subducting slab. This implies that at depth the locked patch is stressed in the down-dip direction. If applicable to subduction zones in general, this result suggests the presence of depth varying stress states on the plate boundary interface.

Bed Character of Thwaites Glacier: Implications for Stability

Emily Schwans
Ph.D. Student, 1st year, Pre-Comps

Advisor: Richard Alley & Byron Parizek

Dave Pollard, Penn State University
Mathieu Morlighem: University of California at Irvine
Helene Seroussi, JPL
Ryan Walker, University of Maryland
Pierre St-Laurent, Old Dominion University

The Antarctic ice sheet has grown and retreated in response to Earth's natural climatic variability. Ice sheet models have reproduced these variations on a continental scale (e.g., Pollard & DeConto, 2009), including simulating how sufficiently large past warming resulted in near-total collapse of the West Antarctic Ice Sheet (WAIS) and global sea-level rise (SLR). WAIS is situated in deep marine basins, and is therefore susceptible to ocean influence (Alley et al., 2015).

The Amundsen Sea Embayment (ASE) is the region of WAIS considered to be most vulnerable to retreat in response to recent ocean warming. Observations indicate that outlet glaciers in ASE are losing mass at an increasing rate. The floating extensions of these glaciers, ice shelves, provide a back-force that supports (or "buttresses") upstream ice. Circumpolar deep water (CDW) rises onto the continental shelf, melts shelves from below, thinning them and diminishing their buttressing ability. In response to loss of buttressing from sub-shelf melting, outlet glaciers in ASE have accelerated, allowing non-floating ice to flow faster into the ocean and raise sea level. This dynamic response highlights the key role these floating extensions play in the stability of outlet glaciers in ASE, and therefore, WAIS as a whole.

Thwaites Glacier (TG) is an outlet glacier in ASE that has the potential to contribute approximately 1 meter of SLR. However, through its connections to other major drainages of WAIS through deep interior basins it could, in total, raise sea level ~3.3 meters (Bamber et al., 2009). Thwaites is grounded on a transverse bedrock high with potential for unstable grounding-line retreat down a reverse-slope gradient as described by the Marine Ice Sheet Instability (MISI) hypothesis (Weertman, 1974; Schoof, 2007); furthermore, its characteristically small ice shelf renders the ASE sector particularly prone to destabilization as a result of oceanic warming (Favier et al., 2014). In models (e.g., Joughin et al., 2014; Mouginot et al., 2014; Rignot et al., 2014), thinning beyond some threshold causes retreat from the stabilizing ridge onto a bed that deepens toward the center of the ice sheet. Many uncertainties exist in projecting retreat from the ridge, including future oceanic forcing, details of bed topography, bed rheology, and more (Scambos et al., 2017).

Modeling using the NASA-JPL Ice Sheet System Model (ISSM) together with targeted Penn State model output (PSU-3d) addresses one of the main uncertainties, namely that of the interactions between oceanic forcing and retreat as a function of basal lubrication through the basal sliding law. By examining simulations of Thwaites' response to removal of all or parts of its ice shelf, and focusing on basal properties and grounding line (GL) behavior over short timescales, we address several critical processes relevant to the stability of WAIS. Results show how the timing, pattern, and magnitude of Thwaites' grounding-line retreat depend on bed character, and highlight key areas of shelf critical to TG's stability. These results also serve to pinpoint areas where additional data on melting rates and bed character are most needed from future data-collection efforts to better model the evolution of this dynamic outlet glacier and constrain SLR projections.

Time-series analysis and numerical modeling of surface deformation at Pacaya Volcano, Guatemala

Judit Gonzalez-Santana
Ph.D. Student, 2nd year, Pre-Comps

Advisor: Christelle Wauthier

Edifice collapse represents one of the most dangerous volcanic hazards threatening communities and infrastructure near volcanoes. In Guatemala, 9,000 people live less than 5 km away from the summit of Pacaya volcano, an active basaltic stratovolcano which shows evidence of past episodes of flank collapse. Additionally, regional field studies have highlighted factors which could promote failure of the SW flank, such as: presence of a weak layer of tephra and ignimbrite pyroclastics below the edifice, the south-sloping regional slope, and preferential loading of the SW flank by lava flows since 1961. To assess the hazards posed by this volcano, a better understanding of the deformation behavior and the factors promoting flank instability, as well as the triggers necessary for collapse, is required. Interferometric Synthetic Aperture Radar (InSAR) is a useful tool for remote monitoring of surface deformation. This technique is used to quantify surface deformation at Pacaya volcano, using Radarsat-2 radar images acquired between September 2010 and November 2017. InSAR time-series analysis is performed in order to examine the evolution of ground surface deformation throughout this period and discern whether flank motion at Pacaya is episodic or continuous. Subsequently, a 3D Mixed Boundary Element Method, which combines the Direct Method and the Displacement Discontinuity method, is used to model the sources of observed deformation. This method accounts for realistic topography, which is substantial at Pacaya. Additionally, it allows modeling perturbations from reservoirs of any shape, tensile cracks and shear faults, as well as taking realistic source interactions into account. The latter is of particular importance for modeling the slip surface in the unstable SW flank of Pacaya. A Monte Carlo neighbourhood algorithm is used to invert the InSAR data and solve for the most likely model.

Lava lakes and satellites: imaging offset magma supply at Masaya volcano

Kirsten Stephens
PhD Student, 3rd year, Pre-Comps

Advisor: Christelle Wauthier

The usage of satellite remote sensing techniques, such as Interferometric Synthetic Aperture Radar (InSAR), have progressively shown the prevalence of deformation centers offset from the main locus of activity in volcanic regions. On 11 December 2015, a new lava lake formed in the Santiago pit crater within the Masaya caldera. Between 6 November 2015 and 1 September 2016, InSAR data sets from various satellites (CSK, RSAT-2, ALOS-2 and Sentinel-1) revealed a deformation center uplifting by ~8 cm in the NW sector of the caldera. Simultaneous inversion of the InSAR datasets using a Monte Carlo neighbourhood algorithm suggest that an inflating spherical magma reservoir best explains the observed deformation, with the center offset ~3 km north of the active Santiago pit crater, and a depth-to-center of ~3 km. The location of the offset reservoir may be the result of pre-existing caldera structures. InSAR time-series analysis suggests that the onset of deformation occurred 6-8 weeks prior to the appearance of the lava lake. Cumulative line-of-sight deformation indicates that the offset region continued to uplift during the first four months of lava lake activity, before plateauing at a consistent uplift level for a period of several months. It is worth noting that geodesy captured the onset of deformation a few weeks before a significant peak in CO_2 was detected by ground based sensors (Aiuppa et al., 2018), emphasizing the need for a multidisciplinary approach to forecasting unrest at volcanoes.

Beyond modeling attenuation: wave attenuation effects, migration imaging, and adjoint sensitivity kernels

Guangchi Xing
Ph.D. Student, 2^{nd} year, Pre-Comps

Advisor: Tieyuan Zhu

Seismic attenuation phenomenon is quantified by the quality factor Q and is especially significant in the presence of fluid in porous media. The attenuation has two coupled effects on the seismic recordings as reduced amplitudes and dispersed waveforms. To take these effects into account, we recently derived a viscoacoustic wave equation with the aid of the fractional Laplacian operators. The new wave equation can rigorously model the frequency-independent Q behavior that is supported by laboratory and in-situ measurements. Moreover, this wave equation can decouple the two attenuation associated effects, which cannot be realized by conventional wave equations. Here, we further develop this wave equation as an engine to simulate the wave propagation in the geologic gas chimney model and the Frio CO_2 injection time-lapse seismic monitoring model to study the attenuation effects. Then, taking advantage of decoupled attenuation operators, we are able to construct the Q-compensated reverse-time migration algorithm and apply it to the gas chimney model for seismic image enhancement. Finally, we formulate the adjoint operator of the wave propagator in this wave equation. Based on it, we simulate the forward and the adjoint wavefields to compute the Fréchet kernels for both seismic velocity and Q using the adjoint-state method. These kernels not only provide the sensitivity of various measurements (traveltime, amplitude, full waveform etc.) with respect to model parameters, but also serve a basis for constructing the time domain waveform inversion for retrieving subsurface seismic velocity and Q properties.

Oral Session 4

Friday, March 29th 10:30 – 11:30 AM

Detecting tectonic and climatic change in lacustrine geochemical records from Olduvai Gorge, Tanzania

Troy Ferland
Ph.D. Student, 2nd year, Pre-Comps

Advisor: Katherine Freeman

D.E. Colcord, Indiana University
A. Shilling, Indiana University
S.C. Brassell, Indiana University
I.G. Stanistreet, The Stone Age Institute (Indiana, USA) & University of Liverpool (UK)
H. Stollhofen, Friedrich-Alexander Universität (Germany)
J. Njau, Indiana University and The Stone Age Institute (Indiana, USA)
K. Schick, The Stone Age Institute (Indiana, USA)
N. Toth, The Stone Age Institute (Indiana, USA)

Olduvai Gorge in northern Tanzania contains a fossiliferous, well-characterized Pleistocene sedimentary record, and provides the opportunity to study the relationship between changing climate, ecology, and hominin evolution. The Olduvai Gorge Coring Project (OGCP) collected three cores (1A, 2A, and 3A) from paleolake Olduvai in 2014 to achieve increased temporal resolution of local climate and ecological data, and investigate the influence and timing of regional climate and tectonics on local signals. We present high-resolution records of bulk organic carbon isotopes (‰), total organic carbon (wt. %) from OGCP Cores 2A and 3A, and organic carbon-nitrogen ratios (C:N) from Core 2A. Previous work at Olduvai linked bulk organic carbon isotopes and TOC to orbitally-paced variations in lake depth and regional hydroclimate dynamics from 1.9-1.7 Ma. C:N ratios from Core 2A show high terrestrial input during the 1.9-1.7 Ma interval, but suggest increased aquatic input elsewhere. We use a mixing model to estimate the terrestrial carbon isotope signal during intervals of mixed input, and evaluate the new record of terrestrial carbon isotopes for changes in mean or variance. TOC and isotope mean and variance changes during intervals of purely lacustrine input are also evaluated as potential indicators of changing lake environment. Identified changes of mean and variance in these records may represent the hydrological impacts of climatic or tectonic evolution in East Africa, such as the onset and cessation of the African Humid Period from 2.0-1.7 Ma, or elevation change in the highlands to the east and south of paleolake Olduvai, including Ngorongoro, Olmoti, Oldeani, and Lemagrut volcanoes.

A Quantitative Model of the Global Rare Earth Element Cycle and Implications for Variability in the REE Composition of Ancient Oceans

Benjamin Davis Barnes
Ph.D. Student, 2nd year, Pre-Comps

Advisor: Lee Kump

Rare earth elements (REEs) represent valuable proxies due to their coherent chemical behavior and mass fractionation in response to complexation and particle scavenging. These processes induce a shale-normalized enrichment of heavy relative to light REEs in the modern ocean, while deviations from this fractionation may be indicative of freshwater mixing or anomalous aqueous geochemistry. The REE composition of carbonate minerals has also been utilized as a proxy for water circulation, paleobathymetry, and redox state in ancient oceans. However, these data are subject to scrutiny as the low levels of REEs in carbonates make them susceptible to overprinting when contaminated by REE-rich siliciclastics, phosphates, and ferromanganese crusts. A common screening practice for local effects rejects data which do not exhibit a positive La anomaly, high Y/Ho, and heavy REE enrichment – characteristics of the modern ocean. This approach assumes that seawater REE composition does not vary over geological time, but without a theoretical framework to suggest otherwise, analytical techniques will be unable to test for evolution in REE fractionation.

In this study, we simulate trends in global oceanic REE reservoirs and fractionation with a simple box model. This treatment calculates a mass balance between input fluxes of REEs (terrestrial weathering, aerosol deposition, hydrothermal fluids, and sedimentary diagenesis) and output fluxes by scavenging. Additional parameters such as climate and weathering, hydrothermal activity, and ocean alkalinity are incorporated as correction factors. By approximating climate and geochemical conditions, REE patterns in ancient oceans may be estimated. Furthermore, we simulate environmental perturbations in Earth's history to measure the amplitude and turnover of the REE response. These preliminary results suggest dynamic global trends in REE fractionation over geologic timescales. Although local effects such as siliciclastic contamination must still be considered when interpreting REE data, future sampling for stratigraphic variation of REE enrichments in pristine carbonates will test our model hypotheses of temporal trends. Through the union of modeling and analytical techniques, REEs may continue to develop as a proxy for paleoclimate and ocean geochemistry.

Oreodonts adapt to expanding grasslands in Miocene North America and then go extinct

Claire Cleveland
Ph.D. Student, 4th year, Pre-Comps

Advisor: Mark Patzkowsky

Oreodonts are one of the most abundant, widespread, and diverse mammal groups in early Neogene North America. As grasslands expanded during the Miocene, open savannas replaced closed forests. This change increased selection for grazing morphologies reflecting a change of diet and movement through feeding patches. Other less abundant groups such as camels and peccaries survived these environmental changes, but oreodonts went extinct. The current paradigm attributes oreodont extinction to a lack of adaptive change. To assess the response of oreodonts to environmental change, a series of 73 skull attributes and 34 postcranial attributes were measured on 237 individuals. All skeletal elements were evaluated for deformation to ensure proportional accuracy in each measurement.

Ecometric analysis of the skull attributes resolves four taxonomic groups through time. The first three groups progress through origination, radiation, and specialization with a directional shift from browsing to grazing morphologies. The final survival group, shifts toward a more generalist morphology of medium size and mixed feeding morphology. Analysis of limb attributes does not indicate a clear trend through time toward grazing morphologies, but does resolve a similar pattern of origination, radiation, specialization, and survival. These results challenge the existing paradigm that oreodonts did not adapt to their changing environment with additional implications for current controversies in oreodont phylogenetics.

Future research will investigate large ungulate community ecologies at broader geographic scales to test biological explanations for oreodont extinction. Testing functional and community explanations for extinction in deep time on large empirical datasets like oreodonts is fundamental to our understanding of diversity and evolution and essential to developing models to interpret extinction risk in modern ecosystems.

Illuminating Fault Zone by Migrating Trapped Waves and Diffraction Waves

Junzhu Shen
Ph.D. Student, 1st year, Pre-Comps

Advisor: Tieyuan Zhu

Fault zone (FZ) is usually characterized as a narrow zone of intense damage and deformation. Because of these highly fractured materials, FZ is considered as a seismically low-velocity zone (LVZ). The LVZs can accumulate aseismic strain and concentrate large stress which can be released and generate ruptures and earthquakes. Obtaining detailed structural information of the FZ is essential to the understanding of past and future ruptures, earthquake cycle and evolution of fault systems. Previous studies mainly use the travel time of FZ waves to model the LVZs but it is still difficult to determine the geometry (e.g., depth and internal structure) of the FZ. Recent deployment of dense seismic arrays across the fault zone make possible using full waveforms. Here we aim to provide a better illumination of FZ by migrating fault zone trapped waves (FZTW) and diffraction waves using seismic wave-equation migration. First, we conduct the waveform analysis of FZ. Our waveform modeling shows that the bottom of the FZ can generate relatively strong FZTWs which propagate along the waveguide and can reveal FZ depth information. We also note that diffraction waves are clearly observed in the array data and are highly dependent on the geometry of FZ. With all these observations, we then propose to combine FZTW and diffraction waves in the framework of wave-equation migration to image the FZ. Our synthetic tests show that the depth and boundaries of FZ can be delineated. We also investigate the effects of internal properties within FZ, source distribution, and array aperture. In the future work we plan to apply this method to San Jacinto Fault Zone (SJFZ) dense seismic array data to image SJFZ.

Poster Session 2

Friday, March 29th 12:30 - 1:45 PM

3D Seismic Array in the Shale Hills Critical Zone Observatory

Lisa Ma
Master's Student, 1st year

Advisor: Andrew Nyblade

Natalie Accardo, Penn State University
Susan Brantley, Penn State University

In June of 2018, we deployed a large-scale seismic survey in the Susquehanna Shale Hills Critical Zone Observatory (SSHCZO) located in central Pennsylvania in order to study the critical zone. The critical zone is defined by the layer extending from above fresh bedrock to the tops of trees. In the SSHCZO, the focus is on regolith processes occurring within a shale lithology in a temperate environment. To learn about the subsurface geology over a general area, we deployed 2100 seismic stations twice to create a grid of dimensions 140 meters by 160 meters with two-meter station spacing. A station consisted of a vertical geophone connected to a Texan data logger that recorded seismic energy released from sledge hammers about 1.4 meters away from the nearest receiver. Initial results from 2-D lines crossing through the 3D grid showed P-wave velocities ranging from 300 to 4100 m/s with variable gradient zones thickening and thinning with topography. The goal is to construct a three-dimensional velocity model with seismic refraction data in order to map porosity extending outwards from known values gathered from boreholes after being able to distinguish velocities illustrating the differing lithologies in the subsurface.

The potential for *Escherichia coli* to recycle phosphate nutrients from human waste

Claire Webster
Ph.D. Student, 1st year, Pre-Comps

Advisor: Julie Cosmidis

As global populations continue to grow, the demand on food production increases exponentially. While the application of phosphate fertilizers can increase crop yields by as much as 50%, mined phosphate rocks are a non-renewable resource expected to be exhausted within the next 50-100 years. Conversely, on the other end of the food chain, vast quantities of phosphate are wasted as nearly 100 percent of consumed phosphate is excreted and discharged as sewage. *Escherichia coli* are a microorganism that naturally occurs within the human urinary system and contributes to the mineralization of phosphatic kidney stones. This study aims to elucidate the mechanisms by which *E. coli* biomineralize phosphates from urine solutions and develop a practical method to recycle phosphates from human waste using microbes on an industrial scale.

Optimization of the biomineralization process is achieved through an experimental approach. *E. coli* are applied to synthetic urine solutions under an array of conditions, and dissolved phosphates and pH are monitored throughout a 20-day incubation period. At the conclusion of the incubation period, mineralized precipitates are analyzed using SEM, TEM, FT-IR, and STXM. These techniques characterize the mineralogical composition of the precipitate and allow for the examination of the microbe-mineral interactions. In preliminary trials, all tested strains precipitated phosphate minerals regardless of the presence or absence of the urease gene, a gene previously thought to control phosphate mineralization. Additionally, nine out of ten tested strains precipitated struvite while one strain precipitated nano-hydroxyapatite, a potentially more efficient mineral for use as a fertilizer.

Sulfate fluxes in mixed lithology watersheds vary with nitrate inputs

Andrew Shaughnessy
Ph.D. Student, 1st year, Pre-Comps

Advisor: Susan Brantley

Xin Gu, Penn State University

Pyrite (FeS_2) is a common mineral in the subsurface that is prone to oxidation, which produces sulfuric acid (H_2SO_4). Over short timescales, the coupling of pyrite oxidation to nitrate reduction can attenuate groundwater nitrate concentrations. This is particularly important in watersheds with agricultural land use, such as the Shavers Creek Watershed, which typically features higher groundwater nitrate concentrations due to sustained fertilizer application. In addition to agricultural contaminants, the Shavers Creek Watershed is also impacted by acid rain. We utilize geochemical and hydrologic datasets collected in the Susquehanna Shale Hills Critical Zone Observatory (SHHCZO) to delineate the sulfur budget in several sub-catchments of the Shavers Creek Watershed as well as several reaches along the main stem of Shavers Creek. Selected sites show variability in lithology (e.g., sandstone, shale, limestone) and land-use (e.g., 0-18% agriculture). We use stream water chemistry, multivariate statistics, bedrock chemistry, and mixing models to delineate sulfate derived from precipitation, pyrite oxidation, and fertilizers. Preliminary results on the sulfur budget at the Shale Hills sub-catchment show that pyrite-derived sulfate seasonally ranges from 0.2 to 99.5% of the total sulfate in the stream. The highest proportions of pyrite derived sulfate occurred during the summer months (June, July, August) when the flow was the lowest and the stream is likely sustained by deeper groundwater flow. The annual pyrite-derived sulfate flux for Shale Hills is 3.0-6.2 x 10-3 mol m-2 yr-1, which is 8.5-17.3% of the total sulfate flux from Shale Hills. Utilizing the results and methodology from this study, we aim to scale up to the Susquehanna River and the Mississippi River Basins to determine pyrite-derived sulfate fluxes for the rivers draining most of the United States. We also aim to determine how land use effects these fluxes.

Groundwater transport history of per- and polyfluoroalkyl substances (PFAS) from a former fire fighter training site

Kalle L. Jahn
Ph.D. Student, 3rd year, Pre-Comps

Advisor: Demian Saffer

Sara A. Lincoln, Penn State University
Katherine H. Freeman, Penn State University

Fire fighting activities at the former fire fighter training site on Big Hollow Road in State College introduced volatile organic compounds (VOCs) and "emerging contaminant" per-and polyfluoroalkyl substances (PFAS) to the underlying dolomite aquifer. In 1999, the site was remediated for VOCs; contaminated soils were excavated and a groundwater pump-and-treat system was installed to clean the shallow Upper Sandy Gatesburg aquifer. Groundwater remediation of PFAS, however, did not begin until 2017. Currently, both VOC and PFAS plumes are co-located, which is unexpected given the different sorption behavior of the two compound groups. Nearby fractures have been identified via fracture zone trace analysis, but slug tests on monitoring wells yield low hydraulic conductivity. This raises questions regarding the local contaminant transport history. Did contaminant transport occur predominantly via fracture flow, or diffuse matrix flow? Do the current plumes represent back-diffusion out of the rock matrix, while the "original" plume rapidly left the monitored area? To answer these questions, I aim to constrain chemical and physical unknowns in the aquifer using reactive transport models. I use MODFLOW and MT3D USGS to identify parameter combinations – hydraulic conductivities, sorption coefficients, dispersivities – that generate the observed co-located plumes. To validate these possible transport scenarios, I compare modeled parameters against field observations and literature values.

Investigating climate change versus land use controls on hillslope erosion and valley sedimentation at the Cole Farm study watershed, central Pennsylvania

Perri Silverhart
Master's Student, 2nd year

Advisor: Roman DiBiase

Over the past several hundred years, agriculture has significantly changed both the magnitude and pattern of sediment transport on a global scale. In order to make informed management decisions, it is necessary to understand how landscapes respond to anthropogenic perturbations across geologic and topographic settings. In the Atlantic Piedmont, accumulations of sediment trapped behind colonial mill dams document impact of widespread land use change. However, an anthropogenic signature of valley floor sedimentation is less obvious in upland landscapes within the nearby Valley and Ridge Province, where Quaternary climate fluctuations and periglacial hillslope processes have driven headwater valley sedimentation over timescales ranging from 103-105 years.

Here, we focus on the 0.66 km2 Cole Farm study watershed, a calcareous shale and limestone catchment within the Susquehanna Shale Hills Critical Zone Observatory that has been continuously farmed since the early 1800's with a transition to no-till practices in the early 1970's. We aim to characterize the geometry and spatial patterns in soil thickness on the hillslopes and of a >4 m-thick colluvial valley fill. To quantify spatial patterns in decadal soil transport and erosion, we are currently analyzing samples from two hillslope soil pit catenas for 137Cs. Preliminary radiocarbon dates from valley cores indicate that at least the top 3.5 m of the valley fill is modern (post 1963). By drawing comparisons to an adjacent catchment, which was once cultivated but was progressively reforested starting in the 1950's, the spatial patterns of soil thickness, topography, and the timing of erosion and sedimentation in these two catchments will help constrain the relative influence of climate versus land use controls on hillslope erosion and valley sedimentation.

Consolidation behavior, permeability, and compressional wavespeeds of sediment entering the eastern Aleutian subduction zone: Implications for the evolution of subducted sediments

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Advisor: Demian Saffer

Parisa Shokouhi, Penn State University

Subduction zones are host to the world's largest and most damaging earthquakes. The oceanic sediment that is subducted and entrained along the plate interface plays an important role in controlling the physical properties and in situ conditions along the megathrust and within the surrounding wall rocks in these systems. In particular, the response of the sediment to complex loading paths is one key factor governing the state of stress and evolution of physical properties with progressive burial and subduction. Deformation begins with uniaxial consolidation outboard of the trench where pore fluid is expelled by pore collapse driven by sedimentation and vertical loading. Sediments that are accreted and incorporated into the upper plate at the trench undergo progressive lateral loading, whereas material underthrust at the trench undergoes dominantly vertical loading, but with a possible component of shearing associated with transfer of stress across the plate interface. The evolution of the of porosity and pore structure is important for understanding both permeability and elastic properties and their distribution down-dip. These properties, in turn, are primary controls on pore pressure, effective stress, fault strength, and rupture propagation.

Here we report on the consolidation behavior of sediment entering the Eastern Aleutian subduction zone. These cores were drilled during Integrated Ocean Drilling Program (IODP) Expedition 341 at Site U1417, located ~60 km seaward of the trench. The samples tested are from 340 mbsf to 700 mbsf and consist of muds with interbedded silt and diamict. These samples were tested under uniaxial, isostatic, and near-critical state loading paths (a state of failure by pervasive shear and at constant volume). We report on the evolution of permeability (k), Vp, and acoustic transmission amplitude as functions of uniaxial consolidation and triaxial loading, and then compare the results to shipboard measurements on cores, seismic survey results, and empirical Vp-porosity models. Under all loading conditions, Vp increases and permeability decreases with decreasing porosity. We also observe that the relationship between Vp and porosity is independent of the loading path, such that the first order control on Vp appears to be porosity.

The Effect of Roughness on the Elasticity and Permeability of Fractured Media

Clay Wood
Master's Student, 2nd year

Advisor: Chris Marone

Benjamin Madara, Penn State University
Parisa Shokouhi, Penn State University
Jiang Jin, Penn State University
Jacques Rivière, Penn State University
Derek Elsworth, Penn State University

We describe laboratory work to elucidate the relation between nonlinear elasticity and permeability of fractured media subjected to local stress perturbations in relation to fracture roughness and aperture distribution. This study is part of an effort to image fluid pathways and fracture properties using locally induced seismicity, associated with fluid injection.

Experiments were conducted in which intact L-shaped Westerly granite samples were fractured in-situ tri-axial condition while forcing deionized water through the subsequent fracture interfaces. After in-situ fracture, we imposed oscillations of the applied effective normal stress and pore pressure with amplitudes ranging from 0.2 to 1 MPa and frequencies from 0.1 to 10 Hz. During these dynamic perturbations an array of ultrasonic transducers (PZTs) continuously generate and transmitted p-wave pulses to monitor the elastic response of the granite samples. We interpret the relative change in p-wave velocities to be an analog for the elastic nonlinearity and relate it to the permeability of the fractured media. The roughness of the fractured interfaces is altered during experiments by shearing the L-shaped samples and then allowing the interface to age before applying dynamic stressing.

We characterize the effect of effective horizontal stress and pore pressure oscillations on the ultrasonic velocity, elastic nonlinearity, by calculating relative changes from before respective oscillations to after. There is an enhancement in permeability at higher oscillation amplitudes and is most prominent with pore pressure oscillations. Finally, elastic nonlinearity and permeability of the fracture is highly dependent on oscillation frequency and nonlinearity decreases with effective horizontal stress oscillations. Though further studies are needed, we infer the frequency dependency is related to pore pressure oscillations moving granular material, created from in-situ fracture and shearing, and creating more flow pathways across the interface.

The Dance between Light and Nano-particles -- Preliminary XAS and TEM Studies of the Coloration Mechanism in Oregon Sunstones

Chengsi Wang
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Advisor: Andy H. Shen, China University of Geosciences

Peter J. Heaney, Penn State University

Oregon sunstone, a variety of gem-quality plagioclase ($Ab_{30-50}An_{70-50}$), is known for its unique optical property that generates red and green body colors coupled with a strong Schiller effect. The unusual bicoloration is believed to be caused by nano-inclusions of elemental Cu, but the coloration mechanism cannot be explained by classical coloration theories and is a decades-long gemological mystery. My research has explored a new theory, called localized surface plasma resonance (LSPR), to understand the optical phenomena in Oregon sunstone.

In order to simulate the gem coloration, Cu was diffused into natural yellow Oregon labradorite crystals, successfully creating the green and red body colors displayed by natural sunstone. Interestingly, in these diffused samples, the Cu concentration is uniform across differently colored areas, ~1000 ppm of Cu in all areas. Under the polariscope, some zones are polechroic between red and green, whereas other zones are isotropically red. UV-Visible light spectra confirm this result, and the absorption wavelength of the red zone is the same as that displayed by copper ruby-red glasses (560 nm).

Since previous studies have attributed sunstone coloration to nano-inclusions of Cu, I used focused ion beam (FIB) milling and high-resolution transmission electron microscopy (HRTEM) to test this hypothesis. Spherical nanoparticles were found in the red-colored zones of both natural and diffused samples. The particles were ~13 nm in diameter and consisted predominantly of Cu. Synchrotron-radiation X-ray absorption near edge structure (XANS) of differently colored zones was performed to explore the valance state of Cu. The results revealed that Cu in both the red and green zones of the diffused sample and the red zone of the natural sample were all likely to be Cu^{1+}-Cu^{2+}. But according to the EXAFS spectra, the local environment around the Cu in the red zones of the diffused and natural sunstones are different. Based on LSPR theory, we suspect that the red color of Oregon sunstone are caused by Cu spherical nanoparticles with the diameter of ~13 nm, but the coloration of green color is still needs more investigations.

Postglacial Icelandic volcanism: the influence of rift maturity

Collin Oborn
Ph.D. Student, 1st year, Pre-Comps

Advisor: Peter LaFemina

The total volume of volcanic output and eruption frequency in Iceland has been steadily decreasing since the last glacial maxima. The response of volcanism to the glacial unloading of the Icelandic crust ~10 kya has been well documented for the Western Volcanic Zone (WVZ)^1. The WVZ initially produced an average of 4 eruptions with an eruptive volume of ~24 km^3 every 1000 years. These values have since fallen more than 75% (to ~1 eruption with ~4 km^3/1000 years). No analogous data have yet been compiled for the same time period for the Eastern Volcanic Zone (EVZ). The EVZ is particularly noteworthy for having been the site of the 1783 Laki (15 km^3) and 8600 BP Thjórsa (25 km^3) eruptions, two of the largest historical basaltic fissure eruptions on Earth. The WVZ generally produces small (< 1km^3) eruptions predominantly from shield volcanoes while the EVZ is dominated by large (> 1km^3; up to 25 km^3) eruptions from caldera-fissure systems. The WVZ and EVZ appear to also differ in the chemical and isotopic heterogeneity of their eruptive output: the WVZ erupts heterogenous low-volume lavas while the EVZ produces large and relatively homogeneous lavas^2. As part of an examination of the temporal evolution of EVZ post-glacial volcanism, we present major element, trace element, and Sr-isotope data for a preliminary set of samples from the Tungnaárhraun, a series of understudied flows erupted from the Barðabunga/Veiðivötn volcanic system. These data will be used to guide further collection of samples from the Tungnaárhraun that will allow us to link these flows to a volcanic system and fill an important gap in the eruptive history of the EVZ.

1. Sinton, J., et al. (2005), Geochem. Geophys. Geosyst., 6(12), Q12009
2. Halldórsson, S., et al. (2018), Contrib. Mineral Petrol., 173(8), 64

Understanding diagenetic effects during the Paleocene Eocene Thermal Maximum (PETM) on carbonate proxy records using calcium isotopes

Mary Reinthal
Master's Student, 1st year

Advisor: Matthew Fantle

The isotopic signature of calcareous foraminifera tests reflects the seawater isotopic chemistry at the time of the shell's formation. This has been used as an indicator of environmental conditions over geologic time. However, the primary signal associated with depositional conditions may actually represent post-depositional secondary processes (i.e. diagenesis) such as precipitation of inorganic calcite on the tests and/or dissolution of specific calcite layers from the tests. These processes can occur in situ during diagenesis or ex situ during sediment storage and can dramatically alter paleoenvironmental and paleoecologic reconstructions, thus leading to ambiguous interpretations in sample analysis. The calcium ($\delta^{44}Ca$) isotopic composition of marine carbonates has shown promise at a variety of spatiotemporal scales as a tracer for various terrestrial processes and for biogeochemical cycling. However, little work has been done to explore the impact of diagenesis on marine carbonate $\delta^{44}Ca$ during a major dissolution event such as the Paleocene Eocene Thermal Maximum (PETM). We modelled a global carbonate ion concentration with depth during the PETM. From this we were able to establish a dissolution gradient in the ocean that will help us identify where diagenesis is occurring and the degree to which it is occurring. This will direct future sampling endeavors.

Oral Session 5

Friday, March 29th 2:00 – 3:00 PM

Constraints on Earth's Thermal Evolution from the Heavy Noble Gas Content of the Mantle

Matthew Reinhold
Master's Student, 2nd year

Advisor: Brad Foley

Andrew Smye, Penn State University

The heavy noble gas content of the mantle is strongly dependent on the input and output of these gases through subduction and volcanism, respectively. The amount of each noble gas that reaches the mantle interior from the subducting slab is governed by the thermal regime of the subduction zone. In hot subduction zones, such as Cascadia, lighter gases such as Ne and Ar are preferentially lost through slab dehydration in comparison to the heavier gases, Kr and Xe; these lighter gases are returned to the atmosphere through arc volcanism, whereas more of the heavier gases remain and become incorporated into the mantle. Alternatively, in cold subduction zones such as Honshu, there is no preferential loss in Ne and Ar compared to Kr and Xe, and each species ends up in the mantle in the same relative proportions to one another as they are in the oceanic crust.

The current tectonic regime of the Earth is that of cold subduction, but was it always so? Here we constrain when the switch from hot to cold subduction occurred in Earth history based on present day noble gas abundances of the mantle. We model the cycling of noble gases between the surface and mantle coupled with the mantle's thermal evolution to answer this question. We consider the classic case of mantle convection where plate tectonics is active throughout Earth history and the heat flux scales with the Rayleigh number to the 1/3 power. Our results indicate the current mantle noble gas abundances are consistent with a history primarily in the hot subduction regime, with the transition to cold subduction occurring no earlier than 700 Ma ago.

Warming Early Mars with Climate Cycling: The Effect of CO_2-H_2 Collision-Induced Absorption

Benjamin Hayworth
Ph.D. student, 2nd year, Pre-Comps

Advisor: James Kasting

Jacob Haqq-Misr, Blue Marble Space Institute of Science
Rebecca Payne, Penn State University
Natasha E. Batalha, University of California, Santa Cruz
Ravi Kummar Kopparapu, NASA Goddard Space Flight Center
Mma Ikwut-Ukwa, Harvard University

Mars' geomorphological record overwhelmingly suggests the existence of liquid water during the late Noachian (~3.8 Gyrs). However, climate models have historically failed to warm early Mar's surface to the freezing point of water as the Sun was approximately 30% less luminous. Since CO_2 alone cannot warm early Mars as it condenses out, recent work has looked at whether minor atmospheric constituents such as H_2 and CH_4 can help warm the early climate. Recent work by Batalha et al. (2016) showed that with the addition of H_2, Mars undergoes limit cycles between 3-4 bars of surface pressure. This transient behavior has the capability of explaining much of Mars' geomorphologic record without demanding a permanently warm and wet climate.

One critique of this work is that it makes use of H_2 outgassing rates nearly 7x that predicted by Ramirez et al. (2014) for a realistic early Mars, as well as surface pressures that are higher than predicted. Using our Habitability Energy Balance Model for Exoplanets (HEx), we ran early Mars cases using radiation schemes from Wordworth et al. (2016) as well as Turbet et al. (2018) to model the collision-induced absorption (CIA) of CO_2-H_2. HEx uses a lookup table of relevant parameters calculated using our 1D radiative-convective model (CLIMA) to interpolate values of outgoing longwave radiation and planetary albedo. We found that limit cycles occur at surface pressures between 0.7 and 1 bar of CO_2 and outgassing rates of H_2 several times lower than that found by Batalha (2016). This is much closer to the paleo-paramters outlined by Kite (2019) and shows the promise of limit cycling as a feasible explanation for much of the geomorphologic record on Early Mars.

A time-resolved synchrotron X-ray diffraction study of goethite and (hydro)hematite formation at a broad range of pH (2-13) and temperatures (70-170°C)

Si Chen
Ph.D. student, 3rd year, Pre-Comps

Advisor: Peter Heaney

Jeffrey E. Post, Department of Mineral Science, Smithsonian Institution

Iron oxides are essential indicators of pH, Eh, temperature, microbial activity, and climate conditions in the Critical Zone. The most ubiquitous and environmentally significant iron oxides precipitated in aqueous environments are two-line ferrihydrite (with approximate formula $Fe^{3+}_{10}O_{14}(OH)_2$), goethite (α-FeOOH), and hematite (α-Fe_2O_3). A comprehensive study of the transformation of 2-line ferrihydrite to hematite and goethite over a wide range of pH (2-13) and temperatures (70-170°C) was conducted through batch and in-situ capillary experiments. The hematite to goethite ratios and crystal growth kinetics were calculated through a combination of Rietveld structure refinement and the time-resolved synchrotron X-ray diffraction (TR-XRD) experiments. Hematite competes with goethite and formed almost simultaneously from the ferrihydrite gel at pH>6. Hematite grows faster than goethite at pH<10 and at higher temperatures. The rate of transformation is much faster in alkaline than in acidic conditions and minimizes at the neutral conditions. Both our batch and TR-XRD experiments have suggested that hematite forms preferentially at the acidic conditions (pH 3-5) whereas goethite is favored at the neutral (pH 7-8) and highly alkaline conditions (pH>11). Iron deficient and hydrous hydrohematite was found at pH 9-11, suggesting that natural hydrohematite precipitates in alkaline solutions.

What's under Bear Meadows?

Joanmarie Del Vecchio
Ph.D. student, 2nd year, Pre-Comps

Advisor: Roman DiBiase

Sarah Ivory, Penn State University
Greg Mount, Indiana University of Pennsylvania
Jorden Hayes, Dickinson College
Sridhar Anandakrishnan, Penn State University

Recent geomorphic investigations in central Appalachia uncovered surprisingly long residence times for upland sediment, and periglacial features once thought to be the product of the Last Glacial Maximum are actually polygenetic features formed under multiple climate cycles. Bear Meadows Bog in Rothrock State Forest provides a unique opportunity to observe both the geomorphic response to climate change as well as the paleoclimate indicators that record past temperature, aridity and ecological boundary conditions. We present new geochemical and geophysical datasets to reconstruct the timing and magnitude of physical and chemical erosion under past climates. We use sedimentological and organic geochemistry datasets to speculate on the topographic and hydroclimate conditions modulating sediment flux from a thawing permafrost environment, as well as the fate of organic carbon mobilized during thaw. Long-lived sedimentary records of landscape response to permafrost thaw will inform numerical models of periglacial hillslope and channel evolution. These, in turn, will provide more accurate estimates of the efficiency with which soil organic carbon is sequestered in modern thawing permafrost environments, a crucial unknown in climate models.

Oral Session 6

Friday, March 29th 3:15 – 4:15 PM

The Characterization of Moderate to Large Magnitude Earthquake Processes Along the North American-Caribbean Plate Boundary

Jonas Kintner
Ph.D. student, 4th year, Post-Comps

Advisor: Charles Ammon

This study focuses on the characterization of earthquake activity along the North American-Caribbean plate boundary between coastal Central America and southern Cuba. We analyze the earthquake processes along this margin by computing precise relative earthquake location and magnitude estimates of M > 3.5 events between 1977-2018. The relocation results improve the alignment of earthquake locations with local and regional tectonic features. The estimated magnitudes of the relocated events using surface-wave cross-correlation amplitudes agree with the GCMT moment magnitudes for the larger events. Like previous studies, we find catalog MS and mb are under-estimating small-event sizes. We also compare the source-time functions and finite-fault estimates of the two largest recent earthquakes in the region, an MW 7.3 earthquake that occurred on 05/28/2009 08:25:04.80 UTC, and an MW 7.5 earthquake that occurred on 01/10/2018 02:51:44.3 UTC. We find that these two events have strikingly different rupture kinematics. The MW 7.3 event that occurred in 2009 was a long-duration, low average slip event with the long rupture. The MW 7.5 event that occurred in 2018 was a shorter duration, high average slip event with a short rupture. Our preliminary interpretation of these differences suggests variable faulting asperities or a role for restraining bend features along this strike-slip system. The improved earthquake location and magnitude estimates along this plate boundary illuminate active fault zones, providing important information for earthquake hazard assessment. This work also contributes to our general understanding of fault rupture involving the oceanic lithosphere.

Seismic Tomography of Southern Africa

Austin White-Gaynor
Ph.D. student, 4^{th} year, Post-Comps

Advisor: Andrew Nyblade

Southern Africa is an exceptional portion of the Earth's plate system and structure. Southern Africa is home to some of the oldest lithosphere on the planet (i.e., several Archean cratons surrounded by Proterozoic mobile belts), and has undergone relatively little Phanerozoic tectonic deformation. The African superplume is present at lower mantle depths beneath southern Africa, connecting to upper mantle low velocity structure beneath East Africa that is associated with continental rifting processes. Southern Africa is also known for its excess topography, > 1 km of non-isostatically supported elevations across a broad region recognized as the African superswell. Despite these unique conditions, there are still many unknowns about the connection between the African superplume and the African superswell. Using newly available datasets, creating a relatively constant grid of broadband stations extending from the western coast of Namibia to the eastern coast of Mozambique, we invert body and surface waves observations from teleseismic earthquakes for lithospheric and sublithospheric P- and S-wave velocity structure across the region. Specifically, to search for evidence of thermally perturbed lithospheric structure in southern Africa, associated with the African superplume and connected to structure in East Africa, we apply body wave tomographic techniques to data from ~700 M > 5.5 earthquakes recorded on 215 broadband stations throughout southern Africa. To constrain sublithospheric velocity structure, and its contribution to the African superswell, we apply surface wave tomographic techniques to observations of ~650 M > 6.5 earthquakes recorded on a similar network of stations. Our model results broaden the footprint of previous regional tomographic investigations, providing new constraints on upper mantle structure outside of the thick, cratonic regions, and are able to address some of the key questions pertaining to the connection between the African superplume and African superswell.

On the driving forces of the Arabian Margin deformation field: A mechanical model study

Thamer Alotaibi
Ph.D. student, 5th year, Post-Comps

Advisor: Kevin Furlong

Understanding the driving forces of the intraplate plate deformation is one of the fundamental problems in tectonophysics. Particularly, on the Red Sea region where multiphase rifting observed. Our GPS stations show velocity residuals with a dilatational strain along the Makkah-Madinah Transtensional zone within the Arabian Margin (Aldaajani et al., in prep). The causes of these GPS residuals along the Arabian Margin are still unknown. Hence, in this work, we are using the finite element modeling approach (Gtecton finite element package) to highlight the mechanical deformation processes of the Arabian Margin whether they related to the Red Sea rifting processes, Arabian Margin interior forces or mantle processes. Our model is a two-dimensional viscoelastic spherical shell. Our results indicate that the GPS residuals are not likely linked with the Gravitational Potential Energy as derived from the uplifted rift margin. Instead, the mantle flow related tractions as derived from shear splitting (Zheng et al., 2014) and mantle convection models (Faccenna et al., 2013) could be a strong driving force candidate for the observed deformation along the Arabian Margin.

Importance of bedrock cliffs in the morphology and erosion of steep landscapes

Al Neely
Ph.D. student, 4th year, Post-Comps

Advisor: Roman DiBiase

Although many steep landscapes comprise a patchwork of soil-mantled and bare-bedrock hillslopes, models typically assume hillslopes are entirely soil-mantled or bare-bedrock, making it challenging to predict how rock properties influence hillslope erodibility and landscape evolution. We studied headwater catchments across the San Gabriel Mountains (SGM) and Northern San Jacinto Mountains (NSJM) in southern California; two steep landscapes with similar climate and lithology, but where bedrock fracture density is ~5× higher in the SGM. We combined new and published detrital in-situ cosmogenic ^{10}Be-derived erosion rates with analysis of high-resolution imagery and topography to quantify how the morphology and abundance of bare-bedrock and soil-mantled hillslopes vary with erosion rate within and between the two landscapes. For similar mean hillslope angles (35-46°), catchments in the NSJM erode at rates of 0.1-0.6 m kyr^{-1}, compared to 0.2-2.2 m kyr^{-1} in the SGM. In both landscapes, bare-bedrock hillslopes increase in abundance with increasing erosion rate; however, more and steeper bedrock is exposed in the NSJM, indicating that wider bedrock fracture spacing reduces soil production efficiency and supports steeper cliffs. Additionally, higher erosion rates in the SGM require a 3× higher soil transport efficiency, reflecting an indirect control of bedrock fracture density on the size of sediment armoring hillslopes. Our data highlight how hillslope morphodynamics in steep landscapes depend on the strength of soil and bedrock and the efficiency of soil production and transport, all of which are variably sensitive to rock properties and influence the partitioning of soil and bare-bedrock on hillslopes.