50th Annual Graduate Student Colloquium

Great Sand Dunes National Park and Preserve, Colorado, Photograph by Austin White-Gaynor

Sponsored by Shell

Hosted by the Department of Geosciences

March 22nd – 23rd, 2018

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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:

Maeva Pourpoint (chair), Erica Pitcavage (chair), Austin White-Gaynor, Jonas Kintner, Rebecca Payne, Heather Jones, Josh Woda, Kalle Jahn

Event Schedule

Thursday, March 22

Kick Off Lunch – 11:30 to 1:00 pm – 5th Floor

Poster Session 1 – 1:00 to 2:15 pm – 5th Floor

Snacks – 2:15 to 2:45 pm – 2nd Floor

Oral Session 1 – 3:00 to 4:45 pm – Pulse of the Earth (Deike 240)

Friday, March 23

Breakfast – 7:30 to 8:15 am – 2nd Floor

Oral Session 2 – 8:15 to 9:45 am – Pulse of the Earth (Deike 240)

Snacks – 9:45 to 10:15 am – 2nd Floor

Oral Session 3 – 10:15 to 11:45 am – Pulse of the Earth (Deike 240)

Lunch – 11:45 to 1:00 pm – 5th Floor

Poster Session 2 – 1:00 to 2:15 pm – 5th Floor

Snacks – 2:15 to 2:45 pm – 2nd Floor

Alumnus Talk – 3:00 to 4:00 pm – Pulse of the Earth (Deike 240)

Reception – 4:30 to 6:00 pm – EMS museum

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:

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 22nd

1:00 – 2:15 PM **Poster Session 1**

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Chas Bolton	*Characterizing precursory phenomena in laboratory stick-slip failure events using unsupervised machine learning*	11
Allison Fox	*The Effect of Gamma Radiation on Mars Minerals: Implications for Perchlorate Formation on Mars*	12
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3:00 – 4:45 PM **Oral Session 1**

Al Neely	*Bedrock fracture spacing controls on the slope and relief of debris flow-dominated channels: Field constraints from the San Gabriel and San Jacinto Mountains, CA*	15
Judi Sclafani	*Structure from motion as a tool for 3D geometric morphometrics: a test using Strophomenid brachiopods*	16
Jonas Kintner	*Low Yield Seismic Source Analysis Using Local and Regional Observations*	17
Guangchi Xing	*Fractal Mechanical Network Based Time Domain Viscoacoustic Wave Equation*	18
Shelby Lyons	*Fossil carbon oxidation prolonged the Paleocene–Eocene Thermal Maximum*	19
Claire Cleveland	*Why didn't diversity, abundance, and geographic distribution protect oreodonts from extinction in Miocene North America?*	20

Friday, March 23rd

8:15 – 9:45 AM **Oral Session 2**

10:15 - 11:45 AM **Oral Session 3**

1:00 – 2:15 PM **Poster Session 2**

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Marit Wyatt	*Formation and evolution of lower continental crust: a petrochronological study of the Ivrea-Verbano Zone, NW Italy*	38
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Elena Stiles	*Quantifying plant extinction and morphological change across the K-Pg boundary in Argentine Patagonia*	46
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Gorki Ruiz	*The Kinematics of the southwestern Caribbean from geodetic GPS data modeling*	49

Poster Session 1

Thursday, March 22nd 1:00 - 2:15 PM

Along Strike Locking Characteristics of the Plate Boundary Zone of the South-Eastern Caribbean Basin

Machel Higgins
Ph.D. Student, 2nd year, Pre-Comps

Advisor: Peter LaFemina

Weber, J.C., Department of Geology, Grand Valley State University
Geirsson, H., Nordic Volcanological Center, Institute of Earth Sciences, University of Iceland

The CA-SA plate boundary zone of the southeastern region of the Caribbean Basin is characterized by the transition from dextral shear in northern Venezuela and the island of Trinidad, to underplating and subducting of SA beneath the CA plate along the Lesser Antilles. Neotectonics studies supports this tectonic regime with a CA-SA relative motion of ~22 mm/yr. The El Pilar Fault Zone (EPFZ), of northeastern Venezuela, has been shown to be a primary fault that accommodates up to ~18 mm/yr of CA-SA motion and has produced several large-magnitude earthquakes in recent history, notably the Cariaco 1997 Earthquake. Moving eastward, the EPFZ steps over to the Warm Springs Fault in the Gulf of Paria pull-apart basin which continues to the Central Range Fault (CRF) onshore Trinidad. On the island of Trinidad, the plate boundary slip is partitioned between three faults, the North Coast Fault, CRF, and the Soldado fault (~3.5 mm/yr, 15 mm/yr and ~3.5 mm/yr respectively). Several previous workers have used geodesy to determine locking and creep characteristics of the EPFZ and CRF. This work investigates the locking on segments of the EPFZ and CRFZ using published geodetic data (Weber et al., 2011; Reinoza et al., 2015) and InSAR measurements. Employing a Monte Carlo approach with the simple elastic dislocation model for segments of the EPFZ, it was found that the El Pilar is locked to a depth of ~7 km in the region near the city of Cumana and, moving eastward, transitions to creep over a distance of 15 km. The same technique was carried out for the CRF and it was found to be creeping on the CRF.

Preferential subsurface water flow through deep oxisols

Kalle Jahn
Ph.D. Student, 2nd year, Pre-Comps

Advisor: Demian Saffer

Tess Russo, The Pennsylvania State University Earth and Environmental Systems Institute
Christopher Neill, Woods Hole Research Center
Paul A. Lefebvre, Woods Hole Research Center

Current deforestation and agricultural expansion within the Amazon and Cerrado regions of Brazil is expected to continue in the coming decades. Understanding the impacts of this land-use change on watershed hydrology is key to mitigating negative effects to ecosystem health and sustaining future agricultural opportunities. Tanguro Ranch – a farm with both forested and cropped land – is located in the Brazilian Amazon-Cerrado transition, and its deep, well-weathered soils (oxisols) are primary controls on the regional hydrology. At Tanguro, the increases in stream solute concentrations usually expected with agricultural expansion have not occurred, despite high fertilizer application rates and increased stream discharge in agricultural watersheds. This has been attributed to preferential unsaturated flow paths that promote vertical solute transport to groundwater and reduce lateral surface and subsurface transport to nearby stream channels. To understand how the unsaturated zone controls water and solute export to groundwater and streams, this study investigates the physical controls on unsaturated flow through these oxisols. We hypothesize that the primary controls are microaggregate soil structures and annual/seasonal variability in rainfall intensity and frequency. To quantify flow paths and residence times, we develop unsaturated flow models for both forested and cropped land. Models are forced by meteorological and vegetation data collected from Tanguro, while soil hydraulic parameters are inversely estimated from soil moisture time series and constrained by soil water retention curves obtained from undisturbed soil samples. These models improve our understanding of water flow and solute transport through oxisols, while also helping us predict future water quality impacts from climate and land use change.

Frictional properties of relic fore arc metasediments from Kodiak Island, AK: Implications for slip in the upper accretionary prism

Peter K. Miller
Ph.D. Student, 2nd year, Pre-Comps

Advisor: Demian Saffer

Hannah Rabinowitz, Lamont Doherty Earth Observatory
Heather Savage, Lamont Doherty Earth Observatory

The slip behavior of subduction megathrusts is controlled by the mechanical and frictional properties of the material entrained along the plate interface. The shallow reaches of subduction thrusts (i.e. <20 km) commonly exhibit a stability transition from an updip aseismic zone, where earthquakes typically do not nucleate, to a deeper seismogenic zone. Recent observations indicate that the transitional region hosts a spectrum of slow earthquake phenomena, including Slow Slip Events (SSE's), tremor, and very low frequency earthquakes (VLFE). However, there remain few detailed experimental studies of relevant fault materials under *in situ* conditions to probe the connections between rock frictional properties and fault slip behavior.

To quantitatively understand the evolution of frictional properties along the upper part of the megathrust, we conducted a suite of shearing experiments at pressures and temperatures similar to *in situ* conditions, using exhumed subduction zone fault rocks composed of metamorphosed clay-rich sediments from Kodiak Island, Alaska. The metasediments we tested have experienced maximum burial depths ranging from ~4-6 to ~10–15 km, and peak temperatures ranging from ~100-125 to ~280 ^{o}C, making them ideal analogs for investigating the evolution of friction across the stability transition and into the seismogenic zone. These samples were powdered and sheared in a triaxial deformation apparatus at conditions ranging from ~25 MPa and 20 ^{o}C, to 195 MPa and 200 ^{o}C. Preliminary results at room temperature show steady state friction values of ~0.56 and rate strengthening behavior (a-b ~ 0.002) with D_c of 19 μm. Ongoing work is characterizing the frictional properties across the stability transition in greater detail.

Links between subduction megathrust earthquakes and upper-plate brittle deformation in the Pacific Northwest and Globally

Kirsty A. McKenzie
Ph.D. Student, 2nd year, Pre-Comps

Advisor: Kevin Furlong

Several recent subduction megathrust earthquakes were associated with significant, synchronous near surface upper plate faulting, which added to local strong ground motion and earthquake damage. In order to investigate the underlying mechanisms responsible for this complex rupture style, we test the following hypothesis*: Basal decoupling at the plate interface of upper plate faults during a subduction megathrust event allows synchronous failure of these faults, potentially with significant fault slip.*

The November 13th, 2016 M7.8 Kaikoura earthquake appears to show this complex rupture style. During this event, there was contemporaneous rupture of the subduction megathrust and slip on several upper-plate strike slip faults (Furlong and Herman 2017); with these surface faults, in spite of their short length, having slip of up to 12 m. A tsunami of 4 m height was generated by the event, in which tsunamigenesis has been attributed to synchronous slip of the megathrust accompanied by slip on an upper plate submarine fault (Bai et al. 2017).

A similar tectonic situation may exist in the Pacific Northwest. Unlike in the New Zealand case, where upper crustal faulting was concentrated in sparsely populated regions, several major upper-plate crustal faults in the Pacific Northwest lie in the vicinity of densely populated metropolitan centers. We utilize GPS and InSAR to observe inter-seismic deformation and characterize plate boundary coupling and LiDAR to characterize current deformation in the Pacific Northwest. Coulomb failure stress and finite element modeling will be used to model the potential effects of a megathrust rupture on upper-plate brittle faults. Key parameters controlling upper-plate fault behavior include the orientation of upper crustal faults, the depth to the subduction interface, and the nature of slip partitioning in an obliquely convergent subduction system. The Pacific Northwest region serves as our case study in investigating the synchronous rupture of a subduction megathrust with upper plate faults. However, results of this research have significance for earthquake hazards at subduction zones globally.

Bai, Y., Lay, T., Cheung, K.F., and Ye, L. (2017). Two regions of seafloor deformation generated the tsunami for the 13 November 2016, Kaikoura, New Zealand earthquake: *Geophys. Res. Lett.*, **44**, 6597–6606.

Furlong, K. P., and Herman, M. (2017). Reconciling the deformational dichotomy of the 2016 *Mw* 7.8 Kaikoura New Zealand earthquake: *Geophys. Res. Lett.*, **44**, 6788–6791.

Characterizing precursory phenomena in laboratory stick-slip failure events using unsupervised machine learning

Chas Bolton
Ph.D. Student, 2nd year, Pre-Comps

Advisor: Chris Marone

Bertrand Rouet-Leduc, Los Alamos National Laboratory
Claudia Hulbert, Los Alamos National Laboratory
Paul Johnson, Los Alamos National Laboratory

Earthquake forecasting is an important problem for mitigating seismic hazard and illuminating the physics of earthquake nucleation. However, progress in this area depends strongly on the ability to track and characterize seismic precursors. Characterization of precursors have traditionally relied on the development of AE event catalogs, which introduces biases and other unknown effects associated with filtering the time series. Therefore, it is not unreasonable to assume that valuable information is lost and along with that key insights into the earthquake nucleation process.

Here, we propose that by employing machine learning (ML) and using the entire time series of elastic radiation we can better characterize the evolution of AE precursors during the seismic cycle compared to event catalog-based approaches. We use data from a suite of friction experiments to study laboratory earthquakes using a servocontrolled biaxial deformation apparatus. Experiments were conducted in the double-direct shear configuration where two fault zones are sandwiched between three rigid forcing blocks. Normal stress on the faults was maintained constant at 2 and 6 MPa and a shearing velocity of 2,10 and 64 μm/s was imposed at the fault zone boundaries. Acoustic time series signals were recorded continuously at 4 MHz from two p-polarized piezoelectric transducers located adjacent to the fault. To investigate acoustic precursors, we first computed 42 statistical features of the continuous time series signal using a moving window. Each time window is approximately 9% of the recurrence interval of the stick-slip cycle and overlaps the previous window by 90%. The ML mean-shift clustering algorithm was then applied to the statistical features in order to find structure within the time series signal.

Our results show a systematic evolution in the acoustic properties as the fault approaches failure. Specifically, we identify three unique clusters for aperiodic stick-slip cycles and find that each cluster is associated with a specific period of the seismic cycle. However, for periodic stick-slip cycles we identify only two unique clusters irrespective of the shearing velocity. In addition, our results suggest that the key information is contained in just a few statistical features, including the acoustic variance and kurtosis. This work suggest that basic statistical features of the time series signal evolve systematically as the fault approaches failure and provide important precursory information about upcoming failure events.

The Effect of Gamma Radiation on Mars Minerals: Implications for Perchlorate Formation on Mars

Allison Fox
Ph.D. Student, 2^{nd} year, Pre-Comps

Advisor: Katherine Freeman

Jennifer Eigenbrode, Goddard Space Flight Center
Alex Pavlov, Goddard Space Flight Center
James Lewis, Goddard Space Flight Center

Observations by the Phoenix lander of the Martian surface indicate the presence of perchlorate in high concentrations. Additional observations by the Sample Analysis on Mars and the Viking Lander 1 indirectly support the presence of perchlorate at other localities on Mars. The evidence for perchlorate at several localities on Mars coupled with its detection in Martian meteorite EETA79001 suggests that perchlorate is present globally on Mars. The presence of perchlorate on Mars further complicates the search for organic molecules indicative of past life. While perchlorate is kinetically limited in Martian conditions, the intermediate species associated with its formation could oxidize Martian organic species. As a result, it is vital to understand the mechanism of perchlorate formation on Mars in order to determine its role in the degradation of organics.

Here, we explore an alternate mechanism of formation of perchlorate by bombarding Cl-salts and Mars-relevant mineral mixtures with gamma radiation both with and without the presence of liquid water under vacuum. Previous work has shown that OClO can form from both UV radiation and energetic electrons bombardment of Cl-ices or Cl-salts, which then reacts with either OH- or O-radicals to produce perchlorate. Past research has suggested that liquid water or ice is the source of these hydroxyl and oxygen radicals, which limits the location of perchlorate formation on Mars.

We demonstrate that trace amounts of perchlorate are formed in samples containing silica dioxide or iron oxide and Cl-salts both with and without liquid water. We did not detect perchlorate in samples that contained sulfate minerals. The formation of perchlorate without liquid water suggests that oxide minerals could be a potential source of oxygen radicals required to produce perchlorate. This finding could help explain the global presence of perchlorate and has implications for the survival of organic molecules on Mars.

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

Si Chen
Ph.D. Student, 2nd year, Pre-Comps

Advisor: Peter Heaney

James Kubicki, UTEP
Jeffrey Post, Smithsonian Institution

Iron (hydro)oxides are abundant and important indicators of pH, Eh, temperature, soil moisture, and climate conditions in the Critical Zone (Schwertmann and Taylor, 1989). Two-line ferrihydrite (with approximate formula $Fe^{3+}_{10}O_{14}(OH)_2$) is a metastable and poorly crystalline iron oxyhydroxide and, over timescales of decades at room temperature, transforms completely to goethite (α-FeOOH) and hematite (α-Fe_2O_3) (Das et al., 2011). The transformation rate depends strongly on the pH and temperature. A comprehensive kinetic study of the reaction of ferrihydrite to goethite and hematite was developed via X-ray diffraction (XRD) techniques and Rietveld analysis. Our batch experiments show that reaction rate is minimized and activation energy is maximized at pH 8. Hematite forms preferentially to goethite in acidic (pH 3-4) and slightly alkaline (pH 9-10) solutions, whereas goethite is favored at near neutral (pH 7-8) and highly alkaline conditions (pH≥11). Time-resolved synchrotron X-ray diffraction (TR-XRD) strongly supported our batch experiments. In heated, sealed capillary experiments, ferrihydrite transformed to hematite directly at pH 5, whereas ferrihydrite transformed to goethite and hematite simultaneously at pH 7. Moreover, TR-XRD observation indicates that the transformation of ferrihydrite to hematite does not necessarily include goethite as the intermediary. Instead, hydrohematite, a hydrous and highly iron-defective iron oxyhydroxide, serves as the precursor before stoichiometric hematite formed at pH 8. This study suggests that hematite and goethite abundances and crystal structures may serve as paleoenvironmental indicators.

Das, S., Hendry, M. J., & Essilfie-Dughan, J. (2010). Transformation of two-line ferrihydrite to goethite and hematite as a function of pH and temperature. Environmental science & technology, 45(1), 268-275.

Schwertmann, U., & Taylor, R. M. (1989). Iron oxides. Minerals in soil environments, (mineralsinsoile), 379-438.

Oral Session 1

Thursday, March 22nd 3:00 - 3:45 PM

Al Neely	*Bedrock fracture spacing controls on the slope and relief of debris flow-dominated channels: Field constraints from the San Gabriel and San Jacinto Mountains, CA*	15
Judi Sclafani	*Structure from motion as a tool for 3D geometric morphometrics: a test using Strophomenid brachiopods*	16
Jonas Kintner	*Low Yield Seismic Source Analysis Using Local and Regional Observations*	17
Guangchi Xing	*Fractal Mechanical Network Based Time Domain Viscoacoustic Wave Equation*	18
Shelby Lyons	*Fossil carbon oxidation prolonged the Paleocene–Eocene Thermal Maximum*	19
Claire Cleveland	*Why didn't diversity, abundance, and geographic distribution protect oreodonts from extinction in Miocene North America?*	20
Austin White-Gaynor	*Tectonic implications for the West Antarctic Rift System from body wave tomography*	21

Bedrock fracture spacing controls on the slope and relief of debris flow-dominated channels: Field constraints from the San Gabriel and San Jacinto Mountains, CA

Alexander Banks Neely
Ph.D. Student, 2nd year, Pre-Comps

Advisor: Roman DiBiase

Lee Corbett, University of Vermont
Paul Bierman, University of Vermont

Small headwater channels in steep landscapes are dominantly carved by debris flow events and form a key link between hillslope and fluvial domains. Surface processes in headwater channels influence 1) landscape response to changes in climate or tectonics; 2) the grainsize and flux of sediment delivered to larger, downstream channels; and 3) the size, extent, and recurrence of hazardous debris flows. Here, we use field observations, cosmogenic nuclides, and high-resolution topographic and imagery data to study headwater channels in rocky landscapes of the Northern San Jacinto Mountains and Eastern San Gabriel Mountains in southern CA. Both study sites have similar runoff regimes and lithology, but bedrock in the San Gabriel Mountains is highly fractured compared to massive bedrock cliffs exposed in the San Jacinto Mountains. Sparser fracture spacing in the Northern San Jacinto Mountains leads to steeper cliffs, coarser sediment, steeper fluvial channels, and a reduction of catchment erosion rates from ~0.6-2.2 mm/yr in the Eastern San Gabriel Mountains to ~0.1-0.3 mm/yr in the Northern San Jacinto Mountains. Debris-flow channels show similar gradients (~35°) in both landscapes, but are 2-3 times longer in the Northern San Jacinto Mountains, increasing headwater channel relief in this mountain range. In both landscapes, field observations indicate that most debris-flow channels are mantled with sediment, but the steepest channels are bedrock-dominated, consistent with a critical slope for colluvial channels that appears to be independent of grain size. We hypothesize that the extended headwater channel network in the San Jacinto Mountains could be a consequence of coarser sediment cover that requires a larger drainage area to initiate fluvial transport rather than debris flow mass wasting, but we also explore the potential controls of hillslope rock mass strength in supporting taller cliffs and thus longer headwater channels. Our findings highlight how changes in rock properties affect the slope and length of headwater channels, both of which control the amount of headwater channel relief and the propensity to transport sediment in destructive mass-wasting events.

Structure from motion as a tool for 3D geometric morphometrics: a test using Strophomenid brachiopods

Judith Sclafani
Ph.D. Student, 5th year, Post-Comps

Advisor: Mark Patzkowsky

Audrey Bourne, Penn State
Carly Gazze, Penn State
Brooke Roselle, Penn State
Max Christie, University of Illinois Urbana-Champaign

Morphometrics is an invaluable tool for quantifying the shape of fossil organisms. It can be used to determine the extent to which individuals are similar and different, which can then be correlated to evolutionary, ecological, or developmental changes. The simplest and most accessible visualization methods (e.g., landmarks, outlines, etc.) perform best in 2-dimensions, which means there is limited ability to quantify shape in 3-dimensions. This is problematic, especially when trying to better understand the relationship between form and ecological function, because many morphological characters thought to be important to this relationship (e.g., globosity, ribbing, texture) are expressed in 3-dimensions. To robustly quantify these shape parameters, it is important to employ a 3D morphometric technique. We argue that a recently developed visualization method called 'structure from motion' (SfM) is ideal for such a task.

SfM is a method of creating a 3-dimensional image from 2-dimensional photographs of an object. This involves taking a series of overlapping photographs with any digital camera (even a camera phone). Photographs are then imported into a computer program that aligns them and converts them into a 3D digital model, essentially a cloud of points. Point clouds from multiple objects can be exported as a data file of points and analyzed via an ordination method, e.g., principal component analysis (PCA).

The application of SfM in the geosciences has so far been mostly imaging outcrops, but its utility is slowly being expanded to hand samples, suggesting that it has great potential for 3D morphometrics. We have developed a method for using SfM to create 3-dimensional point clouds of brachiopod shells. Here we present best practices learned from method development and some preliminary results of Ordovician brachiopods.

SfM is advantageous because it is inexpensive, easy to use, and produces high-resolution images. Its low cost and simplicity is preferable to more technologically complex 3D methods and makes generating large morphological data sets for robust statistical analysis possible. Its ability to capture 3-dimensional features allows for a more complete analysis of shell shape. These advantages make SfM ideal for any fossil organism and an important development to the field of morphometrics.

Low Yield Seismic Source Analysis Using Local and Regional Observations

Jonas Andreas Kintner
PhD Student, 3rd year, Pre-Comps

Advisor: Charles Ammon

Andrew Nyblade, The Pennsylvania State University, University Park, PA
Kyle Homman, The Pennsylvania State University, University Park, PA

Low-yield explosion monitoring introduces new challenges to the current approach to estimating source location, magnitude, and discrimination. Small sources require nearby short period observations, which have an increased sensitivity to geologic heterogeneity, poor signal-to-noise ratios, and in many cases are sparse. Local and regional short periods observations from small shallow seismic sources can be dominated by a regional phase shear waves and Rayleigh waves. Using teleseismic surface wave observations, Cleveland & Ammon [2013] and Cleveland et al. [2015] show the value of using surface waves to estimate precise, relative locations in regions without a nearby seismic network. Using common-station, nearby-event cross correlation time-shift measurements, much of the complexity in wave propagation caused by regional geological heterogeneity is removed (or at least, greatly reduced). In this work, we extend surface wave relocation methods to estimate precise relative locations of small (local magnitudes from 1 to 3) mine blast events across Pennsylvania using local and near-regional distance observations (out to 300 km in distance). We also exploit the cross-correlation amplitude to estimate more precise relative magnitudes (actually log-moments) and develop a more consistent relationship between explosion yield and relative magnitude for various mines throughout the Commonwealth. Our locations are precise enough to allow us to image a time-dependent migration of a mine wall in north-central Pennsylvania. In west-central Pennsylvania, application of the relative location approach collapses a diffuse distribution of small-magnitude industrial events into five discreet clusters associated with particular operations in the area. The work demonstrates that cross correlation methods have the potential for achieving high precision relative location and magnitude estimates from local and regional observations of low yield seismic sources.

Fractal Mechanical Network Based Time Domain Viscoacoustic Wave Equation

Guangchi Xing
Ph.D. Student, 1st year, Pre-Comps

Advisor: Tieyuan Zhu

Viscoelasticity deviates Earth from a perfectly elastic body and brings the associated attenuation effects to seismic waves. These effects are significant in many applications of geophysical techniques so that necessitate incorporating attenuation into governing wave equations used for seismic modeling.

The state-of-the-art techniques for viscoelastic modeling can be categorized into two groups. One is a spectrum of physical descriptions based on various models consisting of mechanical elements including springs and dashpots. These mechanical models, however, lead to a frequency dependent quality factor Q over the seismic frequency range, which is inconsistent with the constant Q observation. The frequency independent feature can be mimicked by an array of mechanical elements but the additional variables introduced by the array brings large extra computational loads. On the other hand, a mathematical model is derived from the constant Q behavior and is adopted by many authors. This model contains fractional time derivates thus requires large memory to store stress-strain history. Recent studies convert the fractional time derivates into fractional spatial derivatives, i.e. fractional Laplacian, and implement it using pseudo-spectral method. While this method avoids storing previous time steps, it is not straightforward to deal with spatially-dependent Laplacian power.

In this study, we reconcile these two categories and provide the mathematical model a physically based motivation by illustrating that it can be described by a fractal network of mechanical elements. Hence, this fractal mechanical network (FMN) model exhibits accurate constant Q feature and can be implemented efficiently using fractional Laplacian. Based on this FMN model, we derive a new time-domain viscoacoustic wave equation with constant powers of fractional Laplacian operators by principal component matching. This new formulation is validated against analytical solutions of dispersion relations for attenuation coefficient and phase velocity as well as synthetic seismograms of homogeneous medium. Besides good accuracy and efficiency, this new FMN wave equation separates the amplitude decay and velocity dispersion effects while enjoys the fixed power terms that independent of model complexity.

Fossil carbon oxidation prolonged the Paleocene–Eocene Thermal Maximum

Shelby L. Lyons
Ph.D. Student, 3rd year, Pre-Comps

Advisor: Kate Freeman

Allison A. Baczynski, Pennsylvania State University
Tali L. Babila, University of California, Santa Cruz
Timothy J. Bralower, Pennsylvania State University
Elizabeth A. Hajek, Pennsylvania State University
Lee R. Kump, Pennsylvania State University
Ellen G. Polites, Pennsylvania State University
Sheila M. Trampush, University of Delaware
Jamie R. Vornlocher, University of Louisiana at Lafayette
James C. Zachos, University of California, Santa Cruz

A hallmark of the rapid and massive release of carbon during the Paleocene-Eocene Thermal Maximum (PETM) is the global scale negative Carbon Isotope Excursion (CIE). The delayed recovery of the CIE, however, indicates CO_2 inputs continued well after the initial rapid onset, although there is no consensus about the source of this secondary carbon. Here, we suggest this secondary input might have derived partly from the oxidation of remobilized sedimentary fossil carbon, as evidenced by biomarker and isotopic signatures preserved in shelf records from the US Mid-Atlantic coast. Multiple independent organic geochemical indicators provide evidence for significant delivery of fossil carbon to the oceans beginning ~10-20 kyr following the PETM onset. Mass-balance calculations show that oxidation of remobilized fossil carbon likely contributed a minimum of 1,000 Pg of CO_2 during the body of the PETM. The estimated mass is sufficient to have sustained elevated atmospheric CO_2 levels required by the prolonged global CIE. Even after considering uncertainties in sedimentation rates, these results indicate enhanced erosion, mobilization, and oxidation of ancient sedimentary carbon delayed recovery of the climate system for many thousands of years.

Why didn’t diversity, abundance, and geographic distribution protect oreodonts from extinction in Miocene North America?

Claire Cleveland
Ph.D. Student, 3rd year, Pre-Comps

Advisors: Mark Patzkowsky and Russell Graham

Extinction is a fundamental question in biology. It is more likely the many will outlive the few and broadly distributed groups will outlive geographically restricted groups. Oreodonts are widely considered one of the most abundant, widespread, and diverse mammal groups in the early Neogene and have one of the most extensive fossil mammal collections in North America. Yet, oreodonts went extinct in the late Miocene. In contrast, less prevalent Artiodactyla with strong ecological similarities and close relationships to oreodonts survived. Here, we will use oreodonts' exceptional fossil record to tease apart mechanisms of extinction during grassland expansion, one of the most important ecological shifts in the Cenozoic.

Data from the NEOMAP database, a combined product of the MIOMAP and Faunmap II databases indicate oreodonts, camelids, and peccaries share closely overlapping biogeographic ranges. Additionally, based on individual occurrence ratios and number of genera, we would expect equivalent or lower extinction risk in oreodonts. The evidence appears to contradict the outcome. As grasslands expanded during the Miocene, open savannas replaced closed forests. This change increased selection for grazing morphologies reflecting a change of diet and distance between feeding areas. A lack of morphological change in oreodonts is cited as a possible explanation for oreodont extinction in the Miocene, but this conclusion is drawn based on comparison with only one Miocene specimen. It is unlikely a single metric of morphological selection, abundance or geographic distribution will fully explain extinction risk. Some metrics will provide stronger resolution than others.

I propose to compare new and established quantitative metrics of distribution and morphological change through time and test the explanatory power of each through linear regression models. Testing extinction mechanisms in deep time on empirical datasets like oreodonts is fundamental to our understanding of diversity and evolution and essential to develop models to interpret extinction risk in modern ecosystems.

Tectonic implications for the West Antarctic Rift System from body wave tomography

Austin White-Gaynor
Ph.D. Student, 3rd year, Post-Comps

Advisor: Andrew Nyblade

Douglas Wiens, Washington University in St. Louis
Richard Aster, Colorado State University
Peter Bromirski, Scripps Institution
Peter Gerstroft, Scripps Instituion
Ralph Stephen, Woods Hole Oceanographic Institution
Terry Wilson, Ohio State University
Paul Winberry, Central Washington University
Audrey Huerta, Central Washington University
Sridhar Anandakrishnan, Pennsylvania State University

The West Antarctic Rift System (WARS) is one of the least understood continental rift system on the planet. The ~1000 km wide WARS includes the Ross Sea Embayment between Marie Byrd Land and the Transantarctic Mountains (TAM). Active volcanism on Ross Island continues to challenge our understanding of the generally quiescent rift system. Previous regional-scale body wave tomographic investigations have identified areas of low seismic wave speeds to ~200 km depth beneath Ross Island. However, the spatial extent of the low velocity structure across the entirety of the WARS remains poorly constrained due to the insufficient resolution of upper mantle structure under the Ross Sea Embayment away from Ross Island. We utilize teleseismic P wave observations recorded on the RIS/DRIS network, which consists of 34 seismometers deployed across the Ross Ice Shelf, along with data from nearby POLENET and TAMSEIS stations to better resolve this region. Relative P wave travel time residuals from 1300 teleseismic events, obtained using a multichannel cross-correlation method, have been inverted for a seismic velocity model of the upper mantle throughout the Ross Sea Embayment. Our results suggest that the low wave speed structure under Ross Island extends roughly halfway across the Embayment and south along the Transantarctic Mountains. This observation is consistent with a two-phase rifting history for the WARS in which broad, late Cretaceous rifting between Marie Byrd Land and the TAM transitioned to ~500 km wide rifting along the TAM margin in the Cenozoic.

Oral Session 2

Friday, March 23rd 8:15 - 9:45 AM

Mapping offshore portions of the Khlong Marui and Ranong faults in Thailand: Implications for seismic hazards in the Thai peninsula

Haley M. Ramirez
M.S. Student, 2nd year

Advisor: Kevin Furlong

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The Ranong and Khlong Marui faults are NNE striking, strike-slip faults that cut across the Thai peninsula and are assumed to continue SSW into the Andaman Sea. They have clear surface expressions onshore, but their potential offshore continuations have not previously been mapped. Five Mw > 4.5 earthquakes have occurred near the inferred offshore extensions of the Ranong and Khlong Marui faults since 2005. However, the maximum possible earthquake magnitudes and recurrence intervals of events on these faults are unconstrained, leaving southern Thailand unprepared for a possible larger (Mw > 6) earthquake.

We conducted a high-resolution multi-channel marine seismic reflection survey in the Andaman Sea to construct an offshore fault map. There are several locations where observed faults cut the surface sediments in the Andaman Sea indicating that these faults have been recently active. These active fault locations were correlated between the seismic lines and with the mapped onshore faults, which gives a new estimate of total fault length. With these data we estimate a revised maximum earthquake magnitude for the Ranong and Khlong Marui faults using empirical relationships between fault length and maximum earthquake magnitude. Using coulomb stress modeling we will examine several scenarios for interaction between the offshore and onshore portions of these faults to better understand the hazard they pose to the Thai peninsula.

Scaly fabrics and veins of the Shimanto Belt, SW Japan: a record for the role of silica redistribution on subduction slip behavior

Gabrielle Ramirez
M.S. Student, 2nd year

Advisor: Donald Fisher

Andrew Smye, Penn State University
Yoshitaka Hashimoto, Kochi University, Japan
Asuka Yamaguchi, The University of Tokyo, Japan

Mélanges in ancient accretionary complexes provide a microstructural record of subduction plate boundary deformation in the seismogenic zone including microstructurally pervasive crack-seal veins filled with quartz, calcite, and albite and scaly fabrics (i.e. anastomosing slip surfaces that accommodate plate motion). There is evidence for silica redistribution from the scaly fabric surfaces to the crack-seal veins, resulting in a healed interface. This study aims to answer the following questions: what are the geochemical changes that occur as a function of depth and temperature in the seismogenic zone? how do crack-seal vein/fracture systems evolve? what role does silica redistribution play in the evolution of slip? is this an open or closed system? To answer these questions, we use EPMA, XRD, XRF, LA-ICP-MS, and microfracture scanline data in conjunction with microstructural observations from the Lower Mugi, Upper Mugi, and Makimine mélanges which were underplated at the range of temperatures that span the seismogenic zone: 130-150°C, 170-200°C, and 340°C, respectively. Therefore, these mélanges are a record for the mechanical and geochemical processes that influence plate boundary slip behavior. Microstructural observations show that the Mugi mélanges are characterized by thicker, anastomosing scaly microfault zones (100's of microns) while the Makimine exhibits thinner, more concentrated scaly microfault zones (10's of microns). Geochemical analyses suggest that there are no significant changes in mineral phases as a function of depth in the seismogenic zone. Immobile elements suggest that silica redistribution significantly increases with depth in the seismogenic zone. Mobile element concentrations suggest a relationship between mobility and paleotemperature. Cumulative frequency plots that show power law vein thickness distributions, combined with crack seal textures in SEM-CL imaging, indicate incomplete sealing of open fractures and runaway vein growth with time. This suggests that these shear zones maintain an open fracture system in the footwall, in contrast to the bounding narrow fault zones with pseudotachylite that likely reflect coseismic failure of a healed fracture system. These differences are consistent with the general observation that the subduction zone is a host to a wide range of slip behavior, from megathrust to slow-slip events. Microstructural and geochemical characteristics of underplated mélanges from ancient accretionary complexes thus highlight processes that influence the evolution of the slip instabilities inherent in seismic behavior.

Distribution of trace metals in soil profiles impacted by wastewater reuse: Examples from Penn State's Living Filter

Jared L. Carte
M.S. Student, 2nd year

Advisor: Matthew Fantle

An understanding of the subsurface transport of trace metals is critical for quantifying metal budgets in wastewater treatment and reuse systems involving natural soils, such as wastewater treatment wetlands and wastewater irrigation sites. Subsurface transport is rarely considered in studies that investigate the fate of metals in wastewater reuse systems, due to the common assumption that trace metals will accumulate in near surface (~ upper 20 cm) soils due to adsorption to soil minerals and plant uptake. This study investigates the subsurface distribution of trace elements in two wetland soil profiles (~1 m depth) at Penn State University's wastewater reuse site, at which all effluent from the University's wastewater treatment plant has been spray-irrigated on crop and forest lands since 1983. As expected, near surface concentrations of many trace metals of concern in wastewater streams, including copper, lead, nickel, and zinc, are enriched by a factor of 1.7-3.5 relative to deep soils. However, concentrations of these elements are also enriched by factors ranging from 1.4-5 relative to deeper soils in certain subsurface horizons, indicating that trace metals are mobilized deeper in soil profiles than previously thought. Significant copper isotopic variations throughout the soil profiles provide evidence that reactions take place within the soil profile leading to trace metal remobilization, contrasting with the previous assumption that trace metals simply accumulate in the near surface. X-ray diffractometry results indicate that trace metal distribution in the subsurface correlates with the presence of smectites, highly reactive clay minerals that can immobilize metals from solution due to adsorption. These results indicate that the fate and transport of trace metals through soils impacted by wastewater reuse is more complex than previously thought, and that simply accounting for trace metal accumulation in near surface soil intervals could lead to an incomplete understanding of the trace metal budget. The mobilization of trace elements through soil profiles also has implications for predicting the water quality impact of wastewater reuse, especially if wastewater irrigation is conducted at a site with a shallow water table where metals could be transported.

Understanding concentration-discharge relationships and anthropogenic solute transport across various lithologies and land uses

Callum Richard Wayman
M.S. Student, 2nd year

Advisor: Susan Brantley

Tess Russo; Earth and Environmental Systems Institute, Mathematics Department at Pennsylvania State University
Beth Hoagland; Geosciences Department, Pennsylvania State University
Brandon Forsythe; Earth and Environmental Systems Institute
Li Li; Civil and Environmental Engineering Department, Pennsylvania State University
Susan L. Brantley; Earth and Environmental Systems Institute

It is important to understand how solute fate and transport is affected by variations in land use and lithology across scales. One of the primary objectives of the Susquehanna Shale Hills Critical Zone Observatory (SSHCZO) project is to use long-term data sets from small catchments such as Shale Hills (0.08 km^2) to larger watersheds such as Shavers Creek (163 km^2). We have collected geochemical and hydrological data from several subcatchments and four monitoring sites on the main stem of Shaver’s Creek, in Huntingon county, Pennsylvania. One subcatchment, Cole Farm (0.43 km^2), is dominated by agricultural land use, and the monitoring locations in Shaver’s Creek main stem drain watersheds with 0 to 25% agricultural area. Long-term data sets have been used to analyze the variations in concentration discharge relationships with respect to changes in land use. We also use synoptic sampling data sets to determine the locations of highest solute fluxes into Shavers Creek. The transport of nutrients between interflow and regional groundwater is important, and we seek to see how this connectivity is reflected in surface water solute dynamics. Sulfur isotopes are being used to begin furthering our understanding of the relative contributions of regional and local groundwater fluxes into streams. Preliminary data shows that excess nitrate load from farms may be flowing into Shavers Creek in shallow, interflow fluxes.

Monitoring Hydrocarbon Migration and Aquifer Degradation near Problematic Shale Gas Wells

Josh Woda
M.S. Student, 2nd year

Advisor: Susan Brantley

Tao Wen, Pennsylvania State University
David Oakley, Pennsylvania State University

Development of horizontal drilling and hydraulic fracturing in Pennsylvania has contributed to increased public concern over water health and public safety. Cases of methane migration into natural waters have been observed due to shale gas development. Very few studies have focused on geochemical conditions in natural waters associated with methane leakage.

A technique to detect and monitor methane migration into surface water has been implemented on Sugar Run in Lycoming County, Pennsylvania near a suspected leaking unconventional gas well. Geologically, the Marcellus shale in this region of Pennsylvania rises steadily to the surface and outcrops approximately four miles from the sample location at the Nittany Anticlinorium. Surface water measurements in Sugar Run and groundwater samples from four homeowner water wells were samples for inorganic ions and dissolved hydrocarbons (C1 + C2). Additionally, samples were collected for noble gas analysis and Sr isotope composition. Surface water shows methane concentrations as high as 8,500 ppb in one of three seeps (area where groundwater directly comes to the surface) located along this stretch. Active bubbling can be observed in each of these seeps. Isotopic analysis of stable carbon isotopes ($\delta^{13}C$ in CH_4) in Sugar Run indicates a thermally mature thermogenic source (-42‰ to -10.3‰), most likely sourced from Marcellus Formation at depth. Cation and anion results from the seeps and adjacent stream samples show elevated concentrations of redox sensitive metals such as Mn, Fe, Co, Ni and As. Homeowner water wells contain elevated H_2S.

Recognizing how geology might be conducive to methane leakage could be important for public safety. In Sugar Run, high aqueous methane concentrations in the seeps and enriched isotopic $\delta^{13}C$ in CH_4 are both consistent with leaking thermogenic methane. High methane could create a reducing environment at depth as indicated by mobilization of metals such as Fe and Mn and decrease in sulfate and nitrate. A reducing environment and an increase in metal concentrations related to unconventional gas exploration could pose issues to homeowners and natural aqueous environments.

Effects of Mixed Distribution Statistical Flood Frequency Models on Dam Safety Assessments: A Case Study of the Pueblo Dam

K. Joel Roop-Eckart
M.S. Student, 2nd year

Advisor: Klaus Keller

Benjamin Seyon Lee, Pennsylvania State University
Caitlin Spence, Pennsylvania State University
Tess Russo, Pennsylvania State University

Statistical flood frequency analysis, coupled with hydrograph scaling, is commonly used for dam safety assessment. The results are highly sensitive to statistical model choice. Past studies typically use a single distribution model, often the Log Pearson Type III or Generalized Extreme Value distributions.

Floods, however, may result from multiple physical processes such as snowmelt or intense rainstorms. These differing processes can result in a mixed distribution of annual peak flows. Engineering design choices based on a single-distribution statistical model may hence be vulnerable to the effects of structural model error. Here we analyze observations from Pueblo, Colorado, where summer snowmelt and intense summer rainfall are key drivers of annual peak flows. This has potential implications for the annual probability of overtopping induced failure of the Pueblo Dam.

We bypass the temporal separation problem by building on previous work of fitting mixed distributions directly to mixed distribution annual peak flows. We first use hydrograph scaling and a flood routing model to determine the design flood. We then analyze annual peak flows, historical floods, and paleo records through both single and mixed distribution statistical models to estimate return periods of the design flood.

We address three questions: (1) How sensitive are the flood frequency results to the statistical model choice? (2) Which statistical model fits the data best? (3) How does this model structural uncertainty impact flood risk assessments?

Oral Session 3

Friday, March 23rd 10:15 – 11:45 AM

Lithospheric drip magmatism and magma-assisted rifting: a case study in the Western Rift, East Africa

Erica Pitcavage
Ph.D. Student, 4^{th} year, Post-Comps

Advisor: Tanya Furman

Wendy Nelson, Towson University

The East African Rift System (EARS) is earth's largest continental divergent boundary and an unparalleled natural laboratory for understanding magmatism related to successful continental rifting. Classic views of continental rifting suggest that faulting and extension are facilitated by ascending magmas that weaken the lithosphere thermally and structurally within basin-bounding accommodation zones. In the EARS Western Rift (WR), many volcanic fields are not aligned along rift-bounding faults, and magma compositions lack evidence for asthenospheric inputs expected along lithosphere-penetrating fault systems. We note that compositional input from the Cenozoic Afar mantle plume is not recognized convincingly in WR mafic alkaline lavas[1]. Rather, magma compositions demonstrate significant input from anciently metasomatized sub-continental lithospheric mantle (SCLM). Destabilization and foundering of metasomatized SCLM has an increasingly recognized role in continental magmatism worldwide, producing volatile-rich, alkaline volcanics when drips of foundered SCLM devolatilize and melt on descent. This magmatism can lead to faulting: the lithospheric thinning that results from this process may play a role in physical aspects of rifting, contrasting with faulting facilitated by asthenospheric melts. Geochemical and geophysical evidence indicates that drip magmatism has occurred in several EARS provinces, including Turkana, Chyulu Hills, and in Afar[2] where it is geographically coincident with successful rifting. We present bulk geochemical data that suggest drip melting of metasomatized SCLM is occurring in several WR volcanic fields. We focus on Bufumbira (Uganda), where mafic lavas are derived from garnet+phlogopite+amphibole+zircon-bearing pyroxenite, indicating a deep metasomatized SCLM source. Isotopic and trace element data suggest that extent of melting increased with depth of melting, a signature of lithospheric drip. We propose that drip magmatism is an important driver of volcanism in the early history of these igneous provinces and may be fundamentally related to the onset of successful rifting.

1. Graham, D. *et al. Goldschmidt Conference Abstracts* (2011).
2. Furman, T., *et al. Geochim. Cosmochim. Acta* 185**,** 418–434 (2016).

Permeability Evolution as a Function of Fracture, Shear, and Dynamic Stressing Under True Triaxial Load

Ben Madara
Ph.D. Student, 4^{th} year, Post-Comps

Advisor: Chris Marone

J. Rivière, Univ. Grenoble Alpes, ISTerre, F-38000 Grenoble, France

We study the effects of fracturing, shearing, and dynamic stress on the permeability of Berea sandstone and Westerly granite. Intact samples are fractured and sheared under true triaxial loading conditions at effective normal stress of 20 MPa. Experiments are conducted using L-shaped, prismatic samples that can be fractured in-situ while monitoring permeability and strength evolution during shear. Fractures are rough, with peak to trough distances up to 5 mm; nominal fracture area is 45x50 mm^2. We find that matrix permeability decreases with increasing differential stress during triaxial loading to failure. Fracture permeability decreases with shear displacement for both rock types tested. Dynamic oscillations of effective normal stress were imposed via pore pressure and applied normal stress at frequency of 1 Hz and amplitudes from 50 kPa to 1 MPa. Pore pressure oscillations resulted in an increase in permeability, while applied normal stress oscillations had no consistent effect on rock permeability. The improved understanding of permeability evolution with shear fracture, displacement, and dynamic perturbations can be applied to the creation and stimulation of natural and engineered reservoir fracture networks.

Delayed calcareous nannoplankton recovery in the K/Pg impact crater: results from IODP-ICDP Expedition 364

Heather L. Jones
Ph.D. Student, 4th year, Pre-Comps

Advisor: Timothy J. Bralower

Christopher M. Lowery, Institute for Geophysics, University of Texas
Jan Smit, Faculty of Earth and Life Sciences, Vrije Universiteit Amsterdam
IODP-ICDP Expedition 364 Scientists

New cores recovered from the Chicxulub Impact Crater (Expedition 364, Site M0077) offer an exciting opportunity to examine the recovery of life at "ground zero". Calcareous nannoplankton, a group of marine autotrophs, were decimated during the mass extinction event. Because these organisms lie near the base of the marine food web, examining their response to this event provides clues as to which ecological and environmental variables were important in facilitating full ecosystem recovery.

The Danian at Site M0077 is represented by indurated limestones with 1-5 mm thick wispy styolites. These sediments reveal that nannoplankton assemblages are dominated by calcareous dinoflagellate cysts and *Braarudosphaera*. Although these taxa are commonly observed in K/Pg sections during the earliest recovery, the abundance of *Braarudosphaera* at Site M0077 is unusual. This taxon is often cited as an environmental stress indicator with an ecological preference for cold water and high nutrients. Coastal ocean sites such as Forada and Agost feature similar *Braarudosphaera* abundances, suggesting this is a shallow water signal.

Cretaceous survivors are rare in the early Danian, and new Paleocene species do not appear consistently until several meters above the boundary. This, coupled with the persistence of *Braarudosphaera* into the latest Paleocene, indicates stressed environmental conditions for millions of years following the event. Paleocene bloom taxa that are typical of Northern Hemisphere recovery assemblages are also observed higher up in the section. With age control, we can therefore determine how delayed nannoplankton recovery was at "ground zero" compared to distal sites.

In comparison to nannoplankton, earliest Danian assemblages of planktic foraminifera (which occupy a higher trophic level) are relatively normal, suggesting faster recovery rates. This disconnect between ecological strategy and recovery rate indicates the conditions that hindered nannoplankton recovery were specific to this group. These observations suggest that environmental and/or ecological variables such as niche space, temperature, nutrients, and light availability were critical in fully restoring the marine ecosystem.

The regional tectonic implications of heterogeneous extension on Red Sea Rift architecture and internal deformation of the Arabian Plate

Thamer Aldaajani
Ph.D. Student, 4th year, Pre-Comps

Advisor: Kevin Furlong

Rocco Malservisi, University of South Florida

The interaction between regional Cenozoic tectonic forces and the inherited architecture and lithospheric strength of the Arabian Plate has played a significant role in initiating Red Sea, NW Arabian Margin, Sirhan rifting, formation of the Dead Sea transform, and associated volcanic activities in that region within the Arabian Plate. Geological observations appear to show that most of the present-day earthquakes and recent volcanic activity in the NW Arabian margin are associated with diffuse extensional structures that are associated with the initiation of extension in the northern Red Sea. This region of diffuse extension falls within an area that is bounded to the east by the Sarhan Rift, to the west by the northern Red Sea Rift, to the south by what is known as the Makkah-Madinah-Nafud (MMN) volcanic line, and to the north by the Mediterranean oceanic crust. We are mapping the regional pattern of Arabian margin rigidity and strain distribution using current displacements/velocities from more than 40 GNSS stations distributed within the Arabian Plate. The data show that the transition between different styles of deformation along the Arabian Red Sea margin corresponds with a transition between southern rigid versus northern non-rigid behavior. This suggests that the preexisting structures within the Arabian plate, which play an important role in controlling plate rigidity, affect earthquake and volcanic activity along the northern Red Sea and within the NW Arabian margin.

Impacts of floodplain restoration on nitrogen transformation pathways along the Cosumnes River, California

Beth Hoagland
Ph.D. Student, 4^{th} year, Post-Comps

Advisor: Susan Brantley

Calla Schmidt, University of San Francisco
Tess Russo, Global Good
Jason Kaye, The Pennsylvania State University
Ryne Adams, University of San Francisco

Throughout the United States and many parts of the world levee construction has resulted in the systematic replumbing of river systems. Levee construction results in major reductions in the timing and frequency of floodplain inundation and fundamentally alters the hydrologic, geomorphic, and biogeochemical processes of a riverine system, thus impacting nutrient delivery and transformations in floodplains. Floodplain restoration via levee removal or setback can affect downstream water quality by restoring soil microbial metabolic pathways such as denitrification, anaerobic ammonium oxidation (anammox), and dissimilatory nitrate reduction to ammonium (DNRA), which in turn transform excess nitrogen. However, few studies have quantified the contribution of all three pathways to nitrate retention in restored floodplains. In this study, we address the following questions: (a) how do restored floodplain characteristics, such as time since reconnection, inundation duration, soil structure, and soil chemistry affect nitrogen transformation pathways? and (b) what is the relative contribution of denitrification, anammox, and DNRA to total nitrogen transformation in restored floodplain soils? To address these questions, we simulated flood conditions in soil mesocosms collected from two floodplains where levees were breached in 1985 and 2014 along the Lower Cosumnes River in the San Joaquin Basin of California. River water enriched with $K^{15}NO_3^-$ tracer was pumped into each mesocosm at a constant rate for a period of 3 months. During this time, samples were collected from the surface water, pore water, and soil for measurements of NO_3^-, NO_2^-, NH_4^+ concentrations, and $\delta^{15}N$ of dissolved gases (N_2 and N_2O). Results revealed that nutrient concentrations were variable during the first 50 h, followed by a linear increase in organic carbon and a linear decrease in nitrate concentrations over the remainder of the experiment. Further, nutrient concentrations and ^{15}N-NO_3 and ^{15}N-NO_2 enrichment in the soils differed between the two floodplains. This study quantifies the relevance of anammox and DNRA to total nitrate retention, characterizes the hydrologic conditions most favorable to each pathway, and estimates the overall potential for floodplain restoration to improve nitrogen retention and cycling in the Cosumnes watershed.

The Effects of Shear Strain, Fabric, and Porosity Evolution on Elastic and Mechanical Properties of Clay-Rich Fault Gouge

Abby Kenigsberg
Ph.D. Student, 4th year, Pre-Comps

Advisor: Demian Saffer

Chris Marone, Penn State
Jacques Riviere, Penn State

Ultrasonic and seismic waves are widely used for probing fault zone mechanical (gouge composition, frictional strength, porosity) and elastic (Vp, Vs, bulk and shear moduli) properties, as they can provide insight into key processes and fault properties during shearing. These include fabric and force chain formation, porosity evolution, and fault zone stiffness, which are in turn factors in fault slip, damage, and healing. We report on a suite of direct shear experiments on synthetic fault gouge composed of 50% smectite /50% quartz at a normal stress of 25 MPa, in which we use ultrasonic wave transmission to continuously monitor compressional and shear wave velocities (Vp, Vs) up to shear strains of ~25, while simultaneously measuring friction and monitoring the evolution of density and porosity.

We find that wavespeeds vary with shear strain, due to fabric development and the evolution of density and porosity. The coefficient of friction peaks at $\mu \sim .47$ at a shear strain of ~.5 – 1, decreases to a steady state value of $\mu \sim .43$ by shear strains of ~4.5- 6 and then remains rather constant to shear strains of 6 - 25, consistent with previous work. Density increases rapidly from 1.78 g/cm^3 to 1.83 g/cm^3 from shear strains of ~0-2 (porosity decreases from ~33% to ~25% over that range), and then more gradually increases to a density of 2.08 g/cm^3 (porosity of ~21%) at a shear strain of ~25. Vp increases from ~2400 m/s to 2900 m/s during the onset of shear until a shear strain of ~ 3, and then decreases to ~2400-2500 by shear strain of 7-9. At shear strains above 9, Vp increases as the layer becomes denser and less porous. Vs and amplitude follow similar trends to Vp. We interpret the co-evolving changes in friction, porosity, and elastic moduli/wavespeed to reflect fabric development and alignment of clay particles as a function of shearing. More specifically, the decrease in Vp at a shear strain of ~3 reflects the clay particles gradually aligning. Once the particles are aligned, the gradual increase of Vp at shear strains of ~7-9 reflects near complete alignment and increased compaction and density. This interpretation is supported by SEM imaging and analysis of a suite of experiments stopped at different shear strains.

Poster Session 2

Friday, March 23rd 1:00 - 2:15 PM

Crustal Structure Across the Appalachian Basin Using Joint Inversion of P-wave receiver functions and Surface Wave Dispersion

Kyle Homman
Ph.D. Student, 1st year, Pre-Comps

Advisor: Andrew Nyblade

Induced seismicity as a result of hydraulic fracturing and the subsequent wastewater disposal process has been a concern in recent years. Although typically small magnitude events, these induced earthquakes can reach magnitudes large enough to cause damage to nearby structures. The majority of induced seismic events occur within old basement faults below the target formation. While most induced seismicity has occurred in the central United States, there are several instances of induced events occurring in the Appalachian Basin such as the magnitude 2.3 Lawrence County, PA event in 2016 and the magnitude 4.0 Youngstown, Ohio event in 2011.

Using data from several permanent and temporary broadband seismic networks, this study aims to determine crustal structure and depth to basement across the Appalachian Basin by jointly inverting teleseismic P-wave receiver functions and surface wave dispersion measurements. P-wave receiver functions are primarily sensitive to shear-wave velocity contrasts and vertical travel times whereas surface waves are sensitive to shear-wave velocities. The joint inversion of the two methods bridges resolution gaps associated with each data set, enabling the development of a higher resolution subsurface model. A better understanding of the crustal structure across the basin will allow identification of areas that may be of high risk for induced seismicity. Preliminary results indicate the use of high frequency receiver functions with dispersion measurements can image basement structure.

Formation and evolution of lower continental crust: a petrochronological study of the Ivrea-Verbano Zone, NW Italy

Damaris "Marit" Wyatt
M.S. Student, 1st year

Advisor: Andrew Smye

The Ivrea-Verbano Zone (IVZ) in northwest Italy is the archetypal section of lower continental crust. The IVZ study area addressed here is dominated by the Kinzigite formation, composed of metasedimentary rocks that equilibrated at depths between 15 and 28 km. Current geologic consensus holds that the lower crust is predominantly mafic, so the Kinzigite formation's position in the lower crust begs two questions: 1.) How were the sediments buried? And 2.) How does incorporation of sediments into the lower continental crust affect the long term thermal evolution of the continental lithosphere?

Here, I present the results of laser ablation split stream inductively coupled plasma mass spectrometry (LASS ICP-MS) study of monazite grains found in amphibolite to granulite facies metapelitic rocks from Val Strona di Omegna, IVZ. Preliminary observations from trace element LASS ICP-MS data suggest that the transition from high to ultra-high temperature (>900 °C) conditions in the lowermost section of the IVZ is critical for the mobility of heat producing elements due to lower crustal melting. This trace element data combined with radiometric dating indicate two temporally and chemically distinct periods of monazite growth, which could potentially provide further insight into the tectonic evolution of the IVZ.

Population shifts of hydrocarbon-degrading microbes incubated under different pressure and temperature regimes in seafloor sediments of the Gulf of Mexico

Uyen Nguyen
Ph.D. Student, 5th year, Post-Comps

Advisor: Jennifer Macalady

Sara A. Lincoln, Department of Geosciences, The Pennsylvania State University
Katherine H. Freeman, Department of Geosciences, The Pennsylvania State University
Ana Gabriela Valladares Juárez, Institute of Technical Biocatalysis, Hamburg University of Technology
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About 3-31% of oil released from the 2010 Deepwater Horizon (DWH) disaster was deposited onto deep Gulf of Mexico (GOM) sediments, where biodegradation is suggestively the main process regulating the fate of the spilled oil. However, information on the dynamics of deep sediment microbial communities in response to oil spill is limited, especially under high pressures. Here, we investigated crude oil biodegradation in laboratory incubation under simulated seafloor conditions, with 13 different core top GOM sediments collected at water depths from 60-1500 m. After 18 days, changes in oil components were analyzed with gas chromatography-mass spectrometry, and 16S-rRNA genes of microbial communities were sequenced on Miseq PE Illumina using universal primers 515F/806R targeting V4 hypervariable regions. In all samples, original diversity decreased as oil degraders increased their abundances. Proteobacteria was the most dominant phylum, followed by Bacteroides and Firmicutes. Gene prediction based on phylogenetic investigation of communities by reconstruction of unobserved states method (PICRUST) showed positive correlations between copy numbers of hydrocarbon-degrading genes and the depletion in total n-alkanes and total polycyclic aromatic hydrocarbons (r^2 = 0.2 to 0.8). While shallow sediments selected for Alcanivorax and Marinobacter, deep sediments had high abundance of Colwellia, Oleispira, and Pseudoalteromonas, known genera of oil-degraders. Constrained analysis of principal coordinates (CAP) further showed separate clusters of post-incubation shallow and deep communities. A subset of deep sea samples incubated at 4^0C at both *in situ* pressure (9-15 MPa) and surface pressure (0.1 Mpa) revealed variation in oil degrader compositions, along with stochastic behavior in hydrocarbon degradation according to pressure change, suggesting that pressure was an important factor shaping microbial communities. Overall, our study advances the understanding of how natural deep water microbial ecology responds to crude oil disturbance under simulated deep sea conditions, which could help guide bioremediation decision makers in case of future deep sea spills in the GOM.

Upper mantle structure beneath the northern part of the East African Plateau using data from the NE Uganda temporary seismic network

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Data from a newly installed temporary seismic array in northeastern Uganda are incorporated into an existing body wave tomography model of eastern Africa to improve imaging of the upper mantle beneath the northern part of the East African Plateau. Nine temporary broadband stations were installed in January 2017 and will be operated through 2018 to obtain data for resolving structure under the northern part of the plateau as well as the East African rift in northern Kenya. Preliminary tomography models incorporate several months of data from stations in NE Uganda, plus many years of data from over 200 seismic stations throughout eastern Africa used in previously published body wave tomography models. The data come from teleseismic earthquakes with mb $\geq$ 5.5 at a distance from each station of 30° to 90°. P and S wave travel time residuals have been obtained using a multichannel cross correlation method and inverted using VanDecar's method to produce 3D tomographic images of the upper mantle. The preliminary results exhibit better resolved structure under the northern part of the East African Plateau than previous models and suggest that the fast-wave speed anomaly in the upper mantle associated with the Tanzanian Craton—which is bounded by the Western and Eastern branches of the rift system—extends across most of northern Uganda.

The effect of deforestation and agriculture on hillslope sediment transport in central Pennsylvania

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Over the past several hundred years, agriculture has significantly changed both the magnitude and timescale of sediment transport on a global scale (1, 2) and in order to make informed management decisions, we must understand how landscapes respond to agricultural perturbations across geologic and topographic settings. In the Atlantic Piedmont, large accumulations of legacy sediment trapped behind milldams provide well established evidence of the signal of agricultural activity (3, 4, 5). However, the signature of valley floor legacy sediment is less obvious in the upland landscapes of the nearby Valley and Ridge Province, where long term climatic controls on sediment transport have been well established (6, 7), but little work has been done to evaluate how agriculture influences soil loss. The lack of abundant legacy sediment in valley fills suggests that 1) these farmed upland landscapes are more resilient to soil loss than the low relief Atlantic Piedmont, 2) eroded legacy sediments have exited these watershed due to an absence of mill dams acting as structural traps, or 3) legacy sediments have trapped in valley axes throughout the watershed. The goal of this project is to understand the timescales and spatial heterogeneity of agricultural soil loss and to evaluate the relative influence of climatic versus anthropogenic controls on sediment transport in this geologic setting. We will quantify recent hillslope erosion rates in the 0.66 km^2 Cole Farm study catchment and make comparisons to the nearby 0.08 km^2 forested Shale Hills study catchment, both of which are part of the Susquehanna Shale Hills Critical Zone Observatory (SSHCZO) in the 162 km^2 mixed land use Shavers Creek Watershed in Huntington County, PA. We will pair observations from shallow geophysical data and hand auger refusal depths with carbon age dates for valley axis fills and erosion rates from ^{137}Cs concentrations along a farmed hillslope transect to evaluate timescales and factors controlling sediment transport.

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Araucarian conifer fossils of Eocene Patagonia may reveal an Australasian rainforest connection

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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. *Araucaria* was prolific worldwide during the Mesozoic, but it has been restricted to the Southern Hemisphere since the end-Cretaceous. 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 Antarctic separation and cooling began in the mid-late Eocene, causing large shifts in the genus' distribution that are still apparent in its modern biogeography. Of the 20 living species of *Araucaria*, 16 belong to a group called Section *Eutacta* and are restricted to Australasia. 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 ever present in Gondwanan South America due to unconvincing fossils of isolated elements, often of only a single organ type. New fossils from Patagonia will greatly clarify *Eutacta*'s evolutionary timeline. Rio Pichileufu, Argentina (RP; 47.8 Ma), and Laguna del Hunco (LH; 52.2 Ma) are two exceptionally diverse and well-dated Eocene rainforest floras recovered from fossil caldera lake deposits in the modern-day steppe of Patagonia. These fossil floras were present before opening of the Drake Passage and thus include lineages that evolved prior to Gondwanan break up. The fossil *Araucaria pichileufensis*, described from its type locality RP 80 years ago[1], appears more closely related to living Australasian *Eutacta* species than the South American *Araucaria* species now growing nearby in the Southern Andes. Large new collections of *A. pichileufensis* including pollen cones, leafy branches, and cone scale organs represent the most complete fossil preservation of *Eutacta* and provide the first strong fossil evidence that Australasian Sec. *Eutacta* once had a South American history. 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.

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Recycling and recharge processes at the Hasandağ Stratovolcano, Central Anatolia: Insights on magma chamber systematics from plagioclase textures and zoning patterns

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We elucidate crystal recycling and magma recharge processes at Hasandağ by investigating compositional zoning patterns and textural variation in plagioclase crystals from Quaternary basaltic andesite through dacite lavas. Previous work on Hasandağ intermediate compositions identified thermochemical disequilibrium features and showed abundant evidence for magma mixing[1,2]. We expand on this work through detailed micro-texture and mineral diffusion analysis to explore the mechanisms and timescales of crystal transport and mixing processes. Thermobarometric calculations constrain the plumbing system to 1.2-2 kbar and 850-950°C, corresponding to a felsic magma chamber at ~4.5 km. Electron microprobe results reveal plagioclase phenocrysts from all lava types have common core (An_{33-46}) and rim (An_{36-64}) compositions, with groundmass laths (An_{57-67}) resembling the phenocryst rims. Low An cores are ubiquitous, regardless of bulk rock chemistry, and suggest a consistent composition within the magma reservoir prior to high An rim growth. High An rims are regularly enriched in Mg, Fe, Ti and Sr, which we attribute to mafic recharge and magma mixing. We assess mixing timescales by inverse diffusion modeling of Mg profiles across the core-rim boundaries. Initial results suggest mixing to eruption processes occur on the order of days to months. Heterogeneous calculated timescales within thin sections indicate crystal populations with different growth histories. Crystals often display prominent sieve-textured zones just inside the rim, as well as other disequilibrium features such as oscillatory zoning or resorbed and patchy-zoned cores. We interpret these textures to indicate mobilization of a homogeneous dacitic reservoir with abundant ~An_{35} plagioclase crystals by frequent injection of mafic magma. Variability in observed textures and calculated timescales manifests during defrosting of a highly crystalline felsic mush, through different degrees of magma mixing. This process results in distinct crystal populations, some of which record punctuated ascent and storage, while others are erupted rapidly after the influx of new magma.

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Lithospheric Structure of Greenland from Ambient Noise and Earthquake Surface Wave Tomography

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We present a high resolution seismic tomography model of Greenland's lithosphere from surface wave analysis. Regional and teleseismic events recorded by GLISN over the last 20 years were used. We developed a new group velocity correction method to alleviate the limitations of the sparse network and the relatively few local events. The global dispersion model GDM52 was used to calculate group delays from the earthquake to the boundaries of our study area. To better constrain the crustal structure of Greenland and cross-validate our group velocity correction approach, we also collected and processed several years of ambient noise data. An iterative reweighted generalized least-square scheme was used to invert for the group velocity maps and a Markov chain Monte Carlo technique was applied to invert for a 3-D shear wave velocity model of Greenland up to a depth of 200 km. Our shear wave velocity model is consistent with previous studies but of higher resolution and we show that in regions with limited station coverage and local seismicity, we can rely on global models to construct relatively large local data sets that can provide some important constraints on regional structures. Our model contains the signature of known geological features and reveals three prominent anomalies: a shallow low-velocity anomaly between central-eastern and northeastern Greenland that correlates well with a previously measured high geothermal heat flux; a deep high-velocity anomaly extending from southwestern to northwestern Greenland that could be interpreted as the signature of a thick cratonic keel; and a deep low-velocity anomaly in central-eastern Greenland that could be associated with lithospheric thinning and upwelling of hot asthenosphere material from the rifting of the Atlantic Ocean around 60 Ma and the passage of the Icelandic mantle plume beneath Greenland between 70 and 30 Ma. Upper mantle temperature and heat flux distribution beneath Greenland are further derived from our velocity model using a grid search approach and some thermodynamic constraints. By delineating the velocity and thermal properties of these anomalies, we hope to better understand how underlying geological and geophysical processes may impact the ice sheet dynamics and influence its potential contribution to future sea level changes.

Expanded record of East African Pleistocene orbital pacing by time-series analysis of total organic carbon abundance and stable isotopes in lake sediments from Olduvai Gorge, Tanzania

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Continuous records of total organic carbon (wt.%) and total organic $\delta^{13}C$ (‰) values were produced from high-resolution samples of the Olduvai Drilling Project (ODP) cores 3A and 2A. These records are linked to variations in lake depth and catchment vegetation, both of which are sensitive to variations in hydroclimate dynamics [1,2]. Using an age model for lake sediments constrained by tephro-correlation, magnetic stratigraphy, and radiometric dates, we evaluated the phase and frequency of inferred climate variations, and compared these relationships to global ice-volume records and regional sea-surface temperature records [3]. Prior work on shorter and lower-resolution sediment records from ancient Lake Olduvai [e.g. 1,2] showed a strong influence of precession cycles on inferred climate at Olduvai Gorge for the interval ~1.910-1.790 Ma. The record presented here expands this timescale backwards to ~2 Ma and significantly increases temporal resolution. The increased resolution allows for identification of subtle shifts in climate pacing and better tests of the potential influence of global, obliquity-paced ocean temperature variations on local rainfall patterns. The continuous record from core 3A enables cross-comparison with marine climate records from sediment cores collected from the eastern Mediterranean Sea and the western Indian Ocean, and comparison of hydroclimate impacts of elevation changes in the highlands to the east and south of Lake Olduvai, including Ngorongoro, Olmoti, Oldeani, and Lemagrut volcanoes.

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

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Sixty-six million years ago, a meteorite impacted the Earth at the Mexican Yucatán Peninsula. The catastrophic atmospheric and environmental consequences of this event triggered the extinction of approximately 70% of Cretaceous terrestrial and marine species. We know much less about what happened in terrestrial ecosystems than in the marine following the impact because the continental geologic and fossil records are much more incomplete. Furthermore, we know relatively little about what happened to terrestrial ecosystems in the southern hemisphere, because the vast majority of continental fossil localities is concentrated in the western interior of North America. Recent studies in Argentine Patagonia suggest that the extinction in the region was less intense, with a lower proportion of species becoming extinct and ecosystems recovering much faster. These results prompt the question; was the end-Cretaceous mass extinction event different in the northern and southern hemispheres? New leaf collections from latest Cretaceous Lefipán Fm. (66-67Ma) and earliest Paleogene Salamanca and Peñas Coloradas fms. (65.7-62.2Ma) in Argentine Patagonia offer the opportunity to address the question of the K-Pg mass extinction using plant macrofossils for the first time in the southern hemisphere. Including over 4,000 specimens, these local collections could add a much-needed data point to fill the knowledge gap of the terrestrial southern hemisphere K-Pg mass extinction. I will quantify the extinction rate of these floral communities using these leaf collections, and use a multivariate approach to track their morphological change across the boundary. The approximate rate could be compared to estimates based on North American floras, and test the idea that extinction was less intense in the southern hemisphere. The leaf morphospace described by multivariate analysis summarizes the leaf characters observed and may help track not only changes in morphological diversity but losses in major groups. Additionally, some leaf characters such as surface area, size, and margin, are correlated to environmental variables and standardized in the literature. Therefore, tracking the overall morphological change of these Patagonian floras across the boundary could reveal the characters undergoing the most significant change, yielding information about prevailing climatic conditions. This information could help us paint an increasingly comprehensive picture of Argentine Cretaceous-Paleogene paleoenvironments.

Stratigraphy controls waterfall morphology

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Rock erodibility is an important factor in setting the pace and pattern of landscape evolution, and stream-power models predict a coupling between steady-state river slope and rock erodibility. If a river traverses variations in bedrock lithology, as is often the case in landscapes with layered stratigraphy for bedrock, we would predict that the longitudinal river profile should adjust based on variations in erodibility. Bedrock channels may form waterfalls in layered stratigraphy, though the exact mechanisms that maintain and erode various waterfall morphologies remains poorly constrained, and measuring section and mapping rock fractures in such landscapes is logistically challenging. Photogrammetry provides a comprehensive way of not only measuring inaccessible section, but also a means of quantifying bedrock properties important for waterfall morphology. Specifically, layered sedimentary rocks exposed in gorges provide ideal conditions for predicting bedrock fracture patterns and lithologically controlled rock strength, which are two factors that should have a major impact on waterfall form. We measure bed thickness, estimate grain size and quantify vertical joint spacing for 60-90 m of stratigraphic section at two sites, and directly connect our stratigraphic observations to waterfall morphology. We observe a strong correlation between the bottom and top of vertical drop-waterfalls and fine-grained thinly bedded intervals followed by coarsening-upwards sequences, topped with an erosion-resistant sandstone caprock. We also observe a connection between thick sequences of sandier beds and steep, narrow channel morphologies we call “chute-waterfalls.” Connecting stratigraphic thickness, composition and patterns to specific landscape morphology will bring us closer to quantifying the influence of rock erodilbiity on landscape evolution.

The Evolution of Porosity During Weathering of Serpentinite and the Creation of Thin Regolith in the Appalachian Piedmont

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Life on Earth relies on the breakdown of impermeable bedrock into porous weathered rock to release nutrients and open pathways for gases and fluids to move through the subsurface. This process shapes landscapes, impacts riverine and ocean chemistry, and regulates long-term atmospheric pCO_2 and pO_2. Serpentinites, though rare, are thought to play a major role in the global carbon cycle because weathering serpentinite draws down CO_2, a primary driver in chemical weathering. Serpentinites have thin regolith (1-2m) even though, in the Appalachian Piedmont, denudation is thought to be similar between serpentinite and more felsic rocks, which have much thicker regolith (15-30m). Although many factors influence the rate of weathering and thickness of regolith, a first-order control on weathering-related mineral-fluid interactions is the production of porosity and distribution of connected pores.

In this study, we evaluated weathering of serpentinites from bedrock to soil along a ridgetop in Nottingham Park, PA. We combined a series of porosity (neutron scattering, SEM, Hg porosimetry, and He pycnometry) and geochemical analyses to determine chemical and physical changes that occur during weathering. As weathering progresses small pores (~2nm in diameter) are occluded and total porosity and pore connectivity decrease in the weathered rock. However, in the upper meter of the profile, total and connected porosity increases as Fe, Mg, Mn, Si, Ni, Cr, and V are depleted. Additionally, bulk density and strain calculations suggest total volume expansion throughout the weathered rock followed by volume collapse in the upper 0.5m of the profile.

We propose that hydration of serpentine minerals at the parent-weathered rock interface, result in volume expansion and the loss of nanopores 1-100nm in size in this weathered rock zone. We infer that loss of porosity limits the infiltration of reactive meteoric fluids into the deeper rock material and restricts the depth of regolith development. Following hydration, serpentine minerals (e.g. antigorite and lizardite) dissolve higher in the weathered rock (>0.5m). Because serpentinite rocks lack a non-reactive mineral such as quartz to provide a supportive skeleton in the regolith, dissolution ultimately leads to collapse in the upper meter of the profile. The evolution of porosity in this profile can help explain why serpentinite regolith is characteristically thin to non-existent in the Piedmont: thin regolith occurs because of porosity occlusion as well as collapse.

The Kinematics of the southwestern Caribbean from geodetic GPS data modeling

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The oblique convergence of Cocos plate (CO) and the collision of Cocos Ridge, an aseismic ridge on the CO plate, with the southwestern margin of the Caribbean (CA) plate drives the northwestward escape of the Central American Fore arc (CAFA) and the northeastward motion of the Panama Region (PR). Motion of the PR is further modified due to its collision with the South American plate (SA). Using a new velocity field from 252 GPS sites, 48 in Panama, mapped active faults, focal mechanism solutions from the GCMT and a local earthquake catalog, we explore the kinematics of the southwestern CA. We test a suite of block configurations within the PR using the TDEFNODE software. Our results suggest that the southwestern CA is segmented into several small rigid blocks; the CAFA, Panama Pacific (PANP), Panama (PANA) and Panama east (PANE). This block configuration is in agreement with the relative motion of the active faults that accommodate the eastward motion of the PR and its collision with the northwest corner of SA. Our results and block configuration gives a better constraint of the kinematics of the southwestern CA. We suggest that the PANA-PANE boundary along the Panama Canal Fault system is taking advantage of the geological boundary of the Chorotega terrain on the west, and the Panama-Choco terrain on the east. Although trenching along the Panama Canal faults suggested 2 to 8 mm/yr of strike slip motion, we did not observe these rates in our GPS observations. Furthermore, few focal mechanism solutions are in agreement with this proposed boundary. The best- fit model indicates high coupling >50% into the block bounding faults and highlight for potential destructive earthquakes and/or tsunamigenic earthquakes into offshore seismogenic zones. The best-fit model highlighted high coupling along the Maracaibo trench, the convergent margin of South America-Caribbean plates, and account for potential big earthquakes in response to its strain accumulation. Future investigations and incorporating new GPS sites along the whole ND block could better improve our understanding of the nature and kinematics of the ND block, and the CA plate, account for seismic hazards in this populated region.