42nd Annual Graduate Student Colloquium

Wall Lake, Uintah Mountains, UT; photo by Megan Pickard

Sponsored by the
Department of Geosciences

April 19-23, 2010

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The Graduate Student Colloquium is a forum where students present their research or research proposal to faculty, friends, and peers. The Colloquium is hosted by the Department of Geosciences and is open to graduate students involved in geosciences research. The colloquium format stimulates research discussion, allows students to practice for national meetings, and helps students improve their presentation skills. The Colloquium assists both the Department and Penn State in maintaining and strengthening their reputations for giving high quality talks and poster presentations at national and international meetings.

Schedule of Events

Event	*Date and Time*	*Location*
Opening Reception	April 19, 10:00	EMS Museum
Poster Viewing	April 19, 10:00 - April 23, 12:00	EMS Museum
Poster Session 1	April 20, 1:00-2:30	EMS Museum
Oral Session 1	April 21, 10:00-12:00	541 Deike
Poster Session 2	April 21, 1:00-2:30	EMS Museum
Oral Session 2	April 22, 10:00-11:00	541 Deike
Oral Session 3	April 22, 1:00-3:30	541 Deike
Oral Session 4	April 23, 9:00-11:30	541 Deike
Entropy	April 24, 6:00	VWF Hall

The Graduate Colloquium Committee wishes to thank the students for sharing their work and the faculty for providing constructive feedback. The Committee also wishes to thank the Shell People Services division of Shell Oil Company and Chevron for their generous financial support, and the Department of Geosciences for hosting this Colloquium.

Graduate Student Colloquium
Committee Members
2010

Claire Fleeger, chair

Bryan Kaproth
Lauren Milideo
Kristina Peterson
Megan Pickard
Andy Rathbun

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:

2009-2010: Aaron Diefendorf and Bryn Kimball
2008-09: Daniel Hummer
2007-08: Gavin Hayes
2006-07: Christina Lopano
2005-06: Shawn Goldman and Courtney Turich
2004-05: 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.

Poster Session One

Tuesday, April 20
1:00-2:30

Presenter	Advisor	Title
Aaron Diefendorf	Katherine Freeman	Global patterns in leaf fractionation: implications for studies of past and future climate change
John Fegyveresi	Richard Alley	Late-Holocene Climate Evolution at the WAIS Divide site, West Antarctica: Bubble Number-Density Estimates
Halldor Geirsson	Peter LaFemina	Towards understanding quiescently active volcanoes: installation of a geodetic and seismic monitoring network at Telica volcano, Nicaragua
Hiroshi Hamasaki	Hiroshi Ohmoto	Helium and carbon geochemistry of hydrothermal fluids on the Southern East Pacific Rise at 11-32 ˚S
Elizabeth Herndon	Susan Brantley	The role of biotic cycling in determining the residence time of industrial pollutants
Christy Miller	Peter Wilf	A Pre-Settlement Flora of the Piedmont Region, PA
Andrew Rathbun	Chris Marone	Localization of Strain and Rate/State Friction
Xuhua Shi	Eric Kirby and Kevin Furlong	Geomorphic response to crustal evolution of the plate boundary, northern California
Heather Tollerud	Matt Fantle	Mapping composition in dust-producing regions: Extending geochemical measurements over large scales with remote sensing
Nicole West	Eric Kirby	Quantifying the relationship between soil erosion and landscape topography along a climate transect

Global patterns in leaf fractionation: implications for studies of past and future climate change

Aaron F. Diefendorf and Kevin E. Mueller
Ph.D. Student, Post-comps

Advisor: Katherine H. Freeman

Fractionation of carbon isotopes by plants during CO_2 uptake and fixation (Δ_{leaf}) varies with environmental conditions, but quantitative patterns of Δ_{leaf} across environmental gradients at the global scale are lacking. This impedes interpretation of variability in ancient terrestrial organic matter, which encodes climatic and ecological signals. To address this problem, we converted 3,310 published leaf $\delta^{13}C$ values into mean Δ_{leaf} values for 334 woody plant species at 105 locations (yielding 570 species-site combinations) representing a wide range of environmental conditions. Our analyses reveal a strong positive correlation between Δ_{leaf} and mean annual precipitation (MAP; R^2=0.55), mirroring global trends in gross primary production and indicating stomatal constraints on leaf gas-exchange, mediated by water supply, are the dominant control of Δ_{leaf} at large spatial scales. Independent of MAP, we show a lesser, negative effect of altitude on Δ_{leaf} and minor effects of temperature and latitude. After accounting for these factors, mean Δ_{leaf} of evergreen gymnosperms is lower (by 1-2.7 ‰) than for other woody plant functional types (PFT), likely due to greater leaf-level water-use efficiency. Together, environmental and PFT effects contribute to differences in mean Δ_{leaf} of up to 6‰ between biomes. Coupling geologic indicators of ancient precipitation and PFT (or biome) with modern Δ_{leaf} patterns has potential to yield more robust reconstructions of atmospheric $\delta^{13}C$ values, leading to better constraints on past greenhouse-gas perturbations. Accordingly, we estimate a 4.6‰ decline in the $\delta^{13}C$ of atmospheric CO_2 at the onset of the Paleocene-Eocene Thermal Maximum, an abrupt global warming event ~55.8 Ma.

Late-Holocene Climate Evolution at the WAIS Divide site, West Antarctica: Bubble Number-Density Estimates

John M. Fegyveresi
M.S. Student

Advisor: Richard B. Alley

A slight cooling of ~1.7°C occurred over the ~2 millennia prior to ~1700 C.E. at the WAIS Divide site, West Antarctica, based on trends in observed bubble number-density values in samples from the WDC06A ice core, and on an independently constructed accumulation-rate history using accurate annual-layer dating corrected for density variations and thinning from ice flow. Density increase and grain growth in polar firn are both controlled by temperature and accumulation rate, and the integrated effects are recorded in the number-density of bubbles as the firn changes to ice. Number-density is conserved in bubbly ice following "pore close-off", allowing reconstruction of either paleotemperature, or paleo-accumulation rate if the other is known. In this study, a new quantitative late-Holocene paleoclimate reconstruction is presented for West Antarctica that made use of new data obtained from the WAIS Divide WDC06A ice core, and the steady-state bubble number-density model developed by Spencer and others [1]. The resultant temperature history agrees closely with independent reconstructions based on stable $\delta^{18}O$ isotopic ratios of ice and modeled borehole data at the site, demonstrating the accuracy of the independent bubble number-density modeling techniques and improving confidence in the overall result. A new ice-flow model suggests that some, but not all of the temperature change, may have been caused by elevation change of the ice sheet at the site. Accumulation rate and temperature dropped together, roughly consistent with control by saturation vapor pressure.

[1] Spencer, M.K., R.B. Alley and J.J. Fitzpatrick 2006. Developing a bubble number-density paleoclimatic indicator for glacier ice. *Journal of Glaciology*, **52**(178): 358-364.

Towards understanding quiescently active volcanoes: installation of a geodetic and seismic monitoring network at Telica volcano, Nicaragua

Halldor Geirsson
Ph.D. Student, Pre-comps

Advisor: Peter LaFemina

Telica volcano is one of many volcanoes in central America following the plate boundary in Central America, where the Cocos plate subducts under the Caribbean plate. Telica belongs to a particular suite of volcanoes that exhibit high levels of background seismic activity, usually long-period events, during non-eruptive periods, and are referred to as "quiescently active volcanoes". Telica has had numerous historical eruptions, the most recent and notable one was in December 1999, as well as many smaller explosion events over the last decade. Telica is representative of many Nicaraguan volcanoes and hence makes a good natural laboratory for quiescently active volcanoes due to its constant level of activity and also due to ease of access to the volcano.

In March 2010 a network of eight continuous GPS stations and six broadband seismometers was installed at Telica as a collaborative effort between The Pennsylvania State University, The University of South Florida, and INETER, Nicaragua. The purpose of the network is to contribute to the understanding of the processes causing the high levels of background seismicity at Telica and assist our Nicaraguan colleagues in monitoring the eruptive hazard of Telica. The network is densest within five kilometers to the summit area, with two CGPS stations located at greater than ten kilometers to constrain magma movements from greater depths beneath the volcano. The network is intended to run for three years, providing data on the relatively unknown crustal deformation of Telica volcano, and the mechanism for sustained high levels of background LP seismic activity.

Helium and carbon geochemistry of hydrothermal fluids on the Southern East Pacific Rise at 11-32 ˚S

Hiroshi Hamasaki
M.S. Student

Advisor: Hiroshi Ohmoto

We report the concentrations and isotopic compositions of He, CO_2, and CH_4 in 34 samples of hydrothermal fluids, collected from 10 sites at 11°18S' – 31°50'S on the Southern East Pacific Rise (SEPR). The SEPR is one of the fastest spreading mid-ocean ridges on earth, with spreading rates ranging from 10 to 15cm/yr.

CO_2 was the most abundant dissolved gas in all samples, with the end-member concentration varying from 6.4 to 130 mmol/kg. Aqueous H_2, the next most abundant volatile species, varied from 140 to 1400 μmol/kg. Dissolved CH_4, CO, and He were present at substantially lower concentrations. The helium isotope ratio, $^3He/^4He$(R/Ra), varies from 7.5 to 9.4 (average 8.5), and $\delta^{13}C_{(CO2)}$ and $\delta^{13}C_{(CH4)}$ values range from -11.3 to -2.8‰ and -43.4 to -16.5‰, respectively.

We have recognized two areas with significant anomalies in $CO_2/^4He$ (45000) and $^3He/^4He$ (8.2-9.4) ratios: one is between 31.2ºS and 31.8ºS, and the other (weaker and widespread) anomalies occur between 17.4 and 21.6ºS. Our results support the suggestion made from a rare gas study by Kurz *et al*. (2005) [1] that the mantle underneath the SEPR is heterogeneous and that the two areas with anomalous gas chemistry represent hot spots.

Concentrations of H_2, CH_4, CO_2 and H_2O in the hydrothermal fluids were used to evaluate the degree of chemical equilibrium, $CO_2 + 4H_2 = CH_4 + 2H_2O$; the $\delta^{13}C_{(CO2)}$ and $\delta 13C_{(CH4)}$ values were used to evaluate the degree of isotopic equilibrium between the carbon species. The results indicate that the gases species retained chemical equilibrium at 600-800ºC, and isotopic equilibrium at 400-800ºC.

The role of biotic cycling in determining the residence time of industrial pollutants

Elizabeth M. Herndon
Ph.D. Student, Pre-comps

Advisor: Susan Brantley

Humans continue to alter global biogeochemical cycles as metals are extracted from rock and dispersed to the land surface as industrial byproducts. Although atmospheric transport of metals potentially impacts broad regions, we do not currently know the extent of dispersal or what effect these deposited metals have on Critical Zone processes. We demonstrate that atmospheric deposition from industrial sources has enriched soils with Mn at the Susquehanna Shale Hills Observatory (SSHO), a small watershed in central Pennsylvania, U.S.A.. Furthermore, we use soils datasets to show that Mn addition to soils may be common in industrialized regions and investigate how biota contribute to Mn retention in soils.

SSHO is a forested first-order watershed developed on grey shale. As part of the Critical Zone Exploration Network, SSHO is undergoing detailed biogeochemical, hydrological, and geomorphological characterization. In addition to understanding the natural development of the watershed, we can use these studies to understand how human perturbation has influenced the chemical evolution of the system over industrial time-scales. Here, we integrate measurements of soil geochemistry with foliar nutrition to show that vegetation stores large quantities of Mn and may act as a "capacitor" that sequesters Mn and releases it to pore waters slowly as organic matter is decomposed. Mechanisms of biogeochemical Mn cycling are investigated using x-ray absorption spectroscopy to characterize redox reactions. Mn-compounds are highly reactive in soil systems and can affect the geochemical behavior of other heavy metals and P, a limiting nutrient in many ecosystems. Furthermore, Mn toxicity can affect both humans and vegetation, necessitating a better understanding of how industrial Mn inputs move through the Critical Zone.

A Pre-Settlement Flora of the Piedmont Region, PA

Christy Miller
M.S. Student

Advisor: Peter Wilf

The pre-settlement floral composition of the Northeastern United States has been studied through pollen assemblages. However, the impact of European settlement on pre-settlement plant communities has not been quantified and no studies have used leaf macrofossils to construct Holocene floral communities in this region. Most published Holocene fossil floras are based on pollen assemblages, deposited seeds and fruit, or on some combination of the above. However, communities constructed using pollen data are prone to errors stemming from long distance transportation of tree pollen. Additionally, pollen grains are frequently identifiable at a coarser taxonomic resolution than macrofossils, causing some degree of taxonomic uncertainty in the published flora. Seeds and fruits can be re-deposited and therefore are prone to time averaging. Leaf macrofossils are representative of a more local community both temporally and spatially and are often identifiable to species. This study aims to use leaf macrofossils to reconstruct the pre-European settlement flora of White clay Creek, Chester County, PA and describe the influence of European settlement on floral community composition. Leaf sub-fossils were collected from the banks of White Clay Creek and identified to the lowest possible taxon using leaf architecture characteristics. Knowledge of the native floral community could have important uses for restoration in this region. During European settlement large-scale sediment accumulation occurred behind milldams. Subsequent dam breaching caused streams to incise into the deposited sediment. This sediment is now being eroded from stream banks causing large-scale sediment loading in downstream areas including the Chesapeake and Delaware Bays[1]. One suggested method of minimizing the impacts downstream is the removal of the sediment and restoration of the natural flood plain and flora. This research will identify a floral assemblage, which, paired with the paleontological data from seeds, can be used as a reference condition for future restoration efforts.

1. Walters, R.C. Merritts, D.J. 2008. *Science*. 319: 299-304.

Localization of Strain and Rate/State Friction

Andrew P. Rathbun
Ph.D. Student, Post-comps

Advisor: Chris Marone

Strain localization plays a key role in determining the frictional stability of brittle shear zones, which in turn influences the rheology and seismic/aseismic behavior of fault zones and deforming glacial till. Velocity weakening and the possibility of stick slip motion are commonly attributed to shear localization. We perform experiments to measure the spatial distribution of shear, the geometry of shear localization, and friction rate/state dependence for sheared granular layers.

Experiments were conducted in a servo-controlled, double-direct shear apparatus with saturated samples at normal stresses ranging from 1 to 25 MPa. The nominal frictional contact area was 100 cm^2 and remained constant during shear. The layer thickness was 0.3-1 cm prior to shear. Experiments were conducted with velocity steps ranging from 1 μm/s to 100 μm/s. Samples included glacial till and two size distributions of pure quartz; mean grain sizes were ~610 μm, 140 μm and 10.5 μm, respectively. Passive strain markers were used in select experiments to track the distribution of strain across the layer. Angular shear strain was calculated via the curvature of the granular shear marker.

Our experiments show that shear strain localizes progressively into a zone of finite thickness near the center of the layer and that after bulk shear strains of ~ 2 most of the slip occurs along a narrow zone. Tracking of the strain markers allows us to quantify the portion of the total layer contributing to shear. We observe evolution of the critical slip distance, Dc, and friction rate parameter, a-b, as a function of net strain accumulation. During the localization process, a-b decreases from ~0.005 at shear strain of 0.5 to near zero at shear strain of 4, remaining positive in the limits of our experiments. Velocity weakening behavior and the possibility of stick-slip motion are commonly attributed to localization of shear. In most cases, velocity increases and decreases are symmetric leading us to favor the Ruina law; however, in some cases larger slip is required after velocity decreases to reach steady sliding friction, opposite the Dieterich law. We attribute this asymmetry to variations in the thickness of the localized shearing layer.

Geomorphic response to crustal evolution of the plate boundary, northern California

Xuhua Shi
M.S. Student

Advisor: Eric Kirby and Kevin Furlong

Topography in northern California Coast Ranges is thought to reflect a complicated interplay between fluvial incision and transitory crustal thickening associated with passage of the Mendocino Triple Junction (MTJ, Furlong and Govers, 1999) since 28 Ma (Atwater and Stock, 1998). Although the structure and geodynamics of the region are well studied (Henstock and Levander, 2000; Hayes and Furlong, 2007), how the landscape responds to rapidly evolving patterns of differential rock uplift remains uncertain. It has been suggested that drainage reorganization results from capture of fluvial systems during northward migration of a wave of high-rate uplift at ~ 2 Ma (Lock et al., 2006). Whether the drainage reorganization is linked to the pattern of differential rock uplift and subsidence due to the MTJ migration, however, can be tested with analysis of stream profiles throughout the modern Eel watershed, as transient fluvial incision associated with drainage reorganization should be encoded in channel profiles (Whipple, 2004).

Our results of the stream profile analysis show that: 1) numerous knickpoints (excluding those directly associated with lithology and tributaries junctions) in the Eel sub-basins lie at ~ 800 m in elevation, separating downstream reaches of high gradients from the upstream of lower gradients; 2) average channel gradients upstream the knickpoints for each basin are similar; same for the downstream ones and, 3) knickpoints are not localized along faults and are independent of a threshold drainage area (Crosby and Whipple, 2006). According to simple model of knickpoint migration (Niemann et al. (2001), these results suggest that the knickpoints form in response to a single perturbation to the Eel drainage by the MTJ migration. In addition, reconstructed incision rate (0.05 - 0.25 mm/yr) based on proposed time of capture (~ 2 Ma) is consistent with short-term erosion rate (0.07 - 0.35 mm/yr) in the South Fork Eel (Fuller et al., 2009) and modern sedimentation rate behind dams (0.34 mm/yr) in Main Stem of the Eel (Porterfield and Dunnam, 1964). Collectively, our stream profile analysis support the proposal that a river capture event occurred at ~ 2 Ma in the Eel River due to the MTJ migration (Lock et al., 2006).

Mapping composition in dust-producing regions: Extending geochemical measurements over large scales with remote sensing

Heather Tollerud
Ph.D. Student, Pre-comps

Advisor: Matthew Fantle

Dust is a critical, yet understudied, component of geochemical cycles. Dust inputs to the ocean have been deemed especially significant in the iron cycle, for instance, since dust stimulates natural iron fertilization and thus potentially affects climate. Dust may also be important to the cycles of other elements, such as calcium (Ca). To determine the importance of dust relative to other geochemical inputs, some estimate must be made of the mass flux of Ca from dust-producing regions. However, understanding the spatial distribution of Ca within terrain known to generate dust has been problematic. Remote sensing may offer a critical perspective with measurement at landscape scales instead of extrapolation from a few point measurements, allowing for investigation closer to the scale at which dust is produced. This study investigates the elemental geochemistry of surface sediments and the distribution of non-silicate bound Ca in a large playa system (Black Rock Desert) in northwestern Nevada (USA). We used satellite-derived hyperspectral data, field-collected ground spectra, surface sediment samples, and Synthetic Aperture Radar (SAR) in our analysis. We collected approximately 50 samples and their spectra from the Black Rock Desert in July/August 2007. We measured the bulk and soluble Ca by ICP-OES and mineralogy by x-ray diffraction (XRD). Assuming all Ca in weak HCl (0.5 N) leaches is derived from calcite, we found that calcite concentrations in a subset of collected samples range from 5 to 15 wt. %. Acid-soluble calcite, which was generally 90 to 100 mol % of the total Ca in sediments (determined by lithium metaborate fusion), correlates well with the relative abundance of calcite determined by XRD analyses. Using hyperspectral measurements of surface reflectance, we found that acid soluble Ca concentration is correlated with the depth of a calcite absorption feature at 2335 nm. We then mapped this depth in satellite hyperspectral data from the Hyperion instrument to estimate calcite content of surface sediments at the playa scale. We calibrated absolute calcite composition by correlating depth of the calcite feature to calibration ground spectra, and ground spectra to acid soluble Ca fraction. Additionally, the mineral content of playa surfaces may be useful as an indicator of processes responsible for generating variations in surface texture, in particular the precipitation of evaporite minerals related to the movement of water. We examined radar data from the ENVISAT Advanced Synthetic Aperture Radar instrument as a proxy for surface texture and relate surface textures in the Black Rock Desert to mineral composition. By elucidating some of the connections between the physical and chemical properties of playa sediments, this work serves as a foundation to predict the effects of changing climatic conditions on dust and to extend observations of modern systems to the geologic past and future.

Quantifying the relationship between soil erosion and landscape topography along a climate transect

Nicole West
Ph.D. Student, Pre-comps

Advisor: Eric Kirby

In recent years, the scientific community has paid increasing attention to the merits of using meteoric ^{10}Be as a tracer for sediment flux. Meteoric ^{10}Be can be a useful tracer as it quickly associates with soil particles upon delivery from precipitation and is then predominately immobile (McKean et al., 1993, Monaghan et al., 1983). Meteoric ^{10}Be is formed in the atmosphere as a product of spallation reactions between cosmic rays and ^{16}O and ^{14}N in the atmosphere. ^{10}Be quickly adheres to dust in the atmosphere and is delivered to the Earth's surface via precipitation. Because of its strong affinity for adsorption to soil particle surfaces, meteoric ^{10}Be concentrations can be used in conjunction with sediment transport laws to determine sediment flux rates (McKean et al., 1993, Monaghan et al., 1983).

My research seeks to quantify the relationship between soil erosion and the evolution of landscape topography along a climate gradient in the eastern United States. A portion of my dissertation research is focused on utilizing cosmogenic ^{10}Be inventories within the Shale Hills Critical Zone Observatory (SHCZO), an NSF-funded observatory aimed at exploring the interaction between hydrology, ecology, and geomorphology in the development and functioning of regolith. The SHCZO is a small catchment (approximately 10,000 m^2) that has developed on the relatively homogeneous Rose Hill shale. The fact that the Rose Hill shale ubiquitously underlies the SHCZO makes it an ideal microcosm for studying the relationship between soil transport rates and landscape topography. The Rose Hill shale extends south along the Appalachian belt and is the parent material of many soils forming along its extent. The Shale Hills Critical Zone Observatory includes a series of partner watersheds that extend from New York State to Alabama, spanning a broad range in both modern and paleo-climate conditions, but all developed on the same lithologic material. By selecting locations along the Rose Hill Shale in varying topographic and climatic environments, we will gain an understanding of how these two factors control erosional processes.

McKean, J.A., et. al., 1993, Geology, v. 21, p. 343-346.
Monaghan, M.C., Krishnaswami, S., and Thomas, J.H., 1983, Earth and Planetary Science Letters, v. 65, p. 51-60.

Oral Session One

Wednesday, April 21
10:00-12:00

Time	Presenter	Advisor	Title
10:00	Melissa Pardi	Russell Graham	Loss of habitat and biodiversity during terminal pleistocene warming: what small mammal fossils tell us about the effects of climate change
10:15	Fred Tugume	Andrew Nyblade	Investigation of the Crustal Structure of the Western Branch of the East African Rift System
10:30	Ashlee Dere	Susan Brantley	Shale weathering across a continental-scale climate gradient
10:45	Tiffany Yesavage	Susan Brantley	Iron cycling in the Shale Hills watershed of Central Pennsylvania: Possible links between microbiology and iron chemistry
11:00	*Break*		
11:15	Timothy Fischer	Peter Heaney	Time-resolved XRD of the siderophore-promoted dissolution of birnessite
11:30	Claire Fleeger	Peter Heaney	Sequestration of Cs by Na- and H-birnessite from pH 3 to 10 as Measured with Time-resolved Synchrotron X-ray Diffraction
11:45	Kristina Peterson	Peter Heaney	Time-resolved X-ray diffraction study of the in situ hydrothermal phase transformation from akaganéite to hematite

Loss of habitat and biodiversity during terminal pleistocene warming: what small mammal fossils tell us about the effects of climate change

Melissa Pardi
M.S.

Advisor: Russell Graham

Previous paleoecological research of the late Pleistocene has largely focused on the dynamics between the arrival of modern humans, climate change, and megafauna extinction. However, the study of smaller animals provides a more complete picture of how climate change affected late Pleistocene ecosystems. To examine large scale patterns in small mammal community structure, 203 fossil faunas from 183 locations east of the Rocky Mountains in North America were compared using non-metric multidimensional scaling. These faunas ranged in age from the last Full Glacial to the late Holocene. Late Glacial faunas were more diverse than late Holocene faunas. Glacial sites were also more taxonomically similar along an East-West gradient. This finding suggests that this gradient steepened during the transition into the Holocene. Heterogeneous environments during the last glacial could produce such patterns, and are also consistent with the presence of late Pleistocene non-analog faunas. These results indicate that North America not only experienced extinctions of organisms at the end of the last glacial, but that some late Pleistocene habitats were also wiped from the modern landscape. These findings provide relevant details about how future climate change may affect patterns in terrestrial biodiversity.

Investigation of the Crustal Structure of the Western Branch of the East African Rift System.

Fred Alex Tugume
Ph.D. Student, Pre-comps

Advisor: Andrew Nyblade

The crustal structure of the western branch of the EARS is imaged using joint inversion of teleseismic P wave receiver functions and fundamental-mode, Rayleigh wave phase and group velocities. The data used in our study were recorded at 20 broadband seismic stations in Uganda in Tanzania. The data collection was done under the first phase of the AfricaArray East Africa seismic experiment, which took place from September 2007 through December 2008. Radial and transverse receiver functions are obtained for teleseismic events in the 30^o to 90^o epicentral distance range, after deconvolving the vertical component from the corresponding radial and transverse components using an iterative, time-domain procedure. The Rayleigh wave phase and group velocities were obtained from an independent tomographic study. Receiver functions are sensitive to shear-wave velocity contrasts and vertical travel-times, and surface-wave dispersion measurements are sensitive to vertical shear-wave velocity averages. Jointly inverting surface wave dispersion measurements and receiver functions provides integrated models of subsurface shear wave velocity structure that explain the observations better than models obtained from either data set separately. Preliminary results yield Moho depths of approximately 40-42 km for stations on the Archean Tanzania Craton, and 38-40 km for stations in the surrounding Proterozoic mobile belts. Estimates of the Moho depth beneath stations in the Western Branch of the East African rift system could not be reliably obtained because of reverberations in sedimentary layers.

Shale weathering across a continental-scale climate gradient

Ashlee Dere
Ph.D. Student, Pre-comps

Advisor: Susan L. Brantley and Tim White

The critical zone, which supports most terrestrial life, encompasses the top of the tree canopy to aquifers beneath the earth's surface. As the central constituent of this zone, soil serves as an interface for gas and water exchange and plays a major role in nutrient cycling that supports ecosystems and agriculture alike. However, the rate at which soil forms in the critical zone, and conversely the rate at which soil is degraded, is not well understood. To investigate the rates of soil formation, a transect of sites across a climate gradient has been established as a Critical Zone Exploration Network (CZEN). Sites within this transect are all underlain by shale, the dominant lithology amongst sedimentary rocks on Earth. This organic-poor, iron-rich Silurian-age shale provides a constant lithology from which soil is forming to minimize variables influencing soil production. The climosequence includes relatively cold and wet sites in Wales, New York and Pennsylvania, with temperature increasing to the south in Virginia, Tennessee and Alabama. Puerto Rico provides a warm/wet end member for the transect, although these sites do not lie on the same shale formation as the Appalachian Mountain sites but are similar in geochemical composition. Geochemical, mineralogical, and cosmogenic isotope analyses are being completed similarly at all sites to allow direct comparisons and eventual modeling of the weathering processes. Preliminary results of Na, which is inferred to be present only as feldspar, from Wales, New York, Pennsylvania, Virginia and Tennessee show soils become more sodium-depleted and the depth to bedrock is significantly deeper at warmer sites. The fraction of Na lost relative to parent material composition at each site varies linearly as a function of mean annual temperature but not precipitation, which may be indicative of the strong role of temperature in controlling weathering of feldspar. Overall, results from the transect will promote a better understanding not only of how climate influences soil production, but also the role human impacts, such as land use and climate change, have on soil formation rates.

Iron cycling in the Shale Hills watershed of Central Pennsylvania: Possible links between microbiology and iron chemistry

Tiffany Yesavage
Ph.D. Student, Pre-comps

Advisor: Susan Brantley

The goal of this study is to investigate whether microorganisms are involved in iron (Fe) cycling within the Shale Hills watershed of Central Pennsylvania. This basin is underlain entirely by the Rose Hill Formation, an iron-rich marine shale that is Silurian in age. The predominant Fe-bearing minerals in the underlying bedrock include the clay minerals illite and chlorite, as well as hematite. In order to better understand systematic changes as they occur in the watershed, regolith samples were collected as a function of depth along a toposequence or catena on the south side of the basin.

Normalized plots of iron concentration with depth in the regolith (referred to as $\tau_{Zr,Fe}$ and $\tau_{Zr,Fe(II)}$ plots) indicate that both total Fe and Fe(II) concentrations tend to be depleted in the regolith relative to bedrock concentrations along the entire catena. This finding suggests that some combination of chemical and physical weathering is acting to deplete Fe from the soils. Two groups of microorganisms are of further interest with regard to Fe cycling, Fe oxidizers and Fe reducers. The abundance of iron-oxidizing bacteria is elevated both in surface horizons and at the soil/bedrock interface. In contrast, the abundance of dissimilatory iron-reducing bacteria appears to be controlled by soil moisture content. These organisms have been successfully cultured from the wetter valley floor, but not from the drier ridgetop and middle slope.

It has been suggested that the stable isotope signatures of Fe (δ^{56}Fe values) can be used to trace microbiological activity in certain types of environments (Beard et al., 2003). Based upon preliminary analyses, the mean δ^{56}Fe value in bedrock material from the basin is ~+0.1‰. Meanwhile, the average δ^{56}Fe value in bulk soil samples collected from different depths along the catena was +0.1‰, with a standard deviation of only 0.1‰.The lack of variation in these values is consistent with the notion that the predominant mechanisms responsible for Fe weathering in the basin include physical weathering and proton-mediated dissolution. Furthermore, we failed to observe significant fractionation in those samples from which Fe-related bacteria were cultured, suggesting that stable isotope values of Fe in bulk soil samples do not reflect microbiological activity in the Shale Hills watershed.

Beard, B.L. et al., 2003. Application of Fe isotopes to tracing the geochemical and biological cycling of Fe. Chemical Geology Special Issue on Isotopic Record of Microbially Mediated Processes, 195: 87-117.

Time-resolved XRD of the siderophore-promoted dissolution of birnessite

Timothy B. Fischer
Ph.D. Student, Post-comps

Advisor: Peter J. Heaney

We used synchrotron time-resolved X-ray diffraction (TR-XRD) to track the complete dissolution of birnessite, a layered Mn(III,IV) oxide, by a siderophore. Siderophores are biogenic molecules that can significantly influence the cycling of transition metals in soils. Researchers have demonstrated that siderophores break down Mn oxide minerals through the formation of siderophore-Mn complexes in solution (*e.g.* [1]). Previously, we explored the reductive dissolution of birnessite by membranes of *Shewanella oneidensis* [2]. In the present study, we wanted to compare the crystallographic effects of membrane-mediated and siderophore-promoted dissolution. Using a flow-through reaction cell, we monitored birnessite dissolution via desferrioxamine B (DFOB) (0.01 and 0.001 M). X-ray diffraction experiments were conducted at the Advanced Photon Source beamline 13 BM-C, and diffraction patterns were collected every 70 s.

In all experiments, the loss of birnessite increased linearly with time until its complete disappearance. Rietveld analysis revealed no significant change in unit-cell parameters until ~70 wt% of the birnessite had dissolved. Beyond this point, the birnessite *c*-axis decreased by a small (~0.01 Å) amount. This contraction was an order of magnitude smaller than that associated with membrane-mediated dissolution. Based on our Scherrer particle size analysis, we postulate that the slight decrease in *c* during siderophore dissolution represents nanoscale strain rather than structural distortion due to multiple redox reactions, as occurred during membrane-mediated dissolution. Our results reveal for the first time that *in situ* crystallographic analyses of dissolving solids can distinguish among different mechanistic pathways of structural collapse.

[1] Duckworth & Sposito (2007) *Chem. Geol.* **242**, 497-508.
[2] Fischer *et al*. (2008) *Am. Min.* **93**, 1929-1932.

Sequestration of Cs by Na- and H-birnessite from pH 3 to 10 as Measured with Time-resolved Synchrotron X-ray Diffraction

Claire R. Fleeger
Ph.D. Student, Pre-comps

Advisor: Peter J. Heaney

High-level nuclear waste storage tanks at the DOE Hanford site in Richland, Washington have leaked more than 1 million gallons of solution that is extremely basic (pH > 13) with high ionic strength and concentrated in radioactive Cs-137 (2×10^{10} Bq/L, equivalent to 0.04 mmol/L). The underlying Ringold Formation consists of poorly consolidated clays, silts, and sands rich in Fe and Mn oxides, including the phyllomanganate birnessite. Interlayer cations in birnessite are highly exchangeable, and it has been demonstrated that millimolar concentrations of aqueous Cs^+ will rapidly exchange for Na^+ in the birnessite interlayer in neutral solutions [1]. For the first time, we have explored diadochic substitution of Cs^+ for Na^+ in birnessite over a wide pH range. The cation exchange products of *in situ* reactions are characterized with time-resolved synchrotron X-ray diffraction (TR-XRD) and inductively coupled plasma-mass spectroscopy (ICP-MS) at pH values ranging from 3 to 10. In these experiments, the rate of exchange of Cs^+ for Na^+ decreased as pH increased. However, the birnessite structure transformed from triclinic to hexagonal symmetry at pH 3. Thus, at low pH, aqueous H^+ outcompeted with Cs^+ and Na^+ in partitioning into the birnessite interlayer.

Hexagonal H-birnessite also readily exchanged interlayer H^+ for Cs^+ from pH 3 to 10, as revealed by *in situ* TR-XRD and ICP-MS. As with Na-birnessite, the rate of Cs^+ cation exchange decreased with higher pH. A transformation of hexagonal H-birnessite to triclinic symmetry at pH 13 and 0.1 M CsOH is reported for the first time; the mechanism of this transformation has yet to be determined.

[1] Lopano, Heaney, & Post (2009), *American Mineralogist* **94**, 816-826.

Time-resolved X-ray diffraction study of the *in situ* hydrothermal phase transformation from akaganéite to hematite

Kristina M. Peterson
Ph.D. Student, Pre-comps

Advisor: Peter J. Heaney

Akaganéite nanoparticles commonly form when chlorine-rich fluids alter metallic Fe, and recently they have been discovered as a biogenic product. Although the precipitation of akaganéite (β-FeOOH) and its subsequent transformation to the stable phase hematite (α-Fe_2O_3) are well documented, the mechanism and the kinetics of this reaction are debated. The difficulty in characterizing the transformation can be attributed in part to the poorly crystalline nature of most natural akaganéite. Additionally, in situ analysis is challenged by the low precipitate yield in hydrothermal experiments within the Fe-Cl-H2O system.

Here we present new observations from *in situ* heating experiments using time-resolved synchrotron X-ray diffraction (TR-XRD) conducted at the Advanced Photon Source (APS). Starting with ferric chloride solutions (0.45 M $FeCl_3$ + 0.01 M HCl), we have collected TR-XRD data of the hydrothermal precipitation of akaganéite and transformation to hematite. Design of a new heater and experimental protocol facilitated our collection of in situ data by precipitate sedimentation at the base of a sealed 0.7 mm quartz capillary. XRD data were collected every 30 seconds at temperatures ranging from 80-200°C. Rietveld refinements using the General Structure Analysis System (GSAS) allowed for quantitative measurements of reaction rates as a function of temperature. Moreover, we determined the dependence of unit cell parameters on temperature and particle size.

In our experiments, the akaganéite to hematite transformation was completed in 100, 20 and 4 minutes at temperatures of 150°C, 175°C and 200°C, respectively. Refined unit-cell parameters for each phase followed the same general trends at all temperatures. Lattice parameters of akaganéite did not significantly change throughout the reaction. The hematite *a* parameter decreased with increasing particle size, but the *c* parameter increased until all akaganéite had transformed, after which it decreased. Our results demonstrate that *in situ* structural and kinetic data of low-yield hydrothermal reactions can be successfully captured using our experimental design and TR-XRD.

Poster Session Two

Wednesday, April 21
1:00-2:30

Presenter	Advisor	Title
Jamie Brainard	Hiroshi Ohmoto	Methane hydrates: a principal source of atmospheric methane?
Michael Cleveland	Charles Ammon	Analysis of recent major outer-rise earthquake rupture characteristics
Amanda Martino	Christopher House	Development of a degenerate PCR method for whole genome amplification of DNA from very low biomass marine subsurface samples
Lauren Milideo	Russ Graham	Actualistic taphonomy of cold and temperate climates: Applications for Pleistocene Paleontology
Megan Pickard	Tanya Furman	Regional Geochemical Trends in Young Basalts Along the Central Anatolian Fault Zone, Turkey
Rachel Piotraschke	Kevin Furlong	Constraints on the Exhumation History of the Klamath Mountains Block from Preliminary Thermal Modeling
Christine Regalla	Don Fisher and Eric Kirby	Topographic signature of Plio-Quaternary contraction in the northeastern Japan forearc
Rebecca Wieczorek	Matt Fantle and Lee Kump	Responses to Rapid Climate Change: Osmium Isotopic Evidence for Changing Weathering Fluxes during the Paleocene-Eocene Thermal Maximum
Jessica Yakob	Maureen Feineman	Investigation of Li distribution in mantle minerals: Insights from experimental petrology

Methane hydrates: a principal source of atmospheric methane?

Jamie L. Brainard
Ph.D. Student, Pre-comps

Advisor: Hiroshi Ohmoto

Methane hydrates occur in deep terrestrial permafrost (up to 400Gtons) and in sediments on marine continental shelves at depths > ~500m. Many researchers have discussed the possible effects of the methane released from the methane hydrate zone (MHZ) on climate, but few have given a numerical estimate and the discussions were based on old (inaccurate) estimates on global hydrate reserves. Based on the temperature-depth profiles for water and sediment columns in major marine basins and on the P-T-salinity phase diagrams of methane hydrates, we have derived the equations linking the thickness of MHZ to the seawater depths, bottom water temperatures, and geothermal gradients. Our calculation gives a value of 4550 Gt of CH4 for the global reserve, compared to a widely used value of 750 to 6400 Gt.

Thickness of MHZ decreases with decreasing pressure (i.e., decreasing sea level) and/or increasing bottom-water temperature. For example, a 10 m drop in sea level or a 1°C increase in the bottom water temperature may result in a release of 19 Gt and 330 Gt, respectively, of CH4 from the seafloor to the overlying seawater (and to the atmosphere). If all the released CH4 accumulated in the atmosphere without being converted to CO2, the atmospheric CH4 concentration may increase by 6.7 ppm and 115.9 ppm, respectively. For comparison, the atmospheric CH4 concentration during the inter glaciation periods was approximately 450 ppb.

Results of our study suggest that large variations in atmospheric CH4 are largely derived from the MHZ, rather than biological activity, and that the increased CH4 release during the interglaciation periods were due to the increased destabilization of the MHZ.

Analysis of recent major outer-rise earthquake rupture characteristics

Michael Cleveland
M.S. Student

Advisor: Charles J. Ammon

Outer-rise earthquakes can help indicate the degree of seismic coupling of a subduction zone megathrust as well help constrain stress transfer processes in underthrusting oceanic lithosphere during the seismic cycle. In addition, outer rise earthquake-related structures may play a significant role in the transport of water into subduction zones, and possibly provide seismogenic structures re-activated during intermediate-depth earthquakes. And finally, although less frequent than large underthrusting events, large outer-rise earthquakes may pose significant hazard since they have been found to display higher stress drops and greater enrichment in high frequency shaking than comparable size interplate events. In this study we analyze and compare the seismic properties of three specific outer-rise sequences, representing relatively diverse tectonic characteristics, including events from southern Vanuatu (formerly New Hebrides), central Kuril Islands, and the Andaman Islands regions. Similar to several important historic events, these recent large outer rise sequences provide information on the transmission of slab-pull generated stresses and their relationship with large underthrusting earthquakes. To allow comparison with the 13 January (Mw 8.1) 2007 central Kuril Islands sequence that we studied previously, we conduct finite-fault analyses of the 16 May, 1995 Vanuatu, Mw = 7.7 and 10 August, 2009 Andaman Islands, Mw = 7.5, outer-rise events using azimuthally distributed teleseismic P and SH waveforms and Rayleigh-wave effective source time functions. The unique tectonic geometry of the Vanuatu event, occurring near the corner of the overriding Pacific Plate, conveys information about the influence of geometry on the outer-rise character. The Andaman earthquake occurred in a region with substantially oblique plate motion where geometrical plate relationships remain somewhat unclear. Considering their seismic properties and relationship to nearby great underthrusting events, analysis of large earthquake outer-rise ruptures can provide insight useful for the evaluation of seismic hazard and increase our understanding stress transfer properties operating within subducting oceanic lithosphere.

Development of a degenerate PCR method for whole genome amplification of DNA from very low biomass marine subsurface samples

Amanda J. Martino
Ph.D. Student, Pre-comps

Advisor: Christopher House

The marine subsurface is one of the least studied microbial environments on earth. One promising tool to expand upon the available knowledge of the organisms inhabiting this environment is metagenomic sequencing. However, the amount of DNA present in even the most organic rich marine subsurface environments has so far proved too little for unamplified sequencing. Consequently, for the metagenomic work done to date in this environment, the DNA was first subjected to some form of whole genome amplification. The most common approach has been to use commercial kits, such as the Repli-G kit from Qiagen. However, in past work, we found that these kits, which use the DNA polymerase Phi29, often produce a high molecular weight product even when no DNA is added to the reaction. As the blank could therefore not be relied upon for a contamination check, past utilizations of this method have involved ensuring that very high amounts of sample DNA made it into each reaction, reducing the effect of any potential contaminants. With many marine subsurface environments, however, the concentration of DNA is simply too low for this to be a feasible solution.

In an attempt to overcome some of the problems with using commercial whole genome amplification kits on DNA from marine subsurface samples, we designed and tested an alternative method. This method, which we have called Random Amplification Metagenomic PCR (RAMP), involves the use of specific primers used in 454 amplicon sequencing, modified to have a degenerate 3' end. The utilization of the polymerase chain reaction is the primary difference between this method and typical whole genome amplification methods. We found early on that this method did not result in production of high molecular weight products from blanks, even after 50 cycles of PCR.

After attempting to optimize experimental conditions, we tested the method at two different times via 454 pyrosequencing of RAMP-amplified *E. coli* DNA. Preliminary analysis of the sequence results from both rounds of sequencing suggested very high bias in genome coverage. Coverage ranged from one-fourth to one-third of the genome, despite obtaining enough sequence data for a theoretical three times genome coverage. Additionally, the results seemed to heavily favor GC-rich regions of the genome. Consequently, in order for this method to have any utility for environmental samples, further improvements will be needed.

Actualistic taphonomy of cold and temperate climates: Applications for Pleistocene Paleontology

Lauren Milideo
Ph.D. Student, Pre-comps

Advisor: Russ Graham

The field of actualistic taphonomy has an extensive body of well-established experimental data for the taphonomic analysis of paleontological and archaeological sites (e.g. ref. 1, 2). Data include bone weathering patterns, carnivore bone damage, and bone accumulation and dispersal models on modern tropical and temperate landscapes. Corresponding information is lacking, however, for colder-climate ecosystems (ref. 2). The importance of climate in affecting taphonomic pathways can be substantial (ref. 2); I am therefore performing actualistic research in cold climates. This study will be relevant to ongoing research into Pleistocene paleontology and archaeology. I am examining decomposition, carnivore activities, and scavenging and bone dispersal of white tail deer carcasses in central Pennsylvania. This research began in early January, continued throughout the winter, and includes seven carcasses currently under study. I am examining the differences in decompositional and scavenging activities as they occur in colder vs. warmer weather. Additionally, I will examine actualistic assemblages from the Black Hills (South Dakota) and the Northwest Territories (now Nunavut). The ungulates in these assemblages are analogous (in terms of taxonomy and niche) to many of those in the North American Pleistocene, as are the carnivores and scavengers present. Once data are assembled, I will employ multivariate statistics to compare and contrast the actualistic assemblages with one another, as well as with selected paleontological and archaeological assemblages originating in colder climates.

Regional Geochemical Trends in Young Basalts Along the Central Anatolian Fault Zone, Turkey

Megan Pickard
Ph.D. Student, Pre-comps

Advisor: Tanya Furman

The regional neotectonics and volcanism along the margins of the Anatolian microplate (Turkey) are broadly well-constrained. The African and Arabian plates currently push Anatolia against the relatively stable Eurasian plate and as a result, Anatolia has had a west-southwest movement for the last 12 Ma in what is called 'escape tectonics'. The tectonic environments and their associated volcanism include slab rollback in Western Anatolia (post-Miocene alkaline basalts and basanites) and slab detachment in Eastern Anatolia (mid-Miocene calc-alkaline to Quaternary alkaline). However, the situation in Central Anatolia is less clear: extensional forces govern the neo-tectonic environment and Pliocene-Recent basalts through basaltic andesites and dacites form large stratovolcanoes in extensional basins as well as both small and large basalt fields. The geochemistry of these basalts requires contributions from a poorly-defined mantle source lithology that has been enriched by subduction processes. However, available plate reconstructions indicate that the leading edge of the subducted African plate did not reach Central Anatolia, suggesting that the subduction environment could be related to closure of the neo-Tethyan Ocean in Paleozoic time. Geochemical compositions of mafic lavas along the Central Anatolian Fault Zone (CAFZ) provide new clarity on the question of the extent of lithospheric melting and the influence of the subducting slab. Moving southward along the CAFZ, incompatible trace element compositions of Central Anatolian basalts increase systematically in La/Nb concentrations and other incompatible trace element indicators trend from MORB and OIB signatures to more enriched values. Small negative Nb and no Ta anomalies are present in basalts from the northern CAFZ, and increase to larger negative Nb anomalies and Ta anomalies in the north. The incompatible trace element variations along the CAFZ point to an increase in lithospheric or slab involvement toward the leading edge of the African plate, i.e., to the south. Here we present new Pb and Hf isotopic data on recent (<15 Ma) mafic lavas along the CAFZ previously analyzed for major and trace elements. Isotopic ratios show greater source heterogeneity than suggested by the trace element data and show no apparent relationship with latitude. The Pb-Pb isotope ratios define a data field similar to modern oceanic sediment, intermediate in composition to Western Anatolia SCLM and the C component and enriched Central Atlantic MORB. In the $^{206}Pb/^{204}Pb$-εHf diagram the Central Anatolian lavas are consistent with mixing between a C-like component on the enriched end of the Central Atlantic MORB trend, and Western Anatolia-like SCLM. The isotopic data support a mixing model between oceanic mantle and subduction modified SCLM sources.

Constraints on the Exhumation History of the Klamath Mountains Block from Preliminary Thermal Modeling

Rachel Piotraschke
M.S. Student

Advisor: Kevin Furlong

The Klamath Mountains of Northern California and Southern Oregon straddle a fundamental transition in the North America plate boundary, and as such their Neogene to recent tectonic history provides a window into the evolution of the plate boundary as it undergoes the transition from subduction (Juan de Fuca) to translation (Pacific) plate interactions. The Klamath terrane presently hosts some of the highest topography along the convergent boundary but the timing of topographic development is not clear. The Klamath topographic massif may have developed during Neogene to recent tectonic history, as a result of young and/or ongoing uplift directly linked to modern plate boundary processes; alternatively, it may reflect relict (Late Cretaceous-early Tertiary) topography. That is, does the existence and uplift history of this domal elevated topography record the plate boundary evolution of North America, or is its location at the subduction to translation transition mere coincidence?

Current interpretations of Klamath evolution include significant pre-Neogene exhumation, implying substantial topographic development prior to the current plate tectonic regime along the western margin of North America. However, PBO GPS data show present-day shortening within the Klamath block indicating possible ongoing shortening-driven uplift.

As a preliminary step in discriminating among various possible uplift scenarios, we are modeling the thermal evolution of plutons that act as the core of the Klamath massif. This preliminary modeling study, which is focused on evaluating a suite of possible uplift/exhumation scenarios, aims to assess the utility of low-temperature thermochronology in distinguishing between comparatively slower cooling associated with the absence of tectonic uplift, and cooling resulting from more distinct tectonic exhumation events; results will also aid in planning thermochronologic sampling.

Topographic signature of Plio-Quaternary contraction in the northeastern Japan forearc

Christine Regalla
Ph.D. Student, Pre-comps
Petroleum related

Advisors: Donald Fisher and Eric Kirby

Late Neogene shortening in northern Honshu, Japan has been documented along a network of reverse faults and fault-related folds in the arc and backarc that record contractional deformation associated with inversion of Miocene basins originally developed during back-arc extension. Neogene deformation of the forearc inboard of the Japan Trench is thought to be dominated by long-term subsidence resulting from subduction erosion. However, new structural and geomorphic data point to significant Plio-Quaternary rock uplift of two basement massifs in the inner forearc of the Japan Trench - the Abakuma and Kitakami massifs. The southern Abukuma massif is bound on the east by the steep, west-dipping Futaba fault zone. Tephras above and below a progressive unconformity at the southern tip of the fault bracket the onset of deformation to ~3.9 to 5.6 Ma, and fault-related fold geometry requires ~2.5 km dip slip. Uplift of the Abukuma massif has imparted a transient topographic signature preserved in the hanging wall of the Futaba fault. A low-relief surface characterized by low hillslope angles and saprolitic bedrock is preserved at the highest elevations in the massif. Near the mountain front however, relief and hillslope angles increase, and the surface is dissected by deeply incised bedrock gorges. Knickzones clustered at ~400m separate low-gradient, alluviated upper channel reaches from high-gradient, bedrock channels. Similarly, topography in the northern Kitakami massif is characterized by high hill slope angles, high relief, and deeply incised bedrock channels. A remnant low-relief surface is preserved at the highest elevations in the massif. Streams that drain the low-relief surface contain knick zones that separate low-gradient upper channel reaches from high-gradient lower channel reaches, and knickzone elevations cluster at ~ 550 m in the central massif and ~ 275m in the northern massif. This topographic response may reflect a transient erosional response to spatially heterogeneous rock uplift along strike of the Kitakami massif or lithologic controls on knickzone position. Assuming that the vertical knickzone propagation rate is approximately equal to rock uplift rates, knickzone elevations are consistent with a <5 Ma onset of uplift in the Kitakami massif. A similar analysis of knickzone propagation in the Abakuma massif, however, yields an onset of uplift more recent than the 3.9-5.6 Ma obtained from independent structural data. We attribute this discrepancy to the removal of the sedimentary cover sequence on the Abukuma massif, such that the present-day distribution of knickzones only record a portion of total rock uplift. We are currently testing this hypothesis using low-temperature geochronology (U-Th/He) and basin-wide erosion rates (^{10}Be) in the Abukuma and Kitakami massifs to further constrain the timing of the transition from subsidence to uplift in the inner forearc of the Japan Trench.

Responses to Rapid Climate Change: Osmium Isotopic Evidence for Changing Weathering Fluxes during the Paleocene-Eocene Thermal Maximum

Rebecca Wieczorek
M.S. Student

Advisors: Matt Fantle and Lee Kump

The response of physical and chemical weathering to temperature changes on the Earth's surface is critical to understanding the long-term effects of global climate change, yet these processes are poorly understood. Weathering is important to the global carbon cycle because it is what ultimately removes carbon dioxide from the atmosphere. However, weathering processes operate over such long timescales that they are difficult to study in the field or to replicate in a laboratory. Isotope geochemical proxies provide an alternate method by helping to reconstruct and constrain weathering responses during periods of climate change in the past.

Here we report a new high-resolution marine osmium isotope record from Svalbard core BH 9/05 in the North Atlantic over the Paleocene-Eocene Thermal Maximum (PETM). The PETM (55 Ma) was a ~170 KY period of rapid warming characterized by large negative excursions in carbon and oxygen isotopes accompanying a substantial warming of the ocean, heavy $CaCO_3$ dissolution, and foraminifera mass extinctions. Osmium (Os) has a relatively short residence time in the ocean, on the order of 10 KY, making it particularly sensitive to rapid climate variations, specifically changes in inputs from weathering sources. Os in this study was measured in bulk samples assuming closed-system decay of ^{187}Re.

Our data shows peaks in $^{187}Os/^{188}Os$ and [Os] (ppt) across the PETM and a subsequent return to steady state, complementing earlier records from other sites which showed a similar result at a much lower resolution. Our record differs significantly from other published records in that the overall increase in the $^{187}Os/^{188}Os$ value (from 0.448 to 0.838) is nearly four times as great. Preliminary modeling suggests this is due to an increase in weathering rather than a change in source lithology. This result implies regional Os heterogeneity in the ocean and enhanced continental weathering at high latitudes.

Investigation of Li distribution in mantle minerals: Insights from experimental petrology

Jessica L. Yakob
M.S. Student

Advisor: Maureen Feineman

The use of lithium as a geochemical tracer has proven to be meaningful for mantle studies due to the large variation in Li isotope ratios in natural materials, high Li diffusion rates, large isotopic mass difference between ^{6}Li and ^{7}Li, and structural compatibility in mantle minerals. Minerals found in mantle xenoliths, such as olivine and diopside, exhibit isotopic disequilibrium with respect to lithium. The conditions causing the disequilibrium can be inferred by comparing Li concentrations and isotope ratios measured in natural samples to experimentally determined equilibrium distributions between olivine and diopside for various temperatures and pressures. However, the equilibrium elemental distributions and isotope fractionation factors for lithium in these minerals at high temperature and pressure are currently unknown. In order to determine the equilibrium temperature dependence of lithium distribution between olivine and diopside, high pressure (14 kbar) and high temperature (700-1100 °C) experiments were conducted using a piston-cylinder apparatus. The data show that for two separate 900 °C experiments of 4 and 24 hours, Li began to diffuse from a carbonate flux into olivine while Li diffusion into diopside was minimal, suggesting that equilibration of Li is faster in olivine than diopside. Equilibrium Li distribution between the two minerals has yet to be achieved. The data also indicate that the carbonate flux partially melted, and the melt is significantly more concentrated in Li with respect to the original powder. To solve the experimental problems of partial melting and inclusions, a revised method has been established using water (with dissolved Li) as the Li source, with crystals of olivine and diopside growing from solution.

Oral Session Two

Thursday, April 22
10:00-11:00

Time	Presenter	Advisor	Title
10:00	Daniel Jones	Jennifer Macalady	Community genomic analysis of extremely acidic sulfur oxidizing cave wall biofilms
10:15	Rebecca McCauley	Jennifer Macalady	Isolation and characterization of microbial communities from Lago Infinito, an anoxic cave lake
10:30	Aaron Regberg	Susan Brantley and Kamini Singha	Using direct-current and complex electrical conductivity to monitor biogeochemical redox reactions
10:45	Andrew Wall	Peter Heaney	Cu isotope systematics of the Butte Mining District, Montana

Community genomic analysis of extremely acidic sulfur oxidizing cave wall biofilms

Daniel S. Jones
Ph.D. Student, Post-comps

Advisor: Jennifer Macalady

Community genomic analyses provide a link between microbial metabolic potential and the biogeochemistry of an environment. In this study we use metagenomics, rRNA methods, culturing, and lipid analyses to explore the community structure and function of extremely acidic (pH 0-1) 'snottite' biofilms from sulfidic caves. Snottites form on cave walls and ceilings in areas where gypsum weathering crusts isolate microbial activity from limestone buffering. Full cycle rRNA methods have shown previously that snottites have very low biodiversity and are dominated by relatives of *Acidithiobacillus thiooxidans*, Thermoplasmatales-group archaea, and *Acidimicrobium spp*.

In order to explore snottite community metabolism, we pyrosequenced 12 megabases (Mb) of metagenomic DNA from a sample collected in the Frasassi cave system, Italy. Taxonomic classification of phylogenetic marker genes in the metagenome agrees with the community structure determined independently using rRNA methods. Unassembled metagenome reads were annotated to COG catagories. Overrepresented functions include cation transport and membrane biosynthesis genes that offer clues about how snottite populations survive in the extremely the low pH of the biofilm matrix. Near-complete genomic coverage of the dominant *Acidithiobacillus* phylotype allowed for the identification of specific sulfur oxidation, carbon fixation, and nutrient uptake mechanisms. The dominant archaea were discovered to be wall-less members of the 'G-plasma' clade in the Thermoplasmatales. Despite lower genome coverage, available data suggest that both the G-plasma and *Acidimicrobium* phylotypes are organoheterotrophs.

We recently obtained two larger metagenomic datasets (roughly 100 Mb each) from snottites collected in the Frasassi (F) and nearby Acquasanta (AS) cave systems. While both datasets are dominated by *Acidithiobacillus spp.*, AS snottites contain a large proportion of archaea related to *Ferroplasma* spp., while F snottites are made up of a more diverse community including 'G-plasma', *Acidimicrobium*, and rare taxa. Comparative analysis of all three metagenomes will provide insight into functions and adaptations unique to each community, as well as to extremely acidic environments in general.

Isolation and characterization of microbial communities from Lago Infinito, an anoxic cave lake

Rebecca McCauley
Ph.D. Student, Pre-comps

Advisor: Jennifer Macalady

Astrobiologists and microbiologists alike are interested in exploring unique microbial communities. Astrobiologists focus on microbes that relate to early life on Earth or life elsewhere in the cosmos, while microbiologists are interested in describing current microbial communities and their diversity. Lago Infinito is a stratified lake with anoxic bottom waters found deep within the sulfidic Frasassi cave system and affords a glimpse at energy-limited subsurface microbial life. The microbes growing in this environment may provide an analogous community to those of the Archean Earth, which would have been energy-limited before the advent of photosynthesis. A suite of methods is being utilized to describe and characterize this community, including DNA analysis and culturing. While less than 1% of bacteria and archaea have been successfully cultured and isolated, the amount of information that can be learned from a culture is much greater compared to an environmental sample.

In October 2009, microbial samples were collected from two biolfilm communities in the anoxic water of Lago Infinito. One biofilm was growing on the cave wall while the other was hanging from the cave wall as rope-like structures. Nine media types were inoculated with samples from these biofilms. Microscopy and fluorescence in situ hybridization (FISH) confirm the presence of archaea and bacteria in several of the cultures. Additionally, 16S rDNA clone libraries of the rope-like biofilm suggest high diversity. The geochemical data for the Lago Infinito environment does not suggest an abundance of chemical energy; therefore, the metabolism of these communities is still undetermined.

Using direct-current and complex electrical conductivity to monitor biogeochemical redox reactions

Aaron Regberg
Ph.D. Student, Post-comps

Advisors: Susan Brantley and Kamini Singha

Direct-current electrical conductivity measurements can be correlated across scales to changes in chemical concentrations due to redox reactions if reaction stoichiometries are understood. In batch experiments, reaction rates for dissimilatory iron reduction calculated from geophysical and geochemical changes were similar to within $\pm$25%. In flow-through reactors, initial conductivity changes corresponded to changes in fluid chemistry. However, under iron-reducing conditions a three-fold increase in electrical conductivity (0.02 S/m – 0.06 S/m) was recorded over 10's of cm. after 11 weeks. An even larger increase (0.02 S/m – 1.2 S/m) was recorded under nitrate-reducing conditions. Models based on percolation theory are consistent with the measured conductivity increase if biofilms are 33 times more conductive than pore fluid. To confirm this hypothesis we performed electrochemical experiments that involved growing iron reducing bacteria directly on an electrode surface. Preliminary data from these experiments demonstrate a thousand-fold increase in the DC electrical conductivity of respiring biofilms. Similar column experiments are being run while collecting complex conductivity measurements (an alternating-current method) in an attempt to further characterize this phenomenon.

Cu isotope systematics of the Butte Mining District, Montana

Andrew Wall
Ph.D. Student, Post-comps

Advisor: Peter Heaney

We present for the first time Cu isotope values of waters and mineral specimens from the Butte Mining District, Butte, Montana. Our goal is to demonstrate the usefulness of Cu isotopes to determine sources of Cu in stream and ground waters and to assess the degree of Cu-sulfide weathering throughout the mining district.

We collected waters from the Berkeley Pit lake, monitoring wells near the lake, and stream samples from Silver Bow Creek and the Upper Clark Fork River downstream of the Butte mine. In addition, we collected Cu-sulfate salts from within the mine and on the flood plain 30 to 60 km downstream from Butte. Cu-bearing sulfide minerals were collected from within the active mine and from an archived collection of hand samples from the underground workings. The $\delta 65Cu$ values were measured using a Finnigan Neptune MC-ICP-MS. Isotope values have a 2σ error of 0.14‰.

Primary chalcocite (Cu2S), chalcopyrite (CuFeS2), and bornite (Cu5FeS4) samples from 700 to 1500 meters depth have $\delta 65Cu$ values that range from -0.30 to 0.37‰, whereas supergene chalcocite closer to the surface has values between 5.07 and 5.64‰. $\delta 65Cu$ values of Berkeley Pit waters and groundwater samples surrounding the pit lake range from 1.56 to 2.32‰. A stream water sample approximately 5 km downstream from the Berkeley Pit has a value of 1.22‰ and surficial Cu-salt samples from weathered mine tailings deposited along the stream approximately 30 km and 60 km below Butte have values of 0.40‰ and 0.32‰ respectively.

Applying published fractionation factors from previous studies to our isotope results, we conclude that the dominant source of aqueous Cu in the immediate mine district is from rapid oxidative weathering of primary sulfide minerals. The isotopic value of the water sample 5 km downstream from Butte may indicate Cu scavenging by sorption to Fe oxides. The source for Cu-rich salts in the flood plain is likely the highly weathered mine tailings deposits from which most of the isotopically heavy Cu (65Cu) has been leached away.

Oral Session Three

Thursday, April 22
1:00-3:30

Time	Presenter	Advisor	Title
1:00	Heidi Albrecht	Katherine Freeman and Jennifer Macalady	Bacteriohopanepolyols in acidic environments
1:15	Kat Dawson	Jennifer Macalady and Katherine Freeman	Quantitative FISH analysis of microbial consortia from biogenic gas field in the Cook Inlet Basin, Alaska
1:30	Leah Schneider	Timothy Bralower and Lee Kump	Global nannoplankton response to early Eocene ocean destratification
1:45	Ying Cui	Lee Kump	A high-resolution record from Svalbard of carbon release during the Paleocene-Eocene Thermal Maximum
2:00	Heath Watts	James Kubicki	Evaluating Arsenic Acid Adsorption onto Fe(III) Clusters with Hybrid Density Functional Theory
2:15	*Break*		
2:30	Alicia Cruz-Uribe	Maureen Feineman	Subduction zone forensics: Unraveling the mysteries of deep geochemical cycling
2:45	Matt Ikari	Chris Marone and Demian Saffer	The Velocity-Strengthening Nature of Marine Sediments and Possible Requirements for Seismic Slip in Subduction Zones
3:00	Bryan Kaproth	Chris Marone	Shear band formation and poromechanical properties; application to unlithified sand, Humboldt County, CA
3:15	Brett Carpenter	Chris Marone	New experimental insights into the frictional behavior of the San Andreas Fault

Bacteriohopanepolyols in acidic environments

Heidi L. Albrecht
Ph.D. Student, Post-comps

Advisors: Katherine H. Freeman and Jennifer L. Macalady

Bacteriohopanepolyols (BHP), are pentacyclic isoprenoid lipids produced solely by bacteria. Hopanes, the corresponding geologically preserved hydrocarbons, are biomarkers that play an important role in reconstructions of the Earth's past biogeochemistry and evolution. Despite their excellent preservation and utility for microbial paleontology, relatively little of the Earth's modern microbial biosphere has been explored with respect to BHP production. Acidic sulfur oxidizing bacteria have been shown to produce BHPs (Rohmer et al., 1984). Acidic environments are correlated with noteworthy geologic events such as, mass extinctions, in geologic history but there are few proxies developed to make inferences about these paleoenvironments (Kump et al., 2005).

The goal of this study is to identify a BHP fingerprint for acidic iron and sulfur oxidizing environments as well as testing whether BHPs are important for microbial adaptation to low pH, oxidizing microbial communities. Bacteria are hypothesized to use BHPs to tune the physical properties of membranes (Kanennberg and Poralla, 1999). We propose to test this hypothesis through the comparison of pure cultures and their associated natural biofilms. Cultures for each species will be grown at a range of pH to test physiological response of BHP production to increases in H^+ concentration.

Preliminary results show that the acidophilic species of sulfur and iron oxidizing bacteria, (*Acidithiobacillus sp. Mu1* and *Leptospirillum sp.*), and their associated biofilms produce BHPs (Figure 1). *Leptospirillium sp.* and it's associated biofilm produce four BHP structures. Two structures are 3β-methylated (methyl positions not yet confirmed.), which may be a potential biomarker for iron oxidizing systems. *Acidithiobacillus sp. Mu1* and its associated biofilm have varying BHPs. The biofilm contains two BHPs, while the cultures can produce as many as six BHPs.

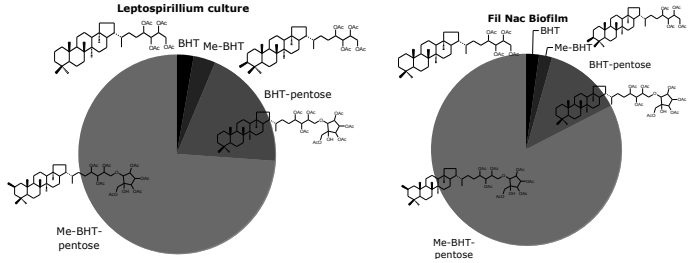

Figure 1. A graphical comparison of *Leptospirillum sp.* and it's associated biofilm. We infer that *Leptosipirillum sp.* is the only BHP producer in the biofilm.

M. Rohmer, P. Bouvier-Nave, G. Ourisson, J. Gen. Microbiol. 130 (1984) 1137.
L.R. Kump, A. Pavlov, M.A. Arthur, Geology. 33 (2005) 397.
E.L. Kanennberg and K. Poralla, Naturwissenschaften. 86 (1999) 168.

Quantitative FISH analysis of microbial consortia from biogenic gas field in the Cook Inlet Basin, Alaska

Katherine Dawson
Ph.D. Student, Post-comps

Advisor: Jennifer Macalady and Kate Freeman

Production water samples from a methane-rich gas field in the Cook Inlet of Alaska host *in situ* microbial communities consistent with microbial methane production from coal and other carbonaceous rocks of Miocene age. A suite of fluorescence *in situ* hybridization (FISH) probes were designed to target groups identified by 16S rRNA tag pyrosequencing of filter-collected production water communities. Based on FISH experiments, the archaeal community is dominated by the obligate methylotrophic, methanogen *Methanolobus,* as well as CO_2-reducing and acetoclastic methanogens such as *Methanosarcina*. We observed spatial variation among the samples in relative population sizes within archaea. Co-varying bacterial communities, associated with the methanogens consist of several major lineages including Bacteriodetes and Firmicutes. We hypothesize that the differences in community structure among closely situated wells in the same field can be attributed to water and rock geochemistry. The community composition suggests a reaction network beginning with the breakdown of macromolecules, followed by fermentation and methylotrophic and acetotrophic methane production. Based on FISH data, the methanogenic community in the Cook Inlet more closely resembles that described for the Fort Union Formation in the Powder River Basin (Green et al., 2008) than the Seelyville Coal Member in the Illinois Basin (Strapoc et al., 2008). We hypothesize that this is due to the higher sulfur content in the Seelyville member (3-5%) as compared to the other two sites (<1%).

Global nannoplankton response to early Eocene ocean destratification

Leah Schneider
Ph.D. Student, Pre-comps

Advisors: Timothy Bralower and Lee Kump

Calcareous nannoplankton are one of the most prolific phytoplankton groups in the world's ocean and are expected to become more abundant with modern global warming. These organisms play a vital role in the global carbon and carbonate cycles by supplying organic and inorganic carbon to the deep sea. The utilization of nutrients by surface plankton and the subsequent transport of organic material to the deep ocean is referred to as the oceanic biological pump (OBP). The transport of organic material into the deep sea is a method of sequestering CO_2; however, the amount of CO_2 stored is regulated by the efficiency of the OBP. In an inefficient system, CO_2 will be released into the atmosphere rather than sequestered. Thus, it is the efficiency of the pump that regulates productivity driven CO_2 sequestration, not the strength of the biological pump, or the amount of organic carbon being produced. In this respect, nannoplankton production can influence atmospheric pCO_2 over long time scales. In this study, we assess how nannoplankton assemblages respond to high surface temperatures, a diminished OBP efficiency, and what the following impact would have been on atmospheric pCO_2 levels during the height of the early Eocene climatic optimum (EECO).

The EECO (~53-50 Ma) encompassed the warmest climate of the Cenozoic, with small latitudinal and oceanic thermal gradients. Atmospheric pCO_2 estimates using boron isotopes, suggest levels as high as 3000 ppm. Fossils from six globally dispersed localities were selected for nannofossil relative abundance counts and compared to previously existing oxygen and carbon isotopes. Our results indicate a dramatic nannofossil turnover event involving the expansion of the genus *Reticulofenestra* at the height of the EECO. This event can be traced to a global decrease in the thermal stratification of the ocean and in the efficiency of the OBP. The weakened stratification would have allowed for greater vertical mixing of nutrients and increased ventilation leading that led to the decline in OBP efficiency. The resulting influx of nutrients would have enhanced nannoplankton productivity and evidently facilitated the Reticulofenestrid expansion. The result of an inefficient OBP is an outgassing of CO_2 into the atmosphere. This decline in OBP efficiency, coupled with enhanced nannofossil production and calcification, would have exacerbated the greenhouse conditions and contributed to continued global warming until the termination of the EECO.

A high-resolution record from Svalbard of carbon release during the Paleocene-Eocene Thermal Maximum

Ying Cui
M.S. Student

Advisor: Lee Kump

Newly analyzed core material from Svalbard presents a highly expanded clastic sedimentary section spanning the Paleocene Eocene Thermal Maximum (PETM). Carbon isotopic analysis of the bulk organic matter extracted from core BH9-05 details the onset of the negative carbon isotope excursion of approximately 4.5‰ over 5 m of section (sampled every 30 cm). The entire excursion is about 50 m in thickness, and is nearly identical in shape to the recently published orbitally tuned record from ODP Site 1263, allowing us to establish a tentative chronology for the core. Using this record to drive an intermediate complexity Earth-system model (Genie-1; http://www.genie.ac.uk), we determine the implied rates of carbon release at the Paleocene-Eocene boundary necessary to replicate the isotope excursion and assuming different alternative isotopic compositions for the possible sources of fossil carbon driving the excursion (methane clathrate, coal/peat/marine organic matter). We find that the peak rate of carbon addition is only a small fraction of the current rate of fossil fuel burning whether the source is methane or organic matter. Model/data comparison, especially the observed and modeled seafloor carbonate dissolution record, favors the smaller (ca. 3000 Pg C) cumulative addition associated with a ^{13}C depleted source (methane). Model sensitivity analysis shows that while the rate and amount of carbon added (for a specified source type) is relatively insensitive to key model uncertainties, the predicted seafloor carbonate dissolution response is quite sensitive to the source type and the presumed initial conditions (ocean alkalinity and initial sedimentary carbonate contents, which affect the ocean's buffering capacity).

Evaluating Arsenic Acid Adsorption onto Fe(III) Clusters with Hybrid Density Functional Theory

Heath D. Watts
Ph.D. Student, Pre-comps

Advisor: James D. Kubicki

The solubility, mobility, chemical reactivity, bioavailability, and toxicity of arsenic vary with the chemical species present. Therefore, understanding and predicting the behavior of arsenic acid in the environment is imperative.

Arsenic acid, the predominant aqueous species of As(V) is represented as $H_nAsO_4^{n-3}$ (where n=0,1,2,or 3). Arsenic acid is strongly adsorbed by iron oxyhydroxides (Jain, 1999), and the adsorption of As(V) is pH dependent (Dixit, 2003). The strong adsorption of arsenic acid onto iron oxyhydroxides is invoked as an important mechanism of natural attenuation of arsenic pollution.

Developing models that can predict the pH-dependent behavior of As species is necessary, because the adsorption of arsenic species onto iron surfaces is a function of pH. To this end, computational chemistry experiments were conducted to predict the effects of charge and hydration during arsenic acid species adsorption onto Fe(III) clusters (Figure 1). Results suggest that hydrated, neutral species are more thermodynamically stable and that their bond distances are in better agreement with EXAFS data, than are the results from anhydrous, charged species.

1. Dixit, S. and Hering, J.C. (2003) *Environ. Sci. Technol.* 37, 4182-4189.
2. Jain A., Ravan K. P., and Loeppert R. H. (1999) *Env. Sci. Technol.* **33**, 1179–1184.

Figure 1: Example complex; $Fe_2(OH)_6(H_2O)HAsO_4^{2-}$

Subduction zone forensics: Unraveling the mysteries of deep geochemical cycling

Alicia Cruz-Uribe
Ph.D. Student, Pre-comps

Advisor: Maureen Feineman

Subduction zones are one of the main surface expressions of plate tectonics, and may occur where two of Earth's plates collide. Subduction of one plate beneath another functions as the primary transport mechanism for materials between the surface and interior of the Earth, both physically and chemically. An understanding of geochemical cycling in subduction zones provides us with the tools to discover valuable natural resources, such as metal ores and natural gas and oil reserves, to develop new resources, such as geothermal energy, and to understand the geologic hazards of subduction zones that affect our daily lives, such as earthquakes and volcanoes. This study focuses on the geochemistry of trace elements in fluids produced during subduction zone metamorphism, which are responsible for generating arc magmas that produce volcanoes. In particular, high-pressure (HP) and ultrahigh-pressure (UHP) metamorphic rocks such as eclogite (subducted oceanic crust) have been identified as valuable resources for studying fluid production in subducting crust within the deeper parts of the subduction zone.

Major and trace element concentrations were determined by EMPA and LA-ICP-MS, respectively, for matrix garnets (2-4 mm) and one garnetite vein in eclogite from the Ring Mountain locality of the Franciscan Complex, Tiburon Peninsula, CA. The garnetite vein (1.8 cm wide) is nearly monomineralic, with garnet grain sizes of 5-70µm, occasional amphibole (~1%) and few inclusions. Inclusion-rich matrix garnet cores display chondrite-normalized REE patterns enriched in HREE, consistent with fractionation during prograde metamorphism. Inclusion-poor matrix rims show enrichment in MREE relative to HREE, perhaps indicative of an amphibole-derived fluid source. Garnetite vein REE patterns also display enriched MREE relative to HREE, which suggests a shared fluid source for garnetite veins and matrix garnet rims. However, Mn concentrations are enriched in the garnetite vein relative to both matrix garnet cores and rims. Because there are no hosts of Mn in this rock other than garnet, the presence of Mn in the vein garnet suggests the involvement of an external fluid. Here we present a two-fluid model for garnet precipitation in which 1) an internally derived fluid, most likely the result of amphibole breakdown during prograde eclogite facies metamorphism, supplied MREE to matrix garnet rims and vein garnet, and 2) an eternal fluid, likely sourced by mélange serpentinite or chlorite, contributed Mn to garnet precipitation only within the garnetite vein. This relationship between vein garnet and matrix garnet rims is strong evidence for fluid mixing and mass transport of major and trace elements between high-grade blocks and matrix mélange within the subduction zone.

The Velocity-Strengthening Nature of Marine Sediments and Possible Requirements for Seismic Slip in Subduction Zones

Matt J. Ikari
Ph.D. Student, Post-comps

Advisors: Chris Marone and Demian Saffer

While many aspects of great subduction zone earthquakes have been well characterized, the mechanisms responsible for the shallow transition from aseismic slip to seismogenic slip remain elusive. At subduction zones, the plate boundary fault localizes within the sedimentary package, usually within clay-rich strata. Thus, large magnitude subduction zone earthquakes should nucleate within fault material containing a large component of clay minerals. Clay gouges, both from natural settings and those used as analogues for fault material, have been the subject of numerous friction experiments measuring frictional strength and frictional stability, which is a quantification of propensity for seismic slip. Fault frictional stability is documented by the parameter (a-b) derived from rate-and-state constitutive laws for frictional sliding. This parameter, if positive, describes velocity-strengthening behavior indicative of stable, aseismic slip; conversely seismic slip should only nucleate within a velocity-weakening material. However, previous experimental work has shown that fault gouges composed primarily of clay minerals are almost always velocity-strengthening. Thus, a fundamental question regarding great subduction zone earthquakes is: what processes are needed to allow seismic slip to occur in an initially stably sliding material?

We present a compilation of friction experiments exploring a wide range of conditions in an effort to determine what may be necessary for seismic slip to occur along subduction megathrusts. These experiments were performed in a biaxial testing apparatus in the double-direct shear configuration using a wide variety of clay-rich fault material analogues, as well as natural fault material sampled from the Nankai subduction zone during IODP Expedition 316. We explore the roles of gouge mineralogy, effective normal stress, shear strain, and lithification state. The data we present suggest that for velocity-weakening to occur in clay-rich sediments, mechanical transformations may be required, such as lithification and cohesive strengthening of gouge combined with slip localization. We suggest that both of these conditions are necessary and that each process individually may be insufficient to cause seismic slip.

Shear band formation and poromechanical properties; application to unlithified sand, Humboldt County, CA

Bryan M. Kaproth
Ph.D. Student, Pre-comps

Advisor: Chris Marone

In response to shear strain, porous granular media may fail in tabular zones of grain deformation, commonly referred to as shear bands. Previous researchers have argued that shear bands form via cataclasis and strain hardening, and that once formed they do not accommodate additional shear-strain. If correct, this hypothesis requires that shear bands are stronger than their parent material, and that parent material strengthens in response to shear-driven cataclasis, each of which may alter the effective permeability. We report on laboratory experiments designed to resolve the frictional strength and permeability of shear bands formed in well-sorted nearshore marine sand and their unlithified parent material, and to elucidate the strength and deformation properties of parent material under conditions of shear-band formation. Experiments were conducted on in situ shear bands and parent material from late Quaternary nearshore marine sand in the footwall of the active McKinleyville thrust fault, Humboldt County, CA. Shear bands are exposed in positive relief, a consequence of reduced grain size and cementation, which result in decreased permeability. Permeability was measured under hydrostatic stress conditions at effective confining pressures from 0.2 MPa - 5.0 MPa . Shear bands have permeabilities of 8.2*10 -15 - 1.3*10 -17 m 2 , which represents roughly a 1 to 3 order of magnitude decrease relative to that of the parent material (7.0*10 -14 - 2.0*10 -14 m 2). We sheared parent material and in situ shear bands in the single-direct shear geometry over a range of probable in situ normal stresses (0.5-1.8 MPa). Shear bands have greater strength than parent material, with the coefficient of internal friction being μ i = 0.623 and μ i = 0.525, respectively. We sheared parent material in the double-direct shear geometry under conditions approximating shear band formation (sliding velocity = 10 μm/s-10 mm/s, σ n = 0.75-1.75 MPa, saturated/dry, shear strain = 0.5-20). We find that parent material strengthens as a function of shear strain throughout individual experiments; frictional yield strength increases by 1 to 9% over a range of shear strain from 0 to 10. We attribute the increase in strength to increased grain angularity and abundance of small particles, both of which are a consequence of pervasive cataclasis. Our results support the hypothesis that shear bands are stronger than their parent material and that parent material exhibits strengthening as a function of shear-driven cataclasis. Further, cataclasis may be responsible for the observed permeability contrast of in situ shear bands and parent material. Ongoing work will analyze the role of cataclasis on parent material permeability as a function of shear strain.

New experimental insights into the frictional behavior of the San Andreas Fault

Brett M. Carpenter
Ph.D. Student, Post-comps

Advisor: Chris Marone

Debate over the apparent low strength of tectonic faults has centered around two basic controls on fault mechanical behavior: low intrinsic friction resulting from mineralogy/fabric, and decreased effective normal stress caused by elevated pore pressure. Phase III of the San Andreas Fault Observatory at Depth (SAFOD) Project provided samples of drilling cuttings across the actively creeping section of the San Andreas Fault at ~3 km depth that inform this debate.

We conducted experiments on a total of eight samples adjacent to and within the fault zone penetrated at 10819 ft (3298 m) measured depth in the SAFOD borehole. We pulverized and sieved all samples to grain sizes < 150 μm. We sheared the samples in a double-direct shear configuration in a true triaxial pressure vessel. Experiments were run at constant effective normal stress (50 MPa), confining pressure (6 MPa) and pore pressure (5 MPa). We saturated the samples with a pore water solution that matches the major ion (Na, Ca, K and Cl) chemistry of fluids sampled at SAFOD. We began each experiment with a "run-in" to establish a steady-state shear fabric and achieve steady-state friction. We then performed velocity stepping tests and slide-hold-slide tests to evaluate friction constitutive properties.

The frictional strength of the fault zone is lower than that of the wall rock (μ=0.35 outside of the fault; μ=0.21 within the fault core). In addition, all of the samples exhibit velocity-strengthening behavior, which is generally consistent with creep rather than unstable slip. A material that exhibits velocity-strengthening behavior shows an increase in steady-state friction in response to an instantaneous increase in sliding velocity. Slide-hold-slide tests indicate healing rates near zero within the fault zone, and higher healing rates in the wall rock.

We characterized all samples by XRD to understand potential mineralogical controls on friction. Wall rock consists predominantly of quartz and K-feldspar, with only trace amounts of chlorite. In contrast, cuttings from the fault zone at 3305 mMD contain significant amounts of smectite (montmorillonite) and minor amounts of a serpentine mineral, in addition to quartz, K-feldspar and minor chlorite. The strong correlation between the clay mineral content and relative frictional weakness and reduced healing behavior of samples in the vicinity of the fault core indicates that the clay mineralogy of the fault core is a fundamental control on the frictional behavior of these fault rocks.

Oral Session Four

Friday, April 23
9:00-11:30

Time	Presenter	Advisor	Title
9:00	Brad Kuntz	Kamini Singha	Solute transport in the Shale Hills Soils
9:15	LaMichelle Arnold	Terry Engelder	A Petrophysical Evaluation of the Geneseo-Burket Shale
9:30	Clayton Magill	Katherine Freeman	Mechanisms of Climate Variability in Monsoonal Africa During the Emergence of *Homo*
9:45	Heather Graham	Katherine Freeman	Biochemical and Morphological Indicators of Light Regime and Productivity in Extant and Fossil Forests
10:00	Kevin Mueller	Katherine Freeman	The relative contribution of different plant biopolymers to stable soil organic matter
10:15	*Break*		
10:30	Karen Whelley	Christopher House	First Steps in Building a Primitive Nucleotide
10:45	Monica Ramirez Carvalho	Peter Wilf	Tracking insect diversity through time: Tropical insect herbivory validates inferences of past insect diversity based on fossil leaf damage.
11:00	Matthew Legg	Kevin Furlong	Thermochronologic constraints on East Coast Basin Evolution in the Hawke's Bay Region
11:15	Sarah Barrett	Charles Ammon	Observations and Analysis of Repeating Earthquakes beneath the Aceh Basin, Northern Sumatra

Solute transport in the Shale Hills Soils

Brad W. Kuntz
M.S. Student

Advisor: Kamini Singha

Interpreting the operation of parameters controlling solute transport is challenging in shales and shale-derived soils because of complex chemical and physical heterogeneity. Quantifying solute transport processes in the weathered shale and soils of the Shale Hills Critical Zone Observatory (SH-CZO) is important in interpreting the residence times of ions in the groundwater system, and consequently weathering rates and age of groundwater. In undisturbed soil columns spanning the breadth of the soil profile from the SH-CZO cores, we are evaluating physical heterogeneity, as well as solute transport parameters such as (1) mobile/immobile porosity, (2) mass-transfer rate between domains, and (3) the behavior of exchangeable ions within the system as material properties shift from soil to consolidated rock.

Soil samples change with respect to color and biogenic fabric or structure with depth, and the frequency of shale bedrock fragments within in the soil increases with depth. Constant flow experiments in the soil provide a hydraulic conductivity of 10^{-6} m/s at 0-15 cm depth. Field-scale hydraulic conductivities from slug and pumping tests of the fractured shale at depth are approximately the same: 10^{-5} to 10^{-6} m/s. A hydraulic test in a triaxial compression chamber places the hydraulic conductivity of the shale matrix, however, at less than 10^{-15} m/s, indicating that fractures control permeable pathways within the shale bedrock. These observations indicate high physical heterogeneity and potentially a very dynamic flow regime in the subsurface that will control flow and transport behavior.

Concentration histories from a conservative tracer test carried out on the uppermost soil column exhibit long tailing behavior, indicative of non-equilibrium transport. Preliminary results suggest that the relative sizes of the mobile/immobile reservoirs significantly change through the soil profile and shale bedrock. Therefore the mass-transfer rate and scales will also likely change as material properties change from bedrock to soil.

A Petrophysical Evaluation of the Geneseo-Burket Shale

LaMichelle Arnold
M.S. Student
Petroleum related

Advisor: Terry Engelder

Gas shales are becoming increasingly important as new technologies are applied to enhance their production of natural gas. The Barnett, the Fayettville, and the Haynesville have all been successful gas shale plays in North America. In addition, the Marcellus has recently stimulated a boom in U.S. shale-gas production. The Geneseo-Burket is a black shale that overlies the Marcellus. It is currently unclear whether it is prospective as a gas shale or not. This study seeks to examine the commercial value of the Geneseo-Burket Shale and characterize the relationship between density and organic matter. This relationship, in collaboration with thickness trends can be used as exploratory tools for developing gas shale reservoirs in the Appalachian Basin.

This study consists of over 300 well logs used to conduct a petrophysical evaluation of the Geneseo-Burket Shale in Pennsylvania and New York. Gamma ray and bulk density well logs, supplemented by well cuttings, are used to derive isopach/structure maps, density curves and the spatial distribution of organic matter. The relationships among these properties and the mechanisms that produce their patterns are also explored. Distinctive density patterns can be observed in well logs of the Geneseo-Burket throughout the basin. Density vs depth trends illustrate considerable deviation from normally compacted shale. Observed lower densities in the Geneseo-Burket are a likely indicator of abnormally high porosities or "overpressure." Density data is also compared with gamma ray logs. They are correlated with a Pearson product-moment correlation coefficient equal to -0.65. This is consistent with the hypothesis that organic matter significantly influences rock bulk density. Since uranium content of Devonian shales is proportional to organic content (Swanson, 1956), variations in gamma ray intensity are proportional to changes in organic content. Organic matter percentages in the Geneseo-Burket are calculated using a method developed by Schmoker (1979). The spatial distribution of organic matter is mapped and increasing concentrations in western Pennsylvania and New York suggest a decrease in clastic dilution. The changes in sedimentation are estimated using formation thicknesses and calculated organic matter. An isopach map is used to illustrate variation in formation thicknesses. The Geneso-Burket extends throughout the northern Appalachian Basin and thicknesses exceed 150 feet in eastern Pennsylvania.

Mechanisms of Climate Variability in Monsoonal Africa During the Emergence of *Homo*

Clayton R. Magill
Ph.D. Student, Pre-comps

Advisor: Katherine H. Freeman

African climate over the past three million years is thought to have progressed towards significantly drier and more variable conditions. However, regional climatic reconstructions have recently challenged this model and present conflicting perspectives on climate change and its role in ecological processes. Environmental hypotheses of hominid evolution directly link variability in regional aridification patterns to times of rapid diversification, but the timing and mechanism(s) governing the influence of climate on our ancient ancestors remains elusive.

Here we present a new record of hydroclimate and vegetation at Olduvai Gorge – the "Cradle of Mankind" – during a time characterized by major mammalian speciation and extinction events. We hypothesize moisture regime and vegetation type (i.e., C_3 versus C_4 plant ecosystems) co-varied with the difference between Atlantic and Indian Ocean sea-surface temperatures (ΔSST), driving monsoon intensity.

We measured the bulk organic $\delta^{13}C$ and molecular $\delta^{13}C$ and δD of perennial lacustrine sediments dated between 1.79 and 1.95 million years ago. Bulk carbon isotopic ratios range nearly 10‰ and correlate strongly with ΔSST. Likewise, molecular $\delta^{13}C$ signatures of biomarkers from terrestrial plants (*n*-C_{31}) fluctuate between ~-22‰ and -36‰, strongly correlating with ΔSST. Using the $\delta^{13}C$ values of *n*-C_{31}, we estimated relative plant group abundance and established a mixing line for deuterium fractionation between water and plant lipids for varying relative abundances C_3 and C_4 vegetation. Interpolated δD values of environmental waters, based on the measured δD values of *n*-C_{31}, are enriched (5‰) and depleted (-40‰) during times of higher and lower ΔSST, respectively. Molecular δD values from the algal-derived *n*-C_{17} alkane are similarly correlated strongly with ΔSST, but are more enriched and range between 80‰ to 40‰, reflecting the additional influence of lake water evaporation.

We interpret these results as evidence of pronounced ecological and hydrological variability in monsoonal Africa during the early Pleistocene, governed by ΔSST patterns. We conclude that dramatic swings on millennial scales between woodland C_3 and grassland C_4 vegetation likely reflect orbital forcing of regional monsoon rainfall and evaporation/precipitation ratios. Our rainfall reconstructions, based on interpolated δD values of *n*-C_{31}, indicate ~350 mm decreases in annual precipitation that occurred in under 10 thousand years, consistent with previous computer models of African rainfall during the Pleistocene. Our paleoclimate data, when considered in the context of the local hominid fossil record, indicate evolutionary and migratory events may have been mediated by environmental variability.

Biochemical and Morphological Indicators of Light Regime and Productivity in Extant and Fossil Forests

Heather V. Graham
Ph.D. Student, Pre-comps

Advisor: Kate Freeman

Closed-canopy forests, in particular, dense, stratified, tropical forests represent a large proportion (~40%) of global terrestrial biomass carbon, at least one-third of global soil carbon and 30-50% of terrestrial productivity. However, estimations of terrestrial habitat productivity in the past are difficult to ascertain from the fossil record. The geologic history of three-dimensional forest structure is poorly known because adaptations indicative of dense forest structure, such as large fleshy seeds or branchless boles are rarely preserved. Leaves and leaf fragments are the most commonly fossilized botanical specimen. This study seeks to identify leaf characteristics that both signify a closed canopy forest and are preserved in the geologic record

Highly productive, dense canopy forests exhibit a drastic attenuation of light, with as little as 2% of total photosynthetic photon flux density reaching the forest floor. This variation in light is expressed as an increase in photosynthetic rate with height and is recorded isotopically during biosynthesis of leaf tissues This study uses a unique collection of leaves acquired in an extant, closed-canopy rainforest via a canopy crane access system along a vertical transect. Analysis of the carbon isotopic composition of these leaves reveals a corresponding distinct vertical enrichment of $\delta^{13}C$ with a 10‰ range from canopy base to canopy top. Similarly, the isotopic composition of the terrestrial organic carbon reflects the enormous contribution of the canopy leaves. We hypothesize that a highly productive dense canopy forest can be identified as a wide range in $\delta^{13}C_{leaf}$ corresponding to a less enriched $\delta^{13}C_{TOC}$. In practice, these conditions could be evaluated in a fossil assemblage by measuring $\delta^{13}C$ of individual fossil leaf cuticle compared to $\delta^{13}C_{TOC}$ of sediment in order to infer terrestrial paleo-productivity.

The relative contribution of different plant biopolymers to stable soil organic matter

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The plant biopolymers cutin, suberin, and lignin have all been hypothesized to play an important role in the stabilization of soil organic matter. Yet the relative contribution of these biopolymers to stable soil organic matter pools is not well known, largely due to analytical challenges in measuring the molecular composition of soil organic matter. We used a combination of wet chemical degradation and gas chromatography mass spectrometry to assess the abundance of lignin, cutin, and suberin in soil fractions with different mechanisms of organic matter preservation. Potential differences in microbial degradation of each biopolymer were also assessed during a year-long soil incubation. Our results show that lignin is not selectively preserved in soil, while cutin and suberin monomers do accumulate in more stable soil fractions. Differences in microbial degradation of each biopolymer were not observed after the incubation, indicating that selective microbial degradation does not play an important role at this time scale.

First Steps in Building a Primitive Nucleotide

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Thomas Cech and Sidney Altman discovered the catalytic properties of RNA, which gave strong experimental evidence for the RNA World. The RNA World is one in which RNA precedes DNA, and performs the dual role of DNA and protein as the sole genetic molecule in the cell. However, it is hypothesized that RNA is too complex to be produced spontaneously on early Earth; therefore, it has been suggested that a simple genetic molecule must have preceded RNA. This precursor genetic molecule would be different in composition from RNA, yet similar in structure.

We used a spark discharge apparatus filled with an atmosphere of N_2, CO_2, CH_4, and H_2 to produce a complex mixture of organic molecules that were likely present on prebiotic Earth. A fluorescent guanine (nucleobase) analog, isoxanthopterin, was added to the spark mixture and the solution was allowed to react at various temperatures (-20 °C, 23 °C, and 100 °C) for three months. We analyzed the spark solution using high performance liquid chromatography with fluorescence detection and mass spectrometry (HPLC-FD-MS). An adduct was detected at all temperatures, which we propose to be the addition of a cyanide molecule to isoxanthopterin as indicated by accurate mass measurements using time of flight mass spectrometry.

In order to further characterize the cyano-isoxanthopterin adduct, we reacted sodium cyanide with isoxanthopterin at 100 °C and analyzed the product by ^{1}H NMR and ^{13}C NMR. The NMR results indicate the adduct formed in the spark discharge apparatus cannot be reproduced in this manner; however, HPLC-FD-MS measurements of this solution are forthcoming. We will also test other nucleobase analogs with a spark solution, as well as a sodium cyanide solution, to determine if the adduct is universal.

Tracking insect diversity through time: Tropical insect herbivory validates inferences of past insect diversity based on fossil leaf damage.

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Insect feeding marks on leaf compression fossils have provided substantial information on the extent and intensity of past phytophagy and the responses of terrestrial food webs to past climate change and extinction events. However, quantitative correlations that can be applied to reconstructing insect diversity through time using leaf damage type (DT) diversity still remain uninvestigated. A confident use of this proxy requires understanding the processes that drive the complex plant-insect interactions in modern communities.

Canopy crane systems provide direct access to the foliage and insect communities of dominant trees in forest assemblages. We surveyed for externally-feeding phytophagous insects on thirteen species of the most dominant trees, palms and lianas each of two lowland tropical forest sites during the wet seasons of 2008 and 2009, using the canopy crane facilities of the Smithsonian Tropical Research Institute in Panama. Insects were captured and fed fresh leaves of the plant species they consumed in order to isolate and record the specific DTs made by each insect. Overall results indicate a positive correlation between DT diversity and the number of culprit species on each host plant, despite the limited number of possible feeding mechanisms any insect can have or the preservation biases in the fossil record against certain DTs. The underlying mechanism is driven by those insect species that make multiple damage types, contributing most of the rare DTs that increase total DT diversity. In contrast, insect species that make only one DT tend to repeat more common and generalized ways of feeding. The number of insect species making multiple DTs follows total insect diversity with a 1:3 relationship. These results validate qualitative insect diversity inferences based on leaf damage and highlight the dependence of DT diversity on the relative abundance of insect species making multiple DTs.

Thermochronologic constraints on East Coast Basin Evolution in the Hawke's Bay Region

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As part of an active plate boundary throughout the Neogene, the thermal evolution of the East Coast Basin terranes along the Hikurangi margin reflect the processes of subsidence and sediment burial, thermal effects of subduction, and exhumation. Using the stratigraphic (burial/exhumation) history of the region as recorded in the Oputouma-1 well in conjunction with Apatite Fission Track (AFT) ages and track length distributions, and vitrinite reflection (Ro) results of samples from the well, we have assessed the thermal history of the basin incorporating improved models of plate motions and the thermal effects of plate boundary evolution (e.g. heat flow effects of extension, subduction emplacement, thrusting). We have used a time-dependent numerical (Finite-difference) thermal modelling approach that explicitly includes effects of crustal heat production distributions, variable thermal properties with changes in lithology, the effects of burial and exhumation, and the effects of subduction emplacement and ongoing subduction. Having access to a vertical section via the well samples extending more than 3.5 km below the surface provides substantial constraints on the range of viable tectonic and thermal histories for the evolution of the basin.

Modeling results indicate the following: (1) The onset of subduction beneath the Hawke's Bay region essentially locked in AFT ages and Ro values due to the subsequent drop in heat flow. Our model reveals the timing of the start of subduction to be in the 25-20 ma time interval. (2) The level of organic maturation indicated by Ro values in conjunction with AFT ages and track lengths requires a relatively high heat flow regime during the Eocene-Oligocene, consistent with plate tectonic results indicating that New Zealand was undergoing extension during that time. (3) Much of the Miocene to Present stratigraphic history of the basin plays little role in driving further maturation of potential source rocks as the thermal regime remains cool as a result of continued subduction. Our thermal models indicate that virtually any organic maturation and hydrocarbon production would occur prior to the ca. 25 Ma initiation of subduction, raising the question of whether appropriate reservoir structures and seals existed at that time.

Observations and Analysis of Repeating Earthquakes beneath the Aceh Basin, Northern Sumatra

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Repeating earthquakes are observed across a variety of tectonic settings. In this study we discuss observations of numerous repeating earthquakes that occurred beneath the Aceh Basin following The Great 2004 Sumatra-Andaman Earthquake. The Aceh Basin is the northernmost in a series of forearc basins located along the Sunda Trench. The plate boundary beneath the basin was relatively aseismic prior to the 2004 megathrust earthquake. An analysis of the moderate-size earthquakes occurring beneath the Aceh Basin in response to the 2004 megathrust provides interesting and important observations of stick-slip faulting near the deep within the seismogenic zone. We use teleseismic and distant regional observations to identify repeating earthquakes that we infer to be located along the plate boundary 30-50 km beneath the seafloor. Analysis of the short-period coda following teleseismic and regional P and regional S waves is used to estimate the distance between repeating events in the same sequence. The coda analysis indicates that in most instances the same asperity is failing in the sequence of repeating events. Despite incredibly consistent coda coherence, events within each sequence show resolvable amplitude differences, which suggest changes in frictional strength occurring throughout the duration of the repeating earthquake sequence. This rapid change (over a few seismic cycles) in strength may be a function of the erosion of the asperity or a change in intrinsic strength. Additional studies of large aftershock sequences, such as the 2010 Chile earthquake, may provide more insight into these questions.