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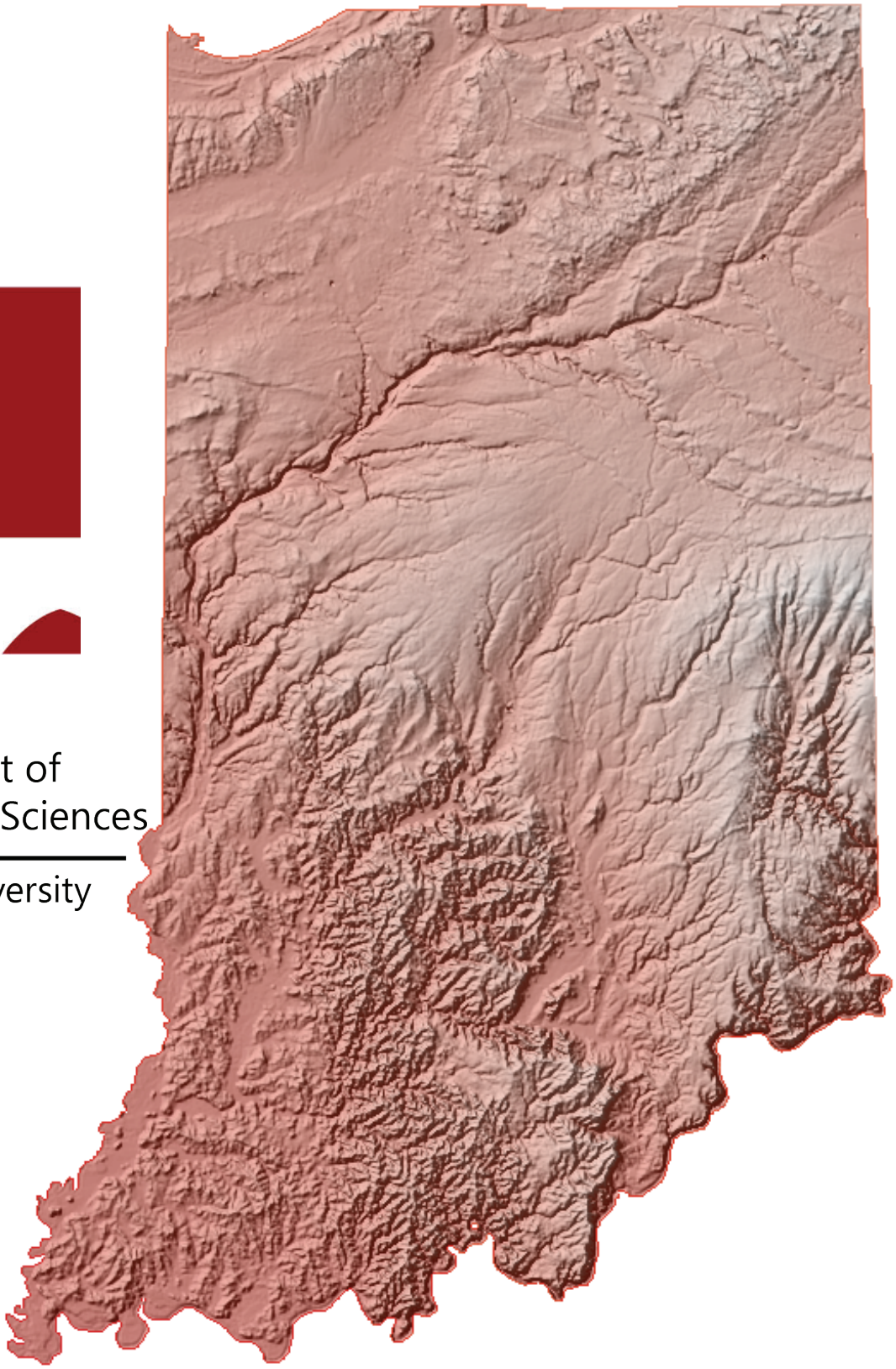

CROSSROADS GEOLOGY CONFERENCE 2016

Welcome

We would like to extend a special thank you to all of those participating in this year's Crossroads Geology Conference at Indiana University. This conference is a rich tradition for the Department of Geological Sciences and we anticipate that this year's submissions will uphold previous standards of excellence. Additionally, we are excited to present our keynote speaker, Steven Goodbred from Vanderbilt University. Finally, we want to thank our sponsors, judges, the Department of Geological Sciences at Indiana University, and all of those who have volunteered their time for the preparation and execution of Crossroads 2016.

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Poster Sessions: 2-hour standard poster presentation (Geology Lobby)

Session 1: Geophysics **9-11 a.m.**	**Session 2: Geomorphology, Sedimentology, and Hydrology** **11:45-1:45 p.m.**	**Session 3: Atmospheric, Geochemistry, Mineralogy, Petrology, and Structure** **3-5 p.m.**
Joshua Arneson	Rebecca Caldwell	Devon Colcord
James Atterholt	Scott David	Ryan Deasy
Pete Bordovalos	Nicholas Downton	Carley Gasaway
Ross Caton	Zhiyang Li	Christen Helou
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		Bryan Wathen
		Suzanne Mulligan

Oral Sessions: 15-minute standard presentations

Time	**Presenter**	**Topic**
10:00 (GY 214)	Molly Williams	Geophysics
10:15 (GY 214)	Ciara Mills	Structural/Petrology
10:30 (GY 214)	Elizabeth Olliver	Geomorphology
10:45 (GY 214)	Qian Zhang	Geochemistry/Hydrology
3:00 (GY 143)	Ryan Sincavage	Sedimentology
3:15 (GY 143)	Andrea White	Sedimentology
3:30 (GY 143)	Joel Leonard	Sedimentology\Tectonics
3:45 (GY 143)	Madison Ferrara	Atmospheric

Friday, April 1st, 2016

8 am	Breakfast (S201)	
9 am	Poster Session 1**: Geophysics	Break
10 am		Oral Session 1 (GY 214)
11 am	Lunch (GY 210)	
12 pm	Poster Session 2**: Geomorphology, Sedimentology, and Hydrology	Break
1 pm		
2 pm	Keynote Talk (GY 126)	
3 pm	Poster Session 3**: Atmospheric, Geochemistry, Mineralogy, Petrology, and Structure	Oral Session 2 (GY143)
4 pm		
5 pm	Break	
	Judges' Meeting	
7 pm	Networking Social at Crazy Horse (214 W. Kirkwood Ave. Bloomington, IN 47404)	

**Note: all poster presentations are in the Geology Lobby

Saturday, April 2nd, 2016	
8 am	Breakfast (S201)
9 am	Awards Ceremony (S201)
	Career Panel Discussion (GY210)
10 am	
	Petroleum Systems Short Course (GY214)
11 am	
12 pm	Lunch (S201)

Keynote Speaker: Dr. Steven Goodbred

Constructing a Land of Superlatives: From process to morphology to stratigraphy in the Ganges-Brahmaputra River delta

The Bengal basin of South Asia lies at the convergence of three tectonic plates, a position that has made it one of the principal repositories for Himalayan sediment over the past 40 million years. Today, the nearly 20-km thick pile of sediment remains the site of confluence for two great rivers of the world, the Ganges and Brahmaputra, which together drain 75% of the monsoon-drenched Himalayan orogen. Delivering a billion tons of sediment per year, these laterally-mobile braided streams have fueled construction of ~150,000 km^2 delta system over the Holocene. At the coast, the delta system interfaces with a dynamic marine environment at the head of the Bay of Bengal, where 3-m tides extend 100 km inland of the shoreline, along with storm surges from the nearly annual tropical cyclones. Sediment transported by these tides and marine incursions are essential to maintaining vast areas of the delta that receive little direct fluvial input. In addition to being geologically superlative, this massive river delta is also home 150 million people living in Bangladesh and West Bengal, India, giving the system great societal relevance – and environmental strain. In this talk we will set the regional background of South Asia, and then connect modern processes to the current deltaic landform that has been built over recent millennia. From these surficial perspectives, we will then move below ground to investigate stratigraphic architecture of the >90-m thick Holocene delta, the development of which ensued promptly after termination of the Younger Dryas cold period ~11,500 years ago.

Using Petrophysics to Determine the Presence of Residual Oil Zones in the Thick IVF Cypress Sandstone at Noble Field, Southeastern Illinois

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The Cypress Sandstone is one of the most prolific oil producing formations in the Illinois Basin (ILB). In addition to prolific conventional oil reservoirs, there may be economically recoverable nonconventional residual oil zones (ROZs) within the fairway of thick, incised valley fill (IVF) facies of the Cypress Sandstone in the central ILB. ROZs are zones of low oil saturation relative to a conventional reservoir, typically below the producing oil-water contact (OWC). The use of carbon dioxide enhanced oil recovery (CO2-EOR) techniques in an ROZ is expected to provide a significant CO2 storage and EOR opportunity. A petrophysical method was developed to use geophysical logs to identify the presence of ROZs in the IVF Cypress Sandstone.

Open-hole well logs were digitized and Archie's equation was applied to resistivity and porosity curves to determine water saturation (*S*w), or the percent of pore volume occupied by water, with the remainder assumed to be occupied by oil. Forty wells were selected from Noble Field in Richland County, Illinois, for petrophysical study because of known production from the IVF Cypress Sandstone. Previous geologic characterization has indicated the presence of a tilted oil-water contact, a key indicator of an ROZ. Preliminary results of the petrographic analysis suggest the possibility of an ROZ. Several wells display a *S*w profile with a zone of slightly higher oil saturation consistently 49–66 ft (15–20 m) below the OWC. Several other wells display a gradual transition from the reservoir to the water-saturated zone instead of a sharp OWC. A map was produced from these 40 wells to show the spatial distribution of oil saturation below the OWC.

The petrophysical method can be validated through oil saturation measurements in the IVF Cypress Sandstone. A visible cut technique using solvents and cuttings is being developed as another indicator of oil in the lower part of the IVF Cypress to validate well log analyses. After the petrophysical assessment of the IVF Cypress Sandstone at Noble is complete, the method will be applied elsewhere in the IVF Cypress Sandstone fairway to evaluate the potential ROZ resource and better understand the spatial distribution of ROZs across the ILB. Ultimately, the findings of this study will aid in evaluating the economic feasibility of CO2-EOR implementation.

Measurements of Seismic Wave Velocities of Rocks in the Homestake Mine in the Black Hills of South Dakota

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The Homestake Mine in the Black Hills of South Dakota is the deepest underground mine in North America. The Mine closed in the late 1990s and has been converted to an underground laboratory facility called Sanford Underground Laboratories. In September of 2015, a team from Indiana University conducted a series of control source seismic experiments at Sanford Laboratory. A land streamer and a hammer source was used in a mine drift located 2000 feet below the surface. We recorded 750 shot points at 1 m intervals. We found the vertical impulse and vertical geophone array were mainly useful to measure S wave speeds; as P wave amplitudes were too small to be reliably picked. We picked first breaks of S waves at offsets greater than 40 m where P and S became well separated. The measure times were converted to velocities by using a least squares line fit. Most of the line was picked twice to reduce outliers and appraise repeatability. The measured velocities were grouped by rock formation. The average of 44 measurements of S wave velocities of the Ellison formation was 3305.35 ± 71.179 m/s. For the Homestake formation the average measured S wave was 3430.14 ± 273.37 m/s. We evaluated the alternative hypothesis and wave speed variations are controlled by shear-wave anisotropy. Both the Homestake and Ellison formations are composed of phyllites and schist with a very strong foliation known to make the rocks anisotropic. In the case of these measurements; however, it appears spatial heterogeneity was not as influential on shear wave velocity as was rock formation.

In December of 2015 and March 2016, Sanford Laboratory conducted a test series of explosions at the 4850 feet level. The explosions were well recorded by a passive seismic array deployed in the mine as part of this project. We measured P wave arrival times from these explosions to further test the seismic anisotropy hypothesis. A fit to first arrival times plotting time versus distance is roughly linear, but the correlation coefficient indicates that this linear relationship is insufficient to fit the data within measurement errors. The analysis of this data ongoing, but the observed deviations are best explained by anisotropy of formation heterogeneity.

A Millennial Time-scale Vertical Deformation Field in Taiwan

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To better understand the feedbacks between erosion and deformation in Taiwan, we need constraints on the millennial time-scale vertical field. GPS and leveling data sets provide measurements of the present-day vertical deformation field over the entire Taiwan island. However, it remains unclear how much of this vertical field is transient (varies over earthquake cycle) or steady and driven by erosion (over millennial time scale). A deformation model is required to decouple transient from steady deformation. This study takes a look at how the 82 mm/yr of convergence motion between the Eurasian plate and the Philippine Sea plate is distributed across the faults on Taiwan. We build a plate flexure model that consists of all known active faults and subduction zones cutting through a 40 km thick elastic plate supported by buoyancy. We use horizontal and vertical GPS data, leveling data, and geologic surface uplift rates with a Monte Carlo probabilistic inversion method to infer fault slip rates and locking depths on all faults across the island.

Developing a truly global delta database to assess delta morphology and morphodynamics

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Delta morphology reflects the interplay of various environmental parameters, though these relationships have only been tested on small datasets with 30-50 deltas. These datasets are biased toward the largest deltas, which typically have compound morphologies, form on passive margins, and may not be representative of the full breadth in delta morphology. With the goal of building more robust predictions of delta morphology to enhance hazard mitigation and resiliency planning, we have developed a truly global delta database including every delta on the world's marine coastlines. Using Google Earth imagery, we first identified all fluvial river mouths (≥ 50 m wide) connected to an upstream catchment. Deltas are defined geomorphically as river mouths that split into two or more active or relict distributary channels, end in a depositional protrusion from the shoreline, or do both. In our database we identified 5,801 river mouths, and 1,426 of those coastal rivers (~25%) have a geomorphic delta. ~75% of deltas exhibit an active or relict distributary network, while the remaining ~25% are single channel deltas with a basinward protrusion. Preliminary morphometric analysis (ratio of shore-parallel width, W, to shore-perpendicular length, L) on a subset of 159 deltas suggests W:L values range from 0.52 (elongate) to 23.6 (broad/cuspate). The median W:L value is 2.68, suggesting the majority of deltas are roughly semi-circular (W:L = 2), and the distribution is heavily skewed to the broad/cuspate deltas (~28% are >4 times wider than they are long). Preliminary comparison to downstream significant wave height data shows that the 'wider' deltas relate to higher wave heights ($R^2 = 0.42$), though the data are scattered. Ultimately, the database will include additional measured morphometrics, including number of channel mouths and delta area, and morphodynamic data derived from serial Landsat imagery.

SOLAR MODE LINES IN LONG PERIOD SEISMIC SPECTRA

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It was shown nearly a decade ago that spectral lines associated with solar free oscillations, also called solar modes, are observable in seismic spectra at long periods (~4 minutes to over two hours). Past studies of this phenomenon have examined the spectra of very long data blocks of 45 days or more taken from single stations with excellent noise performance, such as Pinyon Flat Observatory and Black Forest Observatory. In this project, we attempt to locate solar modes in seismic data instead using an array stack technique to reduce noise. We make use of 18 Transportable Array stations in southern California, form a median beam, and estimate the multitaper spectrum of the beam. We tentatively identify two solar mode candidates with periods longer than 45 minutes in two 50-day data blocks at confidence levels between 95% and 99%. We are also performing this analysis on two 85-day blocks from the Pinyon Flat borehole array, and preliminary results may be available at the time of the conference.

BIOMARKER RECORDS OF CLIMATIC AND ENVIRONMENTAL CHANGE FROM OLDUVAI GORGE

Devon Colcord[1*], Andrea Shilling[1], Katherine Freeman[2], Jackson Njau[1], Ian Stanistreet[3], Harald Stollhofen[4], Kathy Schick[5], Nicholas Toth[5], Simon Brassell[1]

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Studies of hominin evolution in East Africa have provided an unprecedented wealth of evidence over the past century, but many questions about how and why our ancestors evolved remain unanswered. Leading hypotheses, such as the savannah hypothesis and the pulsed climate variability hypothesis (reviewed in Maslin et al., 2015) invoke climatic and environmental variability as critical factors in hominin evolution. The ability to better refine these hypotheses and truly understand what drove hominin evolution requires a more complete and detailed record of the variability of the climate and environment experienced by hominins. Investigations of biomarkers from lacustrine sequences have the potential to fill this knowledge gap by providing reconstructions of diagnostic climatic and environmental parameters.

Olduvai Gorge, located in northern Tanzania, exposes a sedimentary sequence of ~2.0 Ma, which includes multiple deep lake intervals, and although biomarker reconstructions for Olduvai have been previously published (e.g., Magill et al., 2013a,b), these prior studies utilized outcrop samples, which offer only coarse resolution. Magill et al. (2013a) were able to identify cycles between open grassland and forested ecosystems corresponding to the ~21,000 year processional Milankovitch cycle, but the resolution afforded a few data points per cycle, precluding evaluation of any changes occurring at sub-Milankovitch time scales.

A drill core, obtained in 2014 by the Olduvai Gorge Coring Project (OGCP), contains a lacustrine sedimentary sequence ideally suited for biomarker analyses. This section from core 2A between 76.6 to 86.9 meters depth, spanning approximately 20,000 years, was sampled every 16 cm for biomarker and bulk geochemical analyses. Preliminary bulk geochemical analyses (e.g. $\delta^{13}C_{TOC}$) confirm this core section will allow for paleoclimate reconstructions at a resolution that is unprecedented for this region. Future investigation of the full suite of biomarkers in this lacustrine sequence from core 2A, as opposed to utilizing outcrop samples, will enable the production of climate and environmental reconstructions for both the aquatic and terrestrial ecosystems, recording sub-Milankovitch cycle scale changes. Thus, this project will provide an unprecedented temporal record of the climatic and environmental variability experienced by hominins during a critical time in their evolutionary history.

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Morphodynamics of Floodplain Chute Channels

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The formation of chute channels has been demonstrated to play an essential role in regulating river sinuosity and initiating the transformation from a single to multi-thread planform river geometry. Most chute channels occur within the active channel belt, but growing evidence suggests that chute channels can extend far outside of the channel belt, called intra-floodplain chute channels. The origin and function of these chute channels to the fluvial system is not clear. Towards this end we have initiated an empirical and theoretical study of floodplain chute channels in Indiana, USA. Using elevation models and satellite imagery we mapped 3064 km^2 of floodplain in Indiana, and find that 37.3% of mapped floodplains in Indiana have extensive intra-floodplain chute channel networks. These chute channel networks consist of two types of channel segments: meander cutoffs of the main channel and chute channels linking the cutoffs together. To understand how these chute channels link meander cutoffs together and eventually create floodplain channel networks we use Delft3D to explore floodplain morphodynamics. Our first modeling experiment starts from a generic floodplain prepopulated with meander cutoffs to explore what conditions promote and suppress intra-chute channel formation. We find that chute channel formation is optimized at an intermediate flood discharge. If the flood discharge is too large the meander cutoffs erosively diffuse, whereas if the floodwave is too small, channel initiation does not occur. A moderately sized floodwave reworks the sediment surrounding the topographic lows, enhancing the development of floodplain chute channels. Our second modeling experiments explore how floodplain chute channels evolve on the West Fork of the White River, Indiana, USA. We find that the floodplain chute channels are capable of conveying the entire 10 yr floodwave ($Q=1330 m^3/s$) leaving the inter-channel areas dry. Moreover, the chute channels can incise into the floodplain while the margins of channels are aggrading, creating levees. Our results suggest that under the right conditions, chute channel formation can be extensive enough to create channel networks across the floodplain.

Mineralogy of clasts and matrices in a Siluro-Ordovician tectonic mélange: new constraints and new complications on pre-Acadian tectonic evolution in southern New England

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A recently identified tectonic mélange zone occupies an arcuate NE-SW-trending sliver of the eastern Orange Milford Belt in south-central Connecticut. The mélange contains two distinct units: 1) a serpentine-carbonate schist containing ultramafic mineral and lithic fragments; and 2) a polymict argillaceous metaconglomerate. Rock samples were analyzed by powder X-ray diffraction, and quantitative mineral modes were obtained by the Rietveld method. Clasts and surrounding matrices were analyzed separately to identify exotic and native clasts and to discriminate inherited grains from minerals grown during regional Devonian chlorite-grade metamorphism.

The serpentinite contains fragments of grey-white diopside megacrysts up to 40 cm across and clasts of serpentinite 1 mm to >10 m across. These are enveloped by a strongly foliated matrix of carbonate (calcite and/or dolomite) + serpentine + chlorite + magnetite. The matrix-supported metaconglomerate includes subangular to rounded schistose clasts (~1-5 cm). These clasts contain chlorite and garnet in abundances 2-6 times greater than those of their surrounding matrix. Some clasts contain >20% paragonite and minor amounts of epidote, minerals which are present at or below detection in matrix analyses. The strongly foliated muscovite + chlorite + quartz matrix contains minor but systematically higher concentrations of plagioclase and hematite than the clasts. No sample has been observed to contain both serpentine and muscovite. Randomly oriented chlorite porphyroblasts, some >1 cm, composing as much as 10% of the matrix, may represent the equilibration product of these components during Acadian lower greenschist facies metamorphism.

These results suggest the mélange zone was derived from an exhuming metamorphic belt that included high-pressure and ultramafic units erased from the geologic record elsewhere. The pre-Acadian fabric of the MLC greenstones is defined by amphiboles with compositional zonation characteristic of growth during prograde greenschist to epidote-amphibolite facies conditions. However, high-pressure minerals (e.g., glaucophane) have not been identified. The MLC and the provenances of the different mélange units may thus belong to different crustal blocks across a Silurian or even Ordovician suture.

Scaling relationships of fluvial avulsions in sedimentary basins

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A fluvial avulsion is a geomorphological process in which a river channels establishes a new channel in the adjacent floodplain, or reoccupies a pre-existing channel. These fluvial avulsions are the primary process that constructs floodplains and fills alluvial basins. We are able to locate these fluvial avulsions with Google Earth Engine, which is a 28 year timelapse cloud computing platform for processing satellite imagery and other Earth observation data. The fluvial avulsions can then be mapped in Google Earth Pro where we measure different parameters including: channel width, which is the width of the parent channel, average hop length, which is the characteristic distance at which the avulsion channel moves laterally away from the parent channel, and abandonment length of parent channel, which is the distance along the parent channel from the avulsion site to the point of reconnection of the avulsion channel. We mapped avulsions in three sedimentary basins: Himalayan, Andean, and Papua New Guinea. In total, we have collected data for 106 braided and meandering fluvial avulsions; 24 in the Himalayas, 46 in the Andes, and 36 in Papua New Guinea. Analysis of avulsion characteristics show that there is strong similarity in fluvial avulsion style at these three different regions. For example, in all three basins we see the same log-linear trend between hop length or abandonment length, and channel width. Moreover, for all basins studied avulsions have a well-defined ‘shape’, where the abandonment length is 5 times the hop length. This is an interesting result and these analyses suggest that avulsions have distinct scaling characteristics that are largely independent of climate, geology, or tectonics.

Climatological Connection of Tropical Cyclone Intensity and the Tropopause Variability

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Substantial effort has been put into modeling tropical cyclone (TC) climatology in order to understand how tropical cyclone distribution and frequency will be impacted in the future climate. Various modeling studies have shown that an increase in sea surface temperature (SST) will lead to a decrease in overall TC frequency but an increase in frequency of intense TC (Category 4-5). However, little research has been done on upper level atmospheric conditions in relation to TC activity. Recent real-time TC forecasts in the north Western Pacific (WPAC) basin using the Hurricane Research and Forecasting (HWRF) model have consistently captured an intriguing TC structure in almost all Super Typhoon cases in which an upper warm core near the tropopause is seen to form on top of a pre-existing mid-level warm core. Such development of an upper warm anomaly suggests a potentially strong interaction of TCs with the lower stratosphere that has not been fully understood. This study uses the NCEP reanalysis data from 1948-2014 to analyze the connection between the conditions of the tropopause and TC intensity in the North Atlantic (NATL) and WPAC basins. Analyses of the statistical connection between the power dissipation index (PDI) and the TC intensity in the NATL basin shows a strong negative correlation between the PDI and the tropopause height (TPH) from 1948-1980 but a positive correlation during the interval 1981-2014. In contrast, the PDI-TPH correlation is consistently negative in the WPAC basin during the entire period from 1948-2014, indicating overall that the lower the tropopause height is, the stronger the TC intensity would be. In addition to the dominant negative correlation between the PDI and the TPH, we find a significant negative correlation between the stratification of the lower stratosphere and the PDI in both ocean basins. The negative correlation between the PDI and TPH is consistent with recent idealized simulations of the TC development, but appears to be unexplainable in the light of Emanuel's maximum potential intensity theory. Some of these correlations may be the result of data inhomogeneities, but potential physical mechanisms for such correlations between PDI and the tropopause characteristics will be provided.

Investigating The Relationship between Stress and Strain Rate in California using Inverse Modeling of Focal Mechanisms and GPS Data

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A stress inversion model and a strain rate inversion model were created using GPS velocities and focal mechanisms in California to investigate the relationship between principal stresses and strain rates. The abundance of GPS and focal mechanism data in California allow us to create and compare detailed images of stress and strain rate. The total magnitude of stress that drives faulting in the California crust is not known. However, principal stress and strain rate orientations are expected to be aligned in perfectly elastic crust if the total stress magnitude is relatively low. We might expect to find areas where the principal stress and strain rates are unaligned if the total stress magnitude is high. The stress and strain rate models were constructed with the software MATLAB. The focal mechanism earthquake data for California was compiled from the Northern California Earthquake Data Center and the Southern California Earthquake Data Center catalogues. Around 250, 000 focal mechanisms that consisted of a magnitude higher than 3 that occurred between 1981- 2016 were featured in the data format for California. The data format included latitude, longitude, depth, magnitude, strike, dip, and rake. Focal mechanisms were used to compute maps of the spatial variations of principal stress directions and uncertainties. The GPS velocity data were used to compute maps of the spatial distribution of the principal strain rate directions and uncertainties. These maps allow for the comparison between stress and strain rate in California.

Model for the Prediction of Fatalities Resulting from Seismically Induced Landslides

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Earthquake-induced landslides pose a serious threat both to human lives and to economic interests. Larger events can cause landslides that kill hundreds or even thousands of people, as in the 2008 Wenchuan (China) earthquake, which resulted in over 6000 fatalities from landslides. Nowicki et al. (2014) developed a model to predict the probability of seismically induced landslides in near real-time following earthquakes around the world. We aim to extend this model to predict the number of landslide fatalities that are likely to result after any given seismic event. We define a probable landslide exposure index (PLEI) to estimate the number of people in regions likely to be affected by seismically induced landslides and an empirical landslide exposure index (ELEI) to test the accuracy of the PLEI. We used 30 seismic events to develop the PLEI including then eight well-documented seismic events with empirical landslide exposures which form the ELEI: 2008 Wenchuan (China), 1999 Chi-Chi (Taiwan), 2011 Tohoku (Japan), 1989 Loma Prieta (California), 2005 Kashmir (Pakistan), 2004 Chuetsu (Japan), 2014 Eketahuna (New Zealand), and 2006 Kiholo Bay (Hawaii). Using the PLEI, we develop a model that estimates the likely number of landslide-induced fatalities. The data indicate that the population exposure has a correlation with the number of fatalities. After further developing and testing this model, it can be applied to the U.S. Geological Survey's Prompt Assessment of Global Earthquakes for Response (*PAGER*) system to give an accurate estimate of human fatalities minutes after any given seismic event caused by landslides with a high degree of confidence.

CONNECTIVITY OF ORGANIC MATTER & MINERAL PHASES IN SHALES: EXAMPLES FROM THE LATE DEVONIAN-EARLY MISSISSIPPIAN BAKKEN & NEW ALBANY SHALE

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Fourier transform infrared (FTIR) spectroscopy is capable of effectively analyzing and documenting shale composition. Reflectance micro-FTIR complements this spectroscopic technique by offering a means to record heterogeneity in shales without destroying the surface of the sample that is analyzed. The high-resolution imaging with micro-FTIR allows users to distinguish mineralogical compositions as well as organic matter. The in situ nature of micro-FTIR allows for the mapping of different types of minerals and organic matter across a region on a sample's surface. The same region used in reflectance micro-FTIR can be used for microscopic characterization, allowing for a more in-depth analysis of organic matter properties and distribution (Chen et al. 2012a, 2012b, 2014a, 2014b).

Crystalline and deformation ages in the Prospect Gneiss along the Peri-Laurentian margin

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New and existing geochronology shows a long history of deformation in the Prospect Gneiss on the Peri-Laurentian margin between Bridgeport and Seymour, Connecticut. New SHRIMP analyses of magmatic zircons show that the granodioritic Pumpkin Ground (Ohp; 448 ± 3 Ma) and dioritic Beardsley (Ohb; 443 ± 2 Ma) orthogneisses are indistinguishable in age. Field work in newly exposed rocks show that the Pumpkin Ground granodiorite cuts foliations and veins in the Ohb, and contains xenoliths of the Beardsley diorite, suggesting a latest Ordovician age for both units. Some zircon grains analyzed from Ohb are rimmed by younger zircon with a mean age of 431 ± 4 Ma, indicating renewed crystallization in the Silurian. These rims are the same age as titanites (429 ± 3 Ma) recovered from Ohb (Sevigny and Hanson 1993). Our study of these rocks shows that the titanite grains are euhedral and intergrown with fabric-forming biotite and amphibole in S_1. They thus probably grew during the recrystallization of biotite and amphibole and so record the age of S_1. The zircon rims apparently record the same event. Pegmatites cut across this foliation, and are subsequently deformed as S_1 is transposed into S_2. Regional dating of monazite at 406 ± 13 Ma (Sevigny and Hanson 1993) in the related Ansonia leucogranite shows continued syntectonic recrystallization into the Devonian, consistent with garnet dated to be ~380 Ma (Lancaster et. al 2008) in the Wepawaug Group to the east of the Prospect gneiss. The $^{40}Ar/^{39}Ar$ cooling ages of amphibole (~375 Ma) and muscovite (~365 Ma) in these accreted schists (Growdon et. al 2013), as well as in those in the Prospect gneiss (Moecher et. al 1997), record the end of high-grade metamorphism in these rocks, but more Late Devonian syntectonic titanite grains crystallized in Ohp (Sevigny and Hanson 1993). Finally, $^{40}Ar/^{39}Ar$ muscovite crystallization ages (Wathen et al. 2015) document greenschist facies Alleghanian overprinting. Cast in a regional context, these data provide evidence for a high-grade fabric-forming event in the Silurian consistent with the effects of the Salinic orogeny, but strongly overprinted by Acadian metamorphic fabrics and assemblages.

Use of an expanded global earthquake data set to develop a near real-time model for predicting seismically induced landslides

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Here I present a globally applicable statistical model that can be used to rapidly estimate the probability and distribution of seismically induced landslides. This model utilizes ground-shaking estimates from the U.S. Geological Survey's ShakeMap tool, together with globally available proxies for landslide susceptibility factors. The model can be used to automatically generate maps of landslide probabilities, with the ultimate goal of adding fatality and economic loss estimates due to secondary hazards into the USGS Prompt Assessment of Global Earthquakes for Response (PAGER) system. This improved model includes observations from over 25 landslide-triggering earthquakes from a variety of tectonic and geomorphic settings for which I have obtained landslide inventories. This global database is combined with shaking estimates from the ShakeMap Atlas and globally available landslide susceptibility proxies as an input to a logistic regression to build a predictive landslide model. I test a large number of additional landslide proxies, including high-resolution (7.5 arc-second, roughly 250m) slope datasets, topographic position index, slope curvature and aspect, elevation, rock strength, lithology, land cover, mean monthly precipitation, and green vegetation cover. I also introduce a data-sampling scheme that addresses potential systematic errors associated with variability in landslide inventories. Initial results indicate strong relationships between landslide occurrence, peak ground velocity, and slope, with weaker dependence on other properties. I then apply this approach to scenario earthquakes to assess probabilities for future landslides in areas of known seismic risk. Together with ShakeMaps produced by the USGS, this model provides a powerful method for determining where landslides may occur within minutes of any earthquake around the globe, and can provide critical information to relief agencies in the time directly following destructive earthquakes around the world.

Applications of zircon (U-Th)/He thermochronology of the Elkhorn Mountain Volcanics to determine local variations in cooling histories in southwest Montana

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The Tobacco Root Mountains, part of the Rocky Mountains in southwest Montana, is an area that has been influenced by fold-and-thrust style deformations with both thin-skinned (Sevier-style) thrusts and thick-skinned (Laramide-style) thrusts as well as extensional deformation. While a majority of the Rocky Mountains displays a progression from Sevier-style to Laramide-style to extensional deformations, the Tobacco Root Mountains have Sevier-style deformations that truncate Laramide-style deformations and are, therefore, younger than the thick-skinned thrusts. Normal faults cross-cut both styles of thrust faults and are the youngest large-scale deformations in the area.

The Cretaceous Elkhorn Mountain Volcanics, a unit consisting of volcaniclastic conglomerates and sandstones as well as volcanic flows ranging from basalt to rhyolite, outcrops as the youngest unit in the footwall of large-scale Sevier-style and extensional faults. Using (U-Th)/He thermochronology of zircon grains from samples of the Elkhorn Mountain Volcanics from both faults, I will determine how different styles of deformation may cause the cooling history of a geologic unit to vary locally. I also may be able to set constraints on the minimum ages of these faults as well as the required time for the area to transition from compressional to extensional tectonic regimes, depending on the thermochronologic ages I get from my samples. If the samples' reburial has reset their ages, the ages may reflect exhumation via normal faulting or erosion of the thrust fault's hanging wall, meaning those cooling ages could put a constraint on the minimum age of each fault.

Reconstructing paleoenvironments to determine ecological evolutionary drivers for *Homo erectus* during time of Beds III and IV, Olduvai Gorge, Tanzania

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Olduvai Gorge, Tanzania is an important paleoanthropological site that has yielded significant hominin fossils and stone artifacts. Much of the paleoenvironmental research conducted in the past several decades has been focused on the stratigraphically lower Beds I and II, leaving the upper Beds III and IV considerably understudied. In this study, I use lithology and optical petrology on samples from select localities near archaeological sites MNK and VEK in the Side Gorge to begin a detailed stratigraphic analysis on these upper beds to determine depositional environment so that accurate correlations can be made across the gorge. Bed III has traditionally been differentiated from Bed IV in the eastern portion of the gorge by its distinct red color. This characteristic is not present in the western portion of the gorge, where the beds are combined and referred to as Beds III-IV (undivided), and thus Bed III needs to be redefined based on environmental processes. While the lower Beds I and II of this study area contain primarily lacustrine deposits, the upper Beds III and IV are dominated by fluvial deposits and disconformities represented by paleosols. In the localities studied here, the base of Bed III is overlying a tuff of mafic composition at the top of Bed II. Bed III contains primarily red volcaniclastic sandstone and conglomerate. The top of Bed III contains a thick red conglomerate that is scouring an underlying paleosol. The contact between Bed III and Bed IV is marked by an erosional surface on top of the red conglomerate. Bed IV contains primarily gray volcaniclastic channel sandstone and conglomerate, as well as covered recessive slopes. Further research on the depositional processes will allow us to use these criteria to differentiate Beds III and IV in the western portion of the gorge and make large-scale paleoenvironmental reconstructions, which have important implications for the evolution of *Homo erectus*. This will lead to further interpretations of how hominins utilized and interacted with their environment, and how it may have played a role in the evolution of our recent ancestors.

GRAY-SCALE ANALYSIS OF CORAL RUBBLE FROM THE DOMINICAN REPUBLIC USING *IMAGEJ* SOFTWARE

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Analysis of storm frequency and storm wave dynamics can offer a quantitative measure of the effects of global climate change. This project aims to collect gray-scale measurements from images of coral rubble that has been deposited on the beach of Catalina Island, Dominican Republic. The images compose different transects that cover large crescent shaped deposits that have been deposited by large tropical storms. The images are analyzed using *ImageJ* software to obtain gray-scale measurements on an 8-bit black and white scale. Each clast is analyzed by taking the average of the gray-scale values from 35 measurement sites over its surface. The goal is to plot all of the gray-scale values from the clasts on the same histogram, and be able to see distinct groupings that represent the different coral deposits. Endolithic algae grow on the coral rubble and cause it to appear darker with increasing age. Some of the deposits have known ages based on storm data. The older deposits appear darker due to larger growth of microorganisms. Conversely, the younger deposits appear lighter. Combining the gray-scale measurements from the coral and their known dates of deposition may lead to a standard method that can be used for relative age dating of coral rubble whose absolute age is unknown. Such a standard could open opportunities for further research of change in storm frequency and storm wave dynamics. This has larger implications relative to the study of climate change, as storm frequency increases with surface water temperatures.

Experimental Study of the Daly Gap

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It has been observed by many people studying the geology of oceanic hot spot islands that the erupted lavas show a bimodal distribution in composition. Mafic alkali basalt and felsic trachyte are abundant, while there is a near absence of intermediate compositions. The scarcity of compositions that fall between alkali basalt and trachyte is known as the Daly gap. Clague (1978), offered a fractionation model that presents an explanation for why oceanic island volcanic rocks should be bimodally distributed. Clague suggested that SiO2 does not vary directly as a function of increasing fractional crystallization. Instead, approximately halfway through the crystallization history, these systems undergo a rapid increase in SiO2 corresponding to an increase in SiO2 from 50 to 57% with only a small change in the total fractionation, around 15%. This rapid SiO2 increase could transform a fractionating alkali basalt into a trachyte so rapidly that the intermediate composition magmas (55 to 57% SiO2) never have an opportunity to erupt on the surface. This provides an explanation for the low abundance of intermediate volcanic rocks found of oceanic islands. It was also shown that the rapid increase of SiO2 corresponded to a rapid decrease in TiO2 and FeO. The onset of the TiO2 and FeO fractionation is most likely controlled by the crystallization of Fe-oxide which, in turn, is controlled by oxygen fugacity. However, this has never been experimentally tested. The goal of this research is to experimentally test Clague's model by melting and crystallizing charges of alkali basalt composition in a 1 atm furnace at consistently lower temperatures (increments of 20 C) keeping the oxygen fugacity fixed along Ni/NiO oxygen buffer. The composition of the glass and mineral phases in each experiment were analyzed using electron microprobe analysis. These data were used to quantify oxide percentages as a function of percent fractional crystallization in order to track the liquid line of descent of an oceanic island system under 1 atmosphere and Ni/NiO conditions. These results are then compared with those of a similar Crossroads study conducted along the QFM oxygen buffer (Biesiada and Brophy, 2015).

Sedimentary Provenance Evidence for Late Cenozoic Structural Rejuvenation of the Patagonian Andes from the Magallanes Basin, Chile and Argentina 51'30°S

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Sedimentary provenance techniques can track changes in sediment source areas resulting from exposure or isolation of distinct sediment sources during the structural evolution of an orogen and thereby provide evidence for the timing, location, and style of deformation. With the breakup of the subducting Farallon plate ca. 26 Ma, increased convergence rate along the western margin of South America led to structural shortening and deformation in the Patagonian fold-and-thrust belt, and likely orogenic growth, which continued into the early Miocene. We present new sedimentology and detailed sandstone petrography from ~350m of measured section of the Eocene-late Oligocene Río Turbio and latest Oligocene-early Miocene Río Guillermo formations, near Cancha Carrera, Argentina, that document distinct changes in sediment sources through time and show that basin sedimentation is strongly reflective of tectonic influences. Locally, the Río Guillermo Fm. rests disconformably overtop of the shallow marine and estuarine Río Turbio Fm. and represents the first phase of fluvial sedimentation to the basin. Recorded in this interval is the establishment and the evolution of fluvial sedimentation through three distinct phases. At the base is a lower cyclic coarse- and fine-grained avulsion dominated unit which is succeeded by a middle unit of overbank deposition characterized by horizontally bedded silt- and mudstone, and finally an upper channelized coarse-grained unit. Together this assemblage is consistent with increasing subsidence in the basin. Clast counts from interbedded conglomerates are dominated by mafic volcanic clasts and show both an up-section covariance between granitoid and shale clasts and decrease in silicic metavolcanic clasts diagnostic of hinterland sources. Sandstone petrography reveals marked compositional differences between the Río Turbio and Río Guillermo formations. The Río Turbio Fm. is relatively mature and shows compositional affinity with underlying Paleogene and Cretaceous strata, consistent with similar sourcing or recycling. The Río Guillermo Fm. is extremely immature, rich in pyroxene and mafic volcanic lithics that is consistent with hinterland sourcing of the Neogene volcanic arc or Sarmiento Ophiolite Complex.

Facies Characteristics and Sequence Stratigraphy of the Upper Cretaceous Tununk Shale Member, Henry Mountains Region, Utah

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Lower-Middle Turonian strata of the Tununk Shale Member of the Mancos Shale Formation were deposited along the western margin of the Cretaceous Western Interior Seaway during the Greenhorn second-order sea level cycle. Two stratigraphic sections were measured near Hanksville, Utah, in order to examine facies characteristics and variations within the Tununk Shale. Within each section, sedimentological data including lithology, grain-size, bedding thickness, sedimentary structures, paleocurrent direction, bioturbation characteristics, and amount and types of fossil fragments were documented. Relatively unweathered samples were collected at a spacing of approximately 1 m for detailed facies analysis on polished slabs, petrographic analysis in thin sections, and SEM analysis. In addition, lamina/bed-scale variations in physical and biologic attributes of three continuous coarsening-upward successions (i.e. parasequences) within one regional section have been documented to quantitatively determine the relative proportion of sedimentary structures generated by different depositional processes/events, which can be related to depositional setting.

Initial results indicate that the total thickness of the Tununk Shale in this area ranges from 170 to 220 m, and that it consists of at least 48 parasequences. Each parasequence ranges from 1.2 to 13.5 m in thickness, suggesting Milankovitch-scale relative sea level variations (10^4-10^5 years duration). Parasequences are characterized by an upward increase of silt/sand and indications of storm-wave reworking, and a decrease in the proportion of shell fragments towards the top. Based on parasequence stacking patterns, the 48 parasequences can be grouped into 11 parasequence sets, and 3 sequences. Parasequence sets show a progradational stacking pattern characterized by an increasing proportion of storm-influenced facies (from 66% to 93%), suggesting deposition in progradational storm-dominated inner shelf environments during lowstands of sea level.

Vertical facies variations within the Tununk Shale are interpreted to reflect transgression and regression of a storm-dominated offshore mud blanket. The high-frequency sea level cycles marked by parasequence sets and sequences in the Tununk shale are superimposed on the second-order Greenhorn cycle, probably due to the combined effects of glacio-eustasy, episodic tectonism, and climate change.

Insights on porosity and pore size distribution using multiple analytical tools: implications for reservoir characterization in geologic storage of CO_2.

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The successful implementation of geologic carbon sequestration (GCS) depends on the careful evaluation of the characteristics of the storage reservoir. The geologic description and quantification of the physical properties that define a viable reservoir are fundamental for assessing the feasibility of a reservoir both receive and store injected CO_2 in the deep subsurface. Two petrophysical properties, porosity and permeability, constrain the reservoir in terms of its storage potential and injectivity. These two key parameters vary in scale significantly within a reservoir. Likewise, the analytical tools that are useful for measuring these properties also vary and are optimally employed at various scales.

In this investigation, a total of 52 rock samples were obtained from the Cambro Ordovician Knox Supergroup from different depth intervals and spamming a significant area of the midwestern United States, including Indiana, Ohio, and Kentucky. These samples represent the wide range in both the scale and magnitude of the porosity present in this prospective storage reservoir. The samples were analyzed for total porosity and pore size distribution using a variety of techniques including: petrographic image analysis, helium porosimetry, gas adsorption, mercury porosimetry, and (ultra) small angle neutron scattering. These analytical techniques were collectively used to understand the relationship between porosity, permeability, and pore size distribution, bearing in mind that each tool has the ability to measure a different range in pore sizes. In some cases these ranges overlap, offering a unique opportunity to cover a wide range of pore sizes to study, and to understand the validity of employing these techniques collaboratively.

Storing CO_2 by means of capillary entrapment has been identified as one of the safest mechanisms of GCS. Capillary entrapment or "residual saturation", is that portion of the injected CO_2 that remains trapped in micropores after the pressure elevated by the injection process returns to ambient reservoir pressure. Therefore, diagnosing which portion of the total pore system in the reservoir could serve to host such storage is key. Consequently, results from nitrogen and carbon dioxide adsorption and from mercury injection capillary pressure (MICP) are important in that they provide insights on small pore size that otherwise are not resolvable by standard low-pressure helium porosimetry or by image analysis software. Additionally, results from these types of analyses highlight the influence of microporosity on permeability, the key petrophysical parameter for constraining fluid flow through the pore system.

CHARACTERIZING DEFORMATION IN PRECAMBRIAN GNEISSES ALONG THE CARMICHAEL FAULT, SW MONTANA: IMPLICATIONS FOR FAULT CROSS SECTION MODELS AND LARAMIDE LITHOSPHERIC FAULT BEHAVIOR

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The northern Tobacco Root Mountains in SW Montana exhibit a series of NW-trending faults that are believed to have originated in the Proterozoic as extensional faults and reactivated as left-reverse faults during the Laramide orogeny. The Carmichael fault is one of the best exposed examples of these Laramide faults. Archean metamorphic rocks and Paleozoic and Mesozoic sedimentary units occur in both the hanging wall and footwall. Along the trace of the fault, various combinations of lithologies from the sedimentary and metamorphic assemblages are juxtaposed. This geometry provides an opportunity to characterize deformation mechanisms as a function of lithology along the Carmichael fault zone and compare these results to rheological cross section models produced from experiments to determine how well these models correlate with natural cases.

During the summer of 2016, the Carmichael fault and surrounding areas will be mapped at the 1:12,000 and 1:24,000 scale, and structural measurements of foliation, bedding, lineation, and fold and fracture orientation will be collected along the fault and within the host rocks. Two to three 1.5-2 km-long traverses will be carried out perpendicular to the fault, where structural measurements and mineralogical compositions will be recorded. Oriented samples will also be collected for thin section and potential geochemical and/or oxygen isotope analysis. Additionally, a gradient magnetometer will be carried along one or more traverses to gather magnetic anomaly data that will be plotted and used to determine whether magnetic data are useful in identifying the fault zone since the exact trace of the Carmichael fault cannot be directly measured on the surface. I hypothesize that the abundance and degree of deformational features will increase closer to the fault, and mineralogical compositions will reflect retrograde conditions associated with Laramide deformation.

Characterizing the processes that occur within a fault zone will provide more detailed information for geoscientists studying active fault zones, therefore allowing them to produce more accurate structural and deformational models. Macrostructures such as foliation and fold and fracture orientations and microstructures such as microfractures and slip surfaces will yield information regarding the rheological and mechanical characteristics of this fault zone and how it varies along the fault strike, which serves as a proxy for depth. These data also have the potential to show how different lithologies respond to fault-related deformation. Additionally, applying oxygen isotope methods to these fault rocks may provide indications as to the extent to which fluids were present. Determining the presence of water is especially important since it can cause weakening in fault zones and therefore contribute to a reduction in yield strength and a higher likelihood of breakage.

How comparable are nutrient spiraling experiments in space and time?

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Nutrient spiraling is an important metric for many lotic ecosystem studies. Traditional methods to estimate nutrient spiraling rates use stream nutrient tracer additions in a plateau or steady-state approach. One such approach, the Tracer Additions for Spiraling Curve Characterization (TASCC) approach, quantifies nutrient kinetics from ambient to saturation in a relatively rapid and inexpensive experiment. As such, TASCC is growing in popularity to study transport and transformation of nutrients in stream networks. However, TASCC is based on stream solute tracer experiments, which are known to be sensitive to the conditions under which the study is conducted. Results for conservative transport have been observed to vary with discharge and study reach length. Thus, this study seeks to assess the accuracy of the TASCC method in light of these recognized limitations. Our objective in this work is to assess how TASCC experiments can be conducted in a reproducible, reliable framework to yield consistent estimates of nutrient spiraling metrics. Consistency is required to make meaningful comparisons between sites, or between discharge conditions at a give site. We used the transient storage model to simulate TASCC injections, systematically varying discharge, study reach length, reaction rates, and physical processes represented in the model (i.e., with or without hyporheic exchange). The simulated data are analyzed using the TASCC method to estimate nutrient spiraling parameters. We find that TASCC results are ultimately sensitive to the advective timescale of the experiment, and the relative roles of transport and transformation in the study reach. As such, care must be taken to select appropriate experimental conditions to enable fair comparison between studies.

ECOGEOMORPHIC SUCCESSION OF DELTAIC ISLAND WITHIN THE WAX LAKE DELTA, LOUISIANA

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The world's coastal deltaic wetlands are threatened by a combination of relative sea-level rise and human disruption. Protecting and restoring these ecosystems requires a better understanding of the processes governing deltaic land building. Research in tidal salt marshes suggests the presence or absence of vegetation may be an important attribute of land building and maintenance in coastal deltaic environments. However, few models of deltaic land building consider the influence of vegetation. My research seeks to develop a better understanding of the ecogeomorphic succession associated with land building in a delta in south-central coastal Louisiana. I define ecogeomorphic succession as the processes and patterns of geomorphic and ecologic change related to subaqueous deposition, emergence, and maintenance of deltaic land. I focus especially on the transition from subaqueous deposits to emergence of deltaic land as this transition defines the creation of land on deltaic coastlines. To this aim, I conducted a field-based and remote-sensing study of the Wax Lake Delta, an un-intentional but successful river diversion. The study used remote sensing observations from 1985 to 2015, supplemented by field data collected in 2014. Preliminary results indicate deltaic islands develop from one mouth bar or multiple mouth bars that amalgamate, the more common method being the latter. Regardless of whether a deltaic island forms from one or multiple mouth bars, these mouth bars follow a general development pattern of becoming emergent as exposed sediment rather than being colonized by subaqueous vegetation and then becoming emergent. Thus, while vegetation may be important for stabilization and later development of the deltaic islands, it does not appear to play a pivotal role in the transition from subaqueous to emergent. Further improving our understanding of these ecogeomorphic processes could inform restoration efforts focused on the development and execution of river diversions, as well as assess already operating diversions.

SEDIMENTOLOGICAL AND PETROGRAPHIC STUDY OF FINE-GRAINED PARASEQUENCES IN THE LATE CRETACEOUS TUNUNK SHALE OF SOUTH-CENTRAL UTAH – IMPLICATIONS FOR SHALE DEPOSITION IN THE CRETACEOUS WESTERN INTERIOR SEAWAY (CWIS)

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The Tununk Shale, a lateral western equivalent of the lower Mancos shale, is well exposed on the eastern flank of the San Rafael Swell near Hanksville Utah. In the context of a regional sequence stratigraphic study, the aim of this study is an inventory of sedimentary and diagenetic features for selected parasequences (PS) in order to understand processes active during PS development. Marine flooding surfaces are marked by a sharp based winnowed and well sorted silty residual of detrital quartz, feldspar and altered volcanic rock fragments, fossil debris, and mud rip-up clasts. Pore spaces are filled with calcite spar. This basal lag is overlain by bioturbated silty mudstones with starved ripple laminae of coarse silt to fine sand, suggesting combined flow conditions. Sharp-based graded beds of mm to cm scale with bioturbated tops are likely event beds, probably related to storm wave activity. Toward the PS top fine sand increases markedly, wave ripples are common, and large metazoan burrows become abundant. In addition, mafic minerals were observed in the sand fraction, as well as authigenic chlorite development in pore spaces. SEM petrography was conducted on large diameter (12.5 mm) ion milled samples, and showed that siltstones as well as more "muddy" intervals contain abundant fine grained aggregates, such as altered volcanic rock fragments and glass, deformed mudstone rip-up clasts, and fine grained sedimentary rock fragments lacking post-depositional compaction. These aggregates dominate the grain population of siltstone beds, and also appear dominant in intervals of "muddy" appearance. From a physical sedimentology perspective, much of the Tununk appears deposited as bedload transported siltstones, albeit siltstones with "atypical" grains. The mudstone rip-up clasts probably reflect contemporaneous erosion of the Cretaceous seafloor, reworking material that had arrived in the form of fall-out from hypopycnal plumes and bedload mud floccules moved by bottom currents. Volcanic debris probably arrived as ash falls (later reworked) and fluvial transported material. Uncompacted fine grained sedimentary rock fragments suggest input of river borne material from shale outcrops in the hinterland. Overall, these features suggests that sand and silt size shale and volcanic debris was carried to the basin by rivers and redistributed by storm induced currents, and that primary shales were subject to intermittent erosion and supplied mud rip-up clasts.

Discriminating Local Earthquakes from Other Seismic Sources using a Dense Seismic Array in the U.S. Midcontinent

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Local earthquakes found within relatively stable continental regions are predominantly small events that are less well studied than earthquakes associated with tectonic plate boundaries. Our project is to utilize data collected in the third phase of the Ozark-Illinois-Indiana-Kentucky Seismic Experiment (OIINK project) to locate local earthquakes, which ultimately will help to assess earthquake hazards in the region. The third phase of OIINK project was a dense array of seismometers operating throughout Kentucky and Southern Indiana with 60 high-sensitivity broadband digital seismometers deployed along a grid with approximately ~25 km spacing. The small source size of local earthquakes means that a comparatively small amount of energy is released during such earthquakes, and so these events are harder to pick out in seismic traces than larger-magnitude teleseismic and regional events. The task is made considerably more complicated by anthropogenic phenomena. Particularly problematic are the explosions that are generated by surface and underground mine blasting. Due to wide distribution of mines through the study -area, this problem is present throughout the data. We utilize an automated detector program in conjunction with an associator program to find potential events within the body of the data. The detector compares a short-term average to a long-term average of the data and flags any point that goes beyond user specified threshold. The associator looks at the detection table for a given period and compiles detections into potential events using the residuals from feasible location estimates using a grid- search algorithm. However, visual discrimination of events must still be employed as mine blasts have similar seismic signatures to real events. We have visually identified events within a pilot set of 10 days of data from June 1 – 10, 2014 and found 819 distinct seismic events that were picked up by the OIINK array. 59 of these were teleseismic earthquakes from around the world, 20 were regional events, 548 definitive blasts, 3 strong candidates for local events, and 189 events that most likely are mine blasts. The refined parameters for the automated detector and associator found 536 of the 819 events (~65%) with 35 telesiesms (~59%) corresponding with known events, and 41 events that had enough potential to be local events that they were further scrutinized and manually located with one of these locating as a local event but not found in any catalog of events. We are using the results of this pilot period analysis to optimize our analysis strategy for the remaining 18 months of Phase 3 OIINK Data (August, 2013 – January, 2015).

Constructing a landscape: hydrologic and mass balance controls on river path selection, stratigraphic architecture, and surface morphology on the Ganges-Brahmaputra-Meghna Delta

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The Holocene stratigraphic archive of Sylhet Basin, a seasonally flooded, tectonically influenced sub-basin within the Ganges-Brahmaputra-Meghna delta (GMBD) in northeastern Bangladesh, reveals the complex interactions of autogenic dynamics, climate, and mass extraction in a large fluvial system. A dense network of over 400 shallow (up to ~90 m) boreholes have been utilized to document river path selection and downstream fining trends over the past ~10k years. Following sediment aggradation of locally-sourced fine-grained sediment after the Younger Dryas, Sylhet Basin experienced its first Holocene occupation of the Brahmaputra River at ~7.5 ka. A progressive shift of water and sediment routing from the proximal (western) edge of the basin to an active depocenter in the basin interior reflects the evolution of the system from a bypass-dominated regime to one of enhanced mass extraction. This constructional phase of mass extraction in Sylhet Basin (from ~5.0-3.0 ka) is coincident with a regional mid-Holocene weakening of the summer monsoon, suggesting a strong hydrologic control on river path selection via the presence and absence of a seasonal lake in the basin center. Profiles of downstream fining rates along all known Holocene sediment delivery pathways indicate that the system favors a bypass-dominated regime, such that the period of enhanced mass extraction in Sylhet Basin appears to be anomalous. When transformed into a scale-independent chi space, the mid-Holocene sediment lobe of northern Sylhet Basin exhibits predictable sand:mud ratio and facies changes at a position where ~70% of the total mass has been extracted, consistent with studies from other depositional settings. Furthermore, this downstream distance coincides with both a topographic break in slope between the fan delta and the lower fluvial-tidal delta, as well as the backwater length as calculated by a number of different methods. This suggests an inherent coupling between mass extraction, stratigraphic architecture, surface morphology, and delta hydrodynamics.

HEAVY MINERAL ANALYSIS OF GLACIAL TILL IN NORTHERN AND SOUTH-CENTRAL INDIANA TO RECONSTRUCT PATH OF LAURENTIDE ICE SHEET

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The path of the Laurentide Ice Sheet has not been thoroughly explored in Indiana with respect to which lobes, Michigan, Huron-Erie, and Saginaw flowed through the area. Heavy minerals as a means of differentiating between these lobes has been successful across the upper Great Lakes in Michigan and Ontario, but has not been applied in Indiana. For example, Gwyn and Dreimanis (1979) used the relative proportions of heavy minerals within the drift of the southern Canadian Shield, to map compositional variations in till within and between the Superior and Grenville provinces. Similarly, Dworkin et al. (1985) used the relative proportions of heavy minerals in tills from the three lobes in Michigan and determined that heavy minerals could distinguish the lobes as well as their specific provenances: Huron-Erie lobe derived from the Grenville province, Saginaw lobe derived from the boundary between the Grenville and Superior provinces, and Michigan lobe derived from the Superior province.

Heavy minerals from the 250-125 micron sand size in tills from cores and exposures in northern and southern-central Indiana were separated and point counted to create relative percentages of heavy minerals. Preliminary results show that tills from the Michigan and Huron-Erie lobes could be differentiated using heavy minerals. Possible Saginaw lobe samples, however, could not and had assemblages similar to the Huron-Erie lobe. Heavy mineral assemblages of till samples from near the terminal moraine in southern Indiana were consistent with other Huron-Erie lobe tills from northern Indiana.

The preliminary results of this study indicate that heavy mineral assemblages can differentiate between lobes of the Laurentide Ice Sheet in Indiana. Because till in south-central Indiana was likely from the Huron-Erie lobe, this lobe was probably more dominant across much of Indiana south and east of the Wabash River. Its southern margin may have been the ice front that deposited the terminal moraine in Indiana. Heavy minerals may also prove useful to determine provenance of pre-Wisconsin tills and test whether the path of older ice sheets were the same or different than during the late Wisconsin.

Petrology of the Late Devonian Pronghorn Member of the Bakken Formation, Williston Basin, North Dakota, U.S.A.

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Shales and mudstones dominate the sedimentary rock record and play an important role economically as they are sources, seals, and reservoirs for hydrocarbons. Despite this, these rocks are still poorly understood. The Late Devonian-Early Mississippian Bakken Formation is a rock unit of extreme economic importance as it is the top unconventional source for oil production in the United States and is primarily composed of shales and mudstones. The Bakken Formation is located in the subsurface of the intracratonic Williston Basin and is distributed throughout North Dakota, South Dakota, Montana, and Saskatchewan. The core under current analysis was taken in Mountrail County, North Dakota. The Bakken is made up of four members: The Pronghorn Member, Lower Bakken Shale, Middle Bakken, and Upper Bakken Shale. A definitive sequence stratigraphic framework has not yet been established for the Bakken Formation and understanding the sequence stratigraphy will be useful in knowing how and where stratigraphic packages are distributed in the Williston basin. Putting fine-grained sedimentary rocks into a sequence stratigraphic framework is difficult using only conventional methods because sedimentary features are so subtle. This study incorporates high-resolution methods like SEM analysis to describe and understand fine scale features in the Bakken that could otherwise be ignored or misinterpreted. The results presented in this poster presentation are preliminary and provide a look at the fine scale features of the Pronghorn Member through SEM imagery. The Pronghorn has gone unrecognized in previous studies due to its visual resemblance to the Lower Bakken Shale at the hand sample scale and its relatively small thickness. SEM imagery was used to determine the petrology of the Pronghorn and help distinguish it from the Lower Bakken. Clues to where potential sea level change and pH conditions occur are hidden in the mineralogy of the Pronghorn. This is not enough data to indicate transgressive or regressive surfaces within the Pronghorn though and there will likely be no sequence boundaries as it is only 1m thick. The high-resolution petrologic analysis of the Pronghorn Member will prove useful in the development of the Bakken's sequence stratigraphic framework because it is important to accurately distinguish the Pronghorn from the Lower Bakken and to understand what processes occurred during the Pronghorn's deposition.

Three Stages of Andalusite Growth in the Rye Complex, New Hampshire.

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New work on a poorly understood sliver of high grade mylonitic rocks faulted between low-grade Peri-Gondwana terrains in coastal New England, the Rye Complex, shows a complicated, low-pressure, P-T-t path. Rocks from a large outcrop (Fort Stark) near Portsmouth, NH are aluminous and quartzo-feldspathic and contain andalusite, staurolite, cordierite, and sillimanite in various assemblages and textures. Straight inclusion trails of ilmenite and quartz in subhedral garnets, and linear inclusion trails of ilmenite and biotite in andalusite porphyroblasts preserve an older (S1?) foliation. These stage 1 andalusite porphyroblasts are universally undulose. Later, stage 2, andalusite forms rims and replaces staurolite showing pressures < 350 Mpa during this prograde reaction. Sillimanite needles and fibers associated with oriented biotite (S2?) and migmatite indicate that peak temperatures were > ~650ºC and in the sillimanite field. Oriented biotite, ilmenite, and sillimanite inclusions in anhedral andalusite porphyroblasts associated with late cordierite porphyroblasts document a third stage of andalusite growth and a return to the andalusite field after peak metamorphic temperatures. Kinked biotite flakes in S2/S3 folia, muscovite and biotite fish, micro-shear zones, and boudinage of andalusite porphyroblasts, all show evidence for mylonitic ductile (stage 4) deformation during waning lower amphibolite facies metamorphic conditions. Undulose quartz ribbons, dynamically recrystallized quartz, and refoliated muscovite micro-breccia show evidence for continued (stage 5) deformation through green schist facies metamorphism. Together these observations converge to show a strongly dynamic, low pressure clockwise P-T-t path. Detrital zircon U-Pb geochronology and hornblende, muscovite, and K-feldspar thermochronology constrain this high-grade metamorphism to the Cambrian-Ordovician (Taconic Orogeny?) and the lower grade mylonitic deformations to the Acadian and Alleghanian orogenies. Thus this family of fabrics requires significant and sustained transpression through most of the Paleozoic.

EL NIÑO SOUTHERN OSCILLATION AND OCEANIC/ATMOSPHERIC TELECONNECTIONS TO FORECAST SEASONAL WEATHER

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The ocean-atmosphere interactions in the months leading to and during winter can allow for a detailed analysis and forecast of seasonal weather and climate. These interactions are often represented as numerical indices which we can compile and analyze to create analogs. These analogs can be used to represent similar ocean-atmosphere conditions to what is expected in an upcoming winter and used to create winter forecasts. Key factors in this forecast include the Pacific Decadal Oscillation Index, El Niño-Southern Oscillation, North Atlantic Oscillation, Arctic Oscillation, Pacific North American Pattern, and Siberian snowfall extent/expansion. Analyzing analogs along with current and expected oceanic and atmospheric conditions can allow forecasters to make seasonal climate forecasts with some accuracy.

The 2015-2016 winter featured several key factors that led to warmer than normal temperatures throughout the meteorological winter (1 December – 28 February) in Indiana. The dominant patterns were the El Niño-Southern Oscillation and the North Atlantic Oscillation, a reversal from the previous two winters. While many atmospheric and oceanic patterns remained similar to the previous two cold and snowy winters, the equatorial, sub-tropical and Northern Atlantic patterns ultimately generated a warm and less active storm pattern across Indiana for much of winter. These conditions, however, were not constant, which allowed the Pacific North American Pattern and Arctic Oscillation to create a two-to-three week period of much below normal temperatures in late January and early February 2016, very similar to the pattern that prevailed in the previous two winters. This cold period allowed temperatures across Indiana to be normal to slightly below normal for January and slightly above normal temperatures in February, despite large warm anomalies in the final two weeks of the meteorological winter. Overall, the warm pattern prevailed and Indiana ended several degrees above normal for winter 2015-2016 with average to very slightly above average precipitation throughout most of the state.

Roughness of the Mantle Transition Zone Discontinuities Revealed by High Resolution Wavefield Imaging with the Earthscope Transportable Array

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We post-processed 141,080 pairs of high quality radial and transverse receiver functions from the Earthscope Automated Receiver Survey using a variant of what we have called generalized iterative deconvolution method and reshaped the spiking output into different scales of Ricker wavelets. We then used these data as input to our 3D plane wave migration method to produce an image volume of P to S scattering surfaces under all of the lower 48 states. The result is arguably the highest resolution image ever produce of the mantle transition zone. Due to the effect of migration impulse response, different scales of Ricker wavelets provide another important means of controlling the resolution of the image produced by 3D plane wave migration method. Model simulation shows that comparing to the widely used CCP stacking method with receiver functions shaped by Gaussian wavelet, the application of our methods is capable of resolving not only dipping discontinuities but also more subtle details of the discontinuities. Application to the latest USArray data reveals several previously unobserved features of the 410 and 660 discontinuities. Both discontinuities are resolved to a precision approaching 1 km under the stable interior, but degrading to the order of 10 km in the western US due to a probably combination of higher attenuation and velocity heterogeneity not resolved by current generation tomography models. Topography with many 10s of km is resolved at a range of scales. In addition, we observe large variation of relative amplitude on the radial component and large variations in the radial to transverse amplitude ratio that correlate with inferred variations in discontinuity topography. We argue this combination of observations can be explained by roughness at a range of scales. Two of those rough regions showed spatial correlation with where the subducted slab penetrating the transition zone shown in the tomography model. We claim that these rough regions we imaged are indicators of vertical mantle flows through the transition zone.

$^{40}Ar/^{39}Ar$ Ages and Recrystallization Processes in the Alleghanian East Derby Shear Zone

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The timing of retrograde deformation in the East Derby shear zone (EDSZ) in south-central Connecticut is constrained to be Alleghanian by $^{40}Ar/^{39}Ar$ dating of synkinematic muscovite. The 030^{o} trending ductile EDSZ extends from Bridgeport 45 km northeast to Prospect, where it is cut by the western border fault of the Hartford Basin. The shear zone is characterized by phyllonites with the mineral assemblage muscovite + chlorite + albite + quartz + ilmenite and is bound by kyanite and staurolite grade pelitic schists to the east and west. The gradational boundary between peak and retrograde assemblages is marked by the disappearance of high-grade minerals, and the transposition of Acadian folia by phyllonites that dip to the northwest near Prospect and to the southeast near Bridgeport.

Electron (BSE) petrography reveals reaction textures in which prograde biotite + garnet are replaced by lower greenschist facies muscovite + chlorite + ilmenite until few to no traces of the former remain. In mm-scale domains, muscovite truncates chlorite such that P-domains contain nearly pure muscovite. These relationships can be modeled through the application of aqueous activity diagrams. At quartz-saturated greenschist facies conditions on a $a(K^{+}) / a(H^{+})$ vs $a(Fe^{+2}) / a(H^{+})^{2}$ activity diagram, the muscovite stability field expands with decreasing temperature, displacing the muscovite-chlorite boundary, and resulting in chlorite dissolution and the precipitation of muscovite, thus explaining the muscovite-rich P-domains, whereas decreases in pressure expand the chlorite field, explaining the crystallization of chlorite in pressure shadows. Thus the distribution of minerals in the evolving fabric can be explained by incremental reactions between the minerals and the local fluid as some minerals dissolve and others precipitate to maintain equilibrium under changing P-T-X conditions.

The 40Ar/39Ar data from muscovite in the EDSZ record near plateau ages of ~360 Ma in the north and 305 and 270 Ma in the south. These isotopic data are interpreted as crystallization ages due to the petrographic evidence for chlorite-grade recrystallization. These results show that Alleghanian transpression documented in eastern New England, also affects the Acadian metamorphic high in western New England.

QUANTIFYING AVULSION ACTIVITY ON RIVER DELTAS FROM 1984-2012

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Avulsion is the process whereby channelized flow partially or completely reroutes to a new or preexisting channel on the adjacent floodplain. This process constructs delta landforms and stratigraphy, yet not much is known about avulsion activity because avulsions occur infrequently and are hard to observe. Here I use the Landsat satellite data to quantify avulsion activity on deltas throughout the world from 1984 to 2012. From a database of 1,342 deltas, I identified 70 avulsions using time-lapse videos created in Google Earth Engine. For each avulsion I collected morphometric data to quantify behavior as well as explore hydrodynamic controls on their location. On each avulsion, I measured (1) channel centerline lengths of the parent channel (P_L) and avulsion channel (A_L) from the shoreline to the avulsion location; (2) shoreline length (S_L) between the river mouth of the parent and avulsion channel; (3) average parent channel width directly upstream of the avulsion location; (4) take-off angle between the parent channel and the avulsion channel; and (5) avulsion duration. My results show that average avulsion duration was 6.9 years with a standard deviation of 3.5 years. I observed a positively skewed unimodal distribution for all take-off angles in which the mean of the distribution was ~49 degrees. I found that $S_L = 0.57461 P_L^{0.8028}$ ($R^2 = 0.5739$) indicating larger avulsions create more widely spaced river mouths at the shoreline. The ratio of P_L to A_L was nearly 1:1 and ~56% of all avulsion channels were shorter than the corresponding P_L suggesting those channels avulsed to a steeper slope. This insight is consistent with bed slopes of the parent channel (S_P) and avulsion channel (S_A) from 30-m resolution topography data. I tested the hypothesis that P_L scales with the backwater length (B_L). B_L typically scales as the characteristic channel depth (h_c) divided by S_p. To estimate h_c I used hydraulic geometry power-law relationships in conjunction with normal-flow equations. Results indicate that backwater length explains some of the variation in P_L I found in Landsat imagery, but does not explain all the avulsions I observed.

Investigating synaeresis cracks in mudstones—experiments and analogs with potential applications for Martian mudstones

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Mudstone formations are most frequently studied for their valuable hydrocarbon resource potential within shale oil and gas plays, but mudstone sedimentology is also important for understanding the rock record of our planetary neighbor, Mars. The processes that created Martian mudstones can be inferred through studying analogous mudstone facies and sedimentary structures on Earth assuming the Earth processes are well understood, but unfortunately that assumption is not always valid. Specific facies of the Jurassic Summerville Formation of southern Utah are useful analogs to facies of the Sheepbed member of the Yellowknife Bay formation, Mars since both mudstone formations have facies that contain calcium sulfate nodules, calcium sulfate veins, and synaeresis cracks. Synaeresis cracks are mudcracks that form due to subaqueous shrinkage rather than desiccation but the mechanism for producing subaqueous shrinkage is debated and incomprehensive. Since synaeresis cracks are poorly understood on Earth, minimal interpretations can be made from the presence of these structures on Mars. Fluid escape, seismicity, and salinity changes have all been proposed as possible mechanisms for producing subaqueous shrinkage cracks, but it seems that these processes are too different to produce the same structure. Experimentation is necessary to clarify which mechanism dominates, and we therefore plan to experimentally test the most likely mechanism of synaeresis crack formation—subaqueous shrinkage of clay due to changes in salinity—and how the process affects mudstone fabrics at the floccule scale. The results of these experiments will enable us to better identify salinity induced synaeresis in the rock record and to better understand the boundary conditions for this process. Defining the parameters of synaeresis crack formation and studying the context of synaeresis cracks in the Summerville Formation has the potential to lead to more specific interpretations of the depositional environments of Martian mudstones, and ideally, any mudstone that contains synaeresis cracks since these features supposedly only form under specific salinity conditions.

MODELING OF FAULT-CORED ANTICLINES AND ASSOCIATED BLIND THRUSTS IN CENTRAL CALIFORNIA

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Recent literature investigating active folding indicates that crustal-scale anticlines grow primarily through slip on underlying faults. Such studies use the geometry and uplift rates of active fault-related folds to infer fault slip rate based upon an assumed kinematic relationship between fault slip and particle motion in the surrounding crust. Our method focuses on the mechanics of deformation using a boundary element model of flexural slip folding called BEAFS (Boundary Element Analysis of Flexural Slip). In many cases, the shallow geometry (<5km) of natural folds are well constrained by subsurface data, however, the geometry of the causative blind thrust faults is often not well imaged. However, by comparing our numerical simulations with published subsurface data on naturally occurring folds we can determine the extent to which various mechanisms control fold evolution.

We present model results for the underlying faults at Kettleman Hills South Dome and Kettleman Hills North Dome in the San Joaquin Valley of Central California. Blind thrust faults associated with actively growing anticlines pose a significant global seismic hazard. Thus, these anticlines are of particular interest as they are the near the sites of two recent earthquake events—a M_w=6.5 earthquake in 1983 at Coalinga and a M_w=6.1 in 1985 at Kettleman Hills North Dome. We compare our fault geometries, fault slip rates, and uplift rates to published results from kinematic analyses. We find that the underlying fault can be modeled by a simple ramp-flat-ramp geometry, which produces a good fit to the anticline geometry. From our models, the structure at Kettleman Hills North Dome is younger and shows fold growth during earthquake events that is not aligned with the fold axis, but rather occurs along the forelimb. In contrast, we find that Kettleman Hills South Dome is an older structure with fold growth always aligned along the fold axis. In both cases, we find evidence for fold growth due to fault slip as well as through amplification via buckling.

LITHOSPHERIC DISCONTINUITIES IN ILLINOIS BASIN AND THEIR TECTONIC IMPLICATIONS: RESULTS FROM THE EARTHSCOPE OIINK EXPERIMENT

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We present new results from a regional study of the lithospheric structure along a swath from Missouri to central Kentucky crossing the Illinois Basin, a major intracratonic basin in the Central U.S. We selected 13,367 from the 85,139 teleseismic receiver functions from a dense, 140-station Flexible Array of the EarthScope OIINK (Ozark, Illinois, INdiana and Kentucky) experiment, combined with 65 USArray Transportable Array stations, 8 Cooperative New Madrid Seismic Network stations, and station CCM of the Global Seismographic Network. We used Common Conversion Point (CCP) stacking technique to image the lithospheric discontinuities across the southern Illinois basin. The results reveal features in crustal and uppermost mantle structures beneath the study area that have not been described previously. The Ste. Genevieve fault zone in southeastern Missouri and southwestern Illinois has been mapped from northern flank of the Ozark Plateau in southeastern Missouri to southwestern edge of the Illinois basin. Our results indicate that this fault zone might be the surface expression of a profound crustal velocity boundary. Crustal thickness changes across this boundary. Thick crust is observed beneath the Sparta shelf and east of the Wabash Valley fault system. The Ste. Genevieve fault zone, the Wabash Valley fault system and the Du Quoin monocline may be surface manifestations of deep crustal-scale structures, though the lower crust is aseismogenic. High magnetic anomalies in Sparta Shelf region indicate the possibility of magmatic intrusions in the upper crustal. The high gravity anomaly with a low magnetic anomaly in Fairfield basin region may be attributed to magmatic underplates with high-density materials in the lower crust below the Curie depth. Dramatically thin crust is identified beneath both Ozark plateau and Rough Creek graben, with contrasting crustal thinning mechanisms. In Rough Creek graben, the crust underwent horizontal stretching under extensional stresses, while the Ozark plateau may result from the upwelling of mantle materials with high magnetic compositions.

EVALUATING CO_2 STORAGE AND ENHANCED METHANE RECOVERY OF ILLINOIS BASIN COALS USING RESERVOIR SIMULATION

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The Advanced Coal Technology Consortium of the joint US-China Clean Energy Research Center is conducting research on the potential to mitigate carbon dioxide (CO_2) emissions from large stationary emitters by implementing carbon capture, utilization and storage (CCUS) technology. One aspect of this research involves assessing the CO_2 storage and utilization resource potential in each of the four classes of geological reservoirs commonly considered for CCUS: deep saline formations, oil and gas reservoirs, unmineable coal seams, and organic-rich shales. Despite the potential economic benefits of CO_2 utilization for enhanced methane recovery in coal seams, CCUS resource assessments remain highly uncertain because relatively little field testing has been conducted to date. The goal of this research is to reduce uncertainty in the CO_2 storage and utilization resource estimates that are being implemented into complex, integrated CCUS system models by evaluating regional-scale, volumetric-based resource estimates against results from more detailed, local-scale reservoir simulations.

Reservoir simulations were conducted for a case study analysis of twelve potential storage locations surrounding a large coal-fired power plant (3.2 gigawatt capacity) in the Illinois Basin, USA. The commercial reservoir simulator GEM v.2015 (Computer Modeling Group Ltd) was used. Model sensitivity analysis was conducted to guide the selection of a representative range of parameters for the study sites, and results demonstrated that fracture permeability was the most influential parameter, followed by Langmuir constants, initial water saturation, wellbore skin effects, and cleat spacing. Accordingly, a set of low, medium, and high fracture permeability cases were conducted at each site in the study, and four different operational scenarios were also considered based on different cutoff criteria for the CO_2 injection operation. Simulation results indicate that low permeability coals actually lead to more enhanced methane recovery than the higher permeability cases. Results from all the tested permeability cases for three of the four operational scenarios also suggest that regional-scale analyses tend to significantly overestimate the enhanced methane recovery resource potential. Only in the case of extended CO_2 injection did we find notably comparable results between the reservoir simulations and regional-scale, volumetric-based estimates (on average around 0.4 MMscf/acre). Further model testing indicated that increasing CO_2 injection rates can ultimately promote higher levels of CO_2 storage, but the storage resource estimates were still significantly lower than estimates based on regional-scale analyses. This study has provided important guidance for the development of the integrated CCUS system model by demonstrating that low-range resource estimates appear most suitable for the implementation of coal reservoirs into this integrated system model framework.

Using Geometric Morphometrics to Test Species Identifications and Interpretations of Conodont Evolution in the Illinois Basin during the Middle Pennsylvanian

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Conodont fossils are highly valuable for biostratigraphically correlating Paleozoic formations and for interpreting evolutionary change through time. Despite this well-established history, conodont species are still identified with qualitative and ultimately subjective morphologic criteria, which are prone to continual debate. Quantitative methods can provide a more objective and robust approach to identifying species and tracking evolutionary changes in this significant fossil group.

The objective of my research is to use geometric morphometrics (GM), a quantitative method, to test species identifications of the conodont genus *Neognathodus* and to interpret *Neognathodus* evolution throughout the Middle Pennsylvanian in the Illinois Basin.

Preliminary GM groups of *Neognathodus* are congruent with some established species and incongruent with others. GM analysis shows distinct morphologic groups for the species *N. bassleri* and *N. bothrops*, thus these two GM groups are congruent with the established species designations. In contrast, GM analysis shows no significant morphologic difference between the species *N. medadultimus* and *N. medexultimus*, indicating they should be considered as one species, not two. This GM grouping is therefore incongruent with established species designations. Combining the two morphologies into one species suggests evolutionary stability, which disagrees with previous interpretations of gradual morphologic change and evolutionary progression from *N. medadultimus* to *N. medexultimus*. Overall, the ability of the GM analysis to differentiate the more distinct morphologies of *N. bassleri* and *N. bothrops* and coalesce the more similar morphologies of *N. medadultimus* and *N. medexultimus* demonstrates the method is potentially useful to test species identifications. Additional GM work with these and other *Neognathodus* species is required to support and build upon the preliminary interpretations.

Expanded GM analysis will highlight areas requiring additional study on conodont taxonomy and spatial correlation, and may ultimately lead to a highly robust and objective method to correlate Middle Pennsylvanian strata globally and to ascertain evolutionary trends in this significant chordate group.