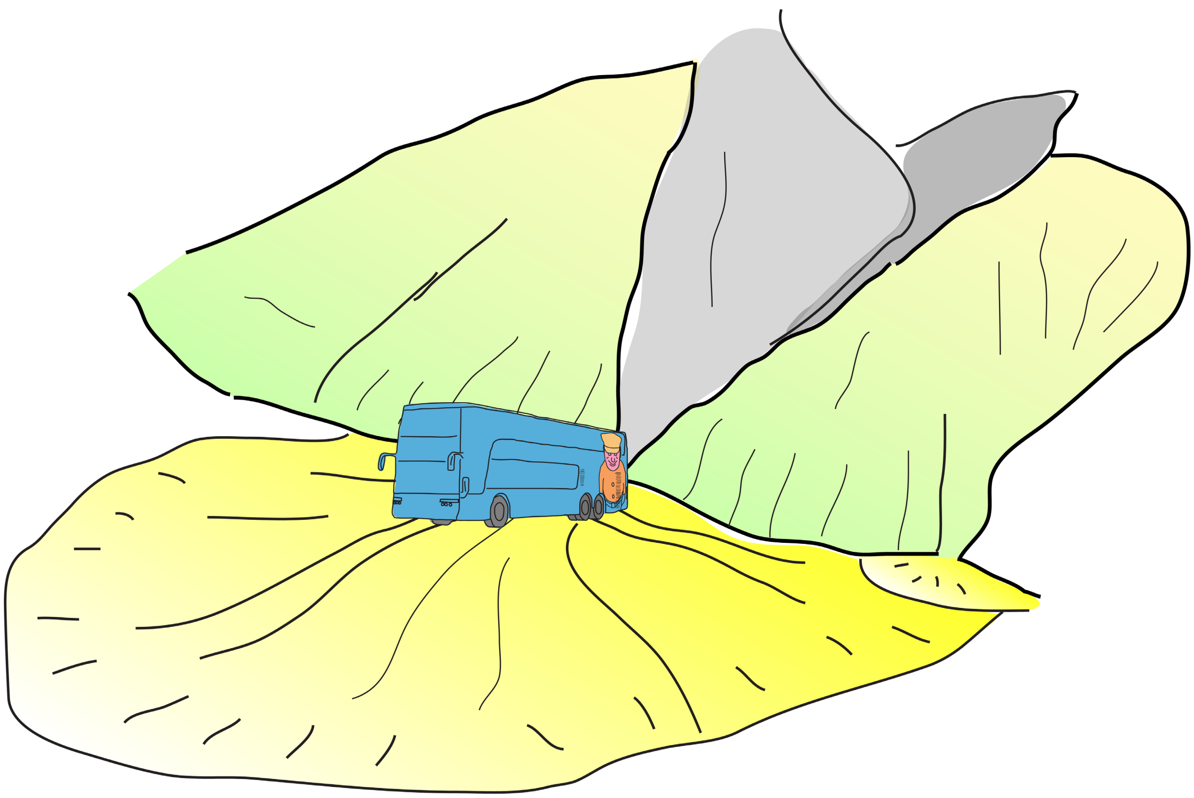
6th Annual Amtrak Club Meeting

# Propagation of climate and tectonic signals through landscapes

May 19-20, 2017

Pennsylvania State University, University Park, PA

hosted by the Department of Geosciences
with support from the Earth and Environmental Systems Institute



organized by Roman DiBiase, Liz Hajek, Joanmarie Del Vecchio,
Evan Greenberg, and Sheila Trampush

| Attendees | |
|---|---|
| Tobias Ackermann | University of Delaware |
| Beth Ames | Boston College |
| Yuning Bai | Franklin and Marshall College |
| Ilya Buynevich | Temple University |
| Julia Carr | Carnegie Museum of Natural History |
| Yunxiang Chen | Pennsylvania State University |
| Margaret Christie | Rutgers University |
| Dori Coplan | Franklin and Marshall College |
| Joanmarie Del Vecchio | Pennsylvania State University |
| Roman DiBiase | Pennsylvania State University |
| Sam Dow | Boston College |
| Kieran Dunne | University of Pennsylvania |
| Paul Eizenhofer | University of Pittsburgh |
| Behrooz Ferdowsi | University of Pennsylvania |
| Joey George | University of Delaware |
| Dru Germanoski | Lafayette College |
| Evan Greenberg | Pennsylvania State University |
| Evan Gross | Franklin and Marshall College |
| Xin Gu | Pennsylvania State University |
| Andrew Gunn | University of Pennsylvania |
| Liz Hajek | Pennsylvania State University |
| Isabel Hong | Rutgers University |
| Hossein Hosseiny | Villanova University |
| Doug Jerolmack | University of Pennsylvania |
| Isaac Larsen | University of Massachusetts Amherst |
| Justin Lawrence | National Science Foundation |
| Dylan Lee | University of Pennsylvania |
| Evan Lewis | Franklin and Marshall College |
| Logan Lewis | Franklin and Marshall College |
| Henry Lin | Pennsylvania State University |
| Virginia Marcon | Pennsylvania State University |
| Nicholas McCarroll | Pennsylvania State University |
| Ryan McKeon | Dartmouth College |
| Nooreen Meghani | Pennsylvania State University |
| Dorothy Merritts | Franklin and Marshall College |
| Frank Pazzaglia | Lehigh University |
| Jim Pizzuto | University of Delaware |
| Sujith Ravi | Temple University |
| Jen Schmidt | Lehigh University |
| Eitan Shelef | University of Pittsburgh |
| Noah Snyder | Boston College |
| Sheila Trampush | Pennsylvania State University |
| Marijn van der Meij | Wageningen University |
| Diane Wagner | Franklin and Marshall College |
| Jennifer Walker | Rutgers University |
| Bob Walter | Franklin and Marshall College |
| Bruce Wilkinson | Syracuse Unviersity |

# Schedule for 2017 Amtrak Club Meeting

## Propagation of climate and tectonic signals through landscapes

**Friday, May 19, 2017**
Location: 22 Deike Building, Penn State University, University Park, PA 16803

**8:00 am:** Coffee, tea, pastries, and poster setup

**9:00-9:30:** Welcome/introductions, 22 Deike Building

**9:30-10:10:** Isaac Larsen (UMass Amherst)
*Modeling canyon carving by glacial outburst floods in the Channeled Scablands of eastern Washington*

**10:10-10:50:** Sujith Ravi (Temple University)
*Interactions between aeolian processes and vegetation in changing landscapes*

**10:50-11:20: Break**

**11:20-12:00:** Ryan McKeon (Dartmouth College)
*Shouldn't the Appalachians be flatter by now? New perspectives on an old landscape from low-temperature thermochronology*

**12:00-12:15 pm:** Frank Pazzaglia (Lehigh University)
*Propagation of climate and tectonic signals through landscapes: Cyclostratigraphy of Pleistocene fluvial deposits and insights into exogenic vs. autogenic process forcing*

**12:15-1:45: Lunch**

**1:45-2:00:** Virginia Marcon (Penn State University)
*Evaluating the effect of lithology on porosity development in ridgetops in the Appalachian Piedmont*

**2:00-2:40:** Eitan Shelef (University of Pittsburgh)
*Hillslopes, permafrost, soil carbon, and their potential influence on Earth's climate*

**2:40-2:55:** Margaret Christie (University of Delaware)
*Quantitative reconstruction of phosphorous concentrations in the tidal Christina River Watershed, DE*

**2:55-4:05: Break**

**4:05-4:20:** Noah Snyder (Boston College)
*Legacy sediment storage in New England river valleys: Anthropogenic processes in a postglacial landscape*

**4:20-5:00:** Dorothy Merritts (Franklin and Marshall College)
*Propagation of base-level change through legacy landscapes in the unglaciated mid-Atlantic region, US*

**5:00-7:00: Dinner and posters in the EMS Museum and Art Gallery**

**Saturday, May 20, 2017**

**8:50 am:** Meet in parking lot behind Deike Building – Vans leave at 9:00 am

**9:00-11:30:** Catskill fluvial stratigraphy exposures along PA322 near Philipsburg

**11:30-12:30:** Lunch (provided) at Whipple Dam State Park

**12:30-3:00:** Periglacial controls on critical zone architecture at Garner Run, Susquehanna Shale Hills CZO

**~3:00 pm:** return to Deike Building

## A comparison of land-use and glacial controls on erosion in the Northeastern United States

Beth Ames[1], Noah P. Snyder[1], Dorothy J. Merritts[2], Robert C. Walter[2], Timothy L. Cook[3], Aakash Ahamed[4]

*[1]Earth and Environmental Sciences, Boston College, 140 Commonwealth Avenue, Devlin Hall, Chestnut Hill, MA 02467 (ameseb@bc.edu)*
*[2]Department of Earth and Environment, Franklin and Marshall College, Lancaster, PA 17604*
*[3]Department of Earth, Environment and Physics, Worcester State University, Worcester, MA 01602*
*[4]Universities Space Research Association, NASA Goddard Space Flight Center, 8800 Greenbelt Road, Greenbelt, MD 20771*

Anthropogenic land-use changes related to deforestation and agriculture have driven erosion in the northeastern United States (NEUS) since European settlement in the 17th century, evidenced by sediment preserved in wetlands and millponds. Glacial history may also have an impact on rates of erosion, as glaciation results in the localized deposition of erosion-resistant materials like tills and provides accommodation space for eroded sediment in lakes and wetlands. While land use history is consistent across the NEUS, the glacial legacy in the northern part of the region may reduce overall sediment supply and mobilization from upland sources. We compare erosion rates between the glaciated and unglaciated NEUS, across various timescales, to test the hypotheses that: (1) historic to modern erosion rates are higher than geologic background rates across the NEUS; and (2) erosion rates south of the Pleistocene glacial limit are higher than those north of it. We mine previously published erosion rates and sediment yields from studies of thermochronometry, cosmogenic nuclide concentrations in stream sediment, lake and reservoir sediment cores, and stream sediment-transport gauging. Results show significantly higher geologic erosion rates (derived from thermochronometry) than modern across the NEUS, perhaps indicating that Appalachian tectonic cycles of uplift and erosion or glacial isostatic history may have had a greater regional effect on sediment mobilization than anthropogenic activity. Higher standard deviations of modern erosion rate distributions suggest, however, that land use affects erosion locally. Erosion rates in the formerly glaciated NEUS are about 40 percent lower than the unglaciated region over multiple timescales, lending support to hypothesis 2. It therefore appears that the regional Pleistocene glacial signal appears more substantial than that of land-use change, with glaciation affecting sediment supply to a significant degree.

## Monitoring Sediment Deposition and Soil Organic Carbon Retention at an Aquatic Ecosystem Restoration Project, Big Spring Run, Pennsylvania

Yuning Bai[1], Robert Walter[1], Dorothy Merritts[1], Chi Xu[1], and Aaron Blair[1]

*[1]Department of Earth and Environment, Franklin and Marshall College, Lancaster, PA, 17604-3003*

The Big Spring Run (BSR) watershed is a sub-basin of the Conestoga River Watershed in Lancaster County, PA, that flows into the Lower Susquehanna River and eventually to the Chesapeake Bay. BSR is listed on the Federal 303D list for impaired water bodies due to high suspended sediment and nutrient loads. BSR is typical of many headwater watersheds in the Piedmont Physiographic Province with low valley slopes (~0.005) and relief (~30 m) and extensive accumulations of legacy sediment that buried pre-settlement valley bottom aquatic ecosystems. Streams in the BSR watershed also are typical of headwater tributaries where valley grade-control structures that led to legacy sediment storage (e.g., milldams) are breached, resulting in channel incision, lateral channel migration, severe bank erosion, and substantial sediment and other nutrient loads. The focus of this study is monitoring of a restoration site along 1$^{st}$- and 2$^{nd}$-order sections of BSR (drainage area 15 km$^2$). The BSR site was selected by Pennsylvania Department of Environmental Protection to evaluate a new approach to aquatic ecosystem restoration. The premise of this new approach is that by removing legacy sediment the natural valley morphology and its aquatic and wetland ecosystems may be restored, along with their functions and services.

A novel wetland-floodplain restoration at BSR occurred in the fall of 2011. Three years of pre- and six years of post-restoration monitoring, involving students and colleagues from thirteen academic and government institutions, includes physical, biological, hydrological, and geochemical response to restoration. For this particular study, long-term post-restoration monitoring focuses on soil organic carbon retention, soil nitrogen content, denitrification, and soil orthophosphate content. Five chemical parameters are measured in soil samples: organic carbon, total nitrogen and nitrate, and total phosphorus and orthophosphate. Measurement of organic carbon follows standard Loss on Ignition and Elemental Combustion analytical (ECA) methods. Total nitrogen is measured by ECA and phosphorus by ICP-OES following nitric acid (EPA 3051), Mehlich-3 and water extraction procedures. We are testing the hypothesis that with organic carbon deposition and retention since restoration, the anaerobic environment and reconnection of surface and groundwater will promote denitrification. As a result, nitrate content in the restored hydric floodplain soil at BSR should decrease over time. Orothophosphate can be sorbed or desorbed from Fe-oxides depending on redox conditions and organic matter content. We are studying the fate of orthophosphate in this restored ecosystem. A comparison between the geochemistry of BSR soils and the upper organic rich hydric soils from an intact Holocene wetland (Great Marsh in Chester County, PA) will be completed during this study. Current LOI results show that the organic carbon content in BSR floodplain soil ranges from 2.0% to 4.8% (mean 3.2%), which establishes a baseline to evaluate carbon post-restoration carbon retention.

## Geomorphological and geophysical aspects of event-scale Aeolian encroachment

Ilya Buynevich[1]

[1] *Earth and Environmental Science, Temple University, Philadelphia, PA 19122, coast@temple.edu*

Active sand dunes of various sizes and morphologies often interact with antecedent topography such as bedrock and glacial relief, fluvial and tidal channels, vegetation, and man-made structures. The resulting interaction affects the adjacent dune segments and the long-term dynamics of the entire dunefields. Where aeolian features are masked by subsequent deposition or modified by development, geomorphological analyses have been complemented with high-resolution geophysical surveys in order to accurately reconstruct aeolian landscape dynamics. This study uses examples from equatorial coast of Brazil, as well as paraglacial settings of the Baltic Sea and Maine, to document geomorphological and geophysical aspects of sand invasion into maritime forests and settlements. Despite humid conditions, onshore winds ensure ongoing migration of parabolic dunes into a mangrove forests at Atalaia, Pará State, Brazil. Ground-penetrating radar (GPR) surveys reveal multiple lateral migration surfaces (buried slipfaces), with apparent dip angles of 30-31°. Numerous hyperbolic (point-source) subsurface anomalies are correlated with partially buried vegetation beneath the leading edge of the dune and its stoss margin. Along the northern Curonian Spit, Lithuania, several mobilization episodes of large dunefields over the past 6,000 years attest to natural triggers and to historical land clearance. Massive dunes up to 60 m in height record the transfer of $10^7$-$10^8$ $m^3$ of sand in a regime of rising sea level, entombing mature forests and fishing villages. As in other European sites, the upper sections of dunes have been deflated leaving near-horizontal exposures. GPR images extend the continuity of key stratigraphic horizons and, where supplemented by paleosol morphology, help reconstruct the parabolic-to-transverse transition and the original dune elevation. Paleo-slipfaces (dip angles: 31-34º) indicate the direction of earlier migration phases and exhibit distinct reactivation surfaces. Laterally extensive horizons enriched in heavy minerals produce prominent subsurface reflections during episodes of increased wind activity. In a deforested outwash plain along mid-coastal Maine, deforested outwash plain resulted in rapid burial of numerous structures. The electromagnetic signal response to a recently buried object of known dimensions offers a direct means of assessing the types of subsurface reflection patterns produced by complex interactions of antecedent 3D objects and 2D-3D dune front morphologies. The downwarping reflections near the top of a buried spring house are the result of sand collapse and have no surface expression. The integration of geomorphic, georadar, sedimentological, and chronological (radiocarbon and optically-stimulated luminescence) datasets is currently underway to understand the styles of sand invasion and examine the interactions between antecedent topography and aeolian landforms.

## Structure-from-motion based CFD modeling of gravel-bed rivers and subglacial conduits

Yunxiang Chen[1], Xiaofeng Liu[1], Roman A. DiBiase[2], and Kenneth D. Mankoff[2]

[1]*Department of Civil and Environmental Engineering, Pennsylvania State University*
[2]*Department of Geosciences, Pennsylvania State University*

This work utilizes computational fluid dynamics (CFD) and the emerging technique of Structure-from-Motion (SfM) to understand the turbulent flow and morphology in geophysical conduits on the surface of planet Earth. Two geological settings were considered, namely gravel-bed rivers and subglacial conduits. They represent open channel flows and pressurized pipe flows, respectively. We developed a semi-automatic workflow for the acquisition of bathymetric data, quantification of roughness and spatial features, preprocessing of the data for CFD simulations and analyzing the simulated results. In this workflow, high resolution topographic data are first acquired using SfM and a Matlab code is then used to quantify the surface geometry using mainly a $2^{nd}$-order structure function. The acquired surface data can then be imported into a CFD code (OpenFOAM in our case) to simulate the turbulent flow fields within the conduits, which is the major driver for the physical and biogeochemical processes which controls their evolution and functionalities. We demonstrate the workflow by showing the example CFD results and the analysis of the roughness and hydraulic resistance within these conduits. The combination of SfM and CFD can be used as a cost-effective and fast method to investigate geophysical fluid flows in similar settings.

## Quantitative reconstruction of phosphorous concentrations in the tidal Christina River Watershed, DE

Margaret A. Christie[1], Donald F. Charles[2], Ronald E. Martin[1], James E. Pizzuto[1]

[1]*Department of Geological Sciences, University of Delaware, Newark, DE*
[2]*Drexel University, Philadelphia, PA*

The tidal Christina River has been impacted by changing land-use practices since the mid-17th Century when European settlers entered the region. These alterations increased the concentration of nutrients in the watershed. Historical phosphorus concentrations were reconstructed from diatom assemblages in sediment cores collected from three sites along the tidal Christina River, DE. Reconstructions were made using a transfer function created with modern diatom and water chemistry data from sites similar in pH, and conductivity to the Christina River in Delaware and Southern New Jersey. A Weighted-Average Partial-Least-Squares model yielded the lowest amount of error in reconstructions. Sample ages (between 1400 years before present and the present) were determined using a combination of $^{210}Pb$, $^{137}Cs$, $^{14}C$, and deforestation chronohorizons based on the ratio of Ambrosia to Quercus. Estimates were compared to the percent of taxa preferring high nutrient concentrations found at each site. In general, phosphorus concentrations were lower prior to European settlement, before beginning to increase to modern levels about 200 years before present.

## A record of coupled hillslope and channel response to Pleistocene periglacial erosion in a sandstone headwater valley, central Pennsylvania

Joanmarie Del Vecchio[1], Roman A. DiBiase[1, 2], Alison R. Denn[3], Paul R. Bierman[3]

[1]*Department of Geosciences, Pennsylvania State University, University Park, PA*
[2]*Earth and Environmental Systems Institute, Pennsylvania State University, University Park, PA*
[3]*Department of Geology, University of Vermont, Burlington, VT*

South of the Last Glacial Maximum ice extent, the landscape in central Valley and Ridge physiogaphic province of Appalachia preserves soils and thick colluvial deposits that retain information about how the landscape responded to changes in Quaternary climate. The topography shows extensive evidence of relict periglacial landscape modification, suggesting vigorous sediment production and transport in climates colder than modern conditions and highlighting the need to identify the mechanics and rates of climate-modulated erosion. Here, we pair geomorphic mapping with in situ cosmogenic $^{10}$Be and $^{26}$Al measurements to estimate erosion rates and residence time of colluvium in Garner Run, a 1 km$^2$ sandstone headwater valley containing relict Pleistocene periglacial features including solifluction lobes, block fields and thick valley fill. Distribution of lobes and blockfields implies an aspect dependence of periglacial processes consistent with regional morphologic observations. $^{10}$Be concentrations in stream sediment, soils, and amalgamated surface boulders are similar, and indicate slow erosion rates (6 m/My) over the past 50-100 kyr. When paired with estimates of colluvial valley fill volume constrained by coring, topographic analysis, and shallow geophysics, we find that episodic accumulation, occurring in two pulses ~300 kya and <100 kya, is equivalent to the long-term sediment production from bedrock lowering. This implies that erosion rates measured within regional ridgelines and basins reflects the integration of slow temperate climate processes and relatively rapid periglacial processes. Thus, in landscapes with slow erosion rates, the critical zone integrates the physical and chemical effects of Quaternary climate cycles, which is important for interpreting modern hillslope hydrology and pedogenesis. Furthermore, we show that sedimentary records in slowly-eroding headwater valleys present opportunities to directly examine climate-modulated hillslope processes.

## Tracing 20th century anthropogenic sediment in the South River, western Massachusetts

Samantha Dow[1], Noah P. Snyder[1], William B. Ouimet[2]

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[2]*Department of Geography and Center for Integrative Geosciences, University of Connecticut, Storrs, CT*

New England has a long history of anthropogenic activity affecting the landscape, including deforestation, agricultural practices, and the construction of dams. Dams in particular have the ability to impound vast quantities of sediment eroded off the landscape. The South River in western Massachusetts is an example of a watershed where mill dam construction coincided with deforestation during the 17th-19th centuries, leading to the impoundment of legacy sediment. Along the river, these deposits act as a source of sediment. The Conway Electric Dam (CED), a 17 m tall dam built in 1906, is located downstream of the mill dams (most of which are no longer intact), and provides a 20th century depositional record for the watershed. The purpose of this study is to link recent deposition behind the CED to the erosion of upstream mill pond and glacial sediment sources using sediment provenance and aerial photograph analyses. I hypothesize that erosion of legacy sediment from mill ponds is the primary source of sediment over the past ~100 years. Hg was used as a geochemical tracer in a mixing model to quantify relative contributions of sediment from glacial and mill pond deposits. Results from the mixing model indicate that erosion of glacial deposits along the banks of the river accounts for ~68 ± 15% of the sediment mobilized during the 20th century, where erosion from mill ponds accounts for ~32 ± 15%. This was paired with a GIS analysis using aerial photographs from 1940 and 2013 to delineate channel banks and calculate changes in channel width following methods in Galster et al. (2008), in order to determine areas of widening or narrowing and changes in sinuosity, comparing reaches with banks composed of legacy and glacial sediment. Results indicate reaches of glacial sediment have been significantly narrowing, but have experienced little to no change in sinuosity (less than 2% increase). Reaches of legacy sediment have not shown significant changes in width, however, they have increased in sinuosity (up to 12%). Overall, results suggest erosion from glacial sources may be more significant than from remobilized legacy sediment in the South River watershed during the 20th century.

## Evidence of, and a proposed explanation for, bi-modal transport states in alluvial rivers

Kieran B.J. Dunne[1] and Douglas J. Jerolmack[1]

*[1]Department of Earth and Environmental Science, University of Pennsylvania, Philadelphia, Pennsylvania, USA*

Gravel-bedded rivers organize their bankfull channel geometry and grain size such that shear stress ($\tau$) is close to the threshold of motion. Sand-bedded rivers on the other hand typically maintain bankfull fluid stresses far in excess of threshold, a condition for which there is no satisfactory understanding. A fundamental question arises: Are bed-load (gravel-bed) and suspension (sand-bed) rivers two distinct equilibrium states, or do alluvial rivers exhibit a continuum of transport regimes as some have recently suggested? We address this question in two ways: (1) re-analysis of global channel geometry datasets, where the novelty here is that we explicitly consider the slope-dependence of critical shear stress ($\tau_c$); and (2) examination of a longitudinal river profile as it transits from gravel to sand bedded. Data reveal that the transport state of alluvial river-bed sediments is bi-modal, showing either near-threshold ($\tau / \tau_c \sim 1$) or suspension ($\tau/\tau_c >> 1$) conditions, and that these regimes correspond to the respective bi-modal peaks of gravel and sand that comprise natural river-bed sediments. Sand readily forms near-threshold channels in the laboratory and some field settings, however, indicating that another factor such as bank cohesion must be responsible for maintaining suspension channels. We hypothesize that alluvial rivers adjust their geometry to the erosion limiting bed and bank material --- which for gravel-bed rivers is gravel, but for sand-bed rivers is mud (if present) --- and present tentative evidence for this idea.

## Creepy landscapes: the granular origins of soil transport on hillslopes

Behrooz Ferdowsi[1], Carlos P. Ortiz[1], Douglas J. Jerolmack[1]

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Soil creeps imperceptibly downhill, but also fails catastrophically to create landslides. Hillslope evolution is often modeled using a nonlinear diffusion law meant to capture these two limiting behaviors, but this description is heuristic. Creep is generally understood as sub-threshold soil movement that results from biological or physical perturbations (burrowing, tree throw, freeze/thaw, etc.), but its mechanistic underpinnings are unclear. Here we examine the granular origins of a creep "transport law", and the nature of the transition to landsliding by Discrete Element Method (DEM) hillslope simulations, and re-analysis of sediment flux measurements in natural landscapes. The DEM model consists of a packing of polydisperse grains inclined at various gradients below, near and above the bulk angle of repose of the granular system. We find creep for slopes below a critical gradient, where average particle velocity (sediment flux) increases exponentially with friction coefficient (gradient). At critical there is a continuous transition to a dense-granular flow rheology, that is in agreement with previous laboratory experiments. We further compare our DEM observations with an experimental hillslope constructed from non-spherical grains and monitored across fast avalanche and slow creep regimes using a combination of pixel-wise image cross-correlation analysis and Dynamic Light Scattering (DLS) method. We find that slow earthflows and landslides exhibit dynamical behavior characteristic of a wide range of disordered materials, also known as “glassy dynamics”; they are described by a two-phase flux equation that emerges from grain-scale friction alone, and contains physically meaningful parameters. This physic-based “glassy” model reproduces topographic profiles of natural hillslopes, showing its promise for predicting hillslope evolution over geologic timescales.

## Storage and residence time of suspended sediment in gravel bars of Difficult Run, VA

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Reducing the export of suspended sediment is an important consideration for restoring water quality to the Chesapeake Bay, but sediment budgets for in-channel landforms are poorly constrained. We quantified fine (< 2 mm) sediment storage and residence times for gravel bars at two reaches along Difficult Run, a 5th order tributary to the Potomac River. Eight gravel bars were mapped in a 472m headwater reach at Miller Heights (bankfull width 11m; total bar volume 114 m3) and 6 gravel bars were mapped in a 420m reach downstream near Leesburg Pike (bankfull width 19m; total bar volume 210 m3). Geomorphic maps also highlighted ways in which Difficult Run has reacted to human alteration of its watershed, depicting smaller-than-normal pool-riffle spacing, abundant LWD, and prolific bank erosion. Grain size analyses of surface and subsurface samples from 2 bars at each reach indicate an average suspended sediment content of 50%, suggesting a total volume of suspended sediment stored in the mapped bars to be 162 m3, or ~257580 kg, comprising 3.2% of the average annual suspended sediment load of the two study reaches. Scour chains installed in 2 bars at each site (a total of 50 chains) recorded scour and fill events from March-November 2016. Scour chain measurements informed calculations of scour chain reworking fractions, the fraction of bar sediment replaced during a measurement period. A Weibull analysis of these reworking fractions was used to compute a 24-year residence time for suspended sediment stored in gravel bars at Difficult Run. Gravel bars do not appear to store a significant amount of the annual suspendable sediment load, so may not be worthy of inclusion in future suspended sediment budgets. However, the 24-year residence time of these deposits reinforces the important role storage has on the downstream transport of suspended sediment in Piedmont streams.

## Massive erosional flux from monsoonal India linked to Late Holocene landcover degradation

Liviu Giosan[1] et al.

[1] *Woods Hole Oceanographic Institution*

The history of soil erosion remains largely unknown before the last few centuries, despite its crucial role in the transfer of sedimentary materials including carbon between terrestrial, atmospheric and oceanic reservoirs. Here we reconstruct a Holocene erosional history from central India, as integrated by the Godavari River in a sediment core from the Bay of Bengal, by fingerprinting sources and quantifying fluxes of the lithogenic fraction and terrigenous carbon. We show that the monsoon decline in the late Holocene, later aided by the Neolithic adoption and Iron Age extensification of agriculture on the Deccan Plateau, vastly increased soil erosion and the age of exported biospheric carbon mixtures. Despite a constantly elevated sea level since the middle Holocene, this acceleration of erosion led to rapid continental margin growth. We estimate that over the whole monsoon domain as well as in other early settled river basins, the impact of soil erosion on the carbon cycle due to ancient landcover degradation was substantial.

## Reconstructing Fluvial Channel Mobility through the Paleocene-Eocene Thermal Maximum (Willwood Formation, Bighorn Basin, Wyoming)

Evan B. Greenberg[1], Elizabeth A. Hajek[1]

[1]*Department of Geosciences, Pennsylvania State University, University Park, Pennsylvania*

Over long timescales, channel-belt mobility in meandering systems includes both local processes, such as lateral migration, and regional processes like avulsion. Reconstructing these types of channel mobility from ancient deposits is important for understanding how ancient river systems responded to past climate change events. For example, the Willwood Formation (Bighorn Basin, Wyoming, USA) was deposited during the geologically rapid Paleocene-Eocene Thermal Maximum (PETM) global warming event. Previous studies have proposed that Willwood rivers changed their lateral mobility and/or their avulsion behavior in response to the PETM event. In an effort to evaluate the nature and degree of changes in Willwood channel-belt migration vs. avulsion, we conducted a detailed analysis of individual channel belts deposited before, during, and after the PETM event. We identified avulsion-generated channel-belt deposits and made detailed maps of intrachannel-belt facies and architecture with a particular focus on constraining the scale, stacking, lateral continuity, and preservation of bar deposits. Our results show that Willwood rivers had similar depths, paleocurrent dispersion, bar-migration patterns, and bar preservation before, during, and after the PETM. This indicates that channel-belt dynamics (including meandering and lateral migration) were relatively insensitive to changes in discharge, sediment-supply, and floodplain conditions during the PETM. However, an apparent increase in avulsion reoccupation at the channel-belt scale through the peak of the PETM suggests that avulsion frequency may have increased relative to lateral channel-belt migration. This study shows how detailed comparisons of channel-belt architecture can help reconstruct channel migration and avulsion dynamics from ancient meandering river deposits.

## Late Pleistocene paleoclimate inferred from sediment infill in a thermal-contraction-wedge in shale bedrock near Carlisle, Pennsylvania

Evan Gross[1], Dorothy Merritts[1], Robert Walter[1], Mark Demitroff[2], and Sebastien Huot[3]

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[2]*School of Natural Sciences and Mathematics, Stockton University, Galloway, New Jersey*
[3]*Illinois State Geological Survey, Champaign, Illinois*

In this study, we infer local paleoclimatic conditions from fine sediment (dominantly sand and silt) in a relict thermal-contraction-wedge, part of a network of polygonal ground patterns within shale bedrock recently discovered in central Pennsylvania. These polygons can be observed in aerial photos taken at certain times of the year due to soil moisture contrasts between the host bedrock and sediment infill within thermal-contraction wedge casts. Sediment from a near-vertical relict wedge about 1.7 m in length exposed in a road cut along Enola Road was analyzed to determine its provenance, mode of transportation, and depositional age. Particle size analyses, scanning electron microscopy and energy dispersive x-ray spectroscopy, x-ray powder diffraction, optical mineralogy and petrography, and optically stimulated luminescence (OSL) dating were among the techniques used to analyze this silty sand.

Results indicate that the feature is an icy sand wedge within shale bedrock that underwent thermal-contraction-cracking approximately 14.9 ±1.8 ka (weighted mean age ± 1 σ for two OSL dates) in an arid periglacial landscape with permafrost. Formation of this feature within highly frost-shattered shale bedrock indicates a mean annual air temperature of at most -4 °C (25 °F) at the time of cracking. Its sediment infill originated from both proximal and distal upwind bedrock exposures and was transported toward the wedge via eolian processes (i.e. saltation, reptation, and creep). Direct eolian infilling was supplemented by other processes, such as slumping and slopewash. Based on the bedrock provenance of some of the sediment, which includes Tuscarora quartzite that crops out along the crest of Blue Mountain to the north, the dominant paleo-wind direction in central Pennsylvania was from the north or northwest. Katabatic winds, flowing off the ice sheet's margin, likely swept across the landscape about the time of thermal-contraction-cracking.

Our findings support the interpretation of the existence of permafrost in what is now central Pennsylvania during the late Pleistocene. At the time of the Last Glacial Maximum (LGM) circa 26.5 to 19 ka, the maximum southern extent of the Laurentide Ice Sheet was ~120 km north of the study area. During post-glacial warming, the southern boundaries of the Laurentide Ice Sheet and zone of permafrost retreated northward. Various types of relict periglacial landforms persist throughout the region in association with the networks of polygonal fissures that we have mapped from aerial imagery. They, like the wedges, might be even older than the OSL dates reported above, with reactivation during successive cold periods after a hiatus in cryospheric activity associated with climate amelioration. Many of these relict landforms, particularly gelifluction lobes, can be detected and mapped with airborne bare-earth LiDAR and closely resemble those prevalent in modern periglacial environments where permafrost exists at present. Analysis of such relict landforms in the mid-Atlantic region yields valuable paleoclimate information regarding landscape response to warming that can inform our understanding of modern periglacial environments during times of permafrost thaw.

## Investigating the porosity development of shale to understand hydrologic controls on hillslope scale weathering

Xin Gu[1], Daniella M. Rempe[2], Joshua West[3], Susan L. Brantley[1,4]

[1]*Department of Geosciences, The Pennsylvania State University*
[2]*Jackson School of Geosciences, The University of Texas at Austin*
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The spatial distribution of weathered rock across actively eroding landscapes strongly influences how water and solutes are routed throughout the landscape. To understand the controls on the evolution of weathering profiles that underlie hilly and mountainous regions, we investigated the porosity formation and chemical weathering of shale samples collected from three catchments located in Pennsylvania, USA (Shale Hills Critical Zone Observatory, SSHCZO), California, USA (Eel River Critical Zone Observatory, ERCZO), and Yilan, Taiwan (Fushan Experimental Forest). These three sites have similar mineralogical composition, but are located in vastly different climate and tectonic settings. In particular, the erosion rate at Fushan (3-6 mm/yr) is much faster than at ERCZO (0.2-0.4 mm/yr) and SSHCZO (0.015 mm/yr), and the average annual precipitation at Fushan is higher (3.4-4.3 m/yr vs. 1.7 m/yr at ERCZO and 1 m/yr at SSHCZO). However, neutron scattering experiments show nearly identical bedrock porosities (3.1-4.6%) of parent rock.

Analysis of the chemical and mineralogical compositions of samples throughout the weathering profile reveal that: 1) carbonate and pyrite are the profile-initiating minerals in all sites and both deplete sharply near the water table under the ridge. 2) Chlorite oxidation also initiates near water table and the extent of oxidation decreases with erosion rate. 3) Illite dissolution only occurs near the land surface in the sites with relatively lower erosion rate (SSHCZO and ERCZO). In all settings, the interface between weathered and unweathered rock roughly coincides with the water table and the samples above water table have higher porosity and water-accessibility than the samples below. However, at Fushan and ERCZO, the porosity and the density of micro-fractures are higher in the weathered zone than observed at SSHCZO. It is possible that the eroding landscape is moving toward a balance between rates of erosion and weathering advance, and that higher density of microfractures at the rapidly eroding Fushan and ERCZO promotes faster water infiltration and faster weathering advance relative to the more slowly eroding SSHCZO. Further investigation of the origin and role of these microfractures is needed to understand the interplay between climate, erosion, and weathering that controls hillslope weathering profiles.

## The role of atmospheric boundary layer stability in dune formation at White Sands, New Mexico

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Aeolian dunes form at the boundary between the atmosphere and sand grains. Given a geological source, they are the product of a cascade of momentum which can be traced through geostrophic wind and the atmospheric boundary layer (ABL) to individual grain motion. Winds in the ABL are always bound vertically by a free-stream velocity aloft and a no-slip condition on the Earth surface, yet their character between these conditions is strongly influenced by the diurnal cycle. This has important implications for the downward momentum flux to the dunes, and therefore their migration and dust emission. During the day, strong surface heating encourages thermal convection and instability that draws shear closer to the dunes. In contrast, the nocturnal boundary layer is stably stratified, requiring more force to overturn colder air onto the warmer air above and perturb the dunes. Theory on inviscid wall-bound stratified flow has quantified the functional form of the horizontal velocity profiles through the ABL during a diurnal cycle, and how it deviates from a canonical `Law of the Wall' form, with the Obukhov length. As is often the case in dune-bearing regions, White Sands National Monument, New Mexico, is characterised by a strong diurnal cycle. Transverse dunes sourced from gypsum crystal laden flats have crests normal to a formative southwesterly wind. A ground-operated LiDAR wind Doppler-laser device was deployed for three days during dune transport season to examine the vertical structure of the winds on the upwind margin of the dune field. We posit that our findings show sand transport is enhanced by unstable, or suppressed by stable, stratification in the ABL, setting a constraint on the formative winds for dune migration and dust emission. This indicates that dunes are generally formed during the day, and that large-scale geostrophic forcing on dunes is regulated by the locally-controlled diurnal cycle.

## Characterizing tropical cyclone sediment transport: 2015 Tropical Cyclone Pam overwash deposits from Vanuatu, South Pacific

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Historical observations and overwash sediments deposited by prehistoric tropical cyclones (TC) enable the assessment of long-term patterns of tropical cyclone variability but are limited in their ability to quantify the intensity of past events. Modern analogues present an opportunity to characterize overwash sediments deposited by a TC of known flooding heights.

On 13 March 2015, TC Pam made landfall on Vanuatu as a Category 5 storm with 10-minute sustained wind speeds as high as 250 km/h. Three months after landfall, we (1) measured the height and inland extent of TC Pam's storm surge, (2) described the sedimentological characteristics of the TC Pam overwash deposits focusing on two of the hardest hit islands, Efate and Tanna, and (3) tested the applicability of an inverse sediment transport model on TC Pam sediments at Tanna. We measured surge heights of 4.20 m above MSL at our study area on Efate and 3.30 m above mean sea level (MSL) at our study area on Tanna. TC Pam deposited a medium-grained (mean: 1.20 Φ), moderately well-sorted (sorting: 0.55 Φ) mixed-carbonate sand with trace amounts of volcanic sediments and coral fragments at Manuro. In contrast, TC Pam deposited a medium-grained (mean: 1.81 Φ), moderately well-sorted (sorting: 0.67 Φ) volcanic sand at Port Resolution Bay. Flow heights associated with TC Pam's storm surge ranged from 3.30 to 4.18 m above MSL. We used a combination of measured flow heights obtained at the Port Resolution Bay site and laboratory derived grain size settling velocities to reconstruct the maximum flow depth estimate of 1.51 m (3.30 m MSL measured estimation of flow depth minus the elevation of the 1.79 m MSL berm) within 11% using an inverse model. We show that this inverse sediment transport model can potentially reconstruct flow depths of prehistoric, landfalling TC's.

## Analysis of the flood inundation maps in a back water model coupled with sediment transport: A case study of Darby Creek, PA

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Darby Creek, in metro-Philadelphia, PA, has been subject hydrologic engineering since the late 17th century. Today, this urbanized creek is considered one of the most flood-prone in the U.S. [Philadelphia Inquirer, 2012]. The creek channel and floodplain are predominately composed of alluvial sediments. During flood events sediment transport increases, geomorphically altering the channel and floodplain. However, most flood inundation mapping does not consider water-sediment interaction and the geomorphic implications. To address the potential uncertainty embedded in neglecting geomorphic processes, this study aims to analyze flood inundation maps through describing the flow velocity field and sediment transport.

This study uses LiDAR and bathymetric data in the International River Interface Cooperative software (iRIC) with FaSTMECH (a two-dimensional quasi unsteady flow solver) to calculate sediment transport relative to hydraulic characteristics of the flow. A flood event April 30th, 2014 is modeled and tested based on stage and discharge data from an upstream USGS gage. For model validation the boundary conditions were set using the USGS gage in combination with two NOAA stream gages on the Delaware River near the outlet of Darby Creek. To account for the effect of different sediment sizes the model uses synthetic grain sizes varying from fine sand to coarse gravel representing the Creek alluvium. The results from this study demonstrate how to incorporate sediment transport in flood inundation maps and can ultimately be used to gain a deeper understanding of sediment transport and sediment storage in the floodplain.

## Direct observation of collective entrainment dynamics in bed load transport

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Bed load transport is a notoriously unpredictable process. A primary component of this unpredictability arises from stochastic fluctuations which require non-trivial averaging. This averaging must be informed by the length and time scales of the fluctuations, and a rigorous method for arriving at the proper averaging scales must link grain scale motion to macroscopic transport. A statistical mechanical framework has been suggested by Furbish and colleagues to accomplish this goal. This model assumes that grain motion is independent of other particles. Experiments show that this is not the case, and that bed load fluctuations possess length and time scales larger than any hydrodynamic scaling. This indicates that fluctuations in grain motion are correlated. These correlations in transport can occur in time as bursts of flux through the system and in space as collective motion of several grains that become locally entrained together. We perform a series of experiments that directly quantifies both temporal and spatial fluctuations in grain motion as the driving frequency of grains fed through the system is varied. As the driving frequency of the system is increased, the time one needs to average over to arrive at a given threshold variance for the flux through the system is decreased (i.e. transport through the system grows less variable in time). Collective grain motion is defined experimentally as spatially clustered movement of several grains at once. The distribution of the size of collective motion events follows an exponential decay that is consistent across driving frequencies. This suggests a picture where collective entertainment of grains is happening in the system all the time but that, as the driving frequency is increased, the intermittency of transport decreases to the point that entrainment events merge together and transport through the system approaches uniformity.

## Modeling canyon carving by glacial outburst floods in the Channeled Scablands of eastern Washington

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Oscillation between glacial and interglacial climates can significantly influence the rates and mechanisms of erosional processes. A dramatic example of a landscape formed by enhanced erosion during glaciation is the Channeled Scablands of eastern Washington, where catastrophic floods from the failure of ice-dams that impounded Glacial Lake Missoula carved deep bedrock canyons into the basalt of the Columbia Plateau. Larger, morphologically similar canyons have been used to make inferences regarding past climates on Mars. Reconstructing the magnitude of the canyon-forming floods is essential for understanding the paleo-environmental and climatic conditions during times that floods significantly altered planetary surfaces, and for understanding how such floods may trigger abrupt climate change. However, canyon topography co-evolves with flood hydraulics, making it challenging to reconstruct paleo-flood discharge. A common method for estimating flood discharges assumes that floods filled the canyons brimful with water; however, an alternate hypothesis proposes that canyon morphology adjusts during incision such that bed shear stresses do not greatly exceed the threshold for erosion. Here we focus on Moses Coulee, which was carved by the Missoula Floods. By combining hydraulic flood simulations and thresholds for bedrock plucking, we show that accounting for erosion thresholds during canyon incision results in near constant discharges and flood depths that are 15 to 40% of brimful estimates. The predicted discharges are consistent with flow-depth indicators from gravel bars within the canyon. In contrast, the brimful flood assumption predicts a significant and monotonic increase in flood discharge as the canyon progressively incised, which is at odds with discharges expected from the glacial lake-outburst flood source. These findings suggest that megaflood-carved landscapes in well fractured rock may evolve to a threshold state for bedrock erosion, which implies significantly lower megaflood discharges than previously thought.

## Evaluating the effect of lithology on porosity development in ridgetops in the Appalachian Piedmont

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Chemical and physical processes work together to breakdown fresh bedrock into friable weathered material. The transformation of bedrock to regolith influences the landscape, releases nutrients, and affects stream, groundwater, and ocean water chemistry. It can be challenging to predict the depth to unweathered bedrock even when lithology, tectonic history, and climatic history are all known because the mechanisms that control the rate of regolith formation are not well understood, and the processes that influence regolith development are closely intertwined.

In order to evaluate lithological controls on weathering of silicate rocks, we evaluated four lithologies—schist, granite, diabase, and serpentinite—within the Appalachian Piedmont along ridgetops. The Piedmont provides an ideal setting to evaluate the lithological influence on weathering because the effects of lithology can be isolated from that of erosion, climate, and tectonic history. In the VA and PA Piedmont, climatic and tectonic variability are regionally limited, regolith thickness is observed to vary with lithology, and the landscape is thought to be in geomorphic steady-state such that the chemical weathering rate is equal to the erosion rate. Here, we explore both chemical and physical controls on weathering. For example, when regolith thickness is plotted versus fracture toughness values compiled from the literature for each lithology, regolith thickness generally increases with decreasing fracture toughness, except for serpentinite.

To understand this observation, physical weathering parameters (porosity, connectivity, and surface area) were evaluated using neutron scattering on Piedmont rocks at different degrees of weathering. Granite and serpentinite porosity are dominated by small pores (3-10nm), whereas pores in schist are characteristically larger (100-1000nm) and more connected. As granite weathers, pores become more connected (especially within the smaller pore range), opening new pathways for reactive meteoric fluids to weather the rock. However, as serpentinite weathers, small pores are occluded and total porosity decreases until the upper meter of the profile. We propose two mechanisms for porosity loss during weathering of serpentinite: 1) low temperature serpentinization of residual olivine resulting in volume expansion and infilling of pores 2) collapse of porosity due to the lack of a non-reactive mineral (e.g. quartz) acting as a supportive skeleton in the regolith. Non-isovolumetric weathering would limit infiltration of reactive fluids deeper into serpentinite, minimizing regolith formation. Given this, fracture toughness and quartz content may be important parameters to consider in terms of predicting regolith thickness.

## Quantifying connections between channel bed microtopography and grain size and shape distribution in mountain streams using structure-from-motion

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Understanding the fluvial system is important to the fields of geomorphology, sedimentology and engineering. The need to determine flood hazards, calculate sediment transport, and conduct stream restoration depends on being able to characterize streambed microtopography and granulometry. In this study we compare direct measures of streambed microtopography using structure-from-motion photogrammetry with traditional methods of surface characterization using Wolman three axis pebble counts, in order to determine how streambed microtopography is influenced by the shape, size and sorting of grains. Specifically, we used ground-based structure-from-motion techniques to quickly and efficiently characterize and analyze exposed gravel beds. Our analysis shows that, in agreement with prior studies, the standard deviation of surface elevations scales with the median intermediate-axis diameter of surface material, $D_{50}$. However, there is a much stronger correlation between $D_{50}$ and a horizontal length scale that emerges from analyzing the 2nd order structure function of bed microtopography. Furthermore, we find that the ratio of horizontal and vertical roughness length scales correlates with the median ratio of long and short grain axes measured in the field. Our results highlight the richness of information encoded in streambed microtopography that is now becoming increasingly accessible with structure-from-motion workflows.

## Shouldn't the Appalachians be flatter by now? New perspectives on an old landscape from low-temperature thermochronology

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The modern topography that we refer to as "The Appalachians" has long been thought to represent the roots of a once great mountain belt; however, the emerging reality appears significantly more interesting. There are aspects of the long-term evolution of this region that fit the eroding roots paradigm. Generally speaking, long-term erosion rates are faster than short-term rates. In many places the modern topography is strongly correlated with lithology. And despite sedimentary and geomorphic evidence for considerable unsteadiness, no Cenozoic cooling ages for low-temperature thermochronometers have been found, meaning no part of the landscape has experienced exhumation and erosion significant enough to reset ages during this time. These observations do indicate that the evolution of the modern Appalachians has on the whole been rather slow, but they fail to explain the nuances that separate the different parts of the range in terms of topographic expression and litho-tectonic setting. Several recent studies that take advantage of new developments in the application and interpretation of low-temperature thermochronology have profoundly changed our view of the origin of topography in this region. At both ends of the range, models reveal prolonged periods (~50 Myr) of accelerated exhumation in valley floors relative to neighboring ridges and summits long after tectonic activity related to rifting had ceased. This spatially variable exhumation generated km-scale relief in both areas and indicates that there is no genetic link between high modern relief and the Paleozoic orogen. Furthermore, it is interesting to note that the central Appalachians have experienced the least post-rift exhumation, but they are currently the area with most dynamic geomorphic processes. By combining these observations it appears that the Appalachian landscape is neither uniformly decaying, nor finished evolving and hides more secrets about the processes that drive its continued modification.

## Propagation of base-level change through legacy landscapes in the unglaciated mid-Atlantic region, US

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Decades of research on the geomorphology of the mid-Atlantic US make it timely to synthesize long-term ($10^4$ – $10^6$) rates of geologic erosion and sediment generation with paleo-ecological and geomorphic records of landscape change. Such a synthesis, we propose, reveals that legacy landscape effects from Pleistocene cold-climate conditions pre-determined Holocene warm-climate landforms and processes throughout the mid-Atlantic region. These periglacial landscape legacies likewise pre-determined the response of modern streams to base-level change from breaching (or removal) of 18th-19th century mill dams that results in channels incised through historic and Holocene sediment into the underlying Pleistocene deposits and landforms.

North of the latitude of approximately present-day Annapolis, Maryland (~39°) relict landforms provide a record of paleo-permafrost, most likely continuous permafrost at some locations, consistent with previous paleocological work that indicates tundra vegetation during the late Pleistocene. Using lidar, orthoimagery, and geomorphic and paleoecological studies, we and our collaborators find the following evidence of past permafrost and its thaw: 1) extensive networks of thermal contraction polygons in shale bedrock; 2) ubiquitous gelifluction sheets and lobes up to 10s of m thick on side slopes and valley bottoms, especially where slopes consist of sandstone or quartzite; 3) retrogressive thaw slumps and other thermokarst features; and 4) water tracks similar to those investigated in the Dry Valleys of Antarctica. At one site in central Pennsylvania, we have dated the sand infill within a relict thermal contraction wedge to 14.9 ± 1.8 ka (1 sigma weighted mean age for two OSL dates; see companion abstract from Gross et al, 2017). Gelifluction on hillslopes produced poorly sorted, matrix-supported deposits indicative of mass movement under saturated conditions. During cold-periglacial conditions with permafrost (and probably during climate amelioration and permafrost degradation), these deposits accumulated in valley bottoms, leading to local aggradation. Periglacial landforms and deposits are less pronounced to the south and found only at higher elevations. We have identified fluvial channel networks buried by colluvium north of ~39° latitude, but this paleo-climatic signature diminishes southward beyond the limits of paleo-permafrost.

Holocene landscape stability was enhanced by Pleistocene cold-climate conditions that led to widespread coarse-grained colluvial deposition on hillslopes and valley bottoms. Our radiocarbon dating and that of others at dozens of mid-Atlantic sites, combined with paleo-seed and other macro-fossil analysis, indicates that valley bottom wetlands supplied by groundwater became established on a substrate of periglacial deposits during the early Holocene in low-order (1st to 3rd) watersheds. An example near Penn State University is Bear Meadows. Oldest radiocarbon dates from organic-rich wetland soils typically are ≤11.2 ka, post-dating the Younger Dryas cold period. At one valley bottom location (Great Marsh, southeastern PA), our calibrated radiocarbon dates of 19.1-19.9 kyrs BP for organic matter in silt immediately below a 12.1-13.2 kyrs BP organic-rich soil indicate a late Pleistocene-Holocene transition erosional disconformity between ~13.2 and 19.1 kyr BP. Multiple lines of evidence suggest this was a time of intense eolian activity and flushing of some sediment along valley bottoms. By early Holocene wetlands had become established at groundwater level throughout the region, and many persisted continuously until European settlement. Sedimentation rates in Holocene wetlands were low, typically <0.1 mm/yr. Widespread mill damming for water power, however, buried many valley bottom wetlands, with 18th-19th c. sedimentation rates at least 10-100 x greater.

Throughout this region others have determined long-term low regional erosion rates of ~11 m $m.y.^{-1}$ (~30 Mg $km^{-2}$ $yr^{-1}$) and sediment generation rates of 26.2 ± 18.3 Mg $km^{-2}$ $yr^{-1}$ from beryllium isotopes (e.g., Portenga et al, 2017), whereas contemporary sediment yields are up to 10 times greater. Our work with LiDAR DEM differencing (acquisition in 2008 and 2014) indicates that erosion of historic reservoir sediment upstream of a breached milldam as a knickpoint propagates through the reservoir can be 1000 times greater than long-term geologic erosion rates. Furthermore, Pleistocene colluvium beneath this historic sediment is more readily scoured because of high stream banks after incision, and can enhance bank erosion as gravel bars of reworked colluvium develop along meander bends. In essence, landscape "memory" strongly affects modern processes and rates of erosion.

## Propagation of climate and tectonic signals through landscapes: Cyclostratigraphy of Pleistocene fluvial deposits and insights into exogenic vs. autogenic process forcing.

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The idea that exogenic environmental (climatic, tectonic and/or eustatic) unsteadiness drives surface process unsteadiness is a well-established canon of geomorphic and sedimentologic research, argued to be well supported in sedimentary and geomorphic archives. The alternative consideration, that autogenic geomorphic and sedimentologic processes precludes clear preservation of exogenic environmental signals enjoys particular and well-deserved recent attention, but generally lacks demonstration across large time and space scales where linked transfer subenvironments are not all well understood. The crux of the problem is that even if the geomorphic system responds linearly, or nearly linearly to quasi-periodic or stochastic exogenic environmental changes, that response should be dampened, or shredded during sediment transport and deposition. The threshold period of the shredding process scales with the size of the source to sink system. This introduces significant ambiguity for many systems because sub-orbitally forced environmental changes, such as millennial-scale climate oscillations, may have periods that overlap with common autogenic processes fueling a spirited and justifiable discussion on precisely what kind of paleoenvironmental, geomorphic process, or tectonic interpretations, if any, could be drawn from sedimentary sequences or geomorphic markers. This presentation explores how quasi-periodic and stochastic exogenic environmental forcing conspires with stochastic and transient autogenic processes to encode, shred, propagate, and preserve geomorphic signals in a sedimentary archive. Two study sites in tectonically active settings in the northern Italian Apennines and Sicily with excellent biostratigraphic, magnetostratigraphic, and cyclostratigraphic data anchored by OSL/IRSL and TCN geochronology, provide a unique opportunity to construct high-resolution time-stratigraphic models and explore how the sediment deposition varies with modern and paleo-erosion rates. Tectonic and exogenic processes seem to dominate these systems across a range of scales. In particular, the texture and stratification of littoral and fluvial deposits in the northern Apennine site record tectonic forcing in the early part of the record, that then is overtaken by climatic forcing in the latter part of the record at orbital time scales. Autogenic forcing is not obvious or recorded in this particular setting. In contrast, the setting in Sicily reveals a high frequency quasi-periodicity in sediment texture and rock-magnetic properties at a multi-decadal or millennial scale that may be related to an autogenic process, like channel avulsions, but also may be indistinguishable from a multi-decadal to millennial climatic oscillation in the western Mediterranean. A landscape evolution model, linking processes in the source to these observations extracted from the sink would be instrumental in deconvolving how climatic, tectonic, and autogenic processes are generated, propagated, encoded, and preserved.

## Propagation of restoration-induced sediment signals through large watersheds drained by alluvial rivers

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Geomorphologists have long understood that storage delays the downstream delivery of sediment, but this process is rarely quantified and typically ignored in watershed sediment modeling. We use a stochastic sediment routing model to evaluate the time required to deliver benefits from best management practices (BMPs) that reduce sediment loading to all first order channels by 50%. The domain is an idealized 71,339 $km^2$ watershed scaled to the Susquehanna R. basin, with constant storage probability (0.015) and storage time distribution function (with values from <1 to >$10^4$ years) that are representative of the mid-Atlantic region. Delivery times for BMP-induced benefits increase rapidly with watershed size, ranging from <1 year for a 57 $km^2$ subwatershed to >$10^4$ years for the entire basin, where transient sediment budgets persist for $10^7$ years. Storage processes and timescales should therefore be explicitly considered when assessing sediment BMPs in large watersheds.

## Interactions between aeolian processes and vegetation in changing landscapes.

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Aeolian processes redistribute sediment and nutrients within desert landscapes with important implications for soil biogeochemical cycling and vegetation dynamics. The differential rates of deposition and erosion by aeolian processes can result in differential rates of hydrological processes such as surface run-off, soil moisture dynamic and infiltration; with implications for vegetation patterns. Vegetation structure and patterns, in turn, affect the spatial dynamics of aeolian transport, soil moisture, and nutrients in the system. Dryland ecosytems are highly susceptible to accelerated soil erosion by wind following disturbances (anthropogenic or natural) which cause a temporary reduction in vegetation cover. Moreover, these ecosystems worldwide are threatened by contemporary shifts in vegetation composition (e.g. encroachment by shrubs, invasion by exotic grasses), which alter the frequency and intensity of disturbances and dust emissions. Here, using extensive tracer-based field experiments (in grasslands and shrublands of North America) and modeling, we investigate the interactions between aeolian processes and vegetation dynamics in landscapes affected by vegetation shifts and recurrent disturbances. Our results indicate that the degree of post-disturbance aeolian transport and its attenuation with time was found to be strongly affected by the antecedent vegetation type and post-disturbance climatic conditions. The interactions among transport processes, disturbances and vegetation dynamics are explored and their roles in dust emissions and land degradation are discussed.

## Differential unroofing across the Eastern Lhasa Block in Southeastern Tibet: Geodynamic links between plateau-scale tectonics and landscape evolution

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Detailed documentation of the exhumation history of southeastern Tibet is important for understanding the coupling of tectonic and surface processes shaping this landscape. We present K-feldspar and biotite $^{40}Ar/^{39}Ar$ and zircon (U-Th)/He thermochronology along both horizontal and vertical traverses within Gangdese batholith to constrain the spatial and temporal pattern of exhumation in the region. We use these data combined with 3D thermokinematic modeling to interrogate patterns of regional erosion and test mechanical models of plateau evolution.

K-feldspar multi-diffusional domain modeling combined with biotite, and zircon data from the region indicate near isothermal or reheating conditions prior to rapid cooling from temperatures greater than 300°C at ~50 Ma. K-feldspar and zircon data from younger plutons in the eastern and western portions of the region indicate another period of rapid cooling occurred beginning at ~20 Ma. However, the magnitude of cooling was significantly greater in the east at this time. Apparent zircon (U-Th)/He ages vary by ~40 Ma E-W across the region. Evidence for an ~10 Ma pulse of rapid cooling near the Yarlung-Nyang confluence in the east is absent west of the rift. These differences in exhumation history between east and west correlate with variation in Moho depth and landscape morphology. These spatial and temporal correlations suggest linkages between deep geodynamic processes and the development of mountain topography. Variability in km-scale exhumation despite accordant mountain summit elevations throughout southeastern Tibet indicates that this region underwent a complex and protracted unroofing history.

## Hillslopes, permafrost, soil carbon, and their potential influence on Earth's climate

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Organic carbon stored in perennially frozen soils (i.e., permafrost) can influence climate because of the feedback between permafrost thaw, carbon release to the atmosphere, and temperature increase. The quantity of this carbon has a primary influence on future climate projections, yet current carbon estimates do not account for the accumulation of soil deposits at the base of hillslopes (hill-toes). This study combines soil profile data with topographic analyses to evaluate the quantity and uncertainty of organic carbon stored in perennially frozen hill-toe soil deposits. We show that in Alaska these hill-toe deposits introduce an uncertainty in the quantity of organic carbon that is larger than state-wide estimates of permafrost carbon, and that a similarly large uncertainty may also pertain at a circumpolar scale. Soil sampling and geophysical-imaging efforts that target hill-toe deposits can help constrain this large uncertainty.

## Legacy sediment storage in New England river valleys: anthropogenic processes in a postglacial landscape

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Walter and Merritts (2008, and subsequent papers) show that legacy sediment associated with deposition in millponds is a common feature in river valleys of the Mid-Atlantic Piedmont region, with 1-5 m of fine sand and silt overlying Holocene soil and Pleistocene periglacial deposits. For this project, we seek to test the hypothesis that these field relationships are seen in New England, a formerly glaciated region with similar history and intensity of forest clearing and milldam construction during the 17-19$^{th}$ centuries. We study three watersheds, using field observations of bank stratigraphy, radiocarbon dating, and mapping of terraces and floodplains using lidar digital elevation models and other GIS datasets. The 68 km2 South River watershed in western Massachusetts exhibits the most extensive evidence for legacy sediment storage. We visited 17 historic dam sites in the watershed and found field evidence for fine sand and silt legacy sediment storage at 14, up to 2.2 m thick. In the 554 $km^2$ Sheepscot River watershed in coastal Maine, we visited 12 historic dam sites, and found likely legacy sediment at six, up to 2.3 m thick. In the 171 $km^2$ upper Charles River watershed in eastern Massachusetts, we investigated 14 dam sites, and found legacy sediment at two, up to 1.8 m thick. Stratigraphically, we identified the base of legacy sediment from a change in grain size to gravel at most sites, or to Pleistocene marine clay at some Sheepscot River sites. In the Sheepscot River, we observed cut timbers underlying historic sediment at several locations, likely associated with sawmill activities. Only at the Charles River were we able to radiocarbon date the underlying gravel (1281-1391 calibrated CE). At no site did we find a buried Holocene soil, in contrast to the field relations commonly observed in the Mid-Atlantic region. This may indicate that the New England sites have eroded to the pre-historic river bed, not floodplain surfaces. We attribute the variation in thickness and presence of legacy sediment at the New England sites to the existence or absence of upstream sediment supply in the form of thick (>5 m) glacial deposits. Of the three study watersheds, the South River has the most extensive glacial sediments, having been occupied by one or more ice-dammed lakes during the late Pleistocene, and the most legacy sediment storage.

## Modifying climate proxy records through autogenic sedimentation: modeling and examples from the Paleocene-Eocene Thermal Maximum

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The stratigraphic record provides a vital opportunity to investigate how changes in climate can impact many different landscapes and seascapes. However, the inherent variability in sedimentation within many depositional environments may mask or remove the signature of climate change. A common solution is to use geochemical proxies – usually collected at regular stratigraphic intervals – to independently identify climate events. This approach does not account for the potentially significant variability in deposition and erosion time series resulting from autogenic landscape dynamics. In order to explore how geochemical proxy records could be overprinted by landscape dynamics, we use a 1D stochastic sedimentation model where we mimic fluvial, lacustrine, shallow marine, and deep marine environmental dynamics by varying the frequency-magnitude distributions of sedimentation rates. We find that even conservative estimates of the frequency and magnitude of stochastic sedimentation variability can heavily modify proxy records in characteristic ways by alternately removing, compressing, and expanding portions of the record, regardless of the magnitude or duration of the climatic event. Our model results are consistent with observations of the carbon isotope excursions of the Paleocene Eocene Thermal Maximum (PETM) preserved within both fluvial (e.g. the Bighorn Basin, Wyoming and the Piceance Basin, Colorado) and shallow marine (e.g. the New Jersey shelf) deposits. Our results suggest that we may be able to use existing geochemical proxy records within well studied, global climatic events, such as the PETM, to constrain the variability in sedimentation present within different depositional environments.

## Examining spatial variability in relative sea-level in the New York City/New Jersey region during the common era

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Relative sea-level (RSL) reconstructions extend the 20th century instrumental record (tide gauge and satellite measurements) of spatial and temporal sea-level variability to provide a much longer context for recent trends and projected RSL rise. Common Era (last 2000 years) RSL reconstructions illustrate patterns of natural variability and include natural phases of climate and sea-level which will improve our knowledge basis for sea-level responses to climate changes.

The northeast U.S. has exhibited varying rates in relative sea-level rise through the Common Era, primarily due to glacial isostatic adjustment. However, other factors such as ocean/atmosphere dynamics, sediment compaction, and the static equilibrium response to land ice changes, further influence the evolution of relative sea-level. The spatial variability is manifest in the tide gauge records. The tide gauge at the Battery, New York City (1856 to 2015) records a relative sea-level rise of 2.8 mm/yr whereas the tide gauge at Sandy Hook, New Jersey (1932 to 2015), 25 km southeast, records 4.1 mm/yr.

Here we present a new reconstruction of RSL in northern New Jersey using geological and tide gauge data. A Common Era sea-level record from northern New Jersey fills in the spatial gap between records completed in southern New Jersey, New York City, and Connecticut. Our field study site is in Cheesequake State Park, where we observed sedimentary sequences dating back 2000 cal. yrs. BP. We use microfossil indicators preserved in salt-marsh sediments as a proxy to reconstruct RSL with decimeter precision. Salt-marsh foraminifera act as reliable RSL indicators because their modern distribution is strongly linked to tidal elevation. The recent application of microfossil-based transfer functions has enabled continuous records of RSL, extending centuries before the modern instrumental period, to be produced with a full consideration of uncertainty. We use a composite chronology of AMS $^{14}C$, pollen chrono-horizons, pollution histories, and a $^{137}Cs$ spike (AD 1963) to achieve multi-decadal temporal precision. The RSL record for northern New Jersey shows a 2.4 m rise during the past 2000 years at a mean rate of ~1.2 mm/yr. This compares to rates from a database of Holocene relative sea-level observations for the U.S. Atlantic coast which found a rise of ~1.4 mm/yr for New Jersey and ~1.3 mm/yr for New York from 4 ka BP to AD 1900 (Engelhart and Horton, 2012).