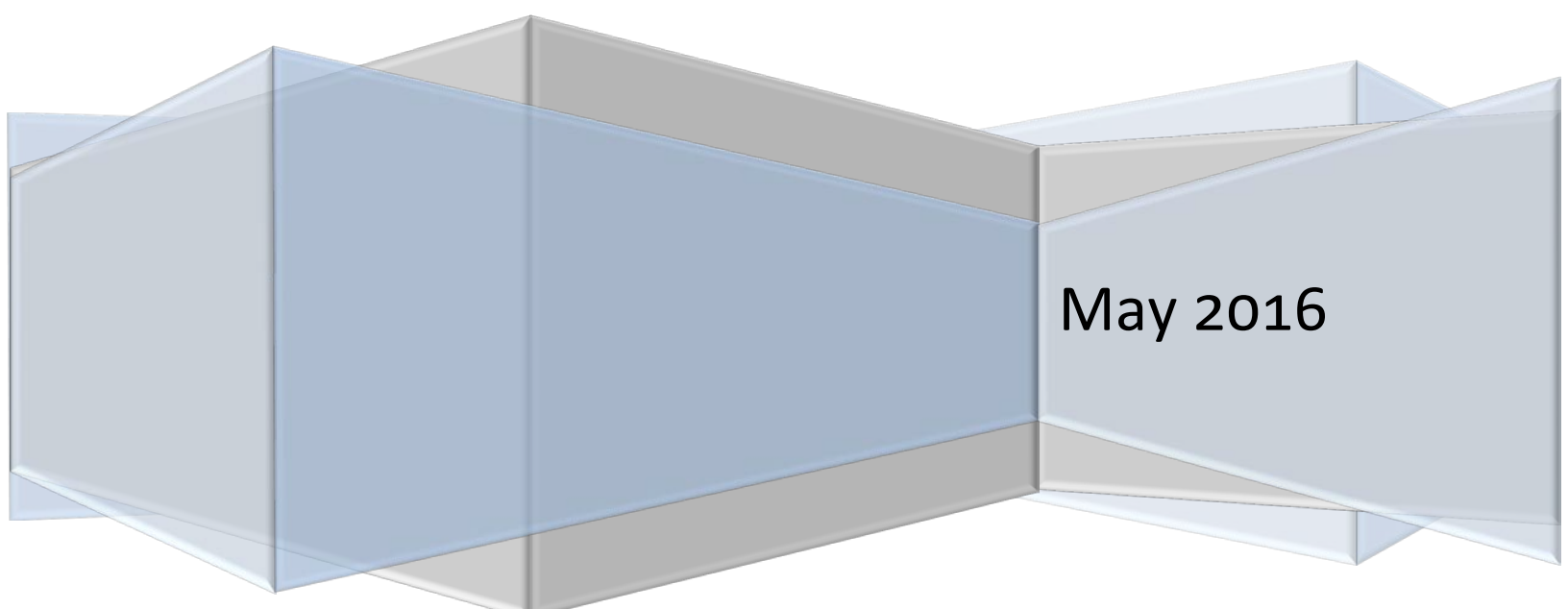**Susquehanna Shale Hills Critical Zone Observatory**

All Hands Meeting Agenda and Abstract Volume

The Pennsylvania State University

University Park, PA

May 2016

SSHCZO All Hands 2016 Agenda

Sunday, May 15

Arrival of out of town participants

Monday, May16   Schedule for Jorden Hayes

7:45am – 8:45am Breakfast with Sue Brantley – meet in lobby of Atherton Hotel

9:00am – 10:00am – Geomorphology Research Group – Roman DiBiase – 306 Deike Building

10:30am – 11:30pm – Hydropedology Research Group – Henry Lin – 205 ASI Building

12:00pm – 3:00pm – Field Trip with Jorden Hayes to CZO, meet in EES Building parking lot – box lunches and water will be provided for RSVP participants.

4:00pm – 5:00pm – Featured Seminar by Jorden Hayes, Assistant Professor at Dickinson College, will present "**Porosity production and distribution in the deep critical zone at the Southern Sierra Critical Zone Observatory, California and the Laramie Mountains, Wyoming**" in **114 EES Building**

5:00pm – 6:00pm Poster Session Set-up

6:30pm – Dinner – Hayes, DiBiase, Russo, and Mount

Tuesday, May 17th   ALL HANDS MEETING - 117 EES Building

800 – 815 Brantley: *Welcome and Introductions and Intro to SSHCZO. Talks are to be 10-12 minutes followed by 5-7 minute Q/A session and 1 minute speaker switchover.*

815 – 9:00 Opening Poster Session

9:05am – 9:20am – CZO Science Overview: The Big Picture (Brantley)

9:20am – 9:35am – Team H1 – **Detecting critical zone response to perturbations by climate and base level in central Pennsylvania using *in-situ* produced 10-Be** (Denn)

9:35am – 9:40am – Discussion of H1

9:40 – 9:55 – Team H1 – **Quaternary climate controls on critical zone form and process at Garner Run** (Del Vecchio)

9:55am – 10:00am – Discussion of H1
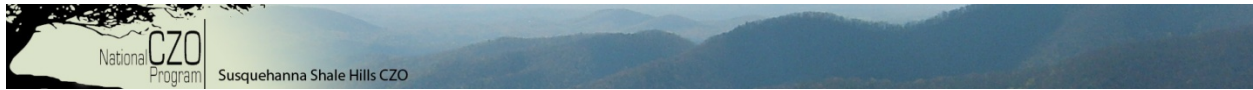
10:00am – 10:15am – Team H2 – **The distribution of weathering reactions across a landscape can be described as a function of biotic and abiotic production and consumption of acids (CO2, DOC) and O2.** (Hill)

10:15am – 10:20 am – Discussion of H2

10:20am – 10:45am – **CZO Data Management and Monitoring Needs** (Arthur)

10:45am – 11:00am *Break and Posters*

11:00am – 11:15am – Team H3 – **Root and Fungal Ecology at SSHCZO** (Szink)

11:15am – 11:20am – Discussion of H3

11:20am – 11:35am – Team H4 – **Geophysical investigations of soil macropores together with soil climate monitoring at Shale Hills and Garner Run** (Guo)

11:35am – 11:40am – Discussion of H4

11:40am – 11:55am – Team H5 – **Developing Regolith-PIHM: a regolith formation model at the hillslope scale** (Xiao)

11:55am – 12:00pm – Discussion of H5

12:00pm – 12:15pm – Team H6 – **Flowpath controls on concentration-discharge relations: a comparative look at headwater streams overlying sandstone and shale bedrock** (Hoagland)

12:15pm – 12:20pm – Discussions of H6

12:30pm – 1:30pm *Lunch and Discussions and Posters – 2217 EES Building*

> *Poster Session Available during Breaks and Lunch:*

- **Complex water quality data along Black Moshannon Creek** (TSN Outreach)
- **Using a spatially-distributed hydrologic biogeochemistry model to study the spatial variation of carbon processes in a Critical Zone Observatory** (Shi et al.)
- **Using LiDAR to model vegetation structure and above-ground carbon storage in the critical zone** (Brubaker and Johnson)
- **Investigating inorganic and organic solute transport in the Shale Hills catchment** (Herndon et al.)
- **Fine-scale aboveground carbon distribution of forests with varying lithology: A comparison across two watersheds** (Johnson)
- **Regional comparisons of forest composition and species dynamics on shale and sandstone lithologies across the Ridge and Valley Province in Pennsylvania** (Reed and Kaye)

- **Water-regolith-energy Interaction in Landscape Evolution and Its Influence on Forming Asymmetric Landscape: An Example from the Shale Hills Critical Zone Observatory of Central Pennsylvania** (Zhang et al.)
- **Using WITCH to examine how today's Critical Zone architecture governs the geochemical evolution of a shale catchment** (Sullivan et al.)
- **Microclimate controls on weathering: Insights into deep critical zone evolution from seismic refraction surveys in the Susquehanna Shale Hills Critical Zone Observatory** (West et al.)
- **Hydro-Climatic Factors Affecting Dissolved Organic Matter Variability in Precipitation at the Shale Hills Critical Zone Observatory** (Iavorivsha et al.)
- **Identity of host tree species may not control the community composition of ecto- and arbuscular mycorrhizal fungi** (Chen et al.)
- **Modeling Soil-Landscape and Its Evolution in the Shale Hills Catchment** (Jiang et al.)
- **Soil Hydrologic Properties in Shale Hills and Garner Run** (Pecce et al.)
- **The activity of deep roots in bedrock fractures at Susquehanna Shale Hills Critical Zone Observatory, USA** (Hasenmueller et al.)
- **Characterizing subsurface lithology and processes at the Susquehanna Shale Hills CZO using multi-scale near-surface geophysical measurement** (Mount et al.)

1:30am – 1:50pm – **Instrumentation at SSHCZO** (Forsythe)

1:50 pm – 2:05 pm – Team H7 – **First steps towards a SSHCZO carbon data assimilation system** (He)

2:05pm – 2:10pm – Discussion of H7

2:10 pm – 2:25 pm – Team H8 – **Using the COsmic-ray Soil Moisture Observing System to understand the hydrological response at Garner Run** –Shi/Xiao

2:25 pm – 2:30pm – Discussion of H8

2:30pm – 2:45pm – Team H9 – **Element losses as particles moving through the subsurface: an implication for geochemistry mass balance** (Kim)
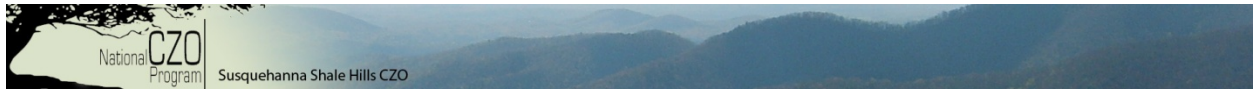
2:45pm – 2:50pm – Discussion of H9

2:50pm – 3:10pm – Collaborations and Outreach Opportunities (Joshua Potter, SCEC)

3:05pm – 3:10pm – Discussion of collaborations

3:10pm – 3:25pm – **Development of the CZO agricultural catchment** (Russo, Forsythe)

3:25pm – 3:30pm – Discussion of Ag Site
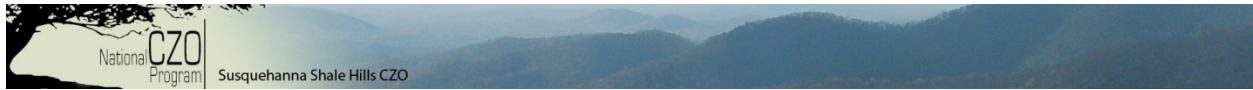
3:30pm – 4:00pm *Break and Posters*

4:00pm – 5:00pm – Discussion: Intra – CZO and Inter – CZO Science Opportunity (pop-ups welcome)

Facilitator – Ken Davis; Notes – Sue Brantley

5:00pm – 5:30pm – Feedback from Jorden Hayes – Observations of the SSHCZO

6:00pm – Happy Valley Brewing Company – for Happys

Wednesday, May 18th – travel day or additional meetings with PSU faculty/students

The 9 original hypotheses

H1 - *Feedbacks among frost shattering, weathering reactions, and the evolution of topography have resulted in an asymmetric distribution of fractures that in turn controls the observed differences in fluid flow in the subsurface between the sun-facing and shaded sides of catchments within Shale Hills and much of the Susquehanna River Basin. (DiBiase, Kirby, Bierman, Singha, Brantley, Lin)*

H2 – *The distribution of weathering reactions across a landscape can be described as a function of biotic and abiotic production and consumption of acids (CO_2, DOC) and O_2. (Kaye, Brantley, Eissenstat, Li)*

H3 – *Trees with deeper roots (oaks) are associated with less frequent tree throw, slower hillslope erosion rates, fewer vertical macropores, faster weathering at depth, and deeper regolith than trees with shallower roots (maples). (Eissenstat, Davis, Kaye, Brantley)*

H4 – *Macropores are important in controlling fluid flow and chemistry in soils derived from various lithologies, but the nature and effects of these macropores differ significantly among shale, calcareous shale, and sandstone. (Lin, Duffy, Eissenstat, Davis)*

H5 – *Greater evapotranspiration on the sunny, north side of Shale Hills means that less water recharges to the stream, explaining why Mg and other cations are less depleted in the regolith on the north compared to the south hillslopes. (Li, Brantley, Kaye, Shi)*

H6 - *Ions that are released quickly from ion exchange sites (Mg, Na, K) throughout the catchment demonstrate chemostatic behavior (~constant concentration in the stream), whereas Fe, Mn, and DOC concentrations vary with changes in watershed-stream connectivity. (Russo, Brantley, Li, Kaye, Shi)*

H7 - *Land-atmosphere fluxes of carbon (C)and water, ground-water hydrology, and ecosystem change are coupled processes at time scales of months to decades. This coupling varies with the lithology and land use and position on the hillslope. (Davis, Shi, Eissenstat, Duffy, Lin, Kaye)*

H8 - *Co-located, intensive, relocatable measurements of soil moisture, tree sap flux, sapwood area, LAI, ground water depth, temperature, ^{18}O and D/H along with a 4-component radiometer, laser precipitation monitor and landscape-level soil moisture (COSMOS) can be assimilated within a multi-scale distributed modeling framework to project physical processes from Shale Hills to Shavers Creek to YWC and Snake Creek watersheds. (Shi, Duffy, Davis, Eissenstat, Lin)*

H9 - *Increasing atmospheric CO_2 in the future will cause higher temperatures and faster weathering of clays in the catchment, increasing streamwater solute loads. (Brantley, Godderis, Li, Duffy, Davis)*
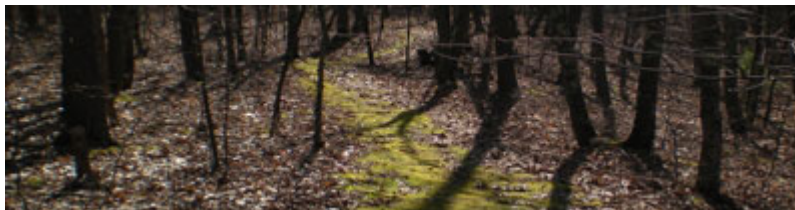
Porosity production and distribution in the deep critical zone at the Southern Sierra Critical Zone Observatory, California and the Laramie Mountains, Wyoming

Jorden Hayes[1,2]; Steve Holbrook[2]; Cliff Riebe[2]; Brady Flinchum[2]; Brad Carr[2]; Pete Hartsough[3]; Daniella Rempe[4]; Chris Novitsky[2]; Janet Dewey[2]

[1]Dickinson College, Department of Earth Sciences, Carlisle, PA; [2]Wyoming Center for Environmental Hydrology and Geophysics, University of Wyoming, Laramie, WY; [3]University of California-Davis, Department of Land, Air, and Water Resources, Davis, CA; [4]University of Texas at Austin, Department of Geological Sciences, Austin, TX

In the deep critical zone, chemical and physical processes generate pore space that allows for infiltration and storage of meteoric water. Pore space may be generated by chemical mass losses as CO_2 and O_2 contained in meteoric water reacts with surrounding rock. Porosity may also be generated through physical processes such as volumetric expansion and the fracturing of intact bedrock. Understanding these processes and their relative importance is challenging because it is dependant on the availability of boreholes and/or geophysics. I will present results from two studies that characterize landscape scale variations in chemical and physical processes by combining borehole and geophysical measurements. Results from both study sites underscore the interplay between chemical and physical processes in shaping deep critical zone architecture.

In the Blair Wallis catchment of the Laramie Mountains, Wyoming, borehole measurements provide evidence that seismic velocities increase with depth primarily due to decreasing fracture density. Moreover, weathered zones, inferred from optical images, are concentrated along fracture planes. Our geophysical results suggest that topographic stresses in combination with regional tectonic stresses control the distribution of fractures. This observation is supported by borehole measurements, which show that fracture density not only decreases with depth but also is lower beneath valleys than ridges. Our analysis of fracture density incorporates not only the total number of fractures, but also fracture aperture.

In the Southern Sierra Critical Zone Observatory, California, geochemical measurements of borehole samples show that volumetric strain dominates over chemical mass losses in producing porosity in saprolite. Our results from cores show that porosity decreases with depth from 0.64 to 0.35 in the upper 11 meters of saprolite. Although rock physics models of seismic velocities correctly predict porosity variations, they cannot distinguish porosity produced by chemical mass loss from porosity produced by physical strain. To overcome this limitation, we quantified bulk density and immobile element concentrations in our samples of saprolite. We found that volumetric strain decreases with depth from 1.29 to 0.26. Conversely, the overall mass loss due to chemical weathering shows no trend with depth. Together these results suggest that the changes in porosity are due to physical rather than chemical processes. By quantifying the relative contributions of chemical mass loss and volumetric strain to the production of porosity, seismic velocities can be used to create maps of volumetric strain across the hillslope.
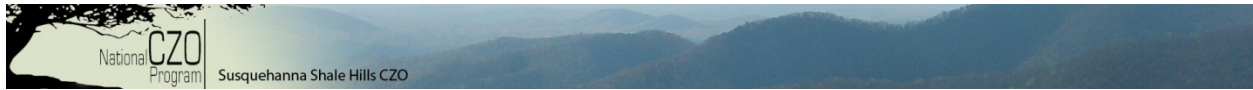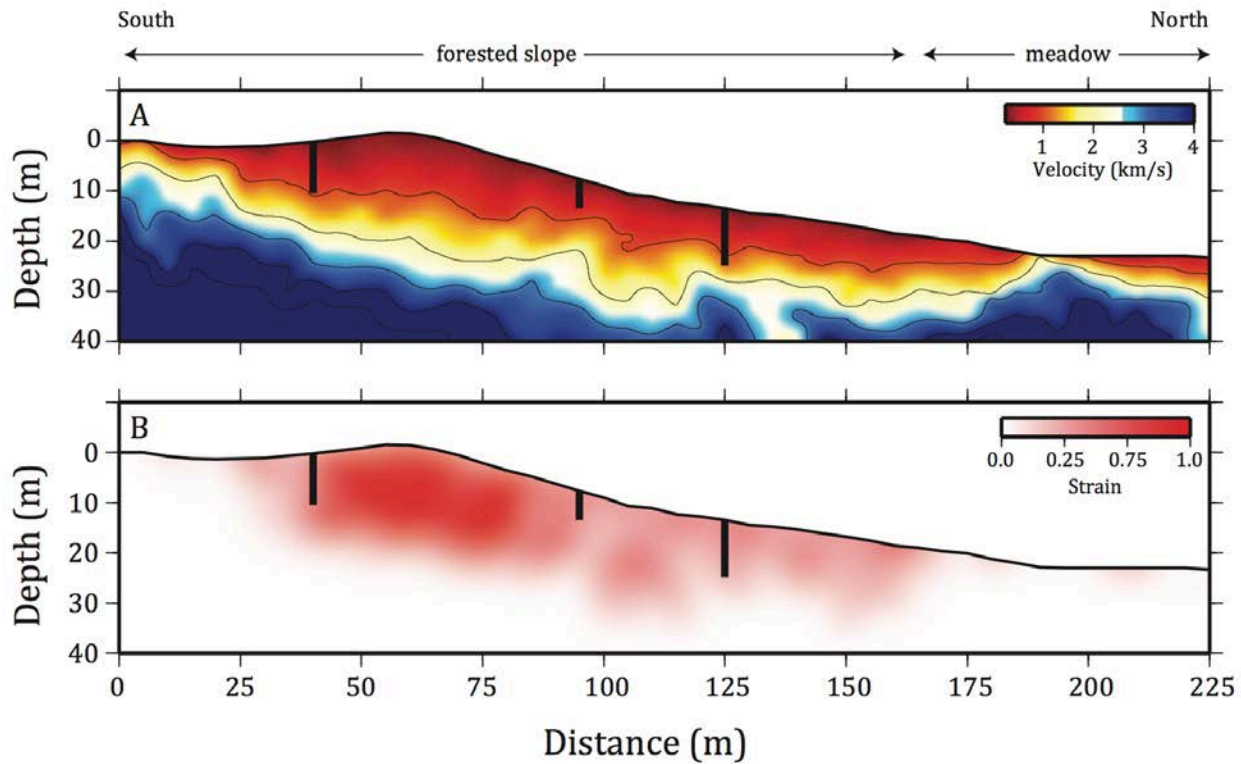
Figure: Traveltime tomography model of p-wave velocities (A) from a seismic refraction survey across a forested slope and meadow in the SSCZO (Holbrook et al., 2014). Maximum volumetric strain across the landscape (B) calculated from porosities inferred by seismic velocities (A). The contribution of chemical mass losses to the overall porosity is accounted for in this model; we assumed 22% average mass loss inferred from mass transfer coefficients. Push core locations shown as black lines in A & B.

Detecting critical zone response to perturbations by climate and base level in central Pennsylvania using *in-situ* produced 10-Be

A. Denn[1] and P. Bierman[2]

[1]Department of Geology, University of Vermont, 180 Colchester Avenue, Delehanty Hall, Burlington, VT 05405; 2Department of Geology and Rubenstein School of Environment and Natural Resources, University of Vermont, Delehanty Hall, 180 Colchester Ave, Burlington, VT 05405

The change of topography with time and the consequent structure of the critical zone is dependent on the production and transport of regolith. We use measurements of *in-situ* cosmogenic ^{10}Be to investigate regolith in central Pennsylvania, a landscape shaped by glacial/interglacial climate cycles and changes in base level. Here, we present updates and preliminary data on our three sites, Shavers Creek watershed, Young Womans Creek watershed, and Hickory Run boulder field. Sample preparation is near completion, and isotopic analyses will be completed in summer 2016.

The upper reaches of Shavers Creek watershed are underlain by sandstone weathered and transported significantly by frost-driven processes that are not currently very active. At this site, we strive to understand the influence of periglacial activity on the generation and movement of regolith downslope on Tussey Mountain and Leading Ridge. We analyze amalgamated soil pit samples, boulder transects, stream sediments, and valley bottom colluvium from Leading Ridge, as well as one mid-slope amalgamated soil pit sample from Tussey Mountain. Preliminary results from boulders on Leading ridge show effective ridgetop exposure ages of ~50 ky, and valley bottom ages of ~100 ky, consistent with known summit erosion rates in the Appalachians (Hancock and Kirwan, 2007) and suggesting downslope transport. Garner Run stream sediments suggest erosion rates of ~8m/My, also consistent with Appalachian erosion rates measured elsewhere (Portenga et al., 2013). Garner Run stream sediments have slightly lower ^{10}Be concentrations than samples from the lowest soil pits, suggesting that the channel contains a mixture of colluvium derived from the entire slope.

Young Womans Creek is a deeply incised sandstone basin where we investigate the role of non-equilibrium topography on the rates of regolith production at a basin scale. Here, we will focus on the influence of fluvial incision into the landscape, contrasting erosion rates in undissected uplands with those in incised valleys. Preliminary data suggest that basin erosion rates range from 13 to 38 m/My (again similar to rates elsewhere in the Appalachians). Erosion rates are lowest in small, gently sloping subwatersheds upstream of knickpoints, and are highest in the middle reaches of the basin, consistent with a transient wave of incision propagating upstream.

Hickory Run Boulder field is the largest of its kind in the eastern United States. This enigmatic, 1-km-long field of boulders has been attributed to frost-induced processes during the last glacial maximum, when the Laurentide ice sheet margin was nearby. Preliminary results suggest the field is much older than previously thought, with our first four measurements showing exposure ages between 200-400 ky implying that the boulder field integrates the effects of multiple glacial and interglacial cycles.

# Quaternary climate controls on critical zone form and process at Garner Run

Joanmarie Del Vecchio[1] and Roman A. DiBiase[1,2]

[1]Department of Geosciences, Pennsylvania State University, University Park, PA 16802
[2]Earth and Environmental Systems Institute, Pennsylvania State University, University Park, PA 16802

The topography, soils, and colluvial stratigraphy of slowly eroding landscapes records the history of critical zone processes integrated over multiple glacial-interglacial cycles throughout the Quaternary. In the sandstone-underlain Garner Run subcatchment of the Susquehanna Shale Hills Critical Zone Observatory, well-preserved periglacial landforms point to significant Pleistocene landscape alteration, and limited modification since, similar to observations throughout much of central Pennsylvania. However, the relative rates of periglacial versus temperate erosion and sediment transport processes are poorly constrained. Additionally, due to sensitivities to temperature and moisture availability, periglacial hillslope processes are likely to be strongly aspect-dependent and may influence modern fluxes of water, solutes, and sediment.

Here we present initial results from LiDAR topographic analysis, field mapping of colluvial soils, and valley-bottom drill-core observations. Through reconstruction of original fold geometries in the synclinal catchment, and through the position and orientation of clearly defined gelifluction lobes, we infer significantly greater sediment flux from south-facing hillslopes, in agreement with regional patterns. Additionally, the grain size and texture of colluvial soils is strongly aspect-dependent, with south-facing slopes exhibiting coarser and rockier surfaces, including open boulder fields. Results from groundwater well drilling indicate the presence of at least 10 m of sandy and blocky colluvial fill in the unchanneled headwater valley floor of Garner Run. Topographic analysis indicates average valley fill thickness of 10-15 m, corresponding to 2-3 m of bedrock lowering on hillslopes, and potentially recording 10^5-10^6 years of hillslope sediment production, spanning multiple climate cycles. Further clarification of the timing of colluvial deposition will come from cosmogenic ^{26}Al/^{10}Be burial dating of quartzite clasts recovered from drilling.
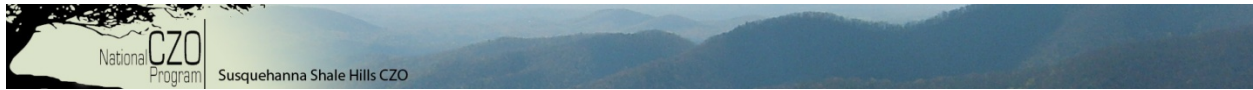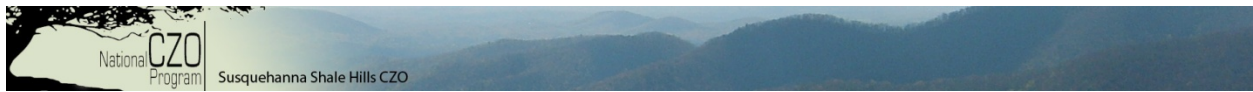
Update on H2 – *The distribution of weathering reactions across a landscape can be described as a function of biotic and abiotic production and consumption of acids (CO2, DOC) and O2*. PI contributors: Kaye, Brantley, Eissenstat, Li; Postdocs and students: Hill, Gu, and Hasenmueller.

This team focuses on field observations of soil pore fluid chemistry and its relation to weathering rates, roots, and soil microbial activity. Our field measurements will inform model development associated with H5 and H7. Likewise, our soil-based measurements can be linked with observations of trees and streams in H3 and H6, respectively for analyses at the catchment scale. Over the past year we have focused on two major efforts: monitoring soil pore chemistry in the Garner Run and Shale Hills catchments, and measuring soil and plant nutrient concentrations in 4 additional sandstone and shale sites.

Over the past year we established GroundHOG soil pore chemistry monitoring sites at Shale Hills and Garner Run. In each catchment, pits were excavated at a ridgetop, south-facing midslope, north-facing midslope, and valley floor positions. All pits in Garner Run were sampled for bulk soil chemistry at multiple depths. All pits in both catchments were instrumented at multiple depths with tubes to manually sample soil gas concentrations, lysimeters to sample pore chemistry, and waveguides to manually sample soil moisture. At midslope pits (2 per catchment) sensors were installed to continuously monitor soil pCO_2 and pO_2. We have been sampling these GroundHOG sites fortnightly during the growing season and monthly during winter, but because of the newness of the installations and sporadic power, we do not yet have a clear picture of differences in pore chemistry among the GroundHOG locations. We expect this picture to emerge over the 2016 growth season when all GroundHOG samplers and sensors will be operational for both catchments.

To determine whether differences in soil chemistry between shale and sandstone sites affect plant and microbial activity we sampled indices of nutrient availability at midslopes of Garner Run, Shale Hills, and 4 additional catchments from each lithology (sandstone vs shale). At Garner Run and Shale Hills we conducted root-ingrowth core studies to determine root growth responses to nutrient additions. There were no clear responses by roots to different nutrient additions, however, over the summer-long incubation period, extractable Ca concentrations in soils from Shale Hills increased substantially compared to Garner Run. We also examined nutrient resorption by leaves of red maple and red oak as an index of nutrient limitation to trees. Preliminary results suggest that for Oak (no pattern in Maple), P resorption is lower on sandstone than on shale, which may reflect lower P availability on the shale.   We will continue to evaluate nutrient availability at these 10 sites in the 2016 growing season.

We expect to complete the 2016 growing season with a robust dataset of concentrations of CO2, O2, and nutrients at the GroundHOG sites and additional shale and sandstone catchments. From these data we hope to gain an understanding of how acid and redox weathering differ on the two lithologies with implications for nutrient availability.
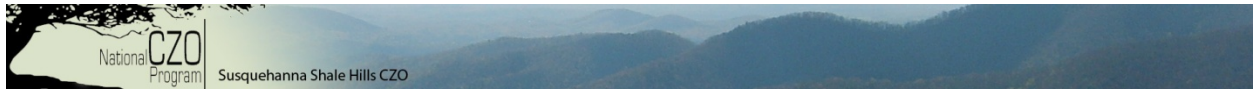
CZO Data Management and Monitoring Needs: Are we monitoring what we need and who is in charge of each monitoring target?

Dan K. Arthur

Earth & Environmental Systems Institute, The Pennsylvania State University, University Park, PA 16802

Investigators in the Susquehanna Shale Hills Critical Zone Observatory collect and produce a large amount and wide variety of data. These data include observations and measurements of meteorology, hydrology, soil and water chemistry, geophysics, and biological processes. A centralized data management process has been developed that will allow researchers efficient access, control, processing, sharing, archiving, and other uses of these diverse datasets. The process described covers data management for current and future uses of the Shale Hills field area, as well as for other locations being set up in the Shavers Creek watershed (Garner Run/Sandstone Site, Shavers Creek). It also conforms to national CZO network goals including sharing of data and/or metadata with the San Diego Supercomputing Center (SDSC) Geoportal and the CUAHSI Hydrologic Information System (HIS) where possible and appropriate. Current status of available CZO data is also described. Datasets available on the local PSU-hosted web site are also available through the national CZO network web site at criticalzone.org.

Sensor-based data from Shale Hills are transmitted in batches to a SQL Server database currently storing and archiving data: Eddy Covariance (Flux Tower); 10-minute, Hourly, and Daily Precipitation; 4-Component Radiation; other Meteorology. Other data currently require site visits to download due to wireless communication and access issues. Web pages for accessing batch sensor data, including controlled access for embargoed data, will be demonstrated.

Root and Fungal Ecology at SSHCZO

Ismaiel Szink[1,2], David Eissenstat[1,2], Tom Adams[1], Weile Chen[1,2], and Lexie Orr[1,2]

[1]Department of Ecosystem Science and Management, Pennsylvania State University, PA, USA

[2]Intercollege Graduate Degree Program in Ecology, Pennsylvania State University, PA, USA

(1) In the majority of terrestrial biomes 80% of plant roots are found in the top 20 cm of soil, and these results conform to observations in soils derived from shale. Observations in sandstone derived soil, however, found root distributions of ~25% at depths of 20-40 cm, compared to ~15% in shale. DNA extraction and fragment amplification techniques (Barcoding) are being performed to identify roots collected from different depths to plant species. This analysis will help determine the role of niche partitioning among species in root distribution across differing lithologies.

(2) Topographic features such as slope position are thought to have a major impact on root- soil interactions. Weekly measurements of soil respiration, water content, and temperature were taken at 200 locations throughout the Shale Hills catchment, and initial findings show that hillslope swales exhibited higher seasonal respiration rates than midslope planar, valley floor, and ridge top positions. Root length density variability, however, could not be explained by slope position.

(3) In temperate forests like Shale Hills, most tree species form symbioses with either arbuscular mycorrhizal (AM) or ectomycorrhizal (EM) fungi. When foraging for heterogeneously distributed nutrients in the soil, tree species differ in their foraging ability primarily by varying the precision of either root proliferation (AM trees) or mycorrhizal hyphal proliferation (EM trees) in nutrient "hotspots". These distinct acquisition pathways between contrasting mycorrhiza types suggest that the relative dominance of AM or EM tress in a forest may play a key role in the biogeochemical cycles of temperate forest ecosystems.

Geophysical investigations of soil macropores together with soil climate monitoring at Shale Hills and Garner Run (Team personnel: Henry Lin, Li Guo, Yuan Wu, Isaac Hopkins, Jonathan Nyquist, Laura Toran, Dave Eissenstat, Tess Russo, Ken Davis)

Macropores are important in controlling fluid flow and chemistry in soils derived from various lithologies, but the nature and effects of these macropores differ significantly among various geologies and soils. We have continued geophysical investigations using ground-penetrating radar (GPR) and electromagnetic induction (EMI) to detect and image soil macropores and related soil hydrologic phenomena in the SSHCZO. Time-lapse GPR surveys together with infiltration experiments provide nondestructive means to map lateral macropore flow pathways in the hillslopes. In addition, we have used field infiltrometers to quantify macropore water flow rate in various soils in the SSHCZO.

Soil climate, mainly referring to soil moisture and soil temperature, is of great importance to understand subsurface hydrology, energy balance, biogeochemical dynamics, and nutrient cycling. Based on the soil climate monitoring using the sensor arrays installed in both the Shale Hills and the Garner Run, we have assessed the variability of soil climate across space (such as different slope aspects, hillslope types, landform units, and soil depths) and time (from short-term diurnal cycles to long-term seasonal and annual variations). We have further examined the correspondence of soil moisture and temperature and detected a significant generally negative relationship between them in the summer and autumn months, while that relationship disappeared during the winter and spring months.

Figure 1: A horizontal slice through the 3D interpolated background GPR data at the depth of the saprock shows lineations, evidence of bedding fabric (dashed lines) that is consistent with the orientation seen in the excavation.
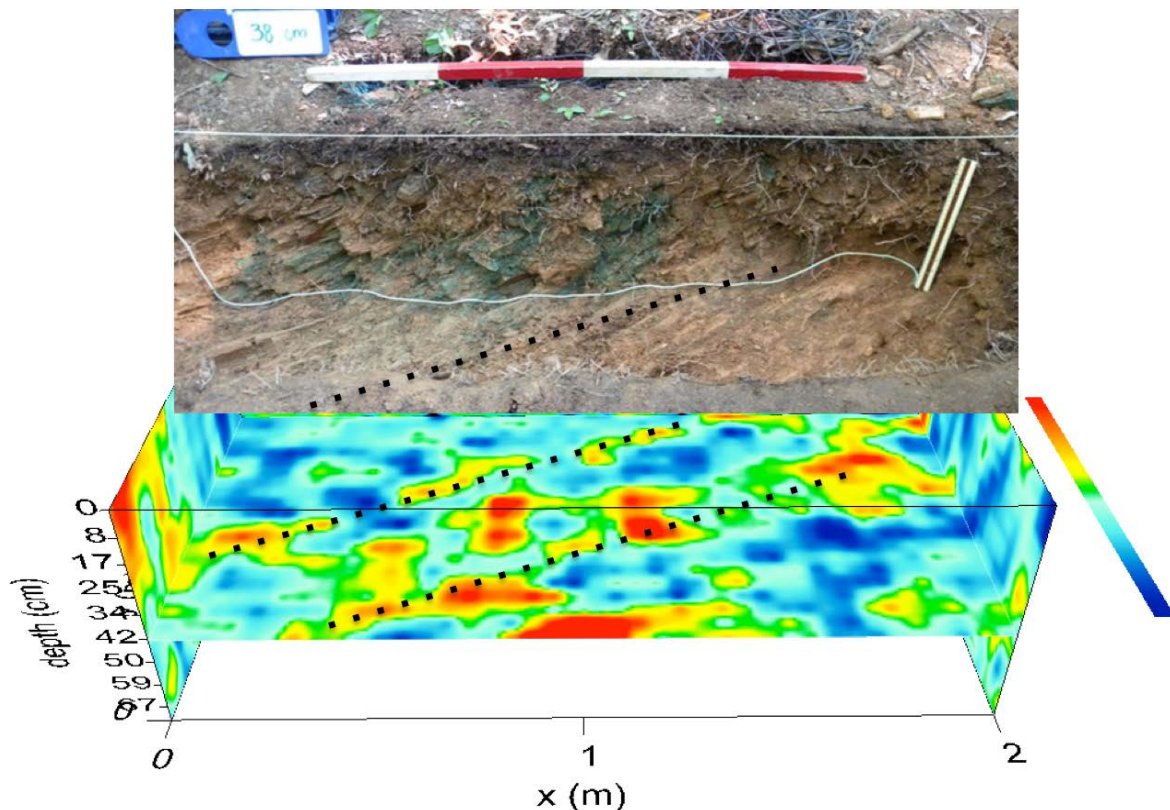
Developing Regolith-PIHM: a regolith formation model at the hillslope scale

Dacheng Xiao[1], Yuning Shi[2], Li Li[1]

Chemical weathering processes transform rock to soil and determines soil texture, bedrock depth, and other hydrological properties. Traditional geomorphological models simulate the transformation using empirical soil production function without incorporating physically-based reactive transport processes. Existing chemical weathering model considers reactive transport processes with simplified hydrodynamics conditions without integrating the evolving regolith properties during weathering. Such simplification misses important feedback loops between hydrological and chemical weathering processes over geological time scales. In this work, we proposed a chemical weathering model with tightly coupled reactive transport and physically-based hydrologic and land surface processes to understand and predict the regolith formation at the hillslope scale.

The hillslope model will represent the geomorphologic, hydrologic, and lithological properties of the 3D catchment and include detailed hydrological processes, chemical weathering, soil erosion, uplift, and the dust deposition. Regolith-PIHM will incorporate detailed water hydrodynamicsas follows: 1) Flux-PIHM will be run to provide seasonal averaged water fluxes including overland flow, vertical flow in unsaturated zones, and lateral flow in saturated zone; 2) the Richard's equation will be used to distribute vertical flow within regolith layers; 3) the reactive transport module will be run for chemical weathering based on calculated hydrologic condition from previous steps with gradually evolving mineral composition, porosity and permeability; 5) soil and rock properties will be updated in the calculation of water fluxes in Flux-PIHM when the changes are sufficiently large (Figure 1). By coupling the hydrologic and chemical weathering processes, Regolith-PIHM will be able to simulate dynamics of regolith formation and illuminate key controls of regolith formation over geological time scales.
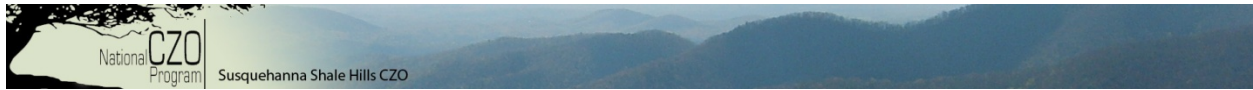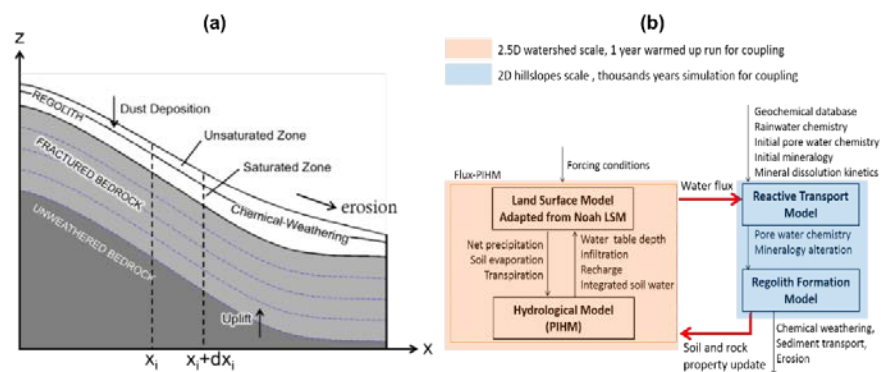

Figure 1 a. Structure and main processes of regolith formation model; b. Strategy for coupling regolith formation model with the Flux-PIHM and reactive transport model.

[1] John and Willie Leone Family Department of Energy and Mineral Engineering, The Pennsylvania State University.
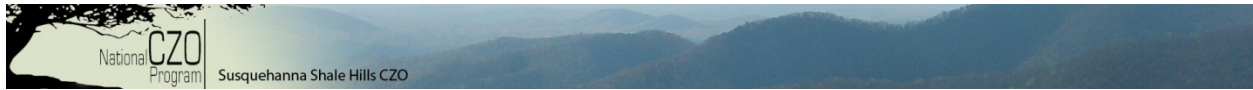[2] Department of Ecosystem Science and Management, The Pennsylvania State University.

Flowpath controls on concentration-discharge relations: a comparative look at headwater streams overlying sandstone and shale bedrock

Beth Hoagland[1], Tess Russo[1], Xin Gu[1], Sue Brantley[1,2]

[1]Department of Geosciences, Pennsylvania State University, University Park, PA 16802
[2]Earth & Environmental Systems Institute, Pennsylvania State University, University Park, PA 16802

In areas unaffected by human disturbance, lithology, regional groundwater inflow, and the extent of hyporheic exchange strongly influence water chemistry. Identifying zones of hyporheic exchange, which involves mixing of shallow groundwater and surface water, is often challenging in headwater environments. This study combines Fiber-Optic Distributed Temperature Sensing (FO-DTS), tracer injection tests, and geochemical methods to map groundwater-surface water interactions along a first-order, sandstone stream in the Appalachian Mountains of central Pennsylvania. The objectives of this study were to (a) identify the primary influences on stream solute dynamics in headwater streams overlying shale or sandstone bedrock, and (b) determine the relative contribution of groundwater discharge and hyporheic exchange on stream water concentration-discharge relations. Concentration-discharge relationships (CQ) and hyporheic characteristics were determined for a headwater stream overlying sandstone bedrock (Garner Run), and compared to a nearby headwater catchment overlying shale bedrock (Shale Hills). Results suggest that CQ in the sandstone catchment is controlled by cation exchange reactions in the hyporheic zone. On the other hand, CQ within the shale catchment is dependent on swale-stream connectivity. Evidence of organo-mineral associations in the hyporheic zone of the sandstone stream indicates the importance of in-stream dynamics on CQ trends in solute-limited catchments.

Instrumentation at SSHCZO

Brandon Forsythe

Earth & Environmental Systems Institute, Penn State University

Instrumentation for SSHCZO is continuing to move forward with new sensor systems being deployed at Shale Hills, along Shavers Creek and at Garner Run. A new flume has been installed in the fall of 2015 in Shale Hills to measure discharge along with conductance and turbidity. Soil moisture and soil gas sensors are installed along a 4-location catena at Shale Hills and the new sandstone forested site. Sap-flow, dendrometer bands, leaf litter traps, and leaf area index measurements are planned at the Shale Hills and sandstone sites. A cosmic-ray probe has been installed in Garner Run in Rothrock State Forest. Flux tower instruments to be installed at the sandstone site at the radio towers on Tussey Mountain continues to be problematic in obtaining additional permits. Streamflow and water chemistry sensors continue to be in operation along Shavers Creek above and below Lake Perez, Shavers Creek Outlet, and Garner Run sites. An agriculture site is being planned. These sensors and our future data collection regime will be presented.

First steps towards a SSHCZO carbon data assimilation system

Yuting He[1], Kenneth Davis[1,2], Yuning Shi[3], Dave Eissenstat[3,4], Jason Kaye[3]

[1]Department of Meteorology, Pennsylvania State University, University Park, PA 16802

[2]Earth & Environmental Systems Institute, Pennsylvania State University, University Park, PA 16802

[3]Department of Ecosystem Science and Management, Pennsylvania State University, University Park, PA 16802

[4]Intercollege Graduate Degree Program in Ecology, Pennsylvania State University, University Park, PA 16802

The terrestrial carbon cycle remains a large source of uncertainty in the current and future global carbon balance, and thus in the projection of future climate. While many ecosystem experiments, field observations, and modeling studies have explored the response of the terrestrial carbon cycle to changing climate and CO_2, little study has been devoted to this topic in the context of complex topography, i.e. the distributions of terrestrial C pools with slope position, and their responses to future climate change.

We are testing a coupled water-carbon-nitrogen model, Biome-BGC, at Shale Hills, against multivariate observations, to explore its ability to reproduce the spatial structures of carbon pools in the watershed. Watershed hydrology is being imposed from observations. The carbon cycle is being tested with observations including aboveground carbon stocks and productivity, soil carbon stocks, soil respiration, leaf area index and catchment-wide net ecosystem-atmosphere carbon fluxes. Observations are being expanded to include soil CO_2 efflux, root growth and soil and leaf chemistry.

With the help of the modeling system, we bring the intensive and diverse observations together to draw an integrated picture of the watershed carbon cycle. Model results suggest that Biome-BGC is able to reproduce the spatial structure of carbon distributions in the watershed to a certain degree with very limited parameter optimization. The modeled structure results from complex interactions among topography, soil conditions, hydrology and the nitrogen cycle.

Continued study is needed to evaluate the watershed carbon-nitrogen-water interactions more fully, and to explore parameter optimization to improve the model performance. Observations of the nitrogen cycle are needed to evaluate the simulated N cycle. Additionally, a model sensitivity analysis is needed to identify the most important model parameters, and what kind of measurements can best constrain the model. This optimized modeling system could then be tested under future climate in complex terrain, and help us better understand the feedbacks between terrestrial carbon cycle and the changing climate.

Using the COsmic-ray Soil Moisture Observing System to understand the hydrological response at Garner Run

Dacheng Xiao[1], Yuning Shi[2], Li Li[1]

Soil moisture is an essential variable in hydrologic, land-surface and reactive transport processes. The intermediate-scale cosmic-ray soil moisture observing system (COSMOS) provides average soil water content measurement over a footprint of 0.34 km² with depths up to 50 cm and an innovative means to understand watershed water dynamics. In this study, the COSMOS observations are used to compare with the predicted soil moisture in the top 10 cm from the Flux-PIHM at Garner Run. The a priori input data (e.g., soil map and parameters, land cover map, topography, and meteorological forcing) are from national dataset and the calibration coefficients for Shale Hills were used. The model-data comparison (Figure 1a) shows that there is a significant bias between simulated and observed top layer soil moisture. It suggests that the rock volume at Garner Run needs to be taken into account to improve Flux-PIHM simulation at Garner Run. Differences in soil properties and land cover properties between Shale Hills and Garner Run may also contribute to the model error.

We use the Flux-PIHM ensemble Kalman filter data assimilation system (Flux-PIHM EnKF system) to examine the effectiveness of COSMOS in constraining Flux-PIHM parameters. A series of observing system simulation experiments (OSSEs) are carried out assimilating various combinations of observations to estimate different model parameters, including van Genuchten parameters α and β, porosity, infiltration hydraulic conductivity, macropore depth. The results of OSSEs show that although the assimilation of COSMOS measurements can improve the model prediction of top layer soil moisture (Figure 1b), it is not effective enough to constrain the key soil parameters like van Genuchten α and β.
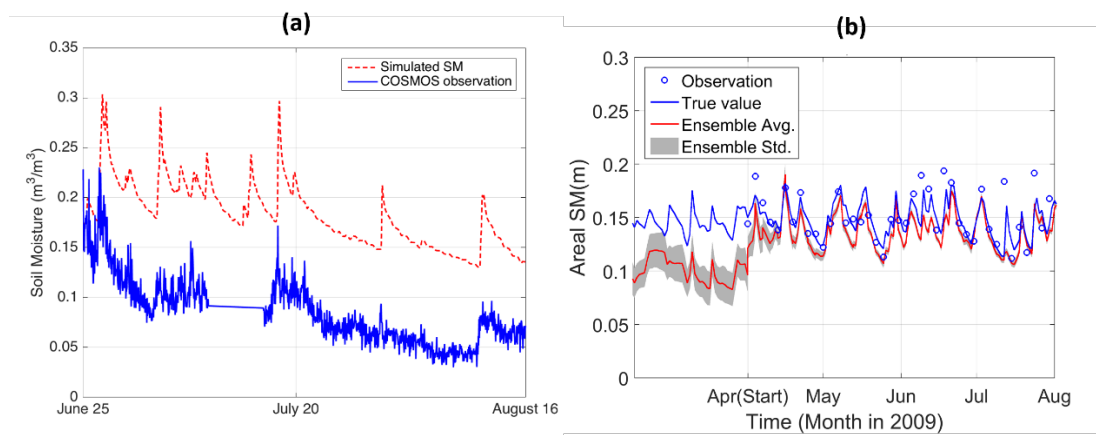

Figure 2 a) Comparision of soil water content between Flux-PIHM (top layer with a thickness of 10 cm) and COSMOS at the Garner Run watershed from 25 June 2015 to 16 August 2015. b) Areal average soil moisture (top layer) prediction and EnKF analysis in an OSSE which assimilates synthetic COSMOS measurements.

[1]John and Willie Leone Family Department of Energy and Mineral Engineering, The Pennsylvania State University.
[2] Department of Ecosystem Science and Management, The Pennsylvania State University.

Element losses as particles moving through the subsurface: an implication for geochemistry mass balance

Hyojin Kim[1], Xin Gu[2], Wenjing Liu[3], Susan Brantley[1, 2]

[1]Earth & Environmental Systems Institute, Department of Geosciences, Pennsylvania State University, University Park, PA 16802

[2]Department of Geosciences, Pennsylvania State University, University Park, PA 16802

[3] Key Laboratory of Shale Gas and Geoengineering, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, China

Several indirect observations made in Shale Hills have suggested that a significant fraction of elements are transported out of the catchment as particle via subsurface flow paths. These observations contradict to the key assumption of geochemistry mass balance computation—net particle losses occur only via physical erosion at the surface. To directly test this hypothesis, we monitored the temporal variability of both solute and solid chemistry in groundwater and stream water at 7-10 hours intervals during hydrologically active periods e.g., snow-melting events or rainstorms. To collect water and particle samples, we employed ISCO automated water samplers and a gravitational filtration system, which filters water samples by gravity upon sampling; thus preserves both particle and water samples. Preliminary results showed that the dissolved Ca concentration (represents most solutes; Figure 1a) in stream display a typical chemostatic pattern; a weak negative correlation between solute concentrations and discharge. However, stream's dissolved Fe concentration (potentially represents the particle flux; Figure 1b) increased sharply at the beginning and end of the hydrologic events. Further investigations will be carried out to document the temporal variability of the morphology, mineralogical composition, and total elemental chemistry of the particle via a scanning electron microscope, an X-ray diffractometer, and a total acid digestion method, respectively. In the future, additional 2-3 rainstorm events will be monitored to identify the seasonal changes of solute and solid chemistry.
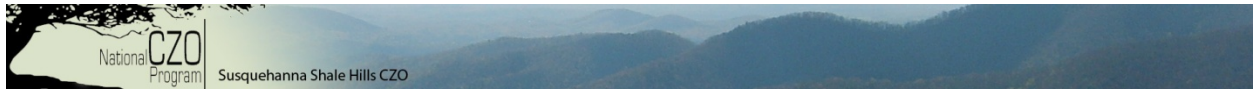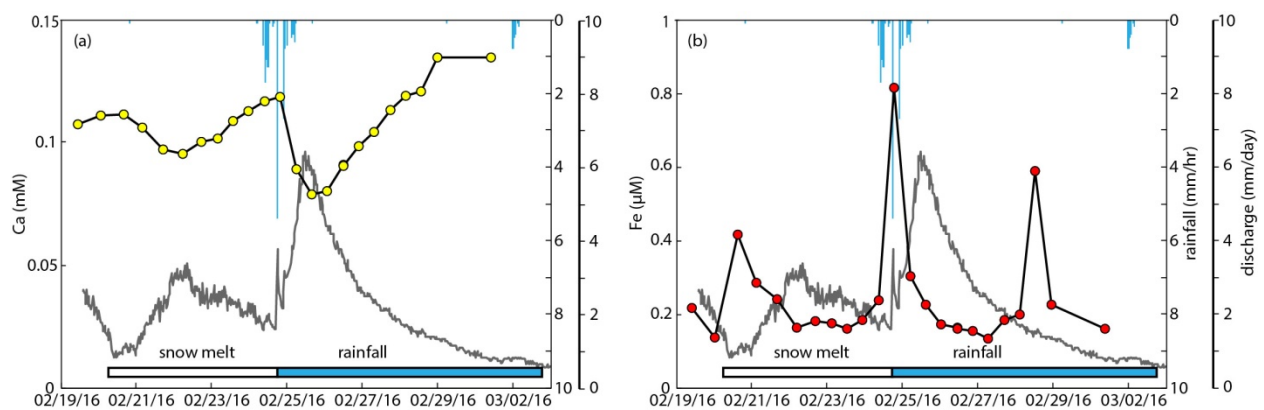

Figure 1. High-frequency (10 hr interval) time-series of the solute concentrations of (a) Ca and (b) Fe in the Shale Hills stream during a snow-melting event (2/22-2/24/2016) and a rainfall (2/25-3/2/2016;16mm).

Development of the CZO agricultural catchment

Tess Russo[1,2], Jason Kaye[3], and Brandon Forsythe[2]

[1]Department of Geosciences, Pennsylvania State University, University Park, PA 16802
[2]Earth & Environmental Systems Institute, Pennsylvania State University, University Park, PA 16802
[3]Department of Ecosystem Science and Management, Pennsylvania State University, University Park, PA 16802

We will provide an update on the status of the CZO agricultural catchment. The update will include a description of the potential sites, and an overview of proposed field instrumentation and data collection. We have selected potential sites on shale in the Shavers Creek watershed with agricultural activity, containing 1st order streams. Instrumentation at the agricultural-shale site will follow the catena plan used currently at Shale Hills and Garner Run. The measurements may be used to assess the impacts of agriculture on CZO processes, as compared to observations at Shale Hills. We will use the presentation time to confirm instrument deployment plans and field visitation schedules, so we can clearly communicate our intentions with the land owners. There will be an opportunity for discussion and modifications to the field plan.

Complex water quality data along Black Moshannon Creek

Lachlan Campbell[1], Isha Chakaborty[1], Riya Chakaborty[1], Zachiah Cook[1], Maria Duiker[1], Hannah Good[1], Andy Kim[1], Samuel Krantweiss[1], Kristen Lenze[1], Emily Lieb[1], Aaron Li[1], Toby Ma[1], Kacy Mann[1], Erica Mi[1], Lena Nyblade[1], Megan Petrine[1], Ben St. Pierre[1], Maria Rodriguez Hertz[1], Oliver Rose[1], Ethan Rowland[1], Farhan Talukder[1], Kathryn Thomas[1], John Donoughe[2], William Lukens[2], Yvonne Pickering[2], Eugene Ruocchio[2], Susan Brantley [3], Matthew Carroll[3], Brandon Forsythe[3], Anna Wendt[3], Jennifer Williams[3]

[1]Earth Science Learning Enrichment Students, State College High School, State College, PA 16801;
[2]Earth Systems Science Faculty Mentors, State College High School, State College, PA 16801;
[3]Earth & Environmental Systems Institute, Penn State University, University Park, PA 16802

*Abstrac*t:
  TeenShale Network (TSN) is a multi-year project aimed at monitoring changes, potentially from fracking, in the water quality of Black Moshannon Creek. The project engages students from State College Area High School with the Earth and Environmental Systems Institute (EESI) at Penn State University through authentic field research. The State College chapter currently includes students in grades eight through eleven. Students collect data and water samples with a multitude of instruments on full day trips overseen by members of the EESI. The water samples are analyzed by the LIME (Laboratory for Isotopes and Metals in the Environment) facilities at Penn State University. Data is then examined by students to monitor changes in water quality. TeenShale Network will continue to test, track, and evaluate the water quality of streams in Central Pennsylvania for the foreseeable future.
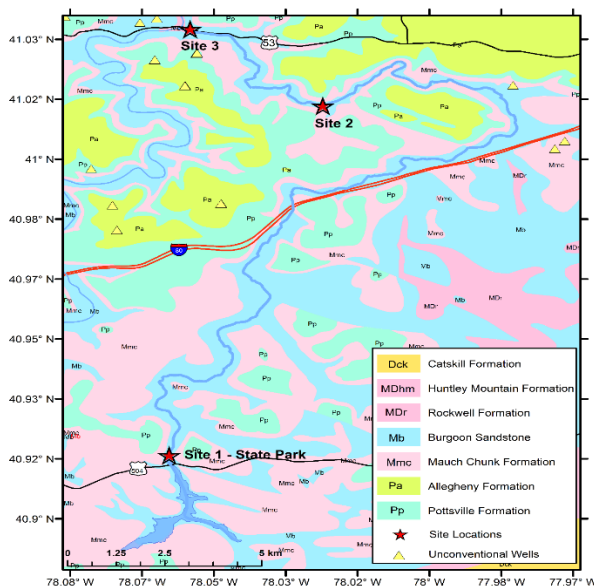
Map, courtesy of Pennsylvania Spatial Data Access (www.pasda.psu.edu), displays the three monitoring locations (red stars) for TeenShale Network and the locations of unconventional wells (yellow triangles). Well information from the PA DEP.

Using a spatially-distributed hydrologic biogeochemistry model to study the spatial variation of carbon processes in a Critical Zone Observatory

Yuning Shi[1], David Eissenstat[1], Kenneth Davis[2,3]

Forest carbon processes are affected by soil moisture, soil temperature, Nitrogen availability and solar radiation. Most of the current biogeochemical models are 1-D and represent one point in space. Therefore they can neither resolve topographically driven hill-slope soil moisture patterns, nor simulate the nonlinear effects of soil moisture on carbon processes. A spatially-distributed ecosystem-hydrologic model, Flux-PIHM-BGC, has been developed by coupling the Biome-BGC (BBGC) model with a coupled physically-based land surface hydrologic model, Flux-PIHM. Flux-PIHM incorporates a land-surface scheme (adapted from the Noah land surface model) into the Penn State Integrated Hydrologic Model (PIHM). Because PIHM is capable of simulating lateral water flow and deep groundwater, Flux-PIHM is able to represent the link between groundwater and the surface energy balance, as well as the land surface heterogeneities caused by topography.

Flux-PIHM-BGC model was tested at the Susquehanna/Shale Hills critical zone observatory (SSHCZO). The abundant observations at the SSHCZO, including eddy covariance fluxes, soil moisture, groundwater level, sap flux, stream discharge, litterfall, leaf area index, aboveground carbon stock, and soil carbon efflux, provided an ideal test bed for the coupled model. Model results show that the vegetation and soil
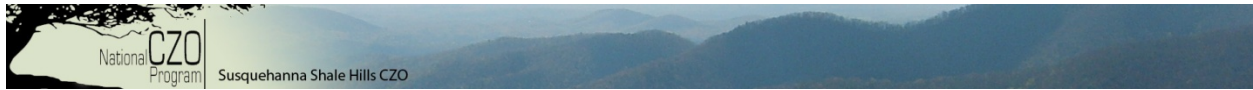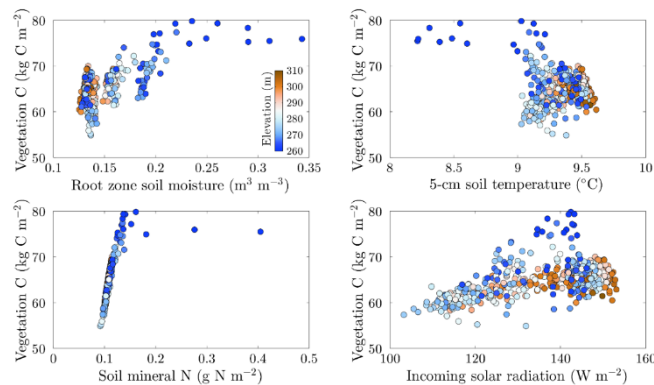

Figure 3 Annual average vegetation carbon plotted as functions of root zone soil moisture, soil temperature, soil mineral N, and incoming solar radiation from Flux-PIHM-BGC simulation. Each point represent on grid in the Shale Hills watershed model domain.

carbon distribution is primarily constrained by N availability (affected by N transport driven by topography), and also constrained by solar radiation and root zone soil moisture. The predicted vegetation and soil carbon distribution generally agrees with the macro pattern observed within the watershed. The coupled ecosystem-hydrologic model provides an important tool to study the impact of topography on watershed C processes.

---

[1] Department of Ecosystem Science and Management, The Pennsylvania State University.
[2] Department of Meteorology, The Pennsylvania State University.
[3] Earth and Environmental Systems Institute, The Pennsylvania State University.
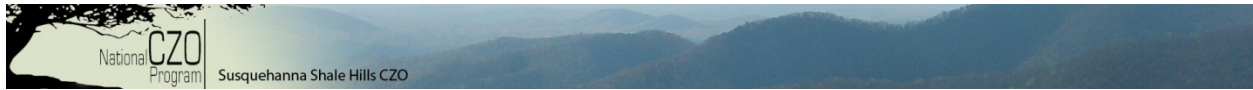
Using LiDAR to model vegetation structure and above-ground carbon storage in the critical zone

Kristen Brubaker and Quincey Johnson

Hobart and William Smith Colleges

Understanding patterns of above ground carbon storage across forest types is increasingly important as managers adapt to the threats of climate change. We compared the fine-scale above ground carbon storage in two watersheds; one watershed was underlain by sandstone bedrock and the other by shale. We sampled tree, shrub, and coarse woody debris across three topographic positions for both watersheds, and calculated the component of carbon stored in each. We then used leaf on and leaf off LiDAR to model carbon storage for each component across the watershed, using a combination of terrain and vegetation metrics from LiDAR. We found that there is an inverse relationship between tree carbon storage and shrub carbon storage across sites. We also found differences in the tree carbon, shrub carbon, and CWD carbon ratios between bedrock types. We extracted over 50 LiDAR-derived variables, both terrain and point cloud. Using machine learning methods, we were able to develop a model of shrub biomass across both watersheds. This should help us to understand the patterns of tree and shrub storage across the landscape scale at the Susquehanna/Shale Hills CZO.

Fine-scale aboveground carbon distribution of forests with varying lithology:

A comparison across two watersheds

Quincey Johnson

Hobart and William Smith Colleges

Understanding patterns of aboveground carbon storage across forest types is increasingly important as managers adapt to the threats of climate changes. This study compares the fine-scale aboveground carbon storage between two watersheds with varying lithology, one of which was underlain by shale bedrock and the other by sandstone. Aboveground forest components such as trees, understory vegetation, and coarse woody debris were sampled across three topographic positions of both watersheds, and allometric equations were used to estimate biomass. Greater carbon storage in trees was found in the shale watershed, however, greater carbon storage in understory vegetation and coarse woody debris was detected at the sandstone site. Greater tree biomass values were found in the toe-slope positions, and greater shrub biomass values were found in the ridge top positions. Using mixed models, a strong effect was found between biomass values and the interaction of watershed and topographic position for all aboveground forest components, showing that although topographic position is an important predictor of biomass values, the importance varies by watershed. The variation in biomass between the two catchments may be due to differences associated with the bedrock of the watersheds, as well as the differences in topographic variables including slope and curvature.

Regional comparisons of forest composition and species dynamics on shale and sandstone lithologies across the Ridge and Valley Province in Pennsylvania

Warren Reed and Margot Kaye
Department of Ecosystem Science and Management, The Pennsylvania State University, University Park, PA, 16802

Spatial variability in forest composition and species dominance have been attributed to many factors such as climate, topography, and land-use history, but there is a lack of quantitative information on the role of bedrock in forest development. Parent material contributes to soil characteristics such as acidity, texture and nutrient content, which can influence forest species assemblages and growth rates. Comparisons of forest structure and dynamics between one shale site (Shale Hills) and one sandstone site (Garner Run) have shown that tree species composition, standing biomass, and tree density are different on the two lithologies, but do these patterns hold true across larger spatial scales? To answer these questions, we analyze forest inventory data from plots across the Ridge and Valley Province collected by the Pennsylvania Bureau of Forestry and the Pennsylvania State Game Commission. Using inventory plot locations and publically available maps of bedrock created by the Pennsylvania Bureau of Topographic and Geologic Survey we identified 158 inventory plots with sandstone as their primary bedrock and 242 with shale (Fig. 1). Preliminary analysis shows that forest basal area, a proxy to aboveground biomass, is approximately 15% higher in shale sites than sandstone, and tree density is approximately 15% lower on shale sites than sandstone. Further analysis will focus on a comparison of forest composition and species dynamics on the two lithologies. The inventory data will be compared to data collected at the Susquehanna Shale Hills and Garner Run Critical Zone Observatory sites to determine whether they are representative of forests found on shale and sandstone bedrock. Analyzing this spatially comprehensive dataset contributes towards understanding the variability and trends of forest composition on shale and sandstone, two major bedrock types of interest across the region.
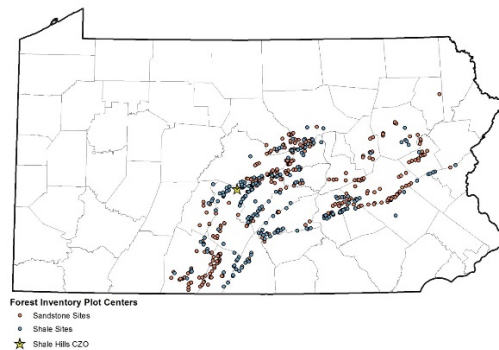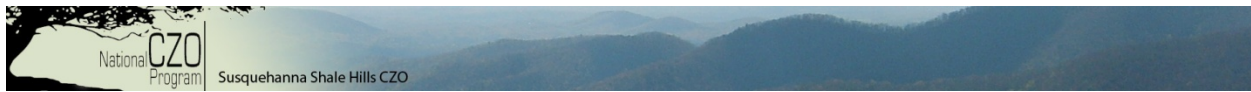

Figure 1. Map of forest inventory plots on shale and sandstone primary lithologies across public lands of the Ridge and Valley Province in Central Pennsylvania.

Investigating inorganic and organic solute transport in the Shale Hills catchment

E.M. Herndon[1], G. Steinhoefel[2], A. Dere[3]

[1]Department of Geology, Kent State University, Kent OH

[2]Department of Geosciences, Penn State University, University Park, PA

[3]Department of Geography/Geology, University of Nebraska – Omaha, Omaha NE

Solute concentrations in streams vary with discharge in patterns that record complex feedbacks between hydrologic, geochemical, and biological processes. Previous research at the Susquehanna Shale Hills Critical Zone Observatory (SSHCZO) identified chemostatic solutes (e.g., Na^+, Mg^{2+}, Si, Cl^-) whose concentrations varied little across a wide range of discharge values, and chemodynamic solutes (e.g., Fe^{3+}, Mn^{2+}, Ca^{2+}, DOC) whose concentrations decreased with increasing discharge. The concentration-discharge pattern of chemodynamic solutes at SSHCZO may be controlled by changing hydrologic connectivity of the stream to organic-rich soil waters under different flow regimes; however, additional research is needed to identify how these elements are transported out of soils and into surface waters.

Here, we investigated the spatial distribution of major elements in surface and groundwater in the catchment and the potential for these elements to be mobilized from soils into pore waters as dissolved cations and colloids. Surface water and groundwater were sampled in early autumn when the ephemeral stream was confined to disconnected pools of water in the channel. Soils from the south planar hillslope transect and sediments from the stream channel were extracted with cold and hot water to evaluate concentrations of mobile colloids and solutes. Ultraviolet-visible spectroscopic indices were used to evaluate aromatic-C in surface water, groundwater, and soil extracts.

Disconnected pools of water were chemically variable along the length of the channel but similar to underlying groundwater. Iron and Mn concentrations in the stream were high near the headwaters (26.7 ± 3.0 and 34.8 ± 3.2 µmol L^{-1}, respectively) and decreased downstream (< 1.0 and < 3.5 µmol L^{-1}). These metal-rich headwaters may contribute to observed pulses of high Fe and Mn in streams following rain events in the dry season. In contrast, Ca concentrations increased downstream while K, Na, and Mg were relatively constant. Groundwater was only minimally connected with the stream channel. The water table was present at > 2.0 m below the land surface along the eastern portion of the channel, rose above the channel in an area of upwelling near well 7, then dropped to > 1.4 m below land surface near the stream outlet. Groundwater in the shale-dominated, eastern portion of the catchment contained elevated levels of Fe and Mn relative to the sandstone-dominated western portion of the catchment. This metal-rich groundwater likely represented shallow interflow that recently infiltrated soil and shallow regolith. Conversely, groundwater near the stream outlet that contained low Fe and Mn but relatively high Ca was likely older, deeper groundwater that upwelled to the stream near the lithologic boundary at Well 7. Groundwater was depleted in DOC but enriched in aromatic-C relative to stream water, suggesting that non-aromatic C was removed by biodegradation during infiltration.
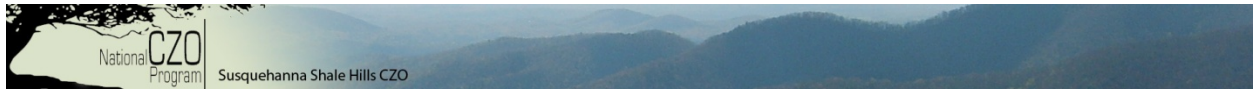
Organic-rich surface soils contained high concentrations of dissolved and colloidal Al, Ca, Fe, Mn, K, and P, indicating the potential for these elements to be mobilized from surface soils during rain events. Stream sediments accumulated abundant colloidal Fe, Al, and P, providing a potential temporary sink for these elements. By integrating soil, surface water, and groundwater chemistry, we can begin to build a better understanding of element mobilization and transport pathways in the catchment.

Hydro-Climatic Factors Affecting Dissolved Organic Matter Variability in Precipitation at the Shale Hills Critical Zone Observatory

Lidiia Iavorivska, Elizabeth W. Boyer, Jeffrey W. Grimm, Kenneth J. Davis, and Christopher J. Duffy

Dissolved organic matter (DOM) is ubiquitous in atmospheric water. Precipitation deposited to the landscape is a source of organic acidity and nutrients to ecosystems. Studies regarding the abundance of OC in precipitation are sparse; and transfer of organics between the atmosphere and land are not explicitly included in most carbon cycle models due to limited data, highlighting the need for further information. Here, we explore the chemical nature of DOM in precipitation at the Shale Hills Critical Zone Observatory in Central Pennsylvania, providing insights regarding inputs of organics from the atmosphere to the landscape. We consider questions of how much DOM is there in precipitation; and how does it vary temporally during precipitation events? Here, precipitation samples were collected sequentially during 91 events during 2012 and 2013, and the variations in DOM quantity and quality were characterized. The events covered various types of meteorological conditions (including hurricane Sandy) and climatic seasons. The relative importance of factors affecting DOM varied between and within events and is linked to storm characteristics and tracks, antecedent dry periods and air temperature, synoptic meteorological conditions, and oxidative atmospheric chemistry.

Water-regolith-energy Interaction in Landscape Evolution and Its Influence on Forming Asymmetric Landscape: An Example from the Shale Hills Critical Zone Observatory of Central Pennsylvania
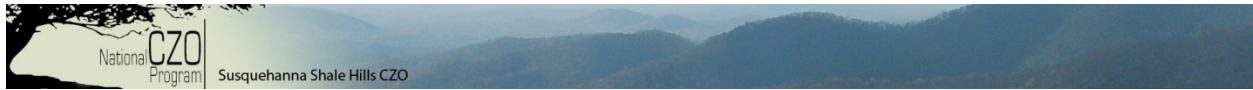
Yu Zhang[1], Rudy L Slingerland[1], Yuning Shi[1], Christopher Duffy[2] and Nicole West[3],

(1) Pennsylvania State University Main Campus, University Park, PA, United States,

(2) Pennsylvania State University, Department of Civil and Environmental Engineering, University Park, PA, United States,

(3) Georgia Institute of Technology Main Campus, Atlanta, GA, United States

Shale Hills Critical Zone Observatory (SSHCZO) is a 0.08 km^2 first order experimental research catchment with relatively homogeneous bedrock, regolith and tectonic uplift, but with an asymmetric slope and thickness of regolith on the north- and south-facing hillslopes. In this paper, we use a hydrological-morphodynamic model (LE-PIHM), which links bedrock, soil, surface and subsurface water flow, plant, energy, and seasonal climate and a land surface model (Flux-PIHM), to address the influence of water-regolith-energy interaction on soil creep process, the possible factors causing slope asymmetry and the spatial distribution of regolith transport at the SSHCZO. Two non-dimensional parameters were used to explore the competitive relationship between regolith diffusion and advection forming self-organized channel spacing, relief and slope length at steady state. Model simulation under seasonal meteorological forcing shows spatial variations of hillslope sediment fluxes. An experimental study using Beryllium 10 at the SSHCZO (West et al 2013) showed that a south-facing planar slope had a greater diffusion flux rate than a planar north-facing slope. The model confirms this relationship in general although there are significant local variations. The largest regolith transport rate by overland flow (advection) occurs at the junctions of main channel and swales. The model simulation further suggests that north-south differences in diffusive flux may be a result of asymmetric solar insolation which affects freeze-thaw frequency and sediment transport through the process of soil creep. This study demonstrates the value of physically-based distributed landscape evolution model on estimating spatial distribution of regolith transport and highlights the critical transition zone.

Using WITCH to examine how today's Critical Zone architecture governs the geochemical evolution of a shale catchment

Sullivan PL[1,2], Goddéris Y[3], Shi Y[2], Xi G[2], Schott J[3], Duffy CJ[4], Brantley SL[2]

[1]Department of Geography, University of Kansas, Lawrence KS,
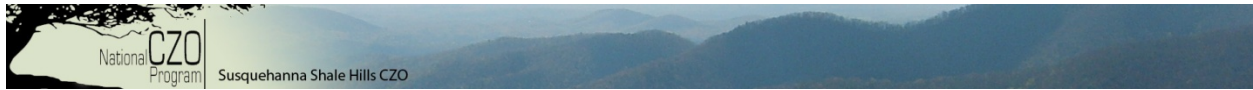[2]Earth and Environmental Systems Institute, Pennsylvania State University, PA
[3]Géosciences Environnement Toulouse, CNRS-Observatoire Midi-Pyrénées, Toulouse, France
[4]Department of Civil Engineering Pennsylvania State University, University Park, PA, USA

Abstract:

To investigate controls on shale weathering and the solute fluxes is a first-order catchment, we linked the physically-based land surface hydrologic model, Flux-PIHM (Penn State Integrated Hydrologic Model) with the weathering model WITCH. Modeling prediction elucidated:

i)   Geometric mineral surface area was need to predict soil water Mg2+ concentrations;
ii) Inclusion of vegetation was need to simulate soil water Ca2+, K+ and Al3+;
iii) Warm temperatures on the sun-facing slopes soils supported greater elemental release rates;
iv) Snow melt dynamics may explain greater extent of weathering on shaded slopes compared to sun-facing slopes.

Microclimate controls on weathering: Insights into deep critical zone evolution from seismic refraction surveys in the Susquehanna Shale Hills Critical Zone Observatory

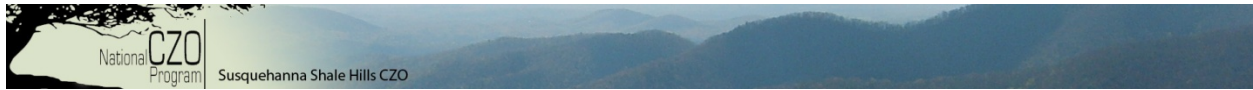[1]West, Nicole, [2]Eric Kirby, [3]Andrew Nyblade and [3,4]Susan Brantley

[1]Georgia Institute of Technology Main Campus, Atlanta, GA, United States,
[2]Oregon State University, Corvallis, OR, United States,
[3]Pennsylvania State University, University Park, PA, United States,
[4]Earth and Environmental Systems Institute, Pennsylvania State University, University Park, PA, United States

The formation of regolith is fundamental to the functioning and structure of the critical zone - the physically and chemically altered material formed from in situ parent bedrock that is available for transport. Understanding how regolith production and transport respond to perturbations in climate and/or tectonic forcing remains a first-order question. At the Susquehanna Shale Hills Critical Zone Observatory (SSHO), high resolution LiDAR-derived topographic data and depths to hand auger refusal reveal a systematic asymmetry in hillslope gradient and mobile regolith thickness; both are greater on north-facing hillslopes. Hydrologic and geochemical studies at the SSHO also suggest asymmetric sediment transport, fluid flow, and mineral weathering with respect to hillslope aspect. Here, we combine shallow seismic surveys completed along 4 hillslope transects (2 north-facing and 2-south facing), 2 ridgetops transects, and subsurface observations in boreholes to investigate the role of climate in inducing fracturing and priming the development of the observed asymmetry. Comparisons of shallow p-wave velocities with borehole and pit observations lead us to hypothesize the presence of three distinct layers at SSHO: 1) a deep, high velocity layer that is consistent with unweathered shale bedrock; 2) an intermediate velocity layer that is consistent with fractured and chemically altered bedrock which overlies unaltered bedrock, and 3) a shallow, slow velocity layer that is consistent with mobile material or shallow soil. Shallow p-wave velocity profiles suggest differences in thickness for both the mobile and immobile regolith material with respect to aspect. Patterns of p-wave velocities with depth are consistent with patterns of fracture densities observed in boreholes and with predictive cracking intensity models related to frost action. The models and data are consistent with climate as a primary driver for the development of asymmetry in the subsurface architecture at SSHO.

Identity of host tree species may not control the community composition of ecto- and arbuscular mycorrhizal fungi

Chen, Weile[a], Koide, Roger[b], Eissenstat, David[a],*

[a] IGDP Ecology and Department of Ecosystem Science and Management, The Pennsylvania State University
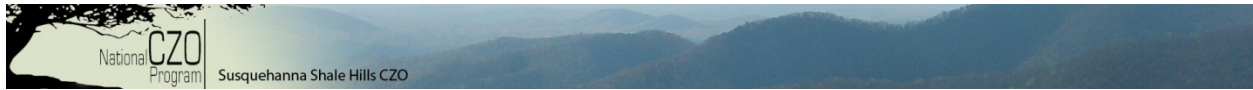[b] Department of Biology, Brigham Young University
*Corresponding author: dme9@psu.edu

Abstract:

Mycorrhizal fungi form associations with most land plants and benefit plants in nutrient acquisition. These mycorrhizal nutritional benefits may depend largely on the fungal identities and their community structures and thus can vary among host plants. However, to what extent host species identity determines mycorrhizal fungal community is still largely unknown. Local environmental conditions may also select for certain groups of mycorrhizal fungi. This study collected root samples from arbuscular mycorrhizal (AM) trees (e.g. maple, tulip poplar) and ectomycorrhizal (EM) trees (e.g. oak, pine) growing together at two nearby sites of different soil properties in central Pennsylvania, U.S.A. One site was derived from limestone and the other derived from shale. Mycorrhizal fungal DNA was extracted from roots and Next-Gen sequencing techniques (Illumina Miseq) were applied to identify the mycorrhizal fungal species and their community composition of each plant host from the two sites.

Mycorrhizal fungal composition differed among host plants, but the difference between sites was even stronger, for both AM and EM fungi. Many of the same fungal operational taxonomic unites (OTUs) were shared among different host species from the same site. In contrast, the overlap of fungal OTUs was small for the same host species from different sites. These results indicated that host specificity was relatively low for mycorrhizal fungi associated with the co-occurring temperate trees. Local fungal species pool that was filtered by habitat conditions may be a key driver shaping the mycorrhizal fungal community composition for both AM and EM trees.

Modeling Soil-Landscape and Its Evolution in the Shale Hills Catchment

[1]Fei Jiang*, [2]Yu Zhang, [1]Li Guo, [1]Henry Lin

[1]Dept. of Ecosystem Science and Management, Pennsylvania State University

[2]Dept. of Civil and Environmental Engineering, Pennsylvania State University

One of the major challenges in soil-landscape modeling is to connect pedon-based pedogenesis, landscape-based evolution, and hydrological processes driving them in an integrated manner. While there have been many models developed for either pedon-based pedogenesis or landscape-based evolution, the coupled modeling system that tightly links soil development and landscape evolution together remains sparse. In this study, we aim to couple landscape evolution in the Shale Hills catchment using the LE-PIHM landscape evolution model with soil genesis of key soil types using a pedogenesis model called SoilGen. In our simulation, LE-PIHM generates the soil loss or deposit on the land surface and soil production from the underlying bedrock, which provide important inputs to SoilGen. The SoilGen simulates the evolution of soil texture, organic carbon, bulk density, and many other soil physical and chemical properties along a soil profile, based on which hydraulic parameters used in LE-PIHM are calculated. Our preliminary results indicate that this considerable coupled dynamics result in significantly different pathways of landscape evolution and soil formation as compared to the traditional methods that handle soil genesis and landscape evolution separately. Moreover, our results emphasize the need for a more effectively coupled modeling system for integrated soil-hydrology-landscape evolution over long-time scales that are driven by energy and water as conditioned by topography (including landform units, slopes, and aspects). We are now in the process of quantifying the amount of energy and water needed to form the current differet types of soils from the shale bedrock in the catchment over the past ~15,000 years. Such an understanding will provide insights into the formation and evolution of the Critical Zone.

Soil Hydrologic Properties in the Shale Hills and the Garner Run

Julian Pecce, Neil Xu, Henry Lin

Abstract

Soil hydrologic properties, such as the saturated hydraulic conductivity (K_{sat}), provide valuable insight into a location's hydrologic response during rainfall events. During a storm event, rainfall is partitioned between infiltration and surface runoff. Understanding how K_{sat} varies as a function of landscape position (e.g., elevation), land use (e.g., forested vs. agricultural land), and soil type (i.e., different textures and classes) has important implications for groundwater recharge, stream discharge, and water quality, as well as nutrient cycling and contaminant transport. Infiltrometers were used in triplicates to measure steady-state infiltration rate to derive K_{sat} at a total of twenty-two locations across two study sites: the Garner Run and the Shale Hills watersheds located in central Pennsylvania. The land use at both the study sites is forested, with the dominant soil type at the Garner Run being Meckesville stony silt loam and at the Shale Hills being Berks-Weikert silt loam. Spatial variability was greater at the Garner Run as compared to the Shale Hills, with the K_{sat} values at the Garner Run ranging from 67.26 - 270 cm/hr, whereas the K_{sat} values at the Shale Hills ranged from 21.96 – 159 cm/hr. Such differences are related to different soil types and geologies in the two watersheds. The Meckesville stony silt loam includes a channery silt loam in the A horizon, which is characterized by many fragments of sandstone. Additionally, slope and forested floor differences could also cause variable K_{sat} values across the two watersheds. This study sheds light on the fundamental importance of soils and geology in understanding watershed hydrology and related management.
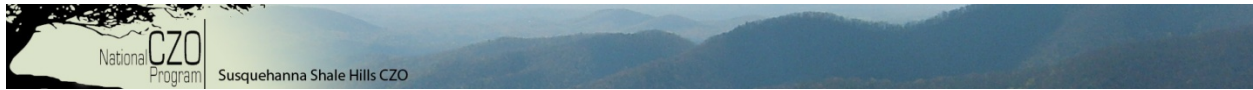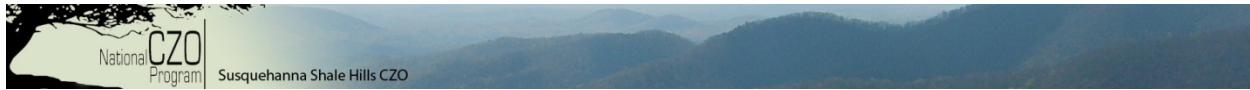
The activity of deep roots in bedrock fractures at Susquehanna Shale Hills Critical Zone Observatory, USA

Elizabeth A. Hasenmueller[1*], Xin Gu[2], Julie N. Weitzman[3], Thomas S. Adams[3], Gary E. Stinchcomb[4], David M. Eissenstat[3], Patrick J. Drohan[3], Susan L. Brantley[2,5], Jason P. Kaye[3]

1. Department of Earth & Atmospheric Sciences, Saint Louis University, Saint Louis, MO, USA
2. Department of Geosciences, The Pennsylvania State University, State College, PA, USA
3. Department of Ecosystem Science and Management, The Pennsylvania State University, State College, PA, USA
4. Watershed Studies Institute and Department of Geosciences, Murray State University, Murray, KY, USA
5. Earth and Environmental Systems Institute, The Pennsylvania State University, State College, PA, USA

Many areas in the world are characterized by shallow soils underlain by weathered bedrock, but root-rock interactions and their implications for regolith weathering are poorly understood. To test the role of tree roots in weathering bedrock, we excavated four pits along a catena in a shale-hosted catchment near the Susquehanna Shale Hills Critical Zone Observatory (SSHCZO), USA. We measured a variety of physical and chemical properties including: (1) root density, distribution, and respiration rates, (2) soil gas, and (3) soil, rock, and rock fracture sediment elemental compositions, mineralogy, and morphology. As expected, root density declined rapidly with depth; nevertheless, roots were present in rock fractures even in the deepest, least weathered shale sampled (~1.8 m below land surface). Root density in the shale fractures was highest at the ridge for all depths and decreased 95% downslope as soils thickened and in spite of increasing rock fracture density. Root respiration rates (per gram of root) in fractures were comparable to those in augerable soil, though the total flux of CO_2 from respiration decreased deeper in the weathering profile due to few roots. Potential microbial respiration rates, estimated with laboratory C mineralization potential, were comparable to measured root respiration rates in shale fractures. We only observed roots in larger shale fractures (> 50 μm) that were coated with granular material. These sediments were mineralogically and geochemically similar to overlying B and C soil horizons with respect to clay composition, element mobility, total C and N, and potentially mineralizable C. Such similarities indicate that the sediment coatings are likely the result of pedogenesis process happened at depth rather than translocation of soil particles downward into the fractures. Shale in contact with deep roots resembled unweathered parent material geochemically. In the bulk soil, depletion profiles (K, Mg, Si, Fe, and Al) relative to unweathered shale reflected characteristic weathering of illite and vermiculized chlorite to kaolinite. Approximately 60% of K and 70% of Mg depletion from soil horizons was attributable to particle transport. The similar process may happen at depth in the fractures. Overall, our data suggest that roots and sediments in shale fractures down to ~1.8 m are qualitatively similar to those in surface soil horizons, with the main difference being that there are simply fewer roots and less soil in the bedrock fractures.

Characterizing subsurface lithology and processes at the Susquehanna Shale Hills CZO using multi-scale near-surface geophysical measurements

Gregory J. Mount[1], Xavier Comas[2], Brandon Forsythe[3], Joanmarie Del Vecchio[4], Li Guo[5], Roman DiBiase[4], Henry Lin[5], Susan Brantley[6]

[1]Department of Geosciences, Indiana University of Pennsylvania, Indiana, PA 15705
[2]Department of Geosciences, Florida Atlantic University, Boca Raton, FL 33431
[3]Susquehanna Shale Hills Critical Zone Observatory, Penn State University, University Park, PA 16802
[4]Department of Geosciences, Penn State University, University Park, PA 16802
[5]Department of Ecosystem Science and Management, Penn State University, University Park, PA 16802
[6]Earth and Environmental Systems Institute, Penn State University, University Park, PA 16802

Large scale, high resolution investigations of the subsurface using traditional methods such as coring are complicated by the number of samples and time required to properly capture the spatial variability in complex hydrogeological systems. Near surface geophysical techniques can be used to quickly collect subsurface data at high spatial and temporal resolution and over several scales of measurement to image the subsurface lithology and capture changes over time that can be linked to hydrogeological processes. In this research preliminary geophysical data including ground penetrating radar (GPR), magnetometry, and terrain conductivity were collected at a series of sites within the Susquehanna Shale Hills Critical Zone Observatory to test the potential of these methods for characterizing subsurface lithology at a variety of scales of measurement (from 10-1000 m).