HOSTS:

THE PENNSYLVANIA STATE UNIVERSITY

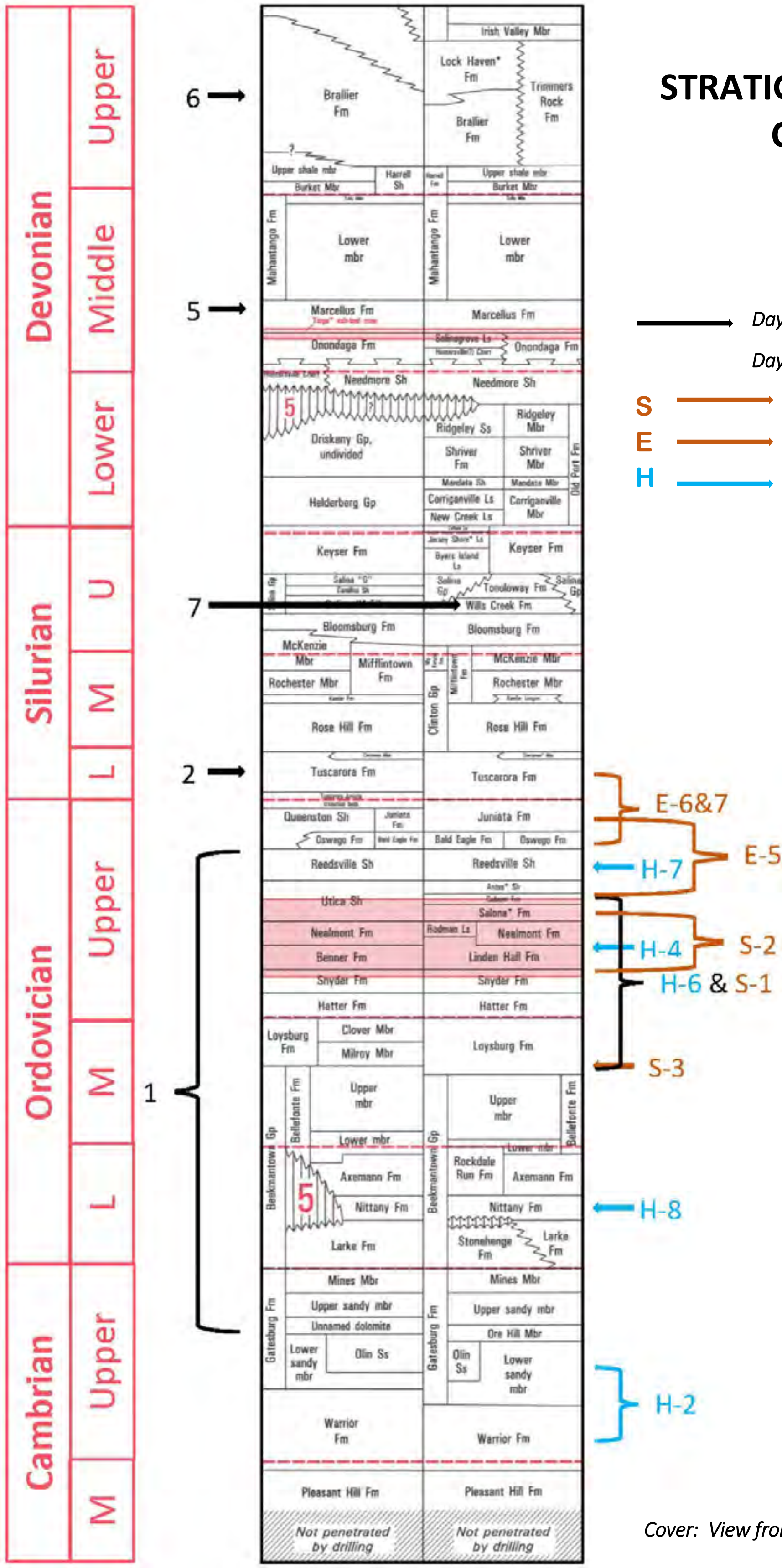
PA DCNR BUREAU OF TOPOGRAPHIC & GEOLOGIC SURVEY

Recent Geologic Studies & Initiatives in Central Pennsylvania

82ND ANNUAL FIELD CONFERENCE OF PENNSYLVANIA GEOLOGISTS

OCTOBER 5 – 7, 2017

FCOPG STRATIGRAPHIC COLUMN



Day 1 Stops

Day 2 Stops

S *Stratigraphy*

E *Engineering*

H *Hydrology*

Cover: View from Jo Hays Vista

ROADLOG FOR THE

82ND ANNUAL FIELD CONFERENCE OF PENNSYLVANIA GEOLOGISTS

OCTOBER 5 — 7, 2017

RECENT GEOLOGIC STUDIES & INITIATIVES IN CENTRAL PENNSYLVANIA

STRATIGRAPHY, ENGINEERING AND HYDROGEOLOGY

STATE COLLEGE, PENNSYLVANIA

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Special Thanks to:

- David "Duff" Gold for a lifetime of dedication to the field of geology and bringing this field conference to fruition. And his wife Jackie for letting us have him.

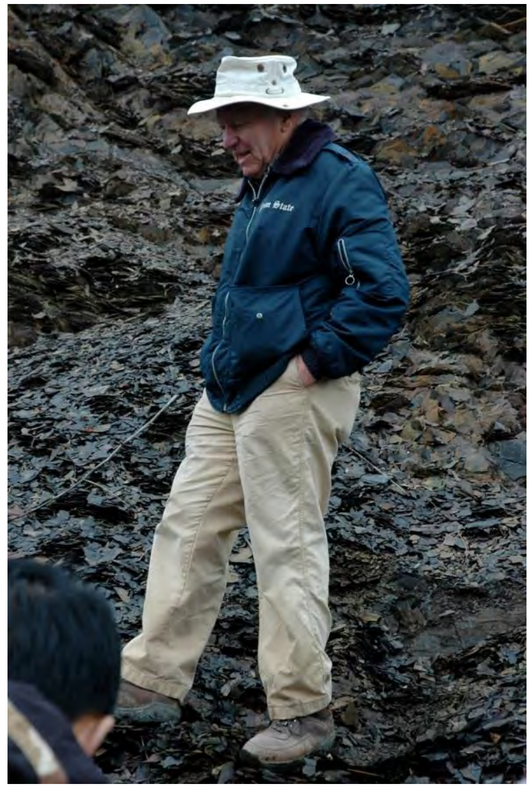
A TRIBUTE TO DAVID P. "DUFF" GOLD

A former Penn State geology colleague said: "Duff's problem is that he is in love with geology." His "problem" is our gain. He is a consummate geologist – researcher, teacher, consultant, and mapping geologist. His interests are diverse: diamonds, carbonatites, fulgurites, rogue kimberlites and lamproites, bentonites, fractals, exploration geology, astroblemes, fracture analysis using remote-sensing, tectonic deformation of ore deposits, rare earths, fission-track dating, geologic mapping – to name a few. He has served on Congressional committees including making recommendations on near-earth asteroids and conditions of the lunar surface as it might have affected manned landings, organized professional field trips, analyzed atomic bomb explosions, trained astronauts, and spoken on diamonds to the American Museum of Natural History. While receiving professional recognition for these efforts, Duff is willing to talk with cub scouts and other youth organizations. He comments: "You never know where the next geologist will come from."

At Penn State, Duff received an award for outstanding teaching. His dedication to teaching is partly reflected in his willingness to purvey geological knowledge with others, in and out of the classroom. There are quite a few of us attending this year's field conference who have benefited from an association with him. He shares field information with professors of neighboring institutions, often taking them on "one-on-one" field excursions. Several years ago my wife asked: "Why do you go in the field with Duff?" My immediate response was: "Because it's a free education. I always learn something new."

The Field Conference acknowledges Duff's many contributions. He has been associated for decades: a field trip leader and editor for the 50th, 68th, and this year's conference. In addition, he was contributor for the 81st conference.

His collaborations with the Pennsylvania Geological Survey have been a mutual admiration society. He has worked with a host of Survey geologists and participates in the STATEMAP program. One of his contributions is the partial training of State Geologist, Gale Blackmer, who was a doctoral student of Duff's.



Since his 1998 retirement as Emeritus Professor of Geology from Penn State, Duff continues his "love of geology," mentoring undergraduate geology students, speaking to classes, meeting with geologists of the Pennsylvania Geological Survey, publishing, meeting with the public on issues such as sinkholes, teaching short courses for the National Well Water Association and PetroChina, attending professional meetings, geological studies at an ancient archaeological site in Southern Egypt, developing courses for a new mining school in Nigeria, consulting, running field trips for Tohoku University, and more. His consulting includes evaluating gravel deposits in Pennsylvania and Maryland, core analyses for Penn DOT, and site evaluations for carbon dioxide sequestrations. In other words, he is not "retired."

Duff writes: "I feel blessed in choosing a career that matched my temperament as an explorer in the physical world, a job that required interaction with young minds, and being at the right place at the right time to participate in interesting programs and initiatives."

This tribute to Duff would be incomplete without a few anecdotes about his geology exploits. His work has been international at times. Early in his career as a doctoral student, his thesis objective was to examine emplacement energy of igneous dikes of the host marble of Oka and St. Hilaire, Quebec. Some initial tests were problematical. He suspected the carbonates were not Grenville Marble but a carbonatite like some he had seen in southern and east Africa. However, this was when students did not question professors. His request for a change in objectives in characterizing the rocks was met with opposition and skepticism. One comment was that the idea of "mantle carbonates" was ridiculous and another was Duff probably also believed in "continental drift." However, three years later, the professor apologized. The site on which Duff worked is now known as the Oka Carbonatite Complex, a 117 Ma old double ring-dike/cone sheet structure that was later mined for niobium and rare earth minerals.

Again working in Canada, Duff was part of a geology field crew. On a particular day, he was the cook. The group had just been resupplied with a backlog of steaks. So, steaks were served. One member of the crew noticed that his steak was somewhat undercooked. He asked Duff if all people from South Africa ate their meat raw. Duff said, tongue-in-cheek, "only when we eat human flesh." For the next two weeks, the guy would not sleep when Duff slept and at the end of the two weeks he shipped out from lack of sleep. He thought Duff was a cannibal.

Charles E. Miller, Jr.

State College, PA

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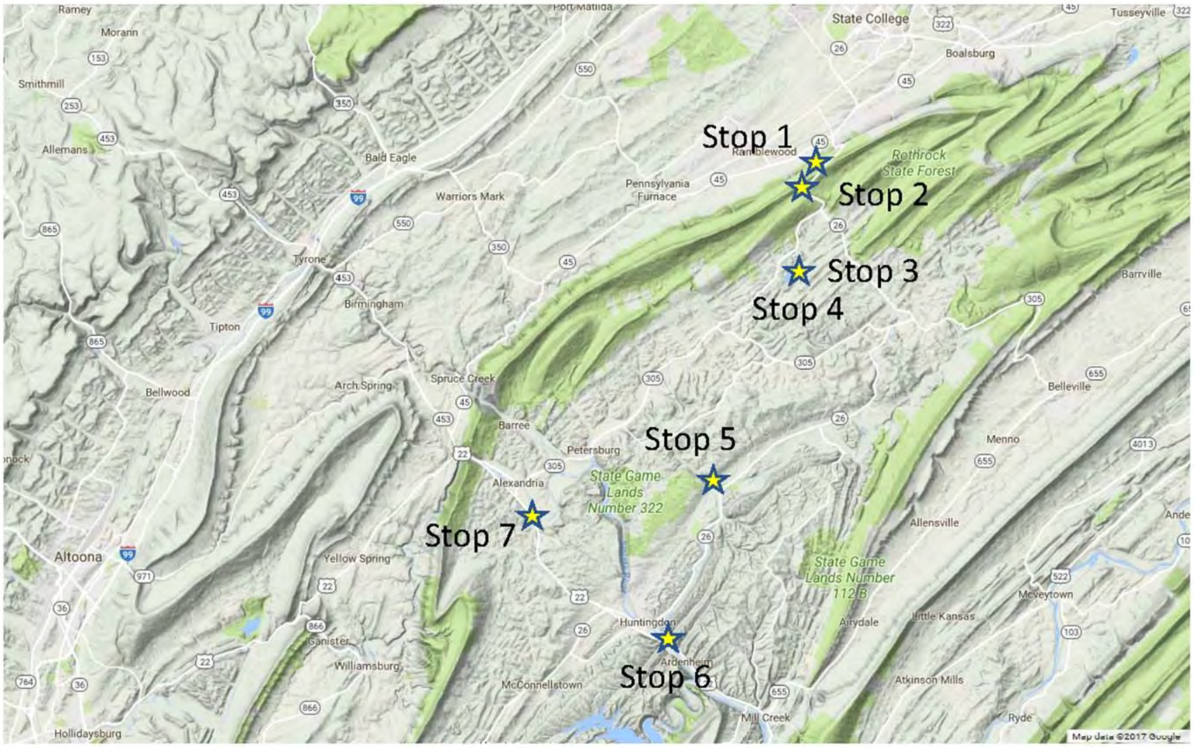
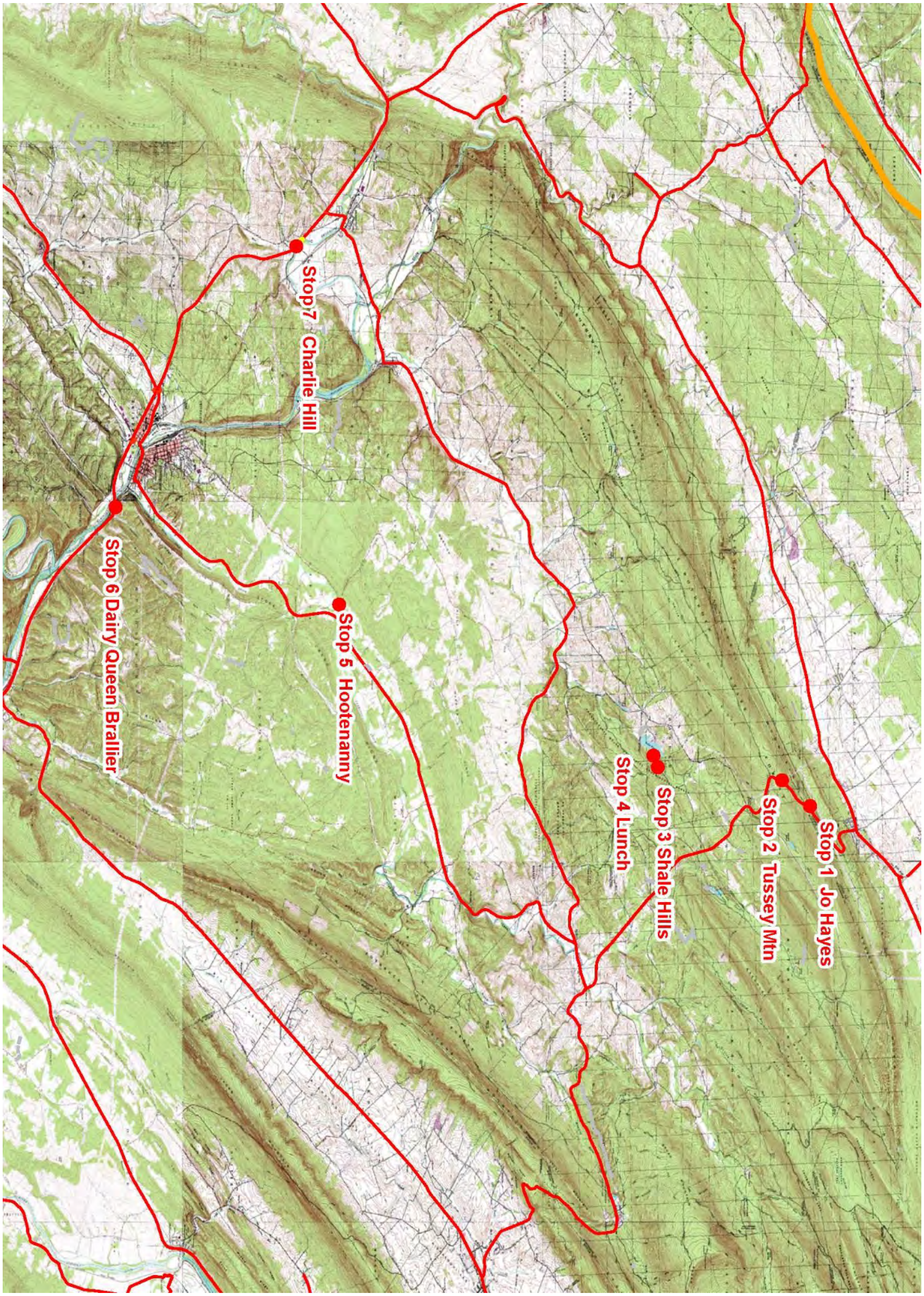
ROADLOG – DAY 1



ATTENTION – DIRECTIONS

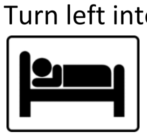
The road-logs for Groups A and B are identical except for sequencing and timing. Both groups will share Stop 1, an overview of Nittany Valley from Jo Hays lookout. Thereafter, Group A (buses 1 & 2) proceed to Stop 2 at Tussey Mountain Boulder Field, and Group B (buses 3 & 4) will drive to Huntingdon for Stops 5, 6, and 7. The excursion to Stop 3 (the Shale Hills Critical Zone Observatory) is handled in the log as a parallel venture with an independent odometer setting. Lunch is Stop 4, a short walk from Stop 3 to the nearby Stone Valley Recreation Center. Group A will visit Stop 3 right before Lunch, with Group B proceeding to Stop 3 right after Lunch. These Shale Hill Observatory field trips address the integrated, interdisciplinary study of weathering process and rates in a closed shale-bedrock drainage basin. Stops 5, 6, and 7, examine, respectively, an outcrop of Marcellus Black Shale, a roadcut in Brallier turbidites with well-developed hydraulic fractures, and mesoscopic-scale disharmonic structures in Wills Creek tidalites. The latter is the classic locality of Charlie Hill, well publicized in early textbooks on structural geology (e.g., Billings, 1954).

- ✓ **GROUP A = (buses 1 & 2) – Shale Hills Critical Zone Observatory in morning; Huntingdon Area in the afternoon.**
- ✓ **GROUP B = (buses 3 & 4) – Huntingdon area in the morning; Shale Hills Critical Zone Observatory during the afternoon.**


Stop 1 Jo Hayes
Stop 2 Tussey Mtn
Stop 3 Shale Hills
Stop 4 Lunch
Stop 5 Hootenanny
Stop 6 Dairy Queen Brallier
Stop7 Charlie Hill

ROADLOAG BELOW IS FOR GROUP A

segment	cumulative	GROUP A – DIRECTIONS
0.0	0.0	Depart side of Ramada Inn and turn right onto Norma St
0.1	0.1	Turn right onto S Atherton St
0.2	0.3	Turn right onto University Dr
1.1	1.4	Continue onto W Whitehall Rd
1.8	3.2	Turn left onto College Avenue/PA 26 S toward Pine Grove Mills.
2.3	5.5	Turn left in Pine Grove Mills on Rte 26 S to McAlevys Fort
2.0	7.5	Pull into Jo Hays Vista parking area.
		STOP 1: Jo Hays Vista **(40.71670°; -77.89408°)**
0.8	8.3	Continue southwest on PA 26 S
		STOP 2: Tussey Mountain boulder fields **(40.70757°, -77.90235°)**
0.0	8.3	Continue southwest on PA 26 S
1.3	9.6	Turn right on Charter Oak Rd
1.7	11.3	Turn left on Red Rose Rd
0.5	11.8	Turn right onto Scare Pond Rd
0.8	12.6	Buses stop and drop people off
		Stop 3: Shale Hills Critical Zone Observatory **(40.66504°; -77.90743°)**
		Buses will drive 0.2 miles past this & turn right onto unnamed road at the recreation center to park and turn around
0.2		**Stop 4: Stone Valley Recreation Center. Lunch!** 
0.0	12.8	Depart Recreation center and turn left onto Scare Pond Rd
1.0	13.8	Turn right onto Red Rose Rd
1.3	15.1	Turn right onto PA 26 S/McAlevys Fort Rd
4.0	19.1	McAlevys Fort. Junction with Rte 305. Turn right on Rte 305 W/PA 26 S.
0.9	20.0	Turn left to stay on PA 26 S/Standing Stone Rd.
9.1	29.1	Turn right onto Cold Springs Rd/SR 1009
0.4	29.5	Buses turn left to park at the Stone Creek Valley Lions Club House
		Walk southwest 240 feet to small borrow pit in road cut on north side

		Stop 5: Hootenanny Camp Borrow Pit (40.554536°; -77.96383°)
0.0	29.5	Turn right out of the parking lot
0.4	29.9	Turn right onto Rte 26 S to Huntingdon
6.1	36.0	Turn left onto 2nd St.
0.1	36.1	Turn left onto Penn St.
0.8	36.9	Sharp left onto US 22 W
0.2	37.1	Park on right in front at the “Move in Storage” Facility
		STOP 6: Brallier outcrop at ‘Dairy Queen’ road cut (40.476806°; -77.997413°)
0.0	37.1	Continue on 22 W
7.5	44.6	slight right onto Grange Hall Rd to Alexandria
0.8	45.4	Turn left onto Bridge St/PA 305 W
1.2	46.6	left onto US 22 E
0.9	47.5	Buses pull off on side of highway
		STOP 7: Charlie Hill Road Cut (40.53953°; -77.08819°)
0.0	47.5	Continue on US 22 E
 0.4	47.9	**Turn left into the Country Sweets Shop buses turn around and park Rest break!**
0.0	47.9	Continue on 22 W
0.9	48.8	slight right onto Grange Hall Rd to Alexandria
0.9	49.7	Turn right onto Bridge St/PA 305 E
0.1	49.8	Turn right onto Main St/PA 305 E
0.2	50.0	left at Juniata Valley Pike and continue on PA 305 E to Petersburg
1.9	52.0	T intersection. Turn right to Petersburg.
0.9	52.8	Left onto King St/Shavers Creek Rd/305 E
6.8	59.6	Continue north on Charter Oak Rd
5.9	65.5	Turn left onto Rte 26 N to McAlevys Fort Rd
4.1	69.6	Turn right on Pine Grove Rd
1.3	70.9	Continue onto PA 26 N/W College Ave
0.9	71.8	Turn right onto W Whitehall Rd
1.8	73.6	Turn left to stay on W Whitehall Rd
0.8	74.4	Turn right onto S Atherton St
0.1	74.5	Turn right onto Norma Street
0.1	74.6	Turn left into the Ramada Inn 

END OF TRIP – DAY 1 – GROUP A

ROADLOAG BELOW IS FOR GROUP B

segment	cumulative	GROUP B – DIRECTIONS
0.0	0.0	Depart side of Ramada Inn and turn right onto Norma St.
0.1	0.1	Turn right onto S Atherton St.
0.2	0.3	Turn right onto University Dr.
1.1	1.4	Continue onto W Whitehall Rd.
1.8	3.2	Turn left onto College Avenue/PA 26 S toward Pine Grove Mills
2.3	5.5	Turn left in Pine Grove Mills on Rte 26 S to McAlevys Fort
2.0	7.5	Pull into Jo Hays Vista parking area
		STOP 1: Jo Hays Vista **(40.71670°; -77.89408°)**
0.0	7.5	Continue southwest on PA 26 S toward Jackson Trail
7.4	14.9	McAlevys Fort. Junction with Rt. 305. Turn right on Rt. 305 W/PA 26 S.
0.9	15.8	Turn left to stay on PA 26 S/Standing Stone Rd.
9.1	24.9	Turn right onto Cold Springs Rd/SR 1009
0.4	25.3	Buses turn left to park at the Stone Creek Valley Lions Club House
		Walk southwest 240 feet to small borrow pit in road cut on north side
		Stop 5: Hootenanny Camp Borrow Pit **(40.554536°; -77.96383°)**
0.0	25.3	Turn right out of the parking lot
0.4	25.7	Turn right onto Rt. 26 S to Huntingdon
6.1	31.8	Turn left onto 2nd St.
0.1	31.9	Turn left onto Penn St.
0.8	32.7	Sharp left onto US 22 W
0.2	32.9	Park on right in front at the "Move in Storage" Facility
		STOP 6: Brallier outcrop at 'Dairy Queen' road cut **(40.476806°; -77.997413°)**
0.0	32.9	Continue on 22 W
7.5	40.4	Slight right onto Grange Hall Rd to Alexandria
0.8	41.2	Turn left onto Bridge St/PA 305 W
1.2	42.4	left onto US 22 E
0.9	43.3	Buses pull off on side of highway
		STOP 7: Charlie Hill Road Cut **(40.53953°; -78.08819°)**
0.0	43.3	Continue on US 22 E
 0.4	43.7	**Turn left into the Country Sweets Shop** **buses turn around and park** **Rest break!**

0.0	43.7	Continue on 22 W
0.9	44.6	Slight right onto Grange Hall Rd to Alexandria
0.9	45.5	Turn right onto Bridge St/PA 305 E
0.1	45.6	Turn right onto Main St/PA 305 E
0.2	45.8	left at Juniata Valley Pike and continue on PA 305 E to Petersburg
1.9	47.7	T intersection. Turn right to Petersburg.
0.9	48.6	Left onto King St/Shavers Creek Rd./305 E
6.8	55.4	Continue north on Charter Oak Rd
4.2	59.6	Turn right onto Red Rose Rd
0.5	60.1	Turn right onto Scare Pond Rd
1.0	61.1	Buses turn right into the recreation center
		Stop 4: Stone Valley Recreation Center **Lunch!** 
0.2 		**Stop 3: Shale Hills Critical Zone Observatory** **(40.66504°; -77.90743°)**
0.2	61.3	Buses turn left out of the Recreation center and pick people up
0.8	62.1	Buses turn left on Red Rose Rd
0.5	62.6	Turn right on Charter Oak Rd
1.7	64.3	Continue northeast on PA 26 N/Mc Alevys Fort Rd
1.3	65.6	Buses stop
		STOP 2: Tussey Mountain boulder fields **(40.70757°, -77.90235°)**
0.0	65.6	Head northeast on PA 26 N/Mc Alevys Fort Rd
2.8	68.4	Turn right onto E Pine Grove Rd
1.3	69.7	Continue onto PA 26 N/W College Ave
0.9	70.6	Turn right onto W Whitehall Rd
1.8	72.4	Turn left to stay on W Whitehall Rd
0.8	73.2	Turn right onto S Atherton St
0.1	73.3	Turn right onto Norma Street
0.1	73.4	Turn left into the Ramada Inn 

END OF TRIP – DAY 1 – GROUP B

STOPS FOR SHALE HILLS CRITICAL ZONE OBSERVATORY

STOP LEADERS – ROMAN A. DIBIASE[1,2]; SUSAN L. BRANTLEY[1,2]; JOANMARIE DEL VECCHIO[2]; ASHLEE L. DERE[3]; DAVID M. EISSENSTAT[4]; LI GUO[4]; JASON P. KAYE[4]; HENRY LIN[4]; GREGORY J. MOUNT[5]; NICOLE WEST[6]; DAVID (DUFF) GOLD[2]

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Overview

This road log focuses on the three stops associated with the Shale Hills Critical Zone Observatory. Due to limited access, the group will split into two sessions after a joint regional overview stop at Jo Hays Vista (Stop 1). Group A will proceed to Stop 2, Stop 3, and then lunch at Stone Valley Recreation Center at Lake Perez (Stop 4), followed by the afternoon Huntingdon trip (Stops 5, 6 and 7). Group B will leave for Huntingdon (Stops 5, 6 and 7) after Stop 1, meet for lunch at Stone Valley Recreation Center at Lake Perez (Stop 4), and proceed to Stop 3 and Stop 2 in the afternoon on the way back to State College.

STOP 1: JO HAYS VISTA

REGIONAL GEOLOGIC OVERVIEW

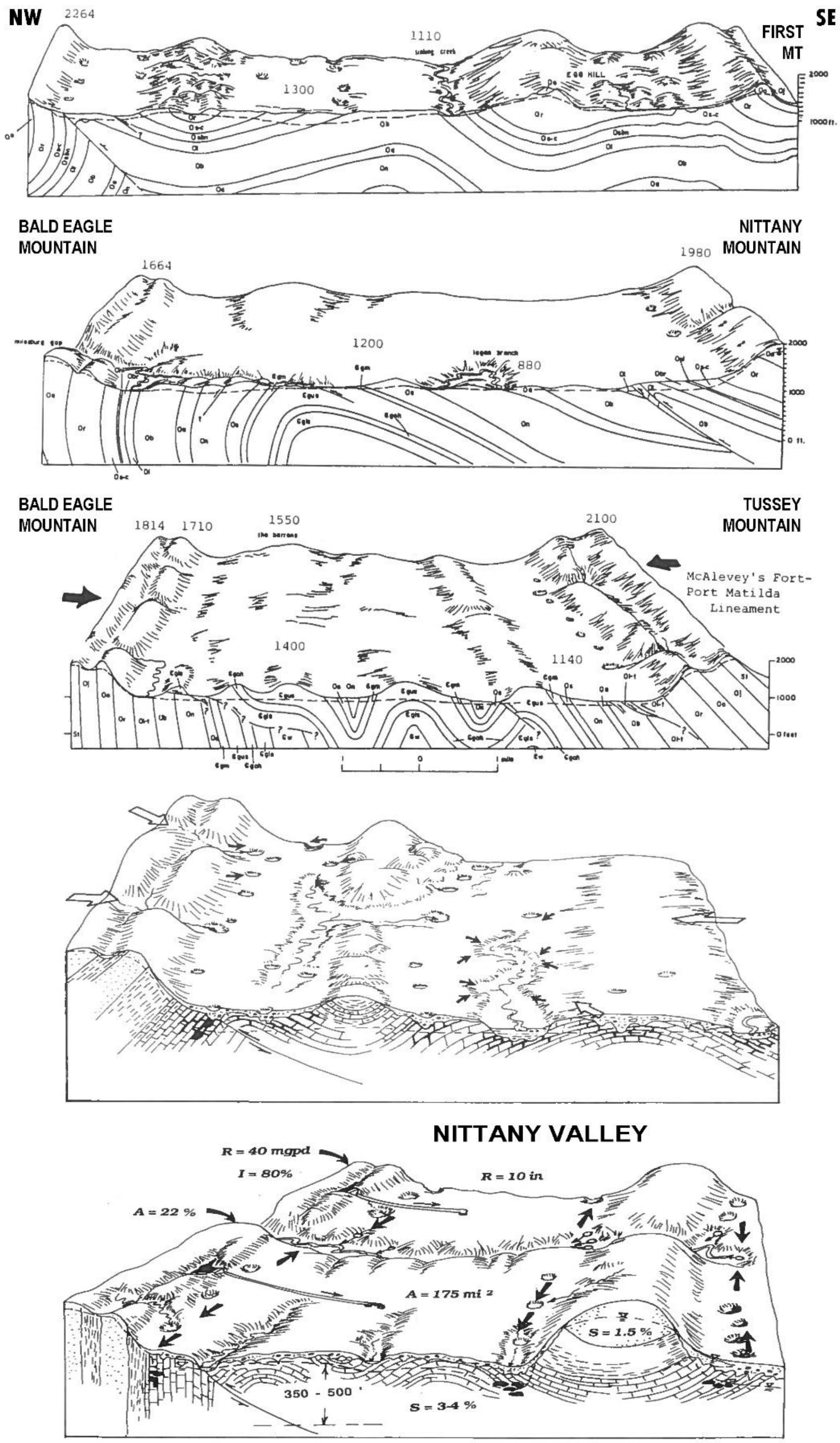
STOP LEADERS – ROMAN DIBIASE[1,2], DAVID (DUFF) GOLD[3]

[1]Earth and Environmental Systems Institute, The Pennsylvania State University, University Park, PA.
[2]Department of Geosciences, The Pennsylvania State University, University Park, PA.
[3]Emeritus Professor, Department of Geosciences, The Pennsylvania State University, University Park, PA.

Introduction (40.71670, -77.89408)

The view to the north is of Nittany Valley, a breached first-order anticlinorium in the Valley and Ridge Physiographic Province with a second-order syncline preserved as high topography in the center of the valley. Nittany Valley is underlain mainly by Cambrian and Ordovician carbonates characterized by dominantly karst terrain, with clastic sedimentary strata (Reedsville) in the ridge slopes and sandstones (Bald Eagle and Tuscarora) forming prominent crests (see Figure 1-1: five cross-section diagrams through the Nittany Valley (Parizek, et al., 1971), and stratigraphic column, inside front cover (Berg, 1983), stops 1 & 2). We are standing on hard, quartz-cemented sandstones of the Silurian Tuscarora Formation, from which ganister had been harvested as a source of refractory stone. As can be observed in the road-cut to our right, much of the landscape here is mantled by relict colluvium from Pleistocene periglacial conditions, including unvegetated boulder fields (Stop 2).

NITTANY VALLEY CROSS-SECTION DIAGRAMS



1.

2.

3.

4.

5.

Figure 1-1. Cross-sections through the Nittany Valley. **(Parizek, et al, 1971).**

STOP 2: TUSSEY MOUNTAIN BOULDER FIELDS

STOP LEADERS – ROMAN DIBIASE[1,2], GREG MOUNT[3], JOANMARIE DEL VECCHIO[2]

[1]Earth and Environmental Systems Institute, The Pennsylvania State University, University Park, PA
[2]Department of Geosciences, The Pennsylvania State University, University Park, PA
[3]Department of Geoscience, Indiana University of Pennsylvania, Indiana, PA

(40.70757, -77.90235)

Earth's surface and shallow (10-100 m) subsurface environment, comprising air, water, biota, organic matter, and Earth materials, encompass the "Critical Zone", the dynamic interface between the atmosphere, biosphere, hydrosphere, and lithosphere (Brantley et al., 2007). Here we are about one mile northeast of Garner Run (Figure 2-1), one of three study catchments within the NSF-funded Susquehanna Shale Hills Critical Zone Observatory (SSHCZO). The 1 km^2 Garner Run catchment was established in 2014 as part of an expansion from the original Shale Hills catchment (Stop 3) to include sites with contrasting lithology and land use aimed at upscaling local measurements to the more geologically complex 164 km^2 watershed of Shavers Creek (Brantley et al., 2016). A third agricultural site in Shavers Creek, not visited on this trip, was instrumented in 2017. For stops 2 and 3, we will be highlighting a selection of recent work from the SSHCZO. For more information on additional research, outreach, and education associated with this project, including publicly available data, please visit the website at: http://criticalzone.org/shale-hills/

At Garner Run, we used lidar topography, detailed surface mapping of regolith texture, and shallow geophysics to quantify the patterns and thickness of colluvial soils, valley fill thickness, and thickness of weathered, in-place bedrock, with implications for spatial and temporal patterns of fluxes of water, solutes, and sediment over a range of timescales. Lidar topography highlights prominent lobate features in a low-sloping valley bench that are thought to be well-preserved solifluction lobes from past periglacial conditions (Figure 2-2). Colluvial cover can be quite thick, and a 9-m drill core in Harry's Valley is entirely within sandy and rocky colluvium. Ground-penetrating radar (GPR) surveys reveal patterns in near-surface regolith structure (DiBiase et al., 2016), highlighting subsurface contacts between colluvium and dipping sandstone bedrock. In the valley floor, attenuation due to clays limits the depth of investigation for GPR, but electrical resistivity and shallow seismic refraction surveys indicate 10-15 m of valley fill.

To characterize the timing of Quaternary landscape processes at Garner Run, we measured the concentration of in situ cosmogenic ^{10}Be and ^{26}Al of both surface material and buried colluvium (Del Vecchio et al., 2016). ^{10}Be concentrations in soils, surface clasts, and stream sediment indicate hillslope lowering rates of 6.3 ± 0.5 m m.y.$^{-1}$ integrated over a timescale of 100 k.y., and when paired with fill-volume estimates constrained by geophysical surveys indicates that the minimum valley-fill age is 300 ± 150 ka. Independent constraint comes from cosmogenic $^{26}Al/^{10}Be$ burial dating of clasts from the Harry's Valley drill core in Garner Run, which require at least two pulses of deposition since 350 ± 110 ka. This record spans at least three glacial terminations and implies limited removal of valley-bottom deposits during interglacial periods (Del Vecchio et al., 2016; Del Vecchio, 2017).

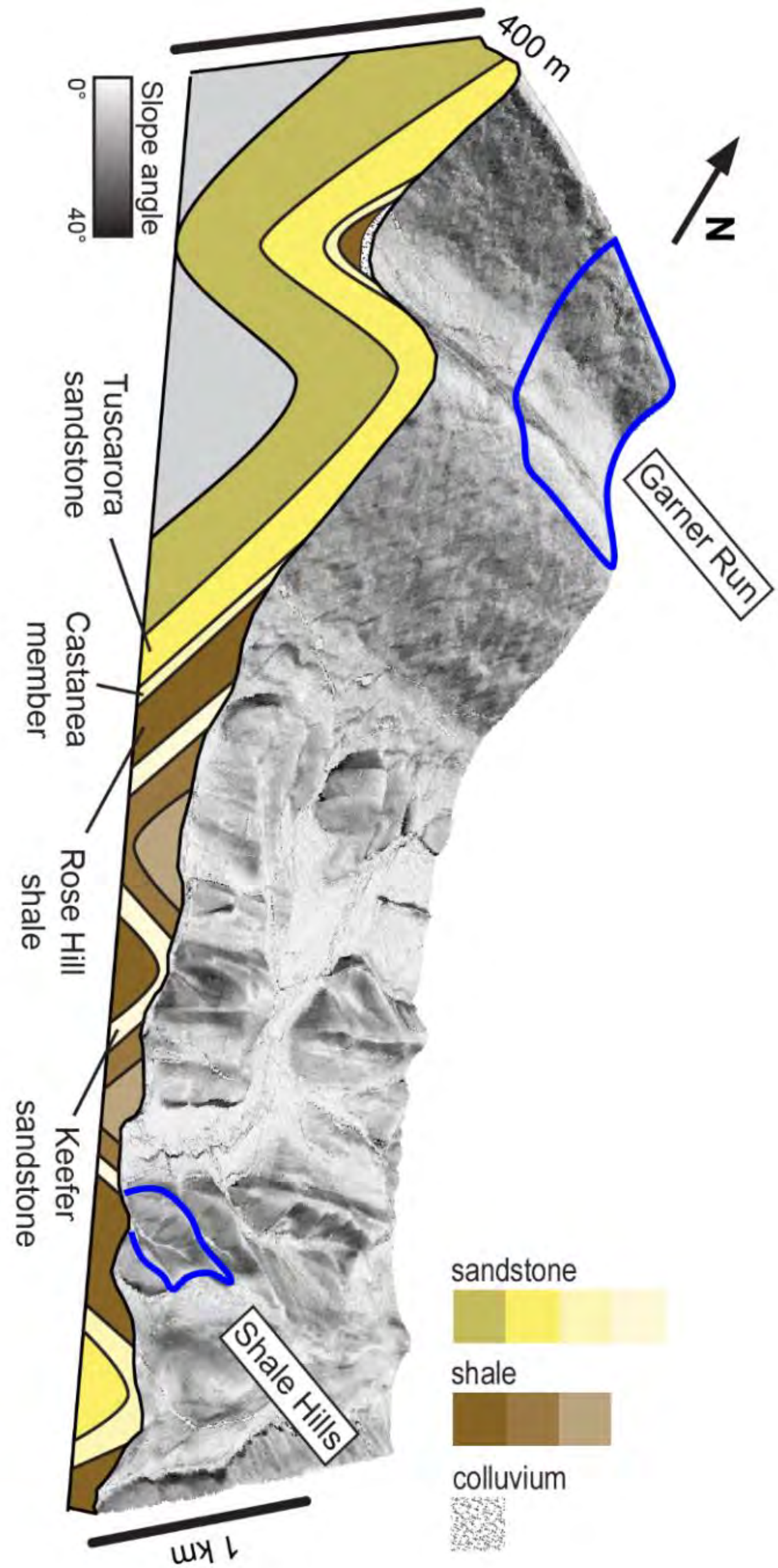


Figure 2-1. Block diagram of Shavers Creek geology and lidar topography showing location of Garner Run and Shale Hills study catchments in the Susquehanna Shale Hills Critical Zone Observatory. Figure modified from Del Vecchio (2017).

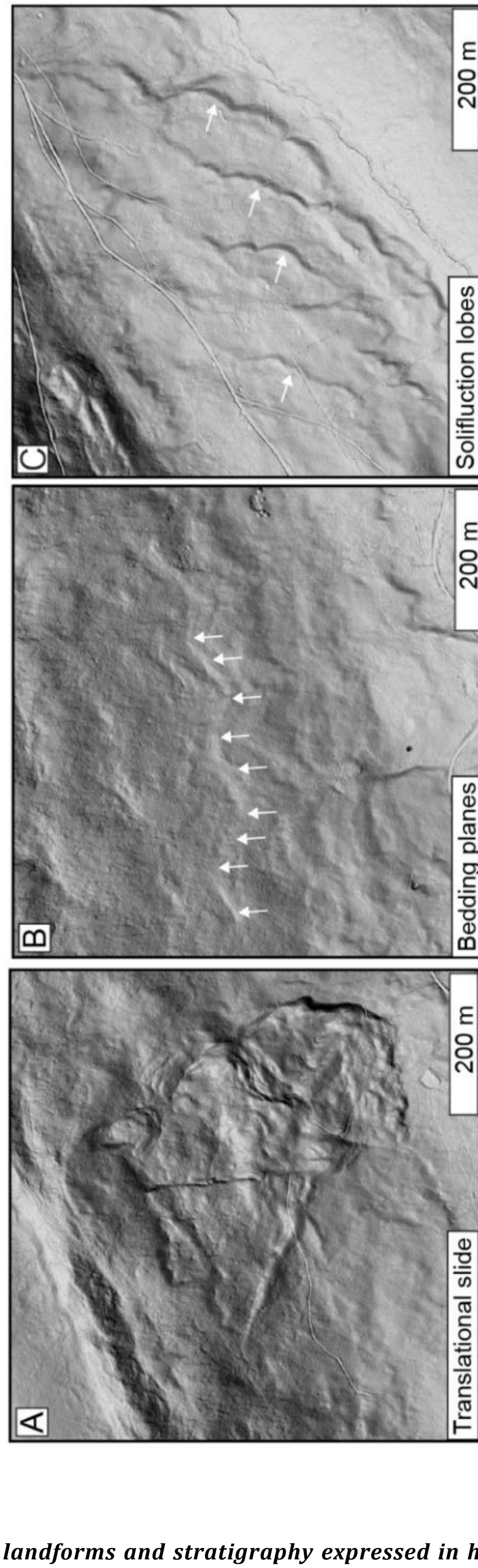


Figure 2-2. Examples of relict periglacial landforms and stratigraphy expressed in high-resolution lidar topography in Garner Run area, including A) mass wasting features; B) shadow bedding planes; and C) solifluction lobe crests. Figure modified from Brantley et al. (2016).

STOP 3: SHALE HILLS CATCHMENT – SUSQUEHANNA SHALE HILLS CRITICAL ZONE OBSERVATORY

STOP LEADERS – ROMAN A. DIBIASE[1,2]; SUSAN L. BRANTLEY[1,2]; ASHLEE L. DERE[3]; DAVID M. EISSENSTAT[4]; LI GUO[4]; JASON KAYE[4]; HENRY LIN[4]; NICOLE WEST[5]
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[2]Department of Geosciences, The Pennsylvania State University, University Park, PA
[3]Department of Geography and Geology, University of Nebraska, Omaha, NE
[4]Department of Ecosystem Science and Management, The Pennsylvania State University, University Park, PA
[5]Department of Earth and Atmospheric Sciences, Central Michigan University, Mount Pleasant, MI

CAUTION

Please note this site is actively monitored (Figure 3). We have flagged a path to avoid disturbing the numerous fragile sensors throughout the watershed, but nonetheless watch your step!

(40.66504, -77.90743)

The 0.08 km² Shale Hills Catchment (Figure 3-1) has been used for hydrologic research since the 1970s, and was established as one of nine NSF-supported Critical Zone Observatories in 2007, with a goal of quantitative prediction of Critical Zone structure and process, focusing on fluxes of water, energy, gas, solutes, and sediments (Brantley et al., 2016). Our research promotes the understanding of how a forested, first-order catchment of shale bedrock evolves over multiple time scales in a temperate climate. This stop hosts a walking circuit of five stations within the Shale Hills catchment (Stops 3A-3E), for which the group will split up due to accessibility.

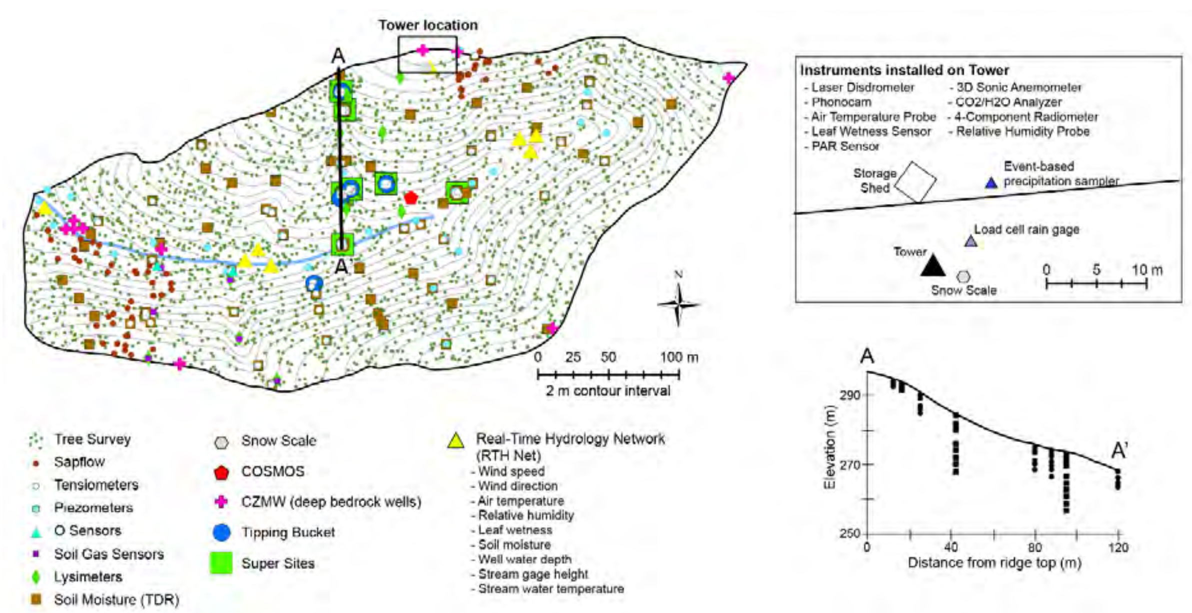

Figure 3-1. Overview map of Shale Hills catchment showing dense instrumentation and sampling approach. Inset cross section shows soil moisture sensors (circles) and lysimeters (squares) along the transect A-A'. Sensor and lysimeter depths are exaggerated by a factor of 5 compared to topography. Figure modified from Brantley et al. (2016).

STOP 3A: Nested reaction fronts under the Susquehanna Shale Hills CZO (Susan Brantley)

From cuttings in boreholes on both the ridgeline and valley floor (pink crosses, Figure 3-1), we identified depths to which weathering has extended underneath the Shale Hills study catchment (Brantley et al., 2013). Pyrite and carbonate concentrations are insignificant at shallow depths (above 23 m and 22 m under the northern ridge and 8-9 m and 2 m under the valley, respectively), which we attribute to dissolution-driven loss of near-surface pyrite and carbonate roughly coinciding with the winter water table. Likewise, illite is lost from the upper 5-6 meter-thick fractured layer, and especially from the soil layer. Chlorite begins to oxidize and lose Mg at the pyrite-oxidation front, and continues reacting to the surface. We argue these depth variations result from weathering reactions between O_2, CO_2, and organic acids and water with the shale bedrock of the Rose Hill Formation (Brantley et al., 2013). Weathering in the subsurface at Shale Hills may commence with oxidation of pyrite and dissolution of carbonate, at least partly because pyrite oxidizes autocatalytically to acidify porewaters and open porosity as oxygen permeates through the vadose zone. These nested reaction fronts describe chemical landscapes in the subsurface which additionally give information about the vertical and lateral flow of subsurface water (Figure 3-2). We hypothesize that wherever we observe sharp reaction fronts (chlorite, pyrite), water may transiently saturate and this perched water table may allow lateral flow downslope. Otherwise, water infiltrates vertically, explaining wide reaction fronts (chlorite). Reaction fronts thus give clues about water flow in catchments.

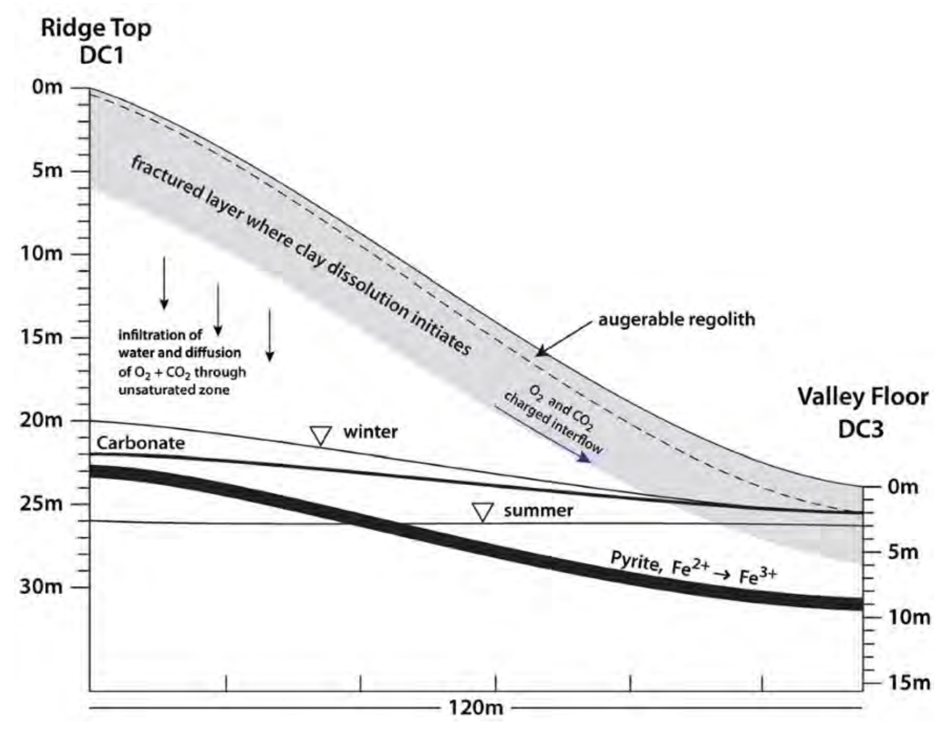

Figure 3-2. Schematic cross section between ridge and valley boreholes in the Shale Hills Catchment (pink crosses, Figure 3), showing hypothesized nested reaction fronts subparallel to the land surface. Triangles indicate winter and summer water table depths. Figure from Brantley et al. (2013).

STOP 3B: Hillslope subsurface flowpaths revealed by repeat GPR (Henry Lin and Li Guo)

At the Shale Hills catchment, we conducted repeated ground-penetrating radar (GPR) surveys to detect subsurface flowpaths and characterize seasonal soil water dynamics. By comparing discrepancies in GPR signals collected before and after natural or forced water infiltration, lateral preferential flowpaths above the interface between soil horizons and through fractured bedrock were detected, and varied as function of landscape position and the associated soil series (Doolittle et al., 2012; Zhang et al., 2014). In thick soils located in swales (Rushtown soils), GPR reflection between soil horizons (i.e., Bw-BC interface and BC-C interface) became clearer during wet seasons due to water accumulation at these water-restricting interfaces. In contrast, GPR reflections at the soil-bedrock interface on planar hillslopes (Weikert soils) became intermittent during the wet seasons, as preferential water distribution in the fractured bedrock reduced the signal contrast between soil and bedrock (Zhang et al., 2014). From a 2.5 m x 0.8 m GPR grid with nine parallel survey lines, we reconstructed a 3-D network of subsurface lateral flowpaths with centimeter resolution, which was validated by real-time monitoring of soil water (Figure 3-3; Guo et al., 2014). Two types of lateral preferential flow networks were detected: the network at the soil-permeability contrast and the network formed via a series of connected macropores. These studies highlight the potential for carefully designed GPR surveys to offer a practical and nondestructive way of in-depth investigation of subsurface hydrology in the field.

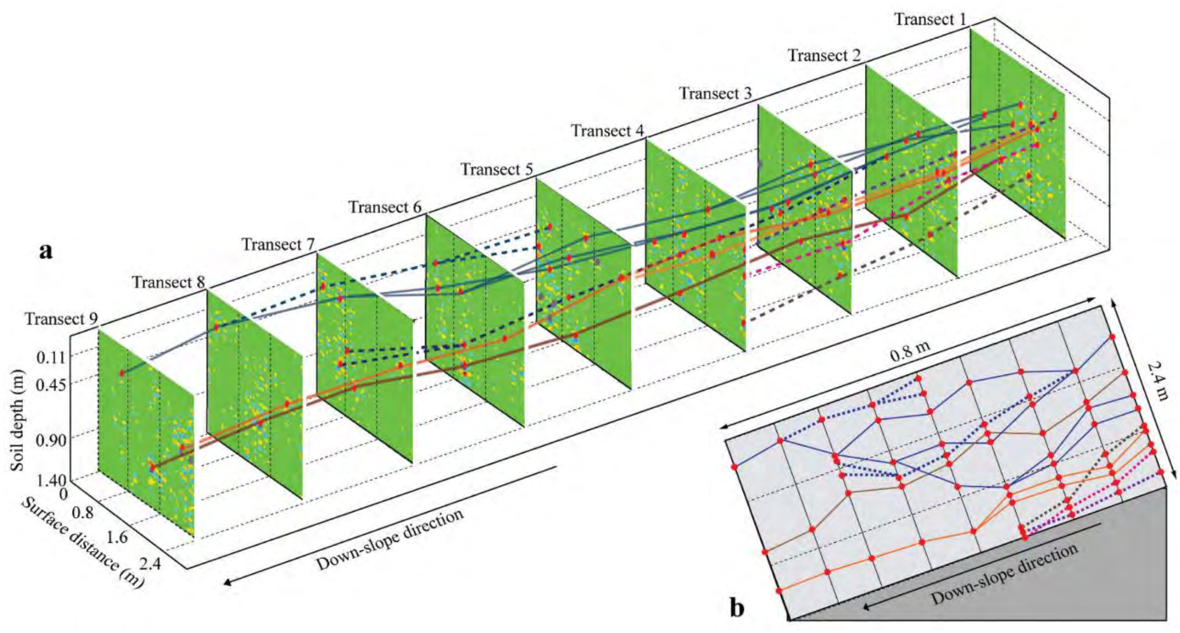

Figure 3-3. Identification of subsurface lateral preferential flow network connectivity at Shale Hills site from 3D GPR survey. Each transect in panel (a) shows reflection differences between standardized radargrams collected before and after infiltration, with red dots indicating nodes of the lateral preferential flow network. Panel (b) shows 2-D projection of the 3-D lateral preferential flow network. Figure from Guo et al. (2014)

STOP 3C: Topographic asymmetry and aspect-dependent soil creep (Nicole West)

Here we are looking at hillslopes that show striking contrast in morphology – both in the Shale Hills catchment and in two adjacent small watersheds (Figure 3-4, A-D). North-facing slopes are in general steeper (mean slope = 20°-22°) than south-facing slopes (mean slope = 11°-17°). Despite this asymmetry, inventories of meteoric ^{10}Be in soils, a tracer for soil transport, indicate that soil flux on both north- and south-facing slopes is similar over the past 10-15 k.y. and increases linearly with distance from the ridgeline (Figure 3-4, E), in agreement with predictions from steady-state soil transport models (West et al., 2013; 2014). Consequently, the topographic asymmetry implies a 2x difference in soil transport efficiency, which we ascribe to differences in microclimate that drive temperature-dependent frost creep.

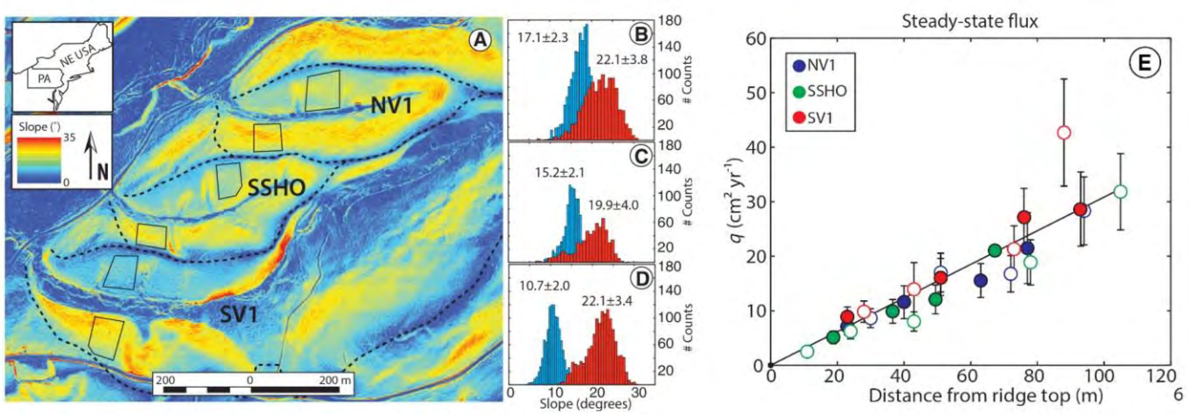

Figure 3-4. A) Slope map of Shale Hills catchment (SSHO) and adjacent watersheds (NV1, SV1) highlighting topographic asymmetry. Histograms of local slope angle on north-facing (red bars) and south-facing (blue bars) hillslopes for B) NV1, C) SSHO, and D) SV1 catchments, with mean and standard deviation of hillslope angle indicated. E) Plot of soil volumetric flux, q, versus distance from ridge top, based on soil meteoric ^{10}Be inventories. Note that soil flux is linear with distance, and similar for both north-facing (solid symbols) and south-facing (open sbols) slopes, despite topographic asymmetry. Figure modified from West et al. (2014).

STOP 3D: Topographic controls on soil respiration (Jason Kaye and David Eissenstat)

Variations in soil pCO_2 and the soil surface CO_2 efflux (i.e., soil respiration) contain information about the biotic controls on weathering and are critical for constraining soil carbon budgets. At the Shale Hills site, we monitored soil gas in six pits monthly for three years (2008-2010) to achieve better estimates of watershed-scale carbon and weathering fluxes (Hasenmueller et al., 2015). We also quantified root mass, length, and respiration in regolith profiles reaching deep into fractured shale bedrock to understand the role of biota on weathering and gas fluxes (Hasenmueller et al., 2017).

Average and seasonal change of soil pCO_2 vary as a function of landscape position. Average pCO_2 is highest in thick soils of convergent topographic swales and lowest along planar slopes and on ridge tops (Figure 3-5); in both settings soil pCO_2 tracks with spatial and temporal patterns in soil moisture, which controls diffusivity of CO_2 through soils (Hasenmueller et al., 2015). Additionally, convergent swales showed greater sensitivity of soil respiration to changes in temperature, suggesting soil moisture, and thus topographic position, modulates soil carbon response to warming.

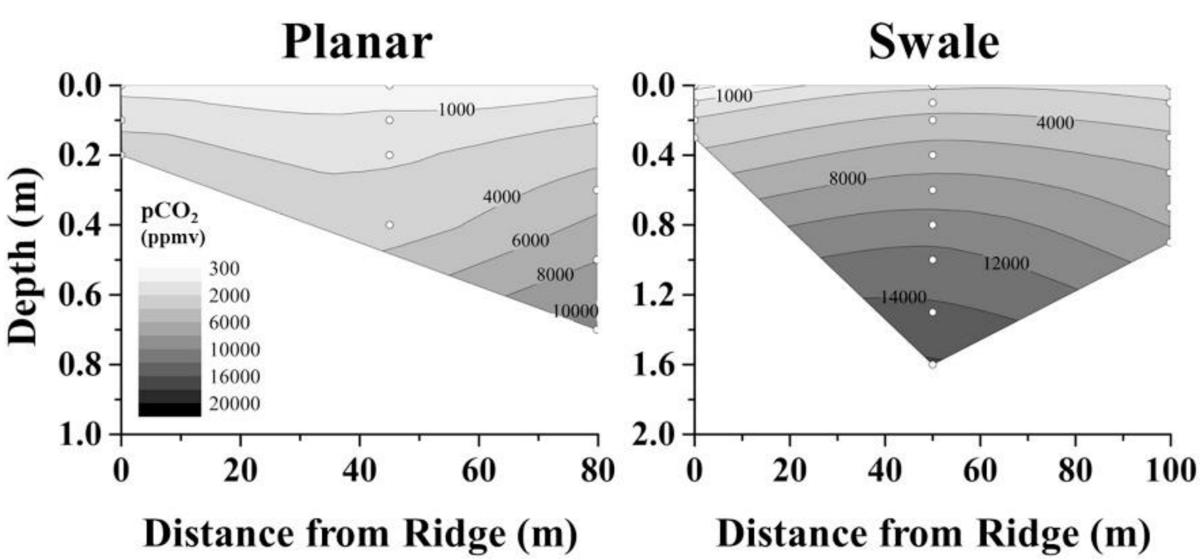

Figure 3-5. Average pCO_2 concentrations from 2008-2010 as a function of distance from southern ridge top and depth along a planar slope (left) and convergent swale (right), highlighting topographic control on soil pCO_2. Small circles indicate sampling depth locations. Figure from Hasenmueller et al. (2015).

STOP 3E: Climate controls on shale weathering (Ashlee Dere)

The Shale Hills site forms one of six study sites along a climate sequence spanning from Puerto Rico to Wales where we have been investigating how temperature and precipitation influence shale weathering and soil development (Figure 3-6). At each site, soil chemistry, mineralogy, and weathering rates determined from residual weathering profiles help elucidate how temperature and precipitation influence the style and rate of shale weathering. In contrast to previous granite weathering studies that identified physical erosion as more important than climate in controlling weathering rates, we found that plagioclase dissolution rates, which appear to control the transformation of bedrock to regolith, vary with temperature and precipitation (Figure 3-6, left panel; Dere et al., 2013). Mineralogical transformations across the transect also show enhanced weathering and soil development with increasingly warm and wet climates (Dere et al., 2016). Although a small fraction of the initial shale mineralogy, the deepest documented weathering reaction is plagioclase feldspar dissolution, which may be the reaction that begins the transformation of shale bedrock to weathered regolith (Figure 3-6, right panel). However, the more abundant chlorite in the shale parent material, and its transformation to vermiculite and hydroxy-interlayered vermiculite (HIV), are more likely controlling regolith thickness in these profiles (Dere et al., 2016). Rare earth element release rates are insensitive to climate and instead depend strongly on parent material composition (Jin et al., 2017), complicating simple predictions for observed variation in soil depth and geochemistry.

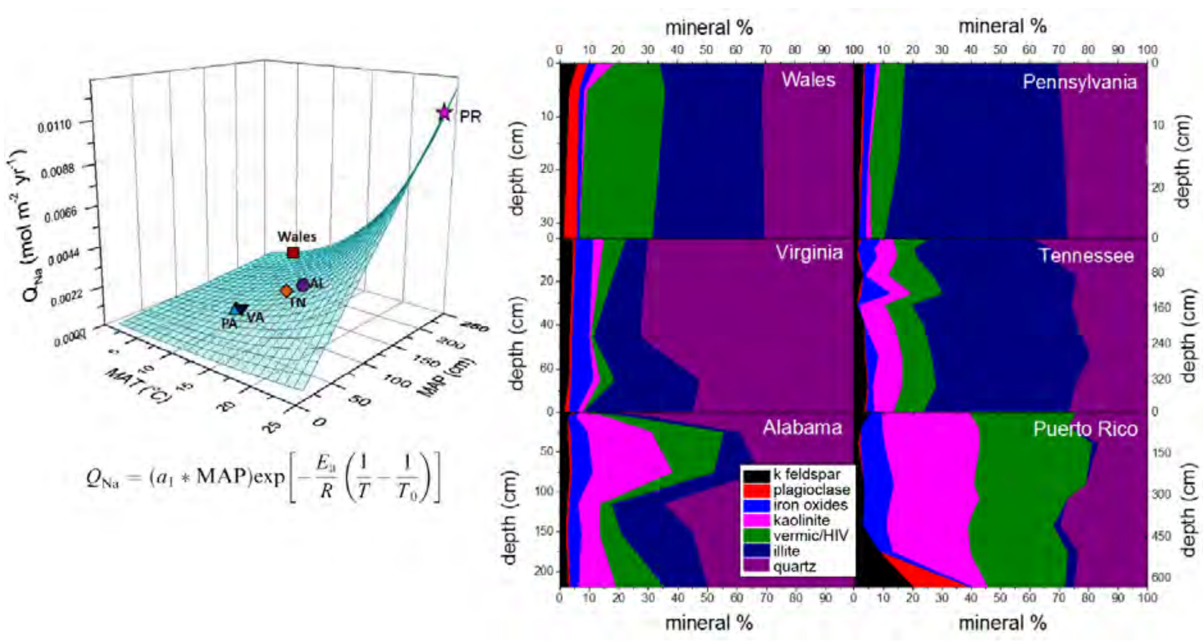

Figure 3-6. Left: Average integrated rate of Na loss, Q_{Na} (a proxy for plagioclase weathering rate), plotted against mean annual temperature, MAT, and mean annual precipitation, MAP, for six shale field sites spanning a latitudinal climate gradient. Mesh surface indicates fit of Arrhenius-type relationship between weathering rate, temperature, and precipitation. AL = Alabama; PA = Pennsylvania; PR = Puerto Rico; TN = Tennessee; VA = Virginia. Figure from Dere et al. (2013). Right: Mineralogical changes with depth for the same field sites. Plagioclase feldspar is labeled in red and vermiculite and hydroxy-interlayered vermiculite (HIV) is green. Figure from Dere et al. (2016).

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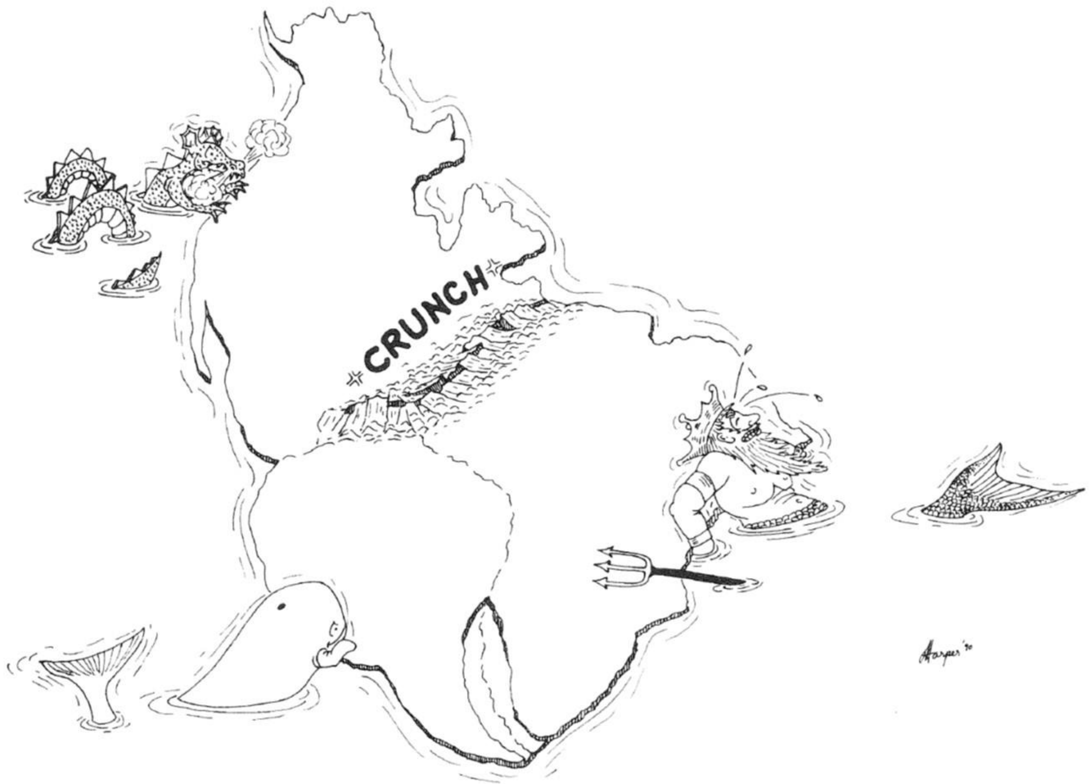
STOP “4” LUNCH

STONE VALLEY RECREATION CENTER,
LAKE PEREZ




RRRRRIIPP

FUN FACTS – DAY 1

Pine Grove Mills

- Founded by Thomas Ferguson in 1791, who bought 321 acres of land for 300 pounds in gold and silver coins.
- The W.D. Ross Farm shown below (just above the "S" in Pine Grove Mills) was built in 1800 and is now called the Limestone Inn. It is owned by geologist Dave and his wife Carrie.(limestoneinn.com)
- In the early 19th century, additional settlements were established, e.g. Gatesburg (iron ore center) and Pattonville (later merged w/ Pine Grove Mills). (twp.ferguson.pa.us/About-Ferguson-Township/)
- It is illegal to trim oak trees in Ferguson Township between April 1 and October 31 (i.e. NOW) without a permit. This limitation was put in place to reduce the risk and spread of oak wilt disease. Oak trees pruned between April 1 and October 31 are more likely to become infected with oak wilt and die. (http://www.twp.ferguson.pa.us/Tree-Fact-Sheets/)

Rothrock State Forest: overturned basal Tuscarora on Route 26

- Rothrock State Forest is named for Dr. Joseph Trimbel Rothrock, a native of Mifflin County, who is recognized as the Father of Forestry in Pennsylvania. In 1895, Dr. Rothrock was appointed the first forestry commissioner to lead the newly-formed Division of Forestry in the Department of Agriculture. Two of Rothrock's major accomplishments during his tenure as commissioner were his land acquisition program and the creation of a forest academy to train foresters for state service.
- In 1903, the forested area now known as the Rothrock was virtually stripped bare of trees to provide wood to make charcoal for the iron furnaces located at Greenwood Furnace in Huntingdon County. These furnaces were used for the smelting of iron ore which was a major industry in the 1700's and 1800's in Pennsylvania. When two of the Greenwood Furnace hearths closed in 1903, Dr. Rothrock was instrumental in helping the Bureau of Forestry purchase approximately 35,000 acres in Huntingdon County from Greenwood Furnace. Other purchases followed until most of the Seven Mountains forest area became state land. These original land purchases were called state forest reserves and were divided into three separate reserves.
- In 1955 the entire state forest system in Pennsylvania was placed under a scientific timber management plan. In the Rothrock, timber management became very important as large stands of nearly pure oak and hickory grew large enough to be harvested for lumber. The forester staff at Huntingdon increased from four to eight.
- In 1933, newly-elected President Franklin D. Roosevelt created the US Civilian Conservation Corps (CCC), (right), a work program for able-bodied and unemployed males. Approximately 93 resident work camps, each consisting of 174-200 young men, were built on Pennsylvania's state forests. Six of these camps were located in the present day Rothrock State Forest.

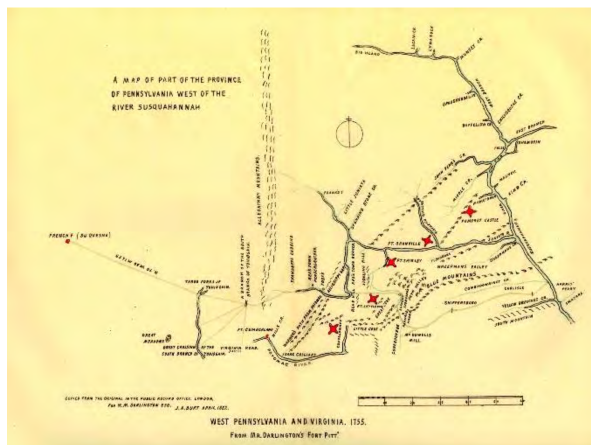
(https://web.archive.org/web/20070808015510/http:/www.dcnr.state.pa.us:80/forestry/stateforests/rothhistory.aspx)

Jo Hays Vista

- Named in honor of University graduate and retired state senator Jo Hays
- During Hays' senatorial term, residents of Pine Grove requested to have the lookout on Pine Grove Mountain cleared due to the number of motorists who would stop at the spot, endangering themselves and other motorists.
- Committee was formed to name the overlook: there was some debate over using "vista" vs "bluff." Eventually was decided with a coin-toss, to the relief of Senator Hays. "I was a little scared about [it being called Jo Hays Bluff]."

(http://www.collegian.psu.edu/archives/article_a65756cf-f66a-59ee-bec9-68b3b31e32fe.html)

McAlevy's Fort



- One of the earliest settlers who came to this spot, the writer finds from personal researches, was Captain William McAlevy, whose name is mentioned frequently in connection with the Revolutionary war and the political troubles of 1788. He was a Scotch Irishman by birth, and formerly resided in Cumberland county, north of Carlisle. He came up to this locality, which afterwards bore his name, about the year 1770. After concluding to settle there, he made a canoe out of a pine tree, in which he descended Standing Stone creek and the Juniata and the Susquehanna rivers to Harris Ferry, and in which he returned, bringing his family up those streams to his future home. The stream was very rocky, the water shallow and his craft light, it struck the rocks and bars, from which it could not be moved by himself, but only by the power of a horse which he kept conveniently near. (The horse was mainly to pull the canoe when it got stuck in sandbars.)

(http://www.usgwarchives.net/pa/1pa/1picts/frontierforts/ff22.html)

- This area, at the time, was mainly inhabited by **Shawnee and Ohio Valley** tribes. This new place was in what is modern-day northern Huntingdon County.
- Fort was constructed to provide protection against these native people. The first few years there were rough, with attacks happening regularly. McAlevy once had a close call when he and a companion were a good ways from the fort. He was shot by a Native American man but was able to run away. His companion wasn't so lucky, being captured and scalped. Following this event though, he made headway and cleared enough land to farm and comfortably support his family.
- During the Revolutionary War, William McAlevy commanded a company that was situated at the northern region of the Juniata Valley, not too far from where he lived. They were tasked with responding to and repelling attacks during the war.

– END LUNCH –

STOP 5: HOOTENANNY CAMP BORROW PIT

MARCELLUS JOINT SETS & WEATHERING, COLD SPRINGS ROAD, HUNTINGDON, PA

STOP LEADERS – DAVID P. "DUFF" GOLD[1], CHARLES E. MILLER, JR. [2], TERRY ENGELDER[3]
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[2] GEOLOGIST (RETIRED), STATE COLLEGE, PA
[3] PROFESSOR EMERITUS OF GEOSCIENCES, DEPARTMENT OF GEOSCIENCES, THE PENNSYLVANIA STATE UNIVERSITY

Joints **(40.554536°, -77.96383°)**

The small borrow pit on the northwest side of Cold Springs Road (located ~1 mile off Rt. 26 to State College) exposes shallow-dipping Marcellus Shale (Oatka Creek Member) on the north flank of the Broadtop Syncline. This outcrop (Figure 5-1) has one of the nicest examples of prominent joint sets (J_1 250°/79°; J_2 290°/80 to 90°) found in the Valley and Ridge Marcellus (Figure 5-2). Note the secondary iron-oxy-hydroxide mineral on the joints and on slaty bedding partings.

Figure 5-1. The Marcellus at the Hootenanny Quarry. Photo looking to the WNW along J_2 joints. J_1 joints cut parallel to the road and define the faces of blocks in this view. Duff Gold for scale. Note soil horizon on top of the shale.

The J_1 and J_2 joint sets are normal to bedding and rotate to vertical when bedding is restored to horizontal (Figure 5-3). The sharp corners of blocks defined by the cross-cutting joints are well developed. The outcrop also contains neotectonic joints with irregular planes. Aside from their irregular or curving planes and their non-systemic nature, there is very little else to allow a distinction between the J_1-J_2 sets and the curving neotectonic joints.

A study of fracture orientation and abundance, completed by Justin Paul, quantified the two major fracture orientations (J_1 and J_2) with well-spaced joints that produced n<0.1 (where n= length of fractures/area analyzed).

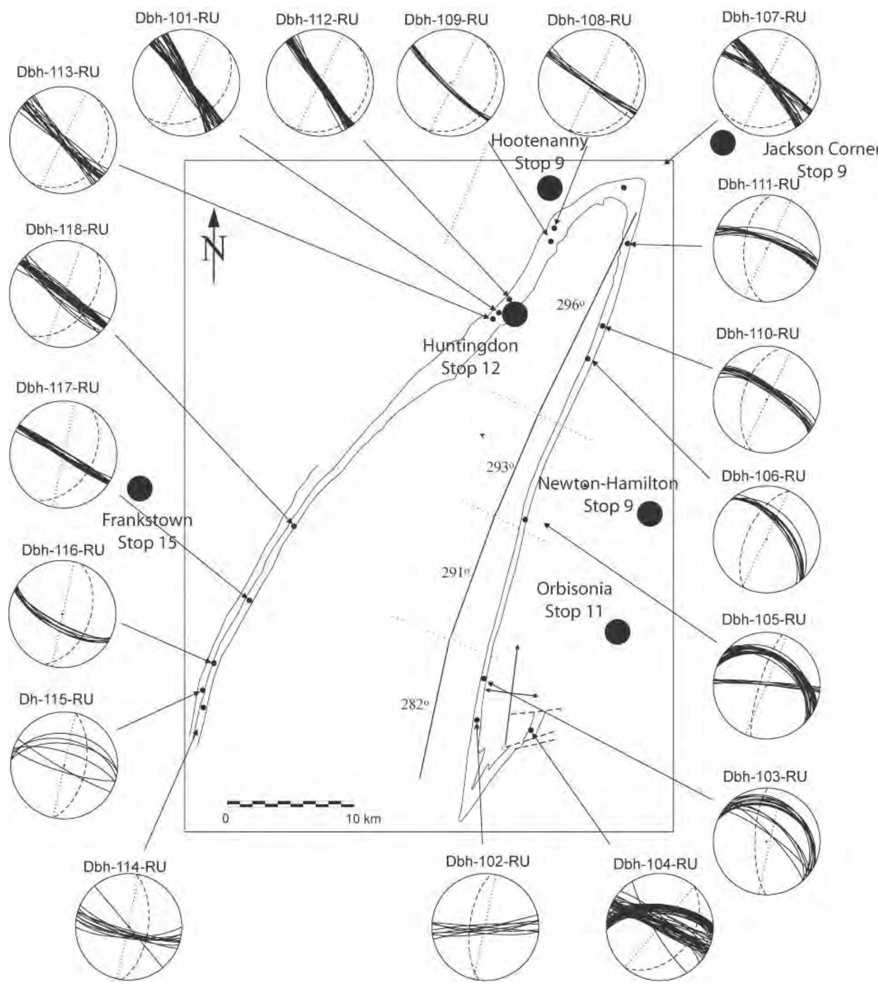


Figure 5-2. Present orientation of cross-fold joints in the vicinity of Broadtop Syncline. Equal-area net projection. Dbh: Brallier and Harrel Fms. undivided, Dh: Hamilton Group, segmented line: local bedding trend. Adapted from Uzcatequi (2004).

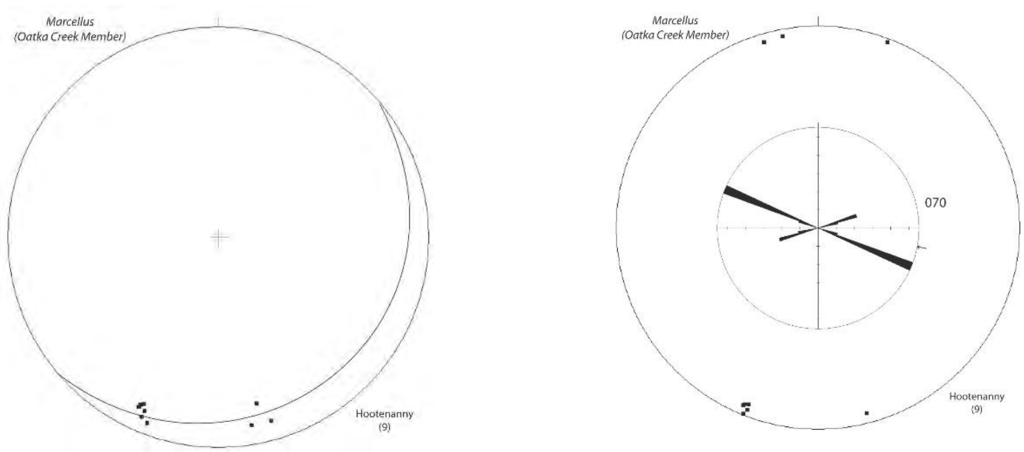


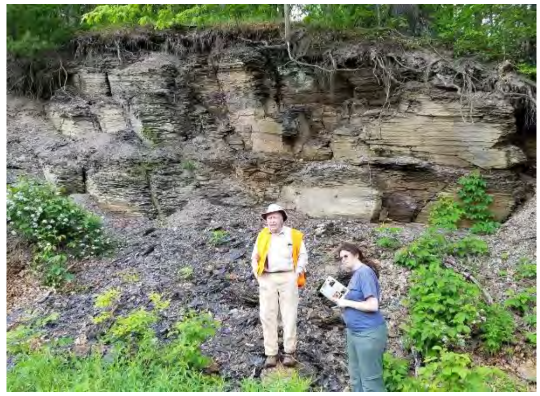
Figure 5-3. Joints plotted in present coordinates (left) and rotated to their position with horizontal bedding using a fold axis plunging 00° toward 050° with a rotation of 16° (right).

Weathering

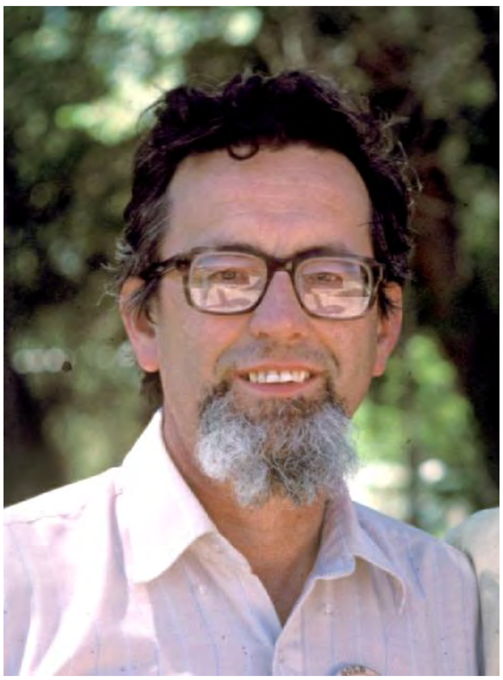
This borrow pit also exposes the soil profile on top of the shale (Figure 5-1). As part of the Shale Hills initiative, element migration during weathering of Silurian shales and mudstones at Shale Hills is compared to the Marcellus black shale. The main objective is to understand overall kinetics of element migration during soil generation in this climate zone. This Marcellus study has special interest due to the formation's high metal content and potential for understanding geochemical reactions during natural weathering and fracking. From 2005-2011, several different local sites were monitored, including one near Jackson's Corner. Major-element survey, trace-element and isotopic analyses of soils and parent materials were performed. Results of this study are described in September 5, 2017 issue of Chemical Geology.

Because the Hootenanny outcrop is the largest Marcellus exposure in this area, it is of interest to our study of how the formation weathers. Major-element survey, trace-element and isotopic analyses of soils and parent materials were performed. One control in studying element migration and concentration during weathering is to constrain the composition of the starting, or parent, material. Parent material was collected as rock chips in auger holes at the soil/rock interface and as outcrop samples. At the Hootenanny outcrop, "fresh" rock fragments were collected and each presented as a powdered value called "Juniata." Interestingly, parent materials sampled at the Hootenanny outcrop were at different stratigraphic elevations in the Marcellus and the major elemental compositions remained relatively consistent except for Al and Fe. The Al is lowest in a ridge top sample and the Juniata sample described here. The Fe content of this sample was also much higher than the other parent materials presented. The Fe could be explained to variations of total sulfide content known to occur in the Marcellus.

GEOLOGICAL WEATHERING



GEOLOGIST WEATHERING



Will White, 1984

Will White, 2012

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STOP 6: BRALLIER OUTCROP AT "DAIRY QUEEN" ROADCUT

WELL-DEVELOPED J_2 JOINTS IN THE BRALLIER SILTSTONES
ROADCUT ALONG PENN ST. OFF ROUTE 22 IN HUNTINGDON, PA

STOP LEADER – TERRY ENGELDER[1]

[3] PROFESSOR EMERITUS OF GEOSCIENCES, DEPARTMENT OF GEOSCIENCES, THE PENNSYLVANIA STATE UNIVERSITY

Observations **(40.476806°,-77.997413°)**

The Brallier Formation is a clastic unit with distal turbidites and shale interbedded immediately over the Burket black shale. Unlike the Mahantango above the Marcellus, this unit has a significant volume of sheet sands that act as distinct mechanical units. With such mechanical units, the pattern of fracturing in the Brallier is distinct from other units visited during this field trip (Figure 6-1). The Brallier, like its counterpart in New York (i.e., the Ithaca Formation), gradually becomes more coarse-grained up section. Where the lower portion of the Brallier was exposed near the Burket, the siltstone interlayers were thinner and finer grained. J_2 joints propagated through these thinner mechanical beds without stopping at bed boundaries. There is no evidence for J_1 joints which favor black shales of the Appalachian Basin. Presumably J_1 would have an affinity for black shale in proximal portions of the Basin as well.

Figure 6-1. Joints in interbedded siltstone of the Brallier Formation in a road cut along Penn Street off Route 22 in Huntingdon, PA. Multiple en-echelon cracks propagate upward into a siltstone layer from a shale-siltstone interface with a J_2 joint in shale acting as the parent.

At this stop, three episodes of joint propagation are evident starting with the mineralized J_2 set often covered with euhedral crystals of quartz (Ruf, et al., 1998). The second set is strike joint with either unmineralized surfaces or coated with a delicate pattern of microscopic crystals of unknown composition.

The third episode of jointing is a late-stage J_2 joint set that by statistical analysis seem to behave like cross joints (Ruf et al., 1998). Certainly, these late joints abut strike joints more commonly than the other way around (Figure 6-2). It is, however, common to see these cross joints (late J_2 orientation) cross cut the strike joints in the Brallier (Figure 6-2). The strike joints are tilted slightly relative to bedding, a sign of fold-related joint growth (Engelder and Peacock, 2001).

Figure 6-2. Joints in interbedded siltstone of the Brallier Formation in a road cut along Penn Street off Route 22 in Huntingdon, PA. Late-stage J_2 joint abutting a strike joint (joint propagating toward hammer).

The development of surface morphology on the joints of the Brallier siltstones is magnificent. Two sets of systematic joints cutting the same bed may exhibit different rupture styles (Ruf et al., 1998). In the Brallier siltstones at Taughannock Falls State Park, joints oriented parallel to the strike of bedding formed prior to dip-oriented joints, as inferred from cross-cutting relationships. The strike joints typically have a surface morphology consistent with that of a short blade crack, whereas the dip joints exhibit a more complex morphology (Figure 6-3). The earlier joints have surfaces with a typical plume-related topography (i.e., 1-3 mm within any cm^2) that greatly exceeds the grain size (< 0.125 mm) of the host bed whereas the later joints have surfaces that are smooth to the touch and a topography on the order of the grain size of the host.

Figure 6-3. J_2 joints in the Ithaca Formation at Taughannock Falls State Park where multiple en-echelon cracks propagate down into shale from a siltstone-shale interface.

The complex, irregular surface morphology on dip joints resembles a frosty window. Joint surfaces often contain one or more irregular primary plume axes with several small secondary detachment ruptures (as indicated by secondary plume axes) branching off them. The detached ruptures behave as individual crack tips each propagating independently and each having a unique propagation velocity, v_{tl}. One detached rupture may outrun an adjacent rupture. It is common for such detached ruptures to terminate against or cut off other ruptures. As a result, the bed-bounded joint surface is a composite of numerous secondary ruptures whose growth direction and v_{tl} were impacted by nearby crack-tip stress concentrations. These are interpreted as subcritical joints with a much slower propagation velocity.

In Devonian clastic sections dominated by interlayered siltstones and shales, joint initiation usually starts in the siltstone layer (McConaughy and Engelder, 2001). During natural hydraulic fracturing least horizontal stress (S_h) is the governing parameter in dictating whether siltstones or shales should joint first and siltstones appear to carry the lower S_h (Engelder and Lacazette, 1990). This is largely because during consolidation siltstones have a lower consolidation coefficient which leads to the lower least horizontal stress (S_h) during compaction (Karig and Hou, 1992). The difference in horizontal stress leads to later jointing in shales at a higher fluid pressure. If there is no rotation of the principal stresses, fluid-driven joints will propagate into the shale in plane with the earlier joints in siltstone. However, if the horizontal stress does rotate, then later, higher fluid pressures will drive en-echelon cracks (i.e., fringe cracks) into bounding shale beds (Pollard et al., 1982; Carter, et al., 2001).

Fluid driven jointing in the Brallier at Huntingdon is witnessed by the trapping pressures of fluid inclusions in euhedral quartz along early J_2 joints (Lacazette and Engelder, 1988; Srivastava and Engelder, 1991). The Brallier also the same natural hydraulic fracture pattern as found in the Ithaca Formation with fringe cracks being driven from the interface of a parent joint.

As a clastic unit in distal turbidites, the Brallier Formation shows ichnofossils and sole markings (Figure 6-4a, and flute casts b).

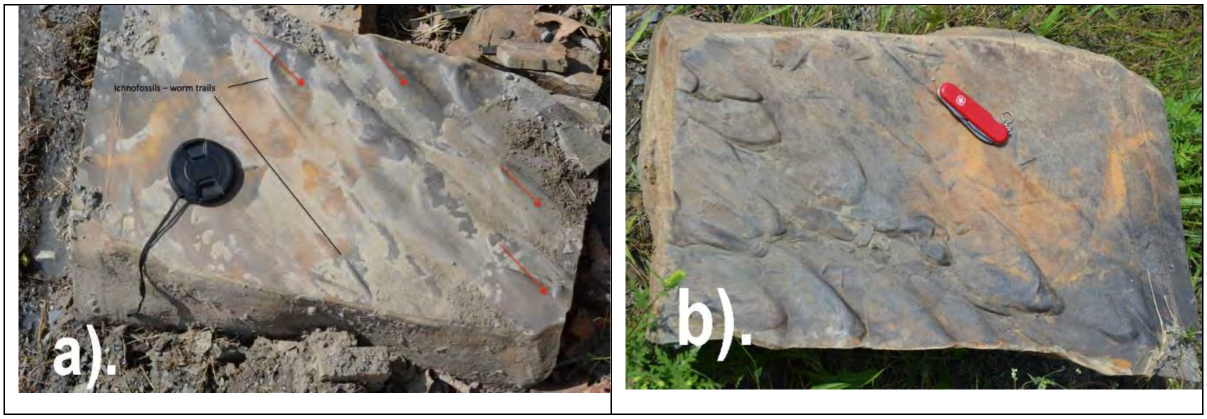

Figure 6-4. Ichnofossils and sole markings (flute casts) in Brallier turbidites. Red arrows (a) indicate current direction.

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STOP 7: CHARLIE HILL ROADCUT

CYCLES IN THE UPPER WILLS CREEK FORMATION, ROUTE 22, 6 MI NW OF HUNTINGTON, PA

STOP LEADERS – DAVID P. "DUFF" GOLD[1], CHARLES E. MILLER, JR.[2]

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Discussion **(40.53953°; -78.08819°)**

The road-cut at Charlie Hill, six miles northwest of Huntingdon on Route 22, was selected to illustrate non-penetrative structural diversity on a mesoscopic scale (Figure S7-1). This structural diversity undoubtedly was enhanced by the range in competency of interbedded limestones, dolostone, mudstones, and shale of the Upper Wills Creek Formation. Structural features include: a large range in shape and style of folds (open to tight), syn- and anti-thetic vergence, a predominance of back-thrust faults, changes in cleavage attitude, and minor thickening in some hinge zones. An anomalous structural style was recognized in sketches by Billings (Figure 47) in his classic textbook *Structural Geology* (2nd edition, 1954). Faill (1973) noted that the asymmetry of kink bands at Charlie Hill is a function of the enveloping surface, and Gwinn and Bain (1964) cited the outcrop as an example of "thin-skinned tectonics." Pohn (1985) noted a fold train, decreasing in wavelength and amplitude with proximity to bounding faults. The changing attitude of cleavage has been attributed to rotation of splay faults (Gold, 1985).

Gwinn and Bain (1964) and Gwinn and Clack (1965) interpreted shoaling-upward cycles in an increasingly more saline environment (Table 1). A typical cycle ranges 5 to 25 feet thick. Each cycle begins with a basal limestone unit (a), grading upward into vaguely laminated greenish-gray mudstone (b), to a greenish) c) to reddish (d) and back to greenish (e) to massive mudstone, to a dolomitic laminated mudstone (f) and capped by a massive dolostone with sharply defined base and top.

TABLE 1. A Gwinn and Bain Cycle for the Wills Creek Formation at Charlie Hill

Facies		*Contacts*	*Facies Symbol*	*Type of Carbonate*
massive dolostone; evaporite vugs			g	D
		sharp contact		
greenish-gray laminated mudstone			f	D
		gradational		
greenish massive mudstone	(upper)		e	D
	(lower)			C
		gradational		
reddish massive mudstone			d	C
		gradational		
greenish massive mudstone			c	C
		gradational		
vaguely laminated greenish mudstone			b	C
		gradational		
interbedded dark shale and limestone (maybe fossilferous or oolitic)			a	C

**not all cycles are complete*

The limestones and dolostones are subtidal and inter-to supratidal, respectively. The evaporite vugs likely represent a sabkha setting. At the outcrop the stations illustrating the lithofacies units in these sequences will be marked by flags in cairns.

Figure S7-1. panorama of the Charlie Hill Roadcut, with vertical exaggeration. Stations will be marked by flags in cairns.

The sketch (Figure S7-2) below attempts to capture the mesoscopic-scale structures through attitudes of lithofacies units. These are shown by patterns in the sketch and numbered from bottom to top (red circles) to develop a stratigraphic sequence.

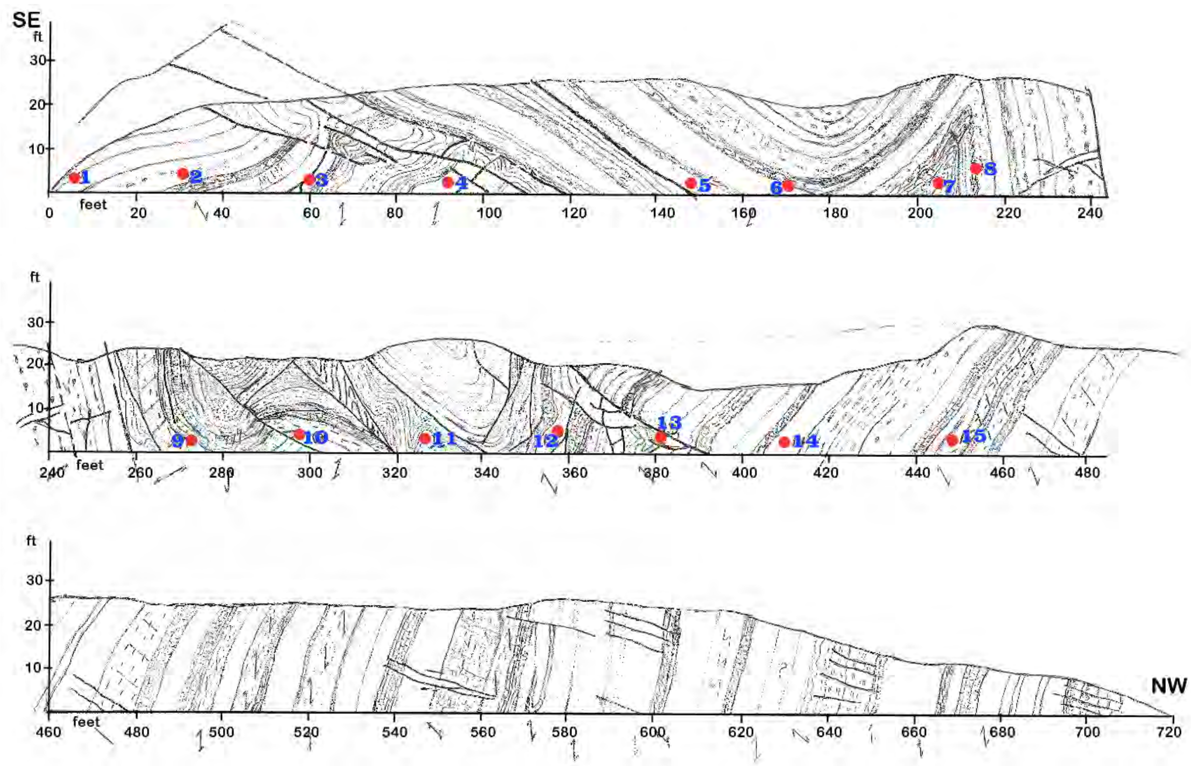

Figure S7-2. Sketch of the Charlie Hill Roadcut. Distances and height are in feet. Stations will be marked by flags in cairns.

The fifteen control points in Table 2 (represent sedimentary lithofacies units identified by Gwinn in Table 1) are keyed spatially to the cross-section in Figure S7-2 above, and to the roadcut at the stop (represented by the Figure S7-1 panorama). Stations at the outcrop in this stop will be marked by flags in cairns. Guber (1985) sketch of the Charlie Hill roadcut from the 50th field conference is also included as Figure S7-3 for reference.

TABLE 2. Lithofacies Units	
13	
12	Thinly bedded and contorted shaley limestone approximately 36 inches thick
11	Blocky, jointed bed 18" thick of gray argillaceous dolostone with shaley interbeds.
10	Massive color-cleaved mudstone bed 5-6 ft thick. At Stn 9 B= 230°/45°; and cleavage is rotated to 040°/50°.
9	Thinly bedded (mm to cm) with microlithons in cm scale; locally contorted with small drag folds.
8	Massive greenish gray mudstone (beds 4-5 ft thick) with evaporite vugs (on decimeter scale). Facies "c"
7	15-inch-thick unit of thin beds (0.5 to 1 cm scale) of carbonate and shale cleaved into lithons 1-3 cm) across, with symmetrical microfolds (S or Z). Cleavage 040°/78° with weak 2^{nd} cleavage 220°/50° appear to a conjugate set, to form a partial kink band.
6	Massive bed (5 ft) of greenish-gray mudstone. Prominent J2 (143°/90°) at Station 3. B = 040°/32°.
5	A 15-inch-thick unit consisting of thin interbeds on a 0.2- to 1-cm scale cleaved into lithons 2 to 5 cm across with s or z drag folds. Spaced cleavage 050°/90°
4	Coherent gray shale, thick beds but not cleaved
3	Massive (40 inches thick) laminated silty f-g light-gray limestone. Scalloped texture. B = 050°/80°; J1 = 220°/64° and J2 = 125°/90°.
2	Brownish-yellow, porous siltstone
1	Blocky Interbeds (3- 10 cm scale), of dololutite and shale

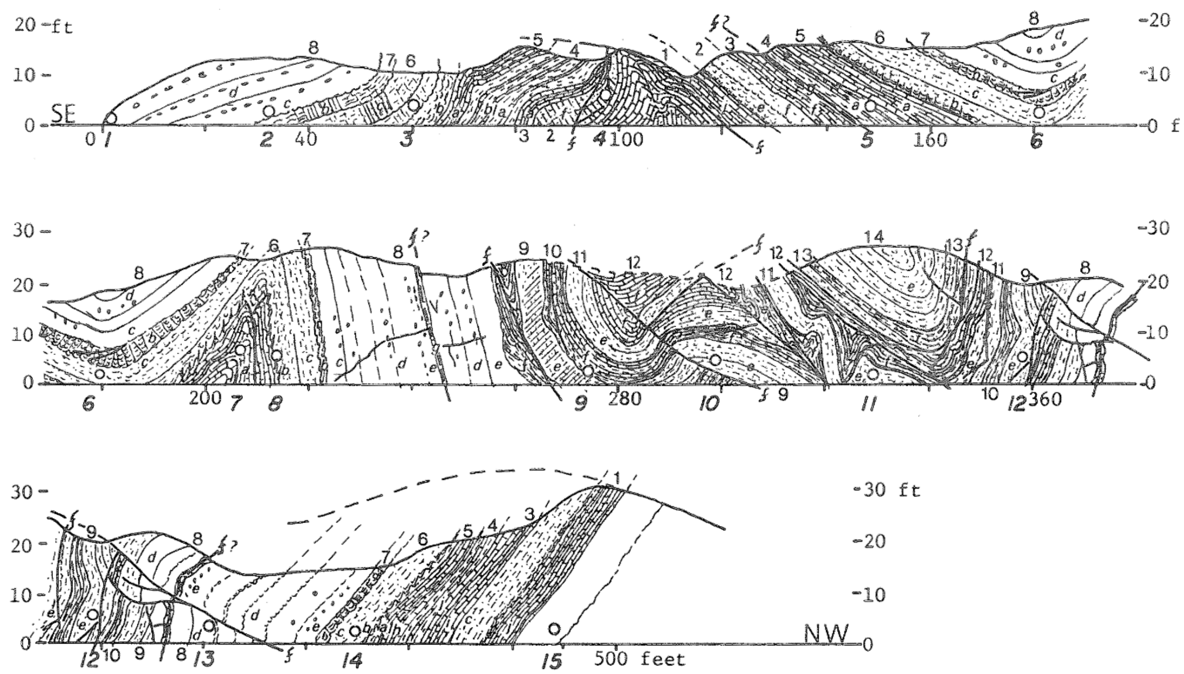

Figure 15. Schematic cross-section for 450 feet of the Charlie Hill road-cut. The orange blaze numbers (1 to 15) and letters (a to i) represent, respectively, marker stations and sedimentary facies units. The litho-structural units are labelled from 1 to 14 in the sketch above, and in white paint on the outcrop. The litho-structural units portrayed in the sketch may include more than one facies unit. Stratigraphically these rocks are assigned to the upper part of the Wills Creek Formation.

Figure S7- 3. Measured section of Charlie Hill from the 50th FCOPG (Guber, 1985). The seven distinct facies recognized (Gwinn and Bain, 1964) have a basal dark shale/limestone bed overlain by 5 units of mudstones distinguished by fabric (massive or laminated and color (greenish and reddish), all capped by a fine grained dolostone. The 14 litho-structural units are identified by Guber, 1985). Fifteen control control points are keyed spatially to the cross-section. Shoaling upward cycles in which the salinity of the environment increase up-cycle (Gwinn and Clack, 1964).

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