HOSTS:

THE PENNSYLVANIA STATE UNIVERSITY

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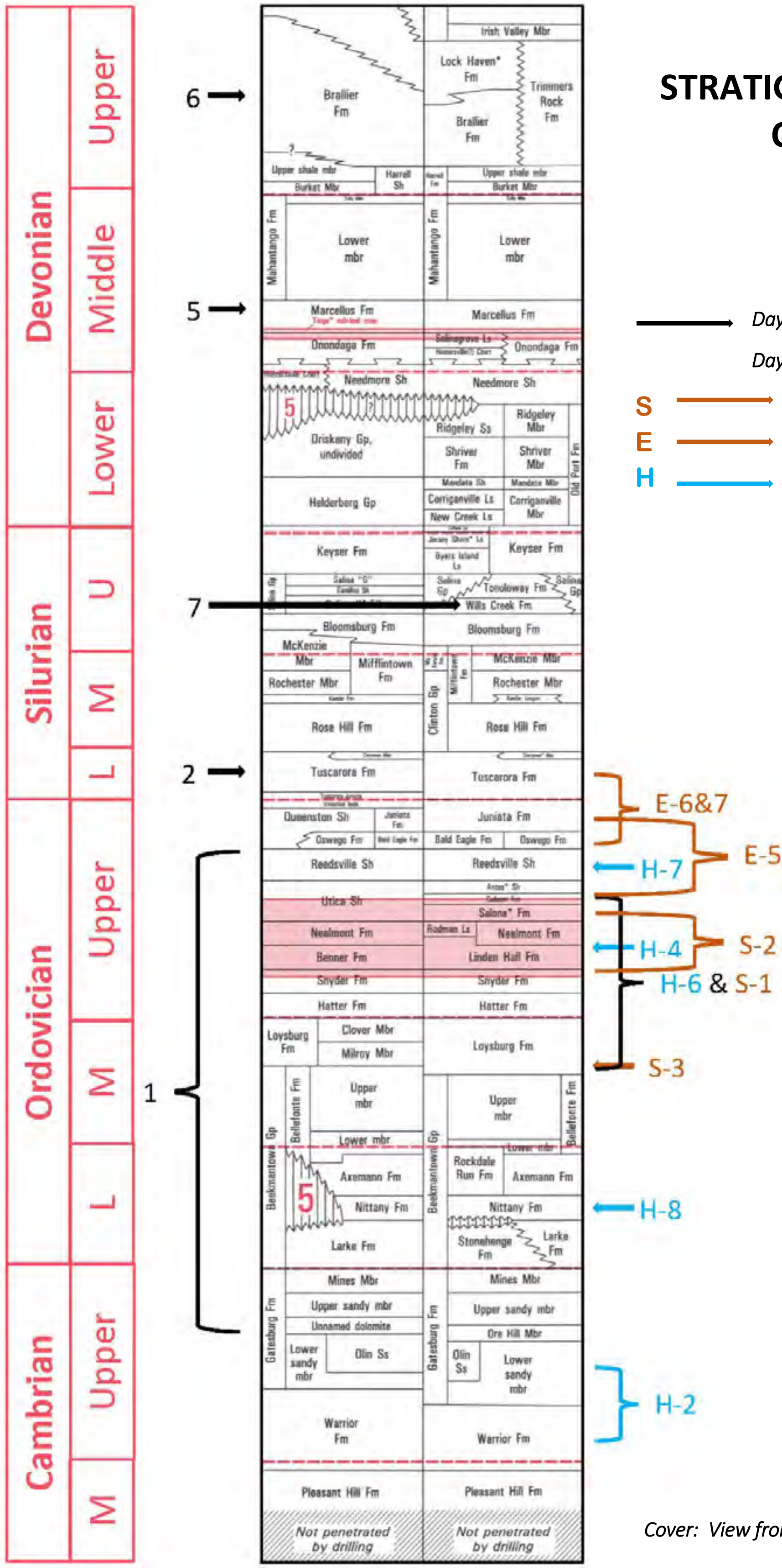
Recent Geologic Studies & Initiatives in Central Pennsylvania

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.

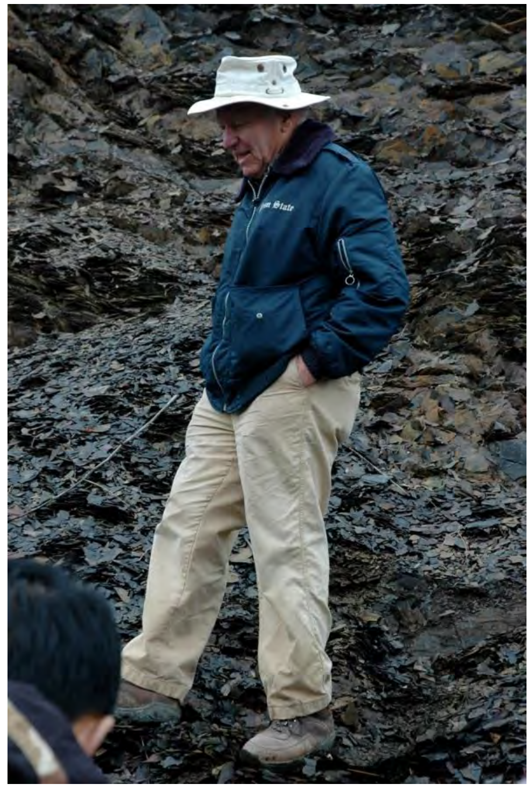
A TRIBUTE TO DAVID P. "DUFF" GOLD

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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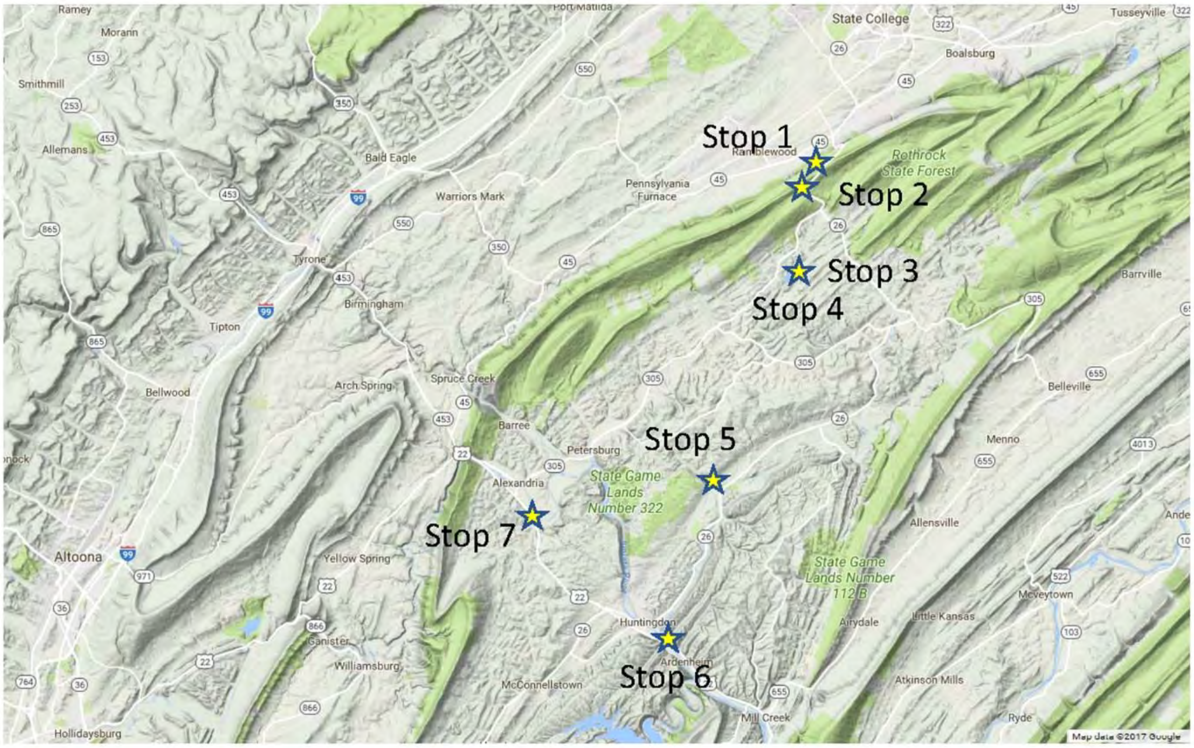
ROADLOG – DAY 1

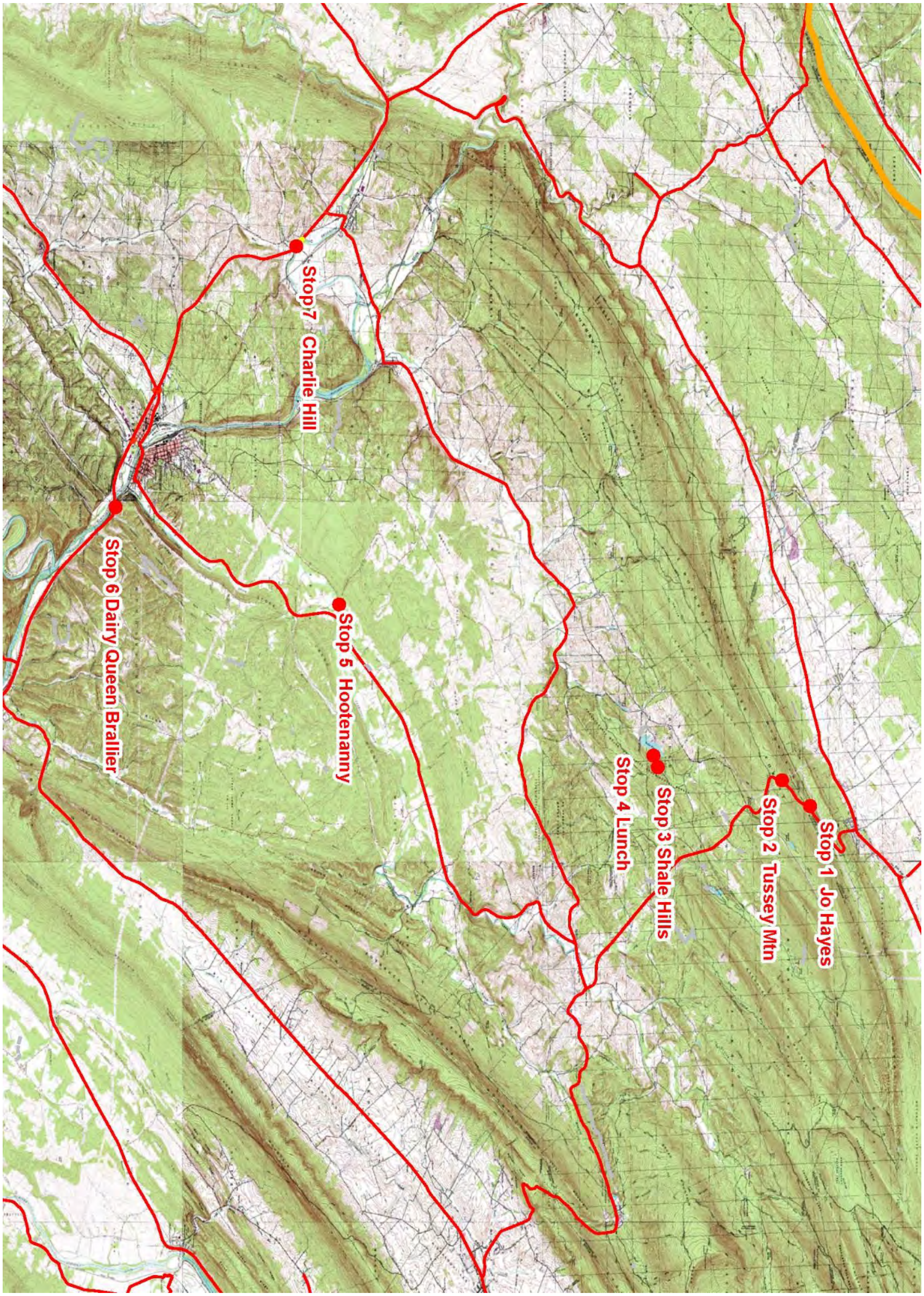


ATTENTION – DIRECTIONS

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).

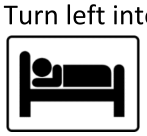
- ✓ **GROUP A = (buses 1 & 2) – Shale Hills Critical Zone Observatory in morning; Huntingdon Area in the afternoon.**

- ✓ **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]

[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 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 Geoscience, Indiana University of Pennsylvania, Indiana, PA
[6]Department of Earth and Atmospheric Sciences, Central Michigan University, Mount Pleasant, MI

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

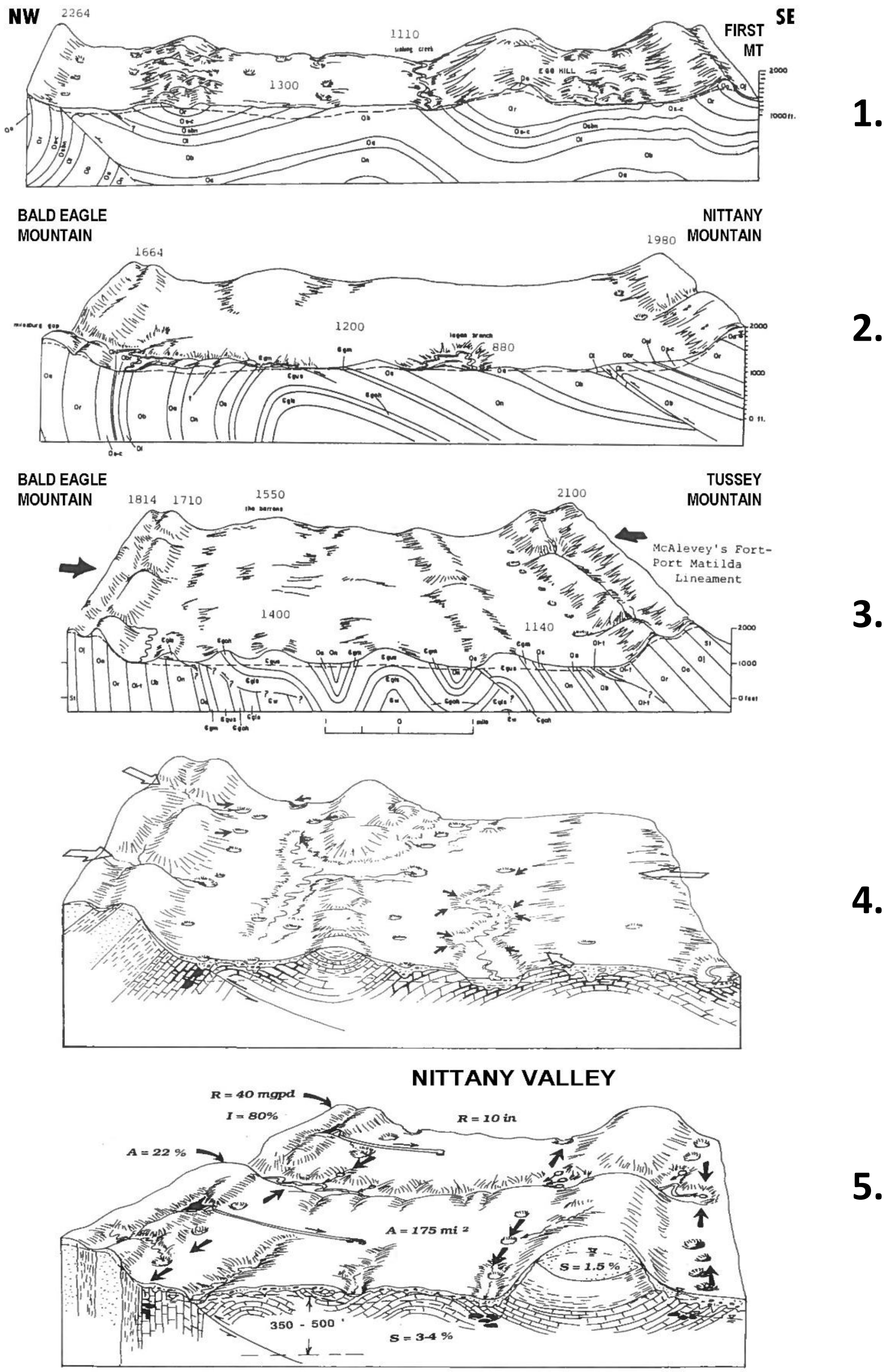


Figure 1-1. Cross-sections through the Nittany Valley. **(Parizek, et al, 1971).**

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).

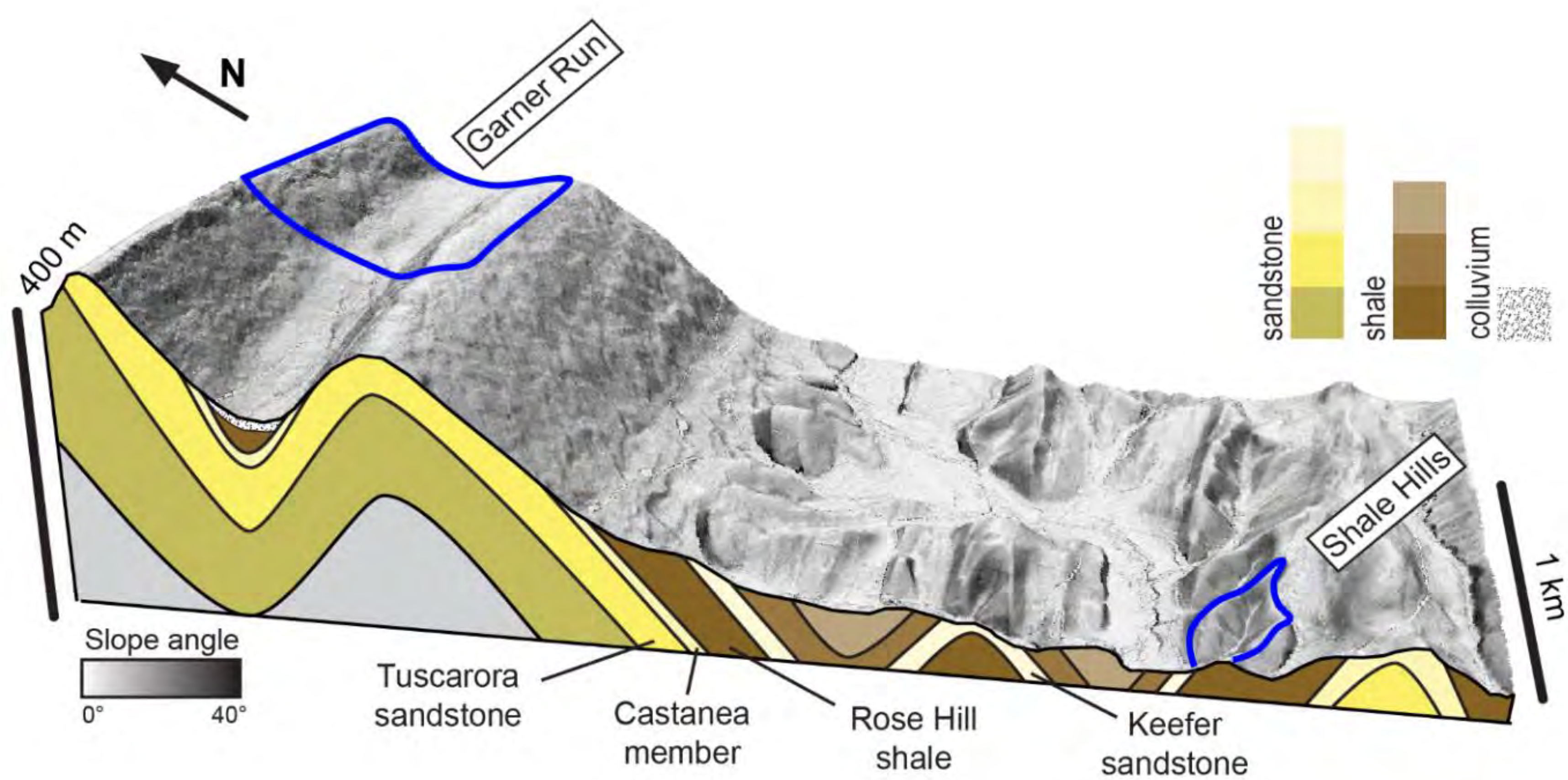


Figure 2-1. Block diagram of Shavers Creek geology and lidar topography showing location of Garner Run and Shale Hills study catchments in the Susquehanna Shale Hills Critical Zone Observatory. Figure modified from Del Vecchio (2017).

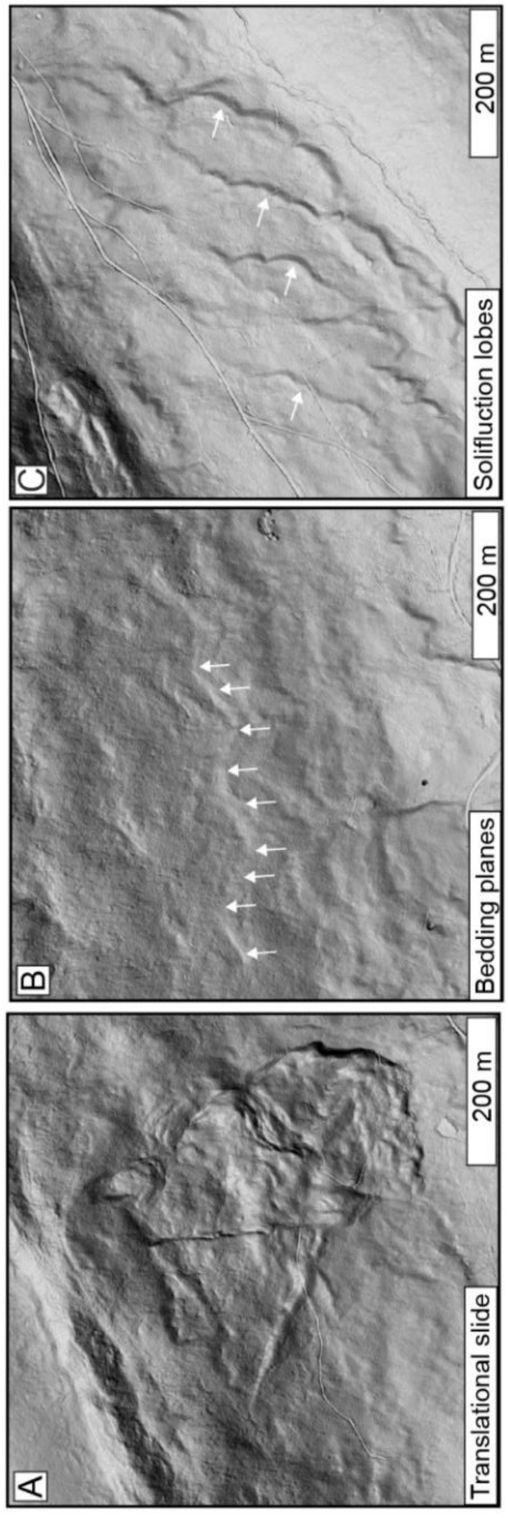


Figure 2-2. Examples of relict periglacial landforms and stratigraphy expressed in high-resolution lidar topography in Garner Run area, including A) mass wasting features; B) shadow bedding planes; and C) solifluction lobe crests. Figure modified from Brantley et al. (2016).

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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[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.

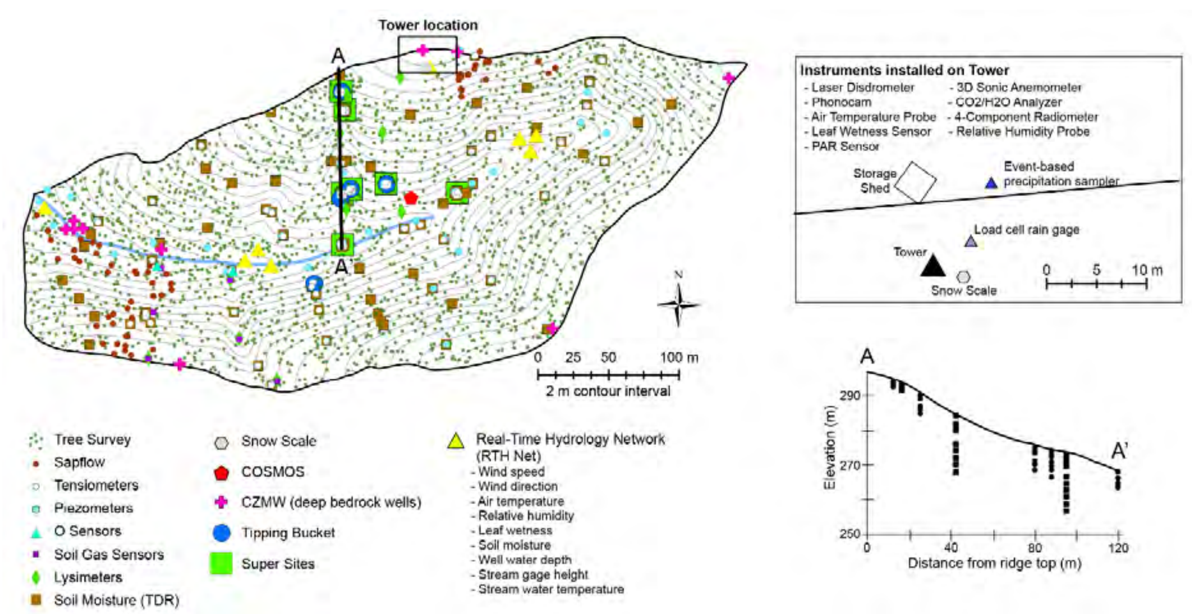


Figure 3-1. Overview map of Shale Hills catchment showing dense instrumentation and sampling approach. Inset cross section shows soil moisture sensors (circles) and lysimeters (squares) along the transect A-A'. Sensor and lysimeter depths are exaggerated by a factor of 5 compared to topography. Figure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

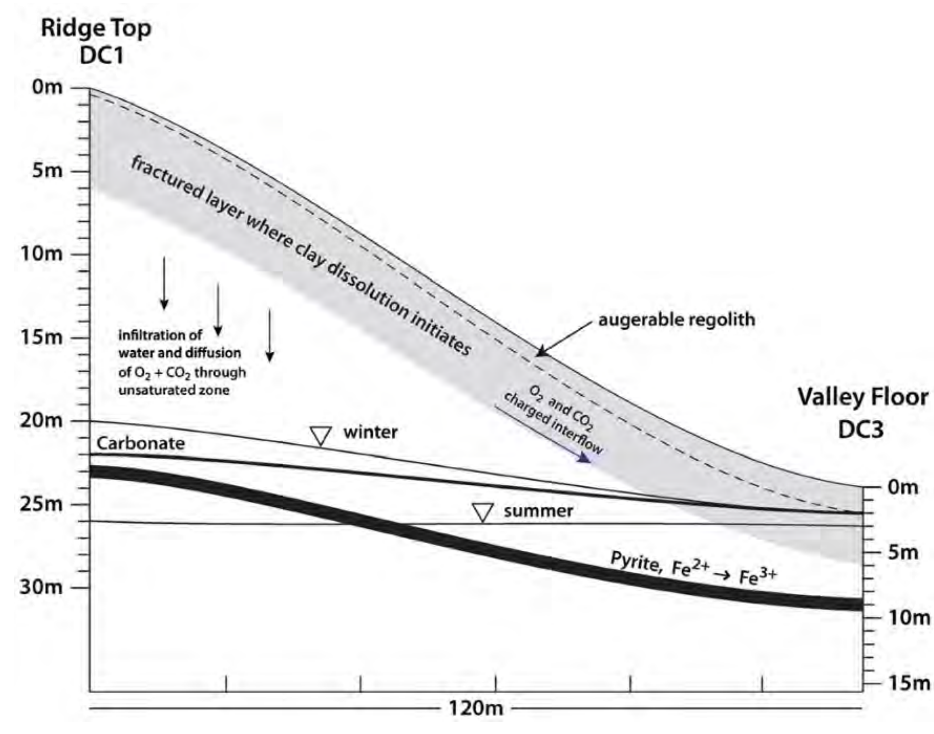


Figure 3-2. Schematic cross section between ridge and valley boreholes in the Shale Hills Catchment (pink crosses, Figure 3), showing hypothesized nested reaction fronts subparallel to the land surface. Triangles indicate winter and summer water table depths. Figure from Brantley et al. (2013).

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.

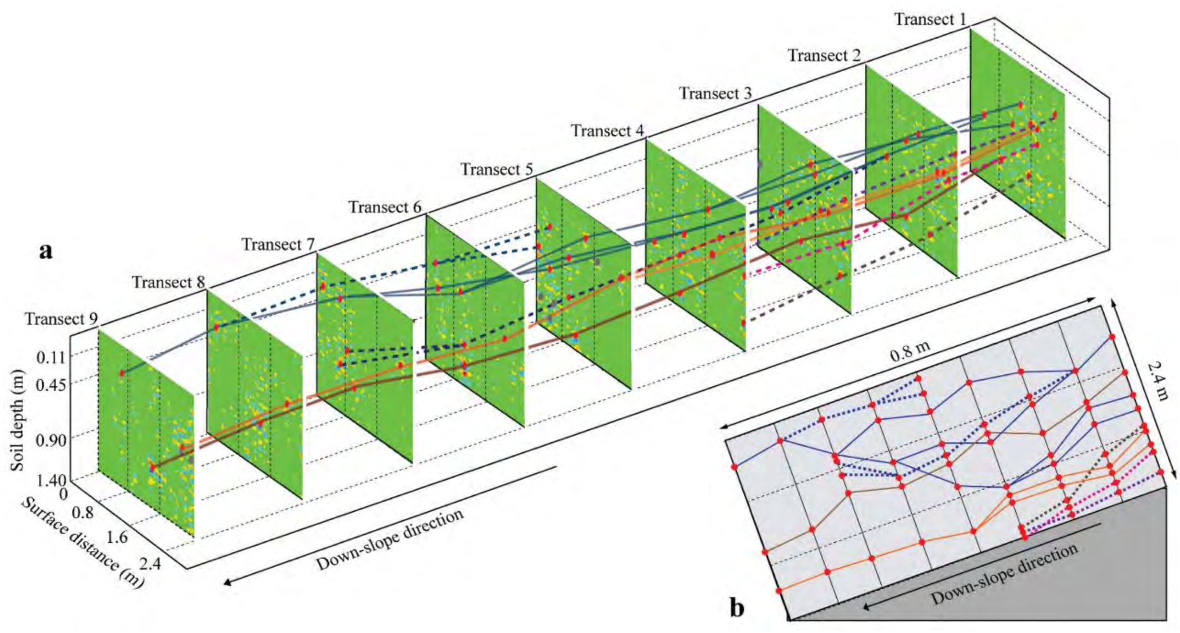


Figure 3-3. Identification of subsurface lateral preferential flow network connectivity at Shale Hills site from 3D GPR survey. Each transect in panel (a) shows reflection differences between standardized radargrams collected before and after infiltration, with red dots indicating nodes of the lateral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

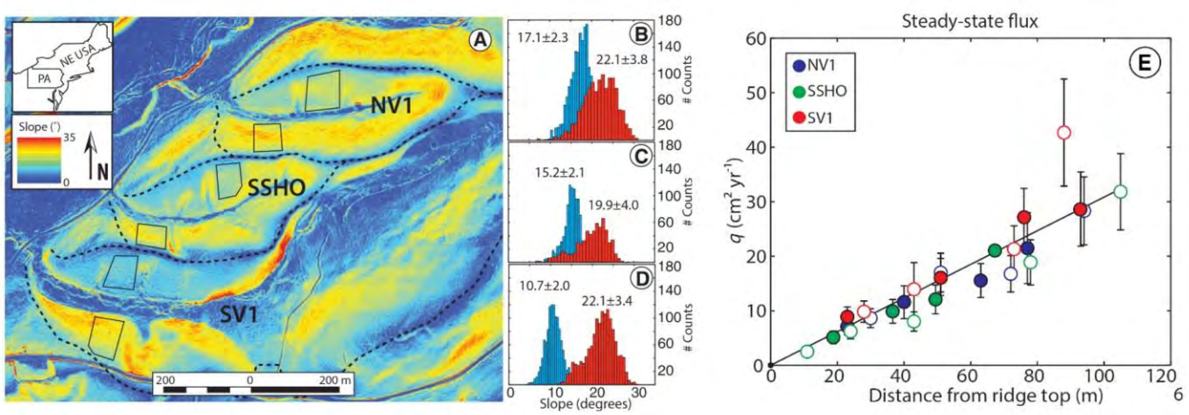


Figure 3-4. A) Slope map of Shale Hills catchment (SSHO) and adjacent watersheds (NV1, SV1) highlighting topographic asymmetry. Histograms of local slope angle on north-facing (red bars) and south-facing (blue bars) hillslopes for B) NV1, C) SSHO, and D) SV1 catchments, with mean and standard deviation 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.

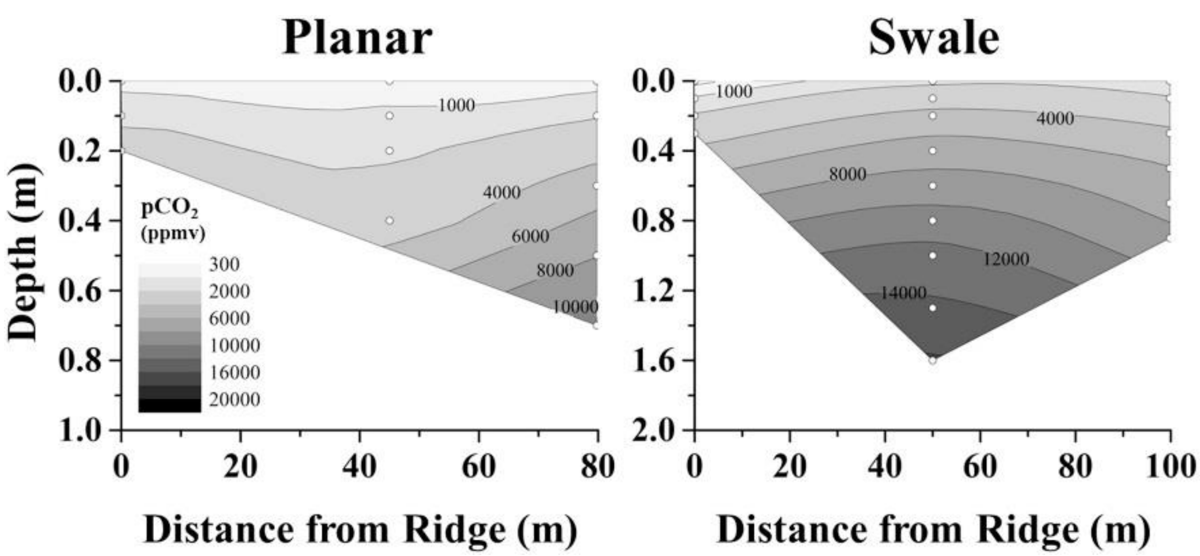
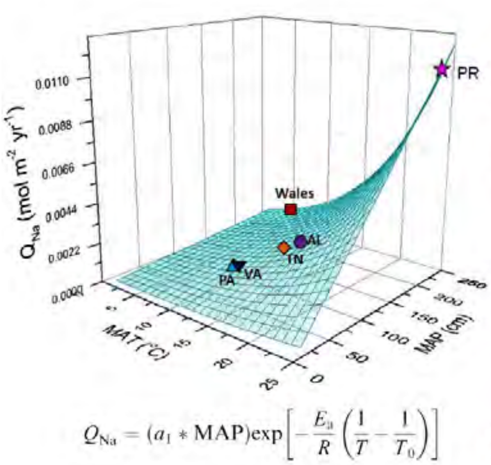


Figure 3-5. Average pCO_2 concentrations from 2008-2010 as a function of distance from southern ridge top and depth along a planar slope (left) and convergent swale (right), highlighting topographic control on soil pCO_2. Small circles indicate sampling depth locations. Figure from Hasenmueller et al.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



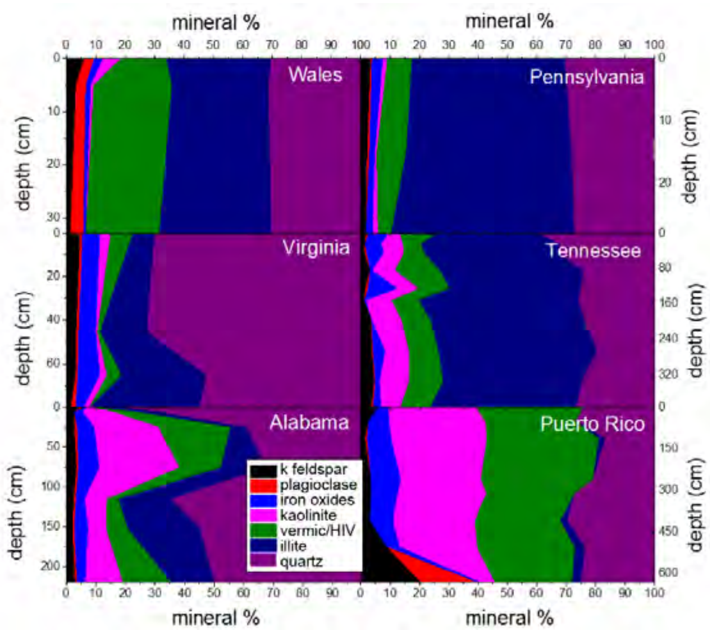


Figure 3-6. Left: Average integrated rate of Na loss, Q_{Na} (a proxy for plagioclase weathering rate), plotted against mean annual temperature, MAT, and mean annual precipitation, MAP, for six shale field sites spanning a latitudinal climate gradient. Mesh surface indicates fit of Arrhenius-type relationship 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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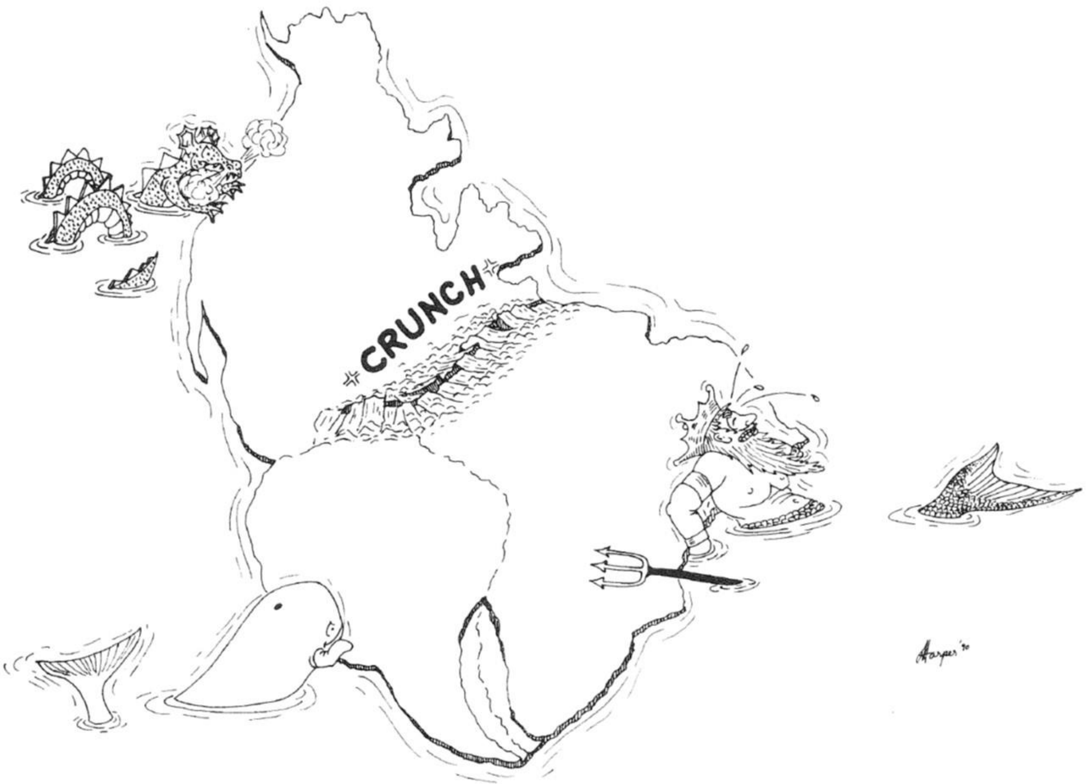
STOP "4" LUNCH

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.

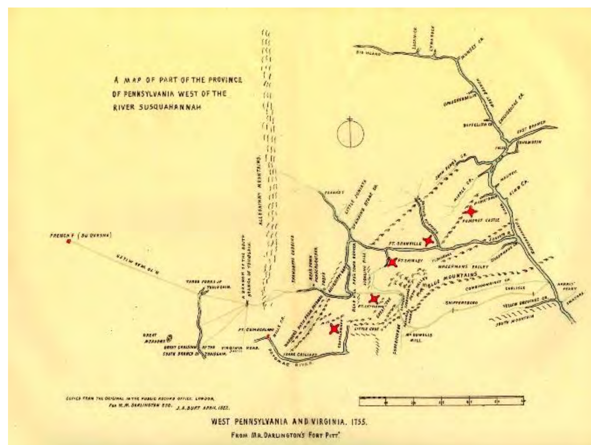
(https://web.archive.org/web/20070808015510/http:/www.dcnr.state.pa.us:80/forestry/stateforests/rothhistory.aspx)

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).

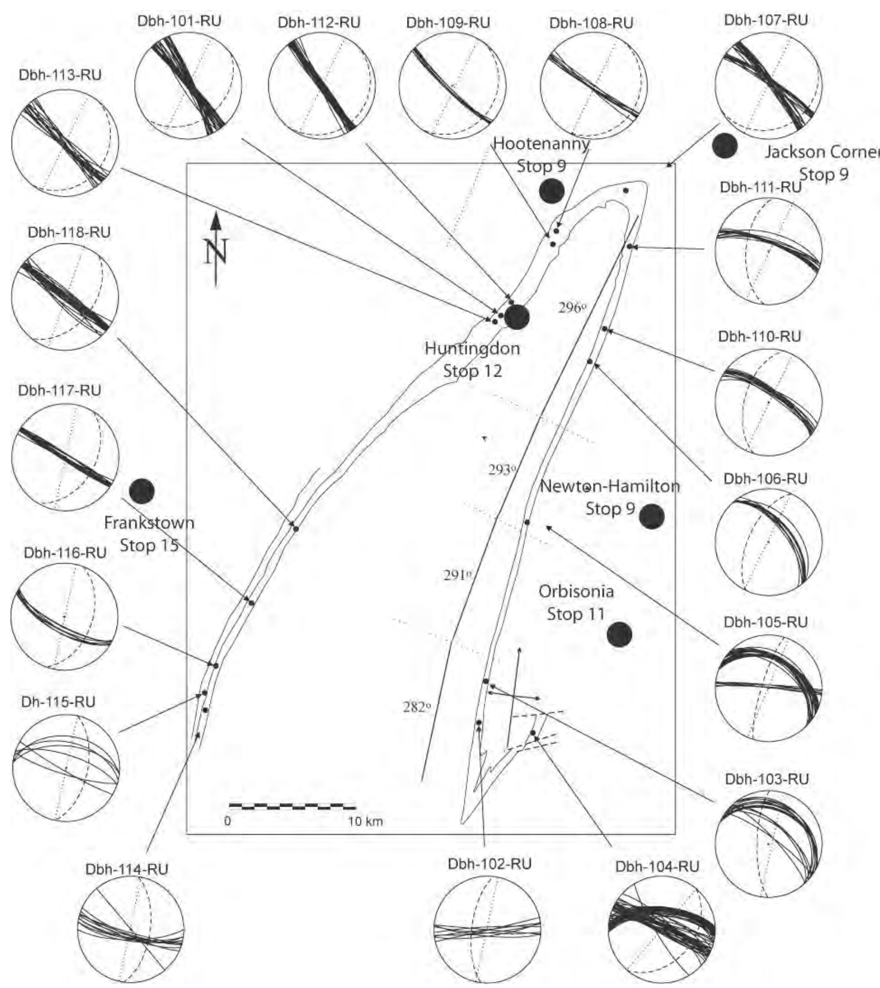


Figure 5-2. Present orientation of cross-fold joints in the vicinity of Broadtop Syncline. Equal-area net projection. Dbh: Brallier and Harrel Fms. undivided, Dh: Hamilton Group, segmented line: local bedding trend. Adapted from Uzcatequi (2004).

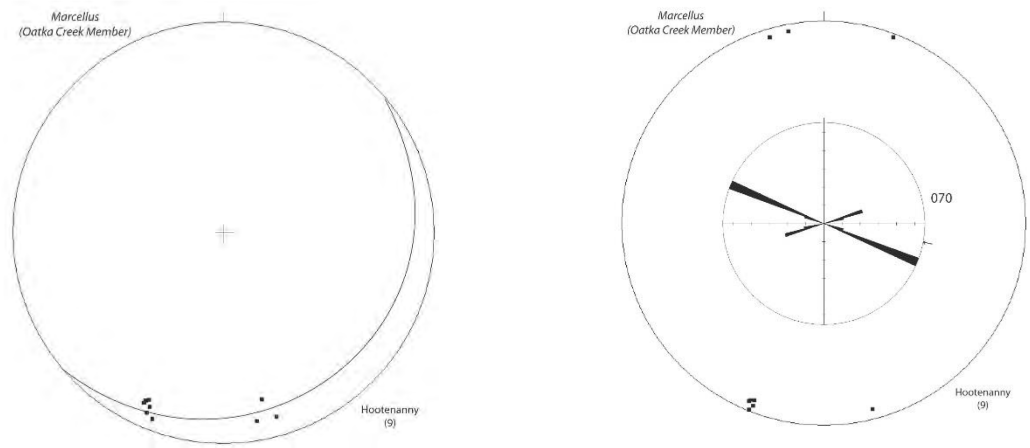


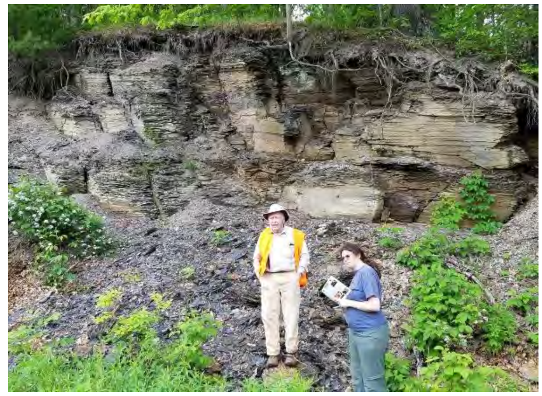
Figure 5-3. Joints plotted in present coordinates (left) and rotated to their position with horizontal bedding using a fold axis plunging 00° toward 050° with a rotation of 16° (right).

Weathering

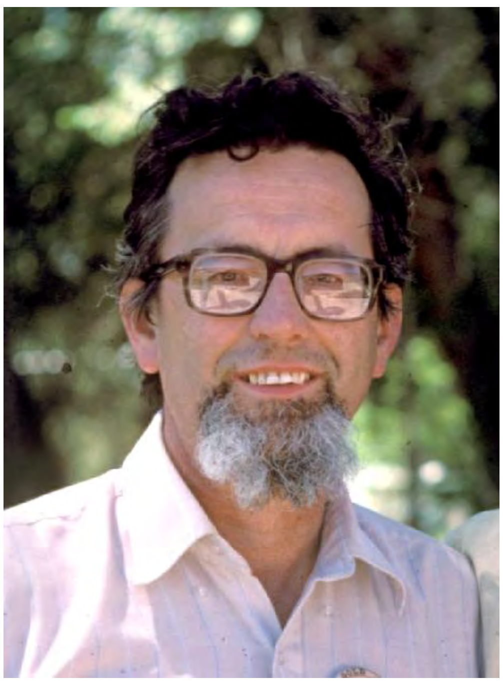
This borrow pit also exposes the soil profile on top of the shale (Figure 5-1). As part of the Shale Hills initiative, element migration during weathering of Silurian shales and mudstones at Shale Hills is compared to the Marcellus black shale. The main objective is to understand overall kinetics of 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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Slingerland, R., Patzkowski, M., and Peterson, D., 2009, PAPG Spring 2009 FT Guide Book

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).

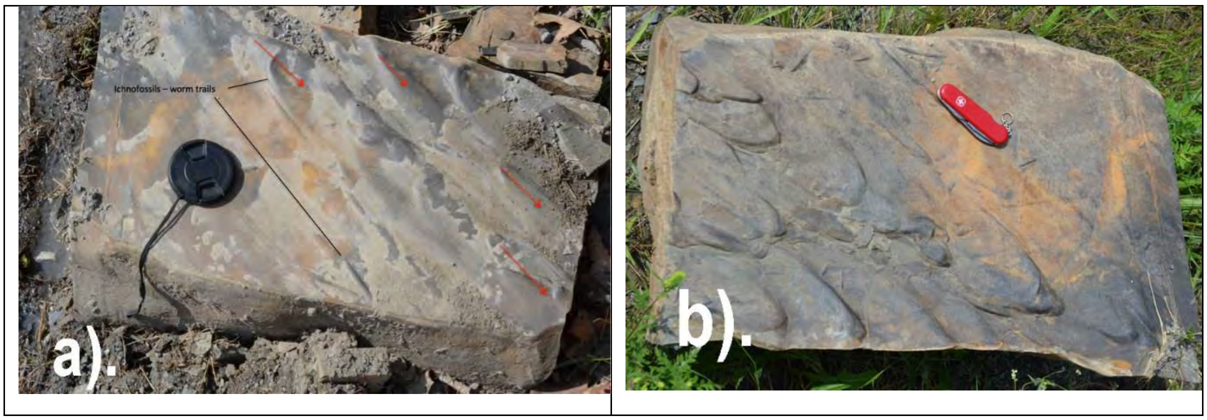

Figure 6-4. Ichnofossils and sole markings (flute casts) in Brallier turbidites. Red arrows (a) indicate current direction.

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STOP 7: CHARLIE HILL ROADCUT

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

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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.

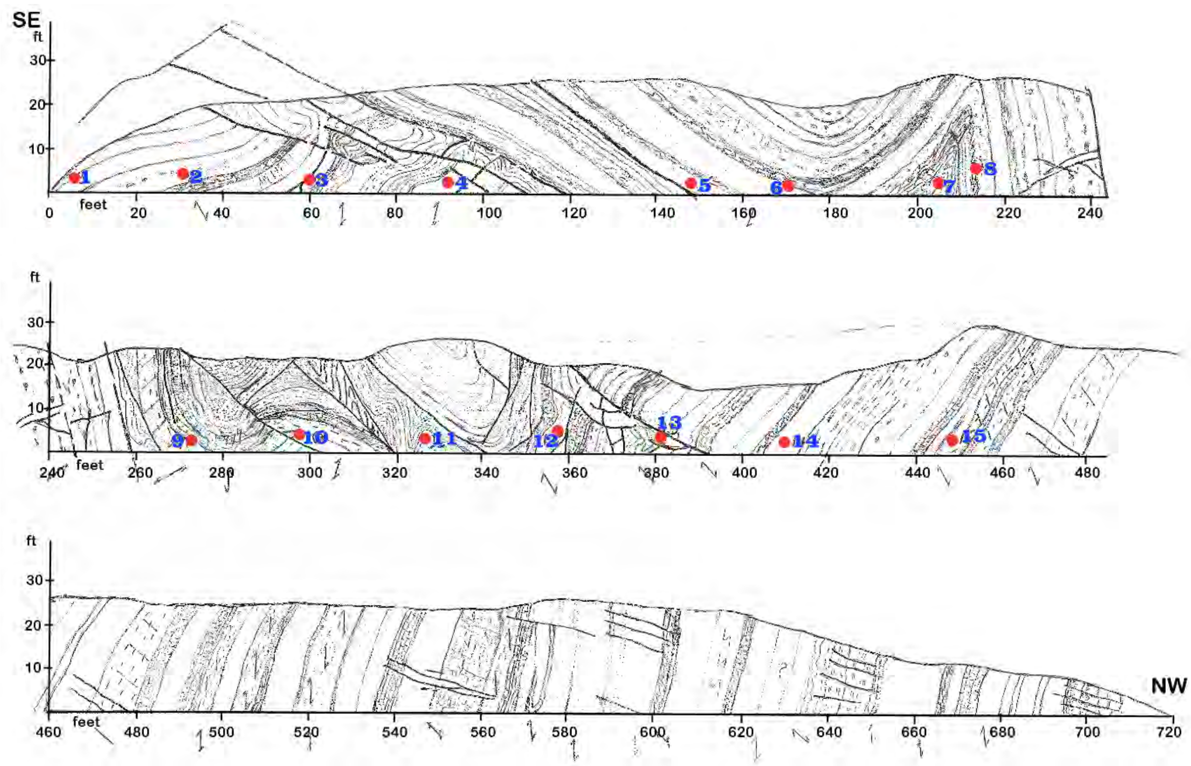

Figure S7-2. Sketch of the Charlie Hill Roadcut. Distances and height are in feet. Stations will be marked by flags in cairns.

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 2nd 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

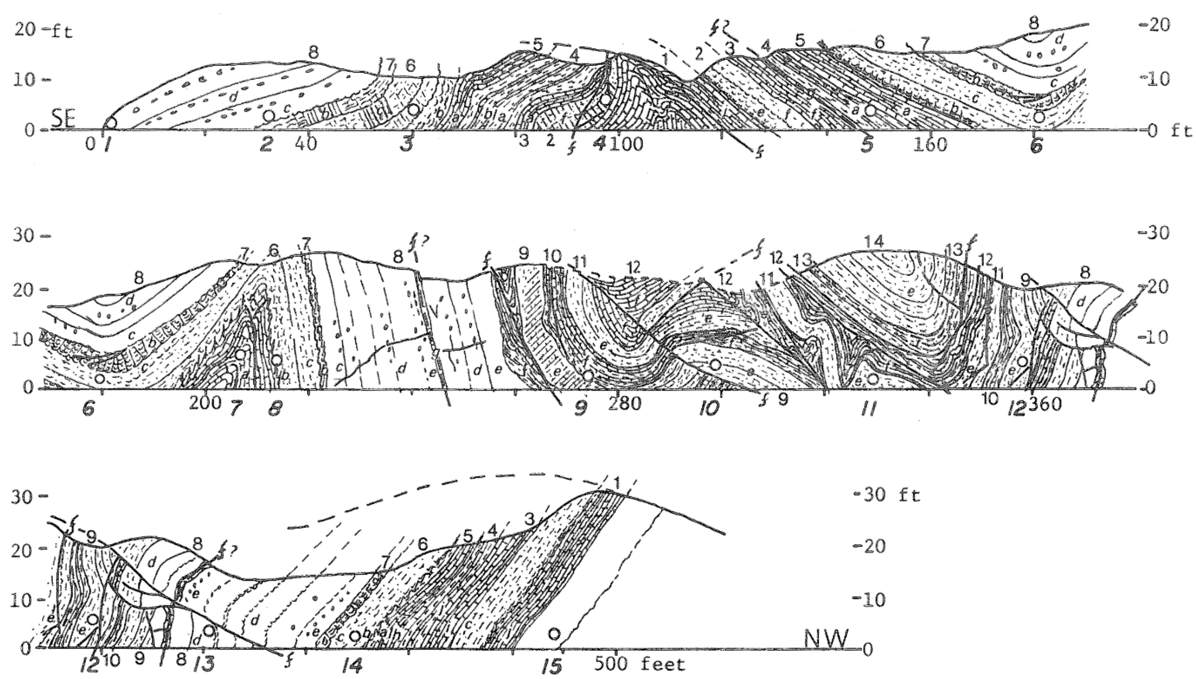

Figure 15. Schematic cross-section for 450 feet of the Charlie Hill road-cut. The orange blaze numbers (1 to 15) and letters (a to i) represent, respectively, marker stations and sedimentary facies units. The litho-structural units are labelled from 1 to 14 in the sketch above, and in white paint on 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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OVERVIEW OF STRATIGRAPHY FIELD TRIP

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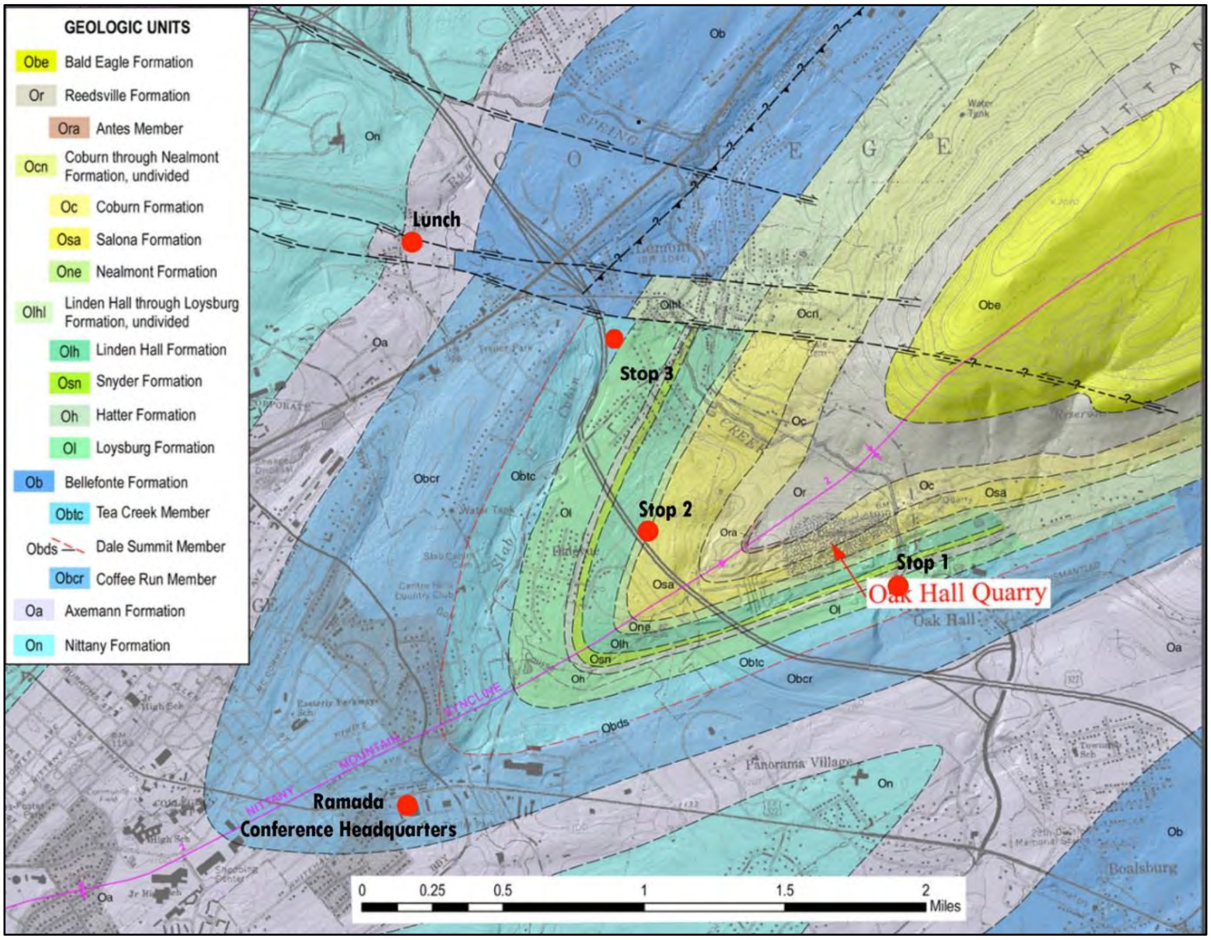
DAVID P. "DUFF" GOLD, EMERITUS PROFESSOR OF GEOLOGY, THE PENNSYLVANIA STATE UNIVERSITY
CHARLES E. MILLER, JR., GEOLOGIST (RETIRED), STATE COLLEGE, PA



This field trip addresses the stratigraphy and structure of the Nittany Mountain Syncline, exposed in the Oak Hall Quarry (Stop 1) and road-cuts on the Nittany Mountain Expressway (Stops 2 & 3), shown above.

The field stops will examine outcrops (and deduced depositional environment) of the lower Salona Formation rhythmites (hemipelagic sediments in deep-ramp setting for distal tempestites), the inferred shallow subtidal, shelf and slope and settings for limestones of the Nealmont and upper Linden Hall Formations at Stop 2.

The focus will be on the sedimentary features in dolostone/limestone interbeds of the Lower Loysburg Formation at Stop 3 that indicate a tidal flat (tidal/supratidal) setting. This road-cut also includes an unbroken succession of dolostone beds of the Tea Creek, clastic beds of the Dale Summit, and dolostone cycles in the upper Coffee Run Member of the Bellefonte Formation.

A recurring theme will be cycles and non-cyclical repetitions. The nature of imposed mesoscopic scale structures (ramp faults, mineralized tension cracks, veins, early and late joint sets, and stylolites) will be examined, and their tectonic implications opened for discussion.

STRATIGRAPHY ROADLOG – DAY 2

segment	cumulative	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
2.1	2.2	Turn left at traffic light onto Warner Blvd to Oak Hall. Military Museum on right. WW1 range for machine gunners on left.
0.7	2.9	Underpass
0.2	3.0	Pass intersection to Mt Nittany Expressway and Rte 322 west
0.1	3.1	Drive through Oak Hall Village
0.5	3.6	Bridge over Spring Creek
0.3	3.9	Oak Hall Quarry plant on right. Continue on Boalsburg rd. for about 100 yards
0.1	4.0	Turn left and park on gravel road above stock-pile bins.
		**Stop 1: Overview of the Oak Hall Quarry** 40° 47' 56" N; 77° 48' 20"W
0.0	4.0	Turn right on Boalsburg Rd.
0.8	4.8	Turn right to merge onto US322 W towards State College
0.8	5.6	Note outcrop of the Dale Summit Member of the Bellefonte Formation on right.
0.3	5.9	Axis of Nittany Mountain syncline.
0.1	6.0	Buses park to side of freeway
		**STOP 2. Road-cut on Mt Nittany Expressway** 40° 47' 47.4" N; 77° 49' 18.54" W, to 40° 47' 55.4" N; 77° 49' 26.34"W ***PLEASE STAY EAST OF THE GUARD RAIL***
0.2	6.2	***Buses drive ~0.2 miles to end of outcrop and pick people up***
0.4	6.5	Overhead bridge
0.5	7.0	Buses park to side of freeway
		**STOP 3. Road-cut on Mt Nittany Expressway** 40° 48' 12.67" N; 77° 49" 37.74" to 40° 48' 34.86" N; 77° 49" 31.56" ***PLEASE STAY BEHIND THE GUARD RAIL***
0.5	7.5	***Buses drive ~0.45 miles to end of outcrop and pick people up***
0.0	7.5	Continue west on US 322
0.9	8.4	PA 26 exit
0.2	8.6	Turn right onto PA 26 N/E College St
0.6	9.2	Turn left onto Houserville Rd
0.7	9.9	Turn left onto Puddington Rd
1.0	10.9	Turn left into the Millbrook Marsh Nature Center
		**Stop 4: Lunch** 40.813376, -77.838310

STOP S-1: OAK HALL QUARRY

STOP LEADERS – DAVID P. "DUFF" GOLD[1], CHARLES E. MILLER, JR.[2], TERRY ENGELDER[3]
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Overview **(40°47'56"N, 77°48'20"W)**

Nittany Valley is a breached 1st order anticline (the Nittany Arch or Anticlinorium) that preserves a karst valley underlain by Cambrian and Middle to Upper Ordovician carbonates in the Valley and Ridge Physiographic Province. Younger clastic sediments (Upper Ordovician and Silurian age) crop out in the sub-parallel trending ridges to the northwest and southeast, as well as in the 2nd order syncline, appropriately named the Nittany Mountain Syncline (by Butts and Moore, 1936) that preserves Nittany Mountain near the crest of the anticlinorium.

Figure S1-1 illustrates the Stratigraphy of the State College Quadrangle (left), with a portion of measured section in the Oak Hall Quarry (right) highlighting the Bentonite marker beds in the Coburn, Salona and Linden Hall formations that we will see in Stop 2. **Figure S1-2** shows the formations in the Oak Hall quarry, with the cross-section of the Nittany syncline through the quarry. Oak Hall quarry has a footprint of approximately 3000 feet by 1400 feet in the southeast limb, and produces approximately 500,000 tons of aggregate per annum from 7 benches to an elevation of 960 feet above mean sea level. **Figure S1-3**, showing the formations we will visit in stop 3, was generated from measured section from the fourth bench of the Oak Hall quarry.

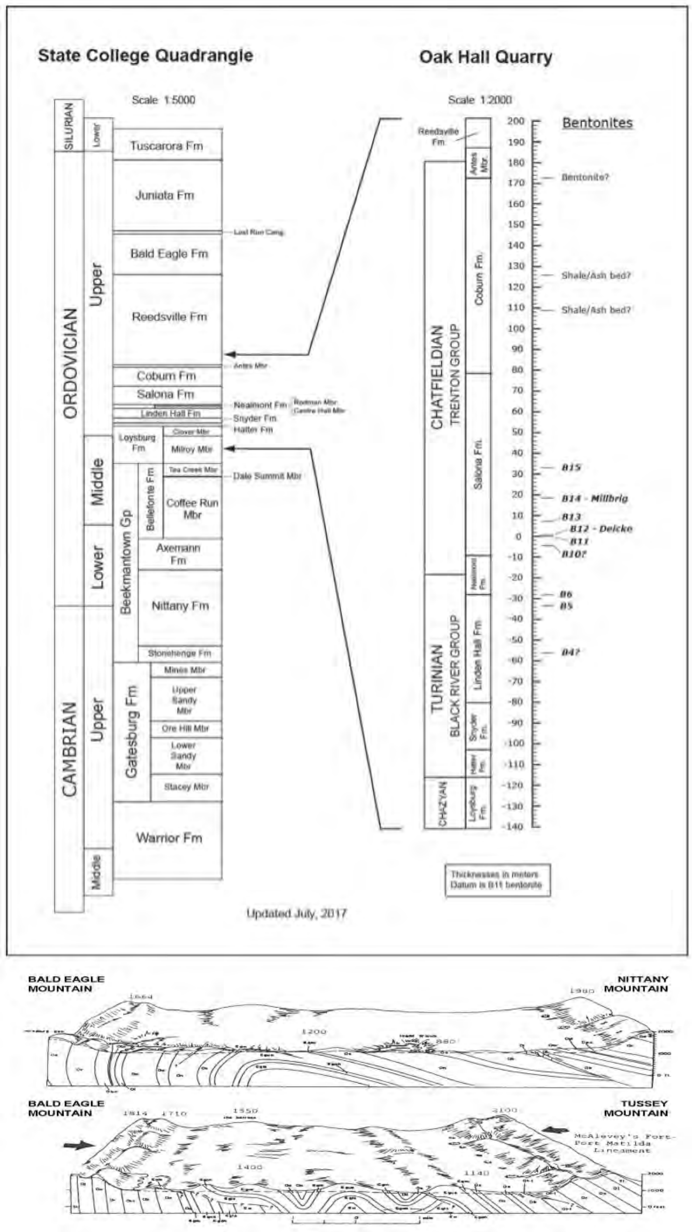

Figure S1-1. Cambro-Ordovician section in State College Quadrangle (left), blowup of Oak Hall Quarry section (right) showing Ordovician bentonites in the formations we will visit in Stop 2. Cross-sections of Nittany Valley (after Parizek, 1971, bottom).

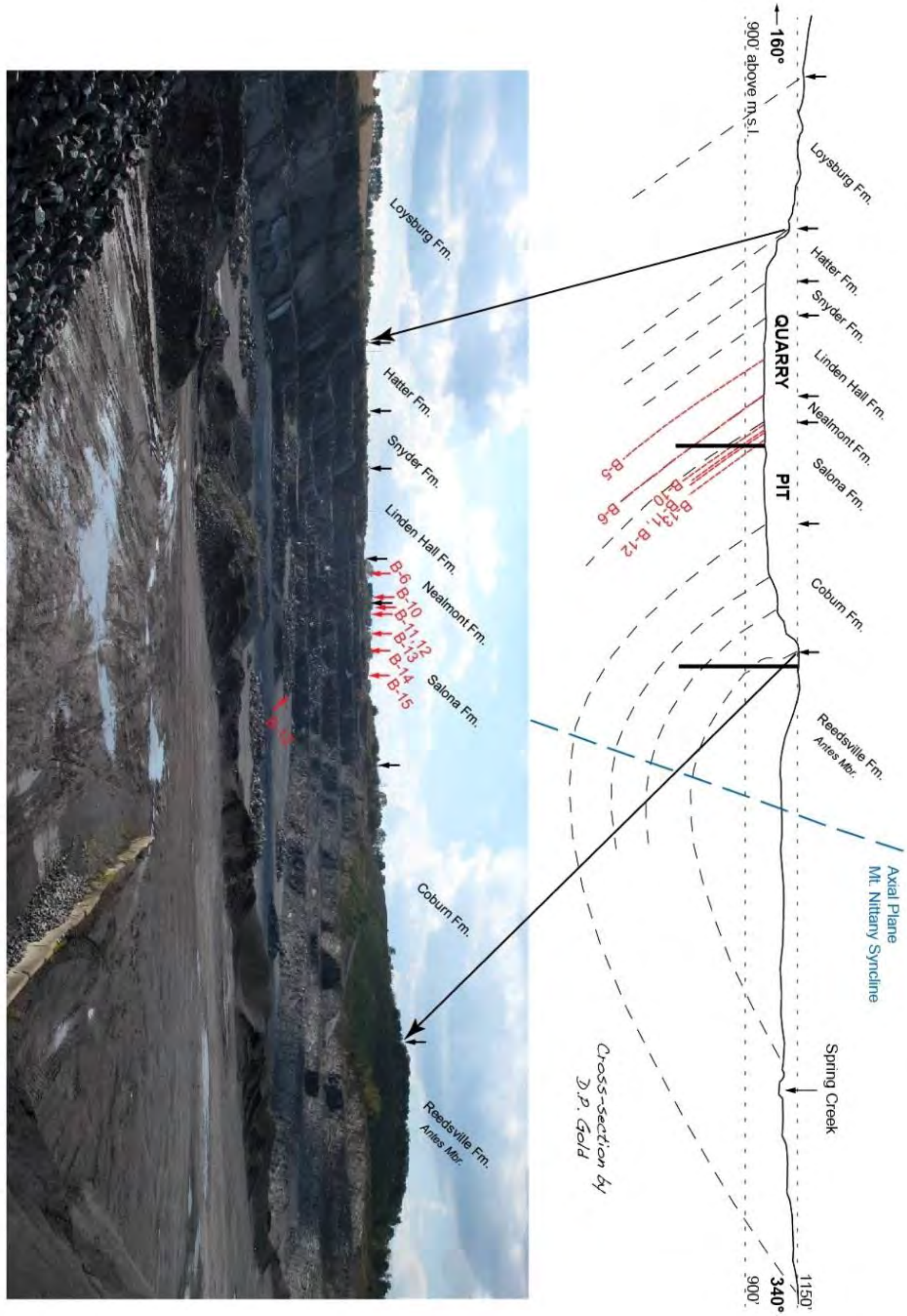

Figure S1-2. Geology and cross-section of strata in the Oak Hall quarry. Viewed from the northeast. (photo Oct. 2014)

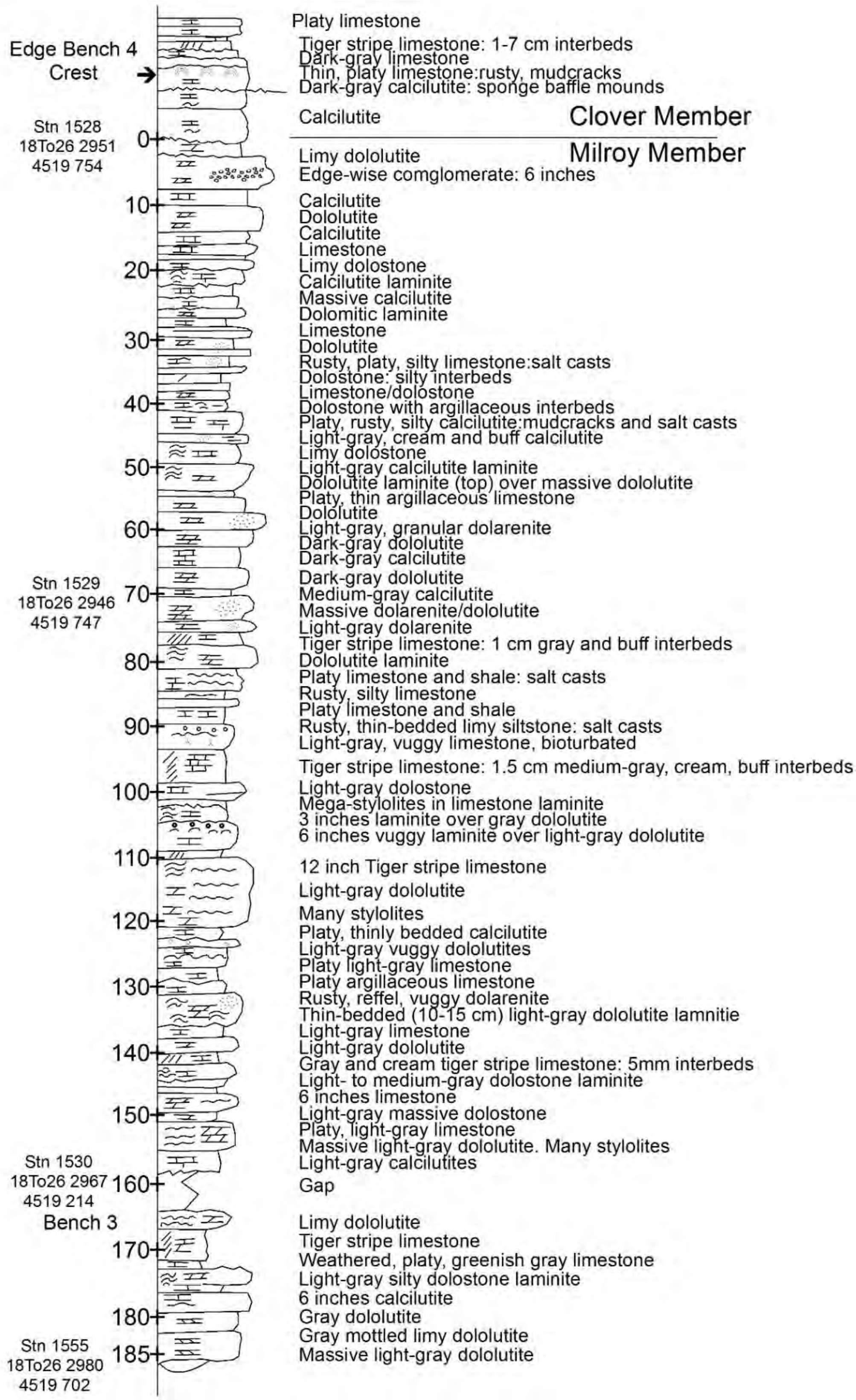

Figure S1-3. Stratigraphy from measured section in Bench 4 of Oak Hall Quarry (Rose-Anna Behr, 2017)

Reference:

Butts, C. and Moore, E.S., 1936, Geology and mineral resources of Bellefonte Quadrangle, Pennsylvania: U.S. Geological Survey Bulletin 855 111 p.

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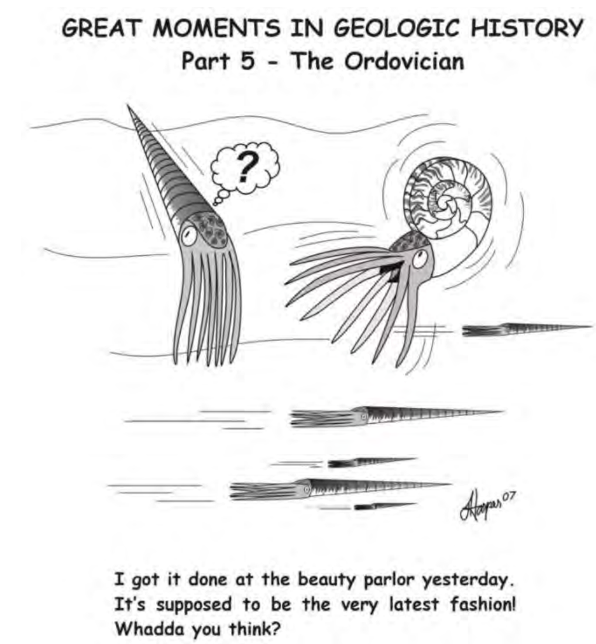

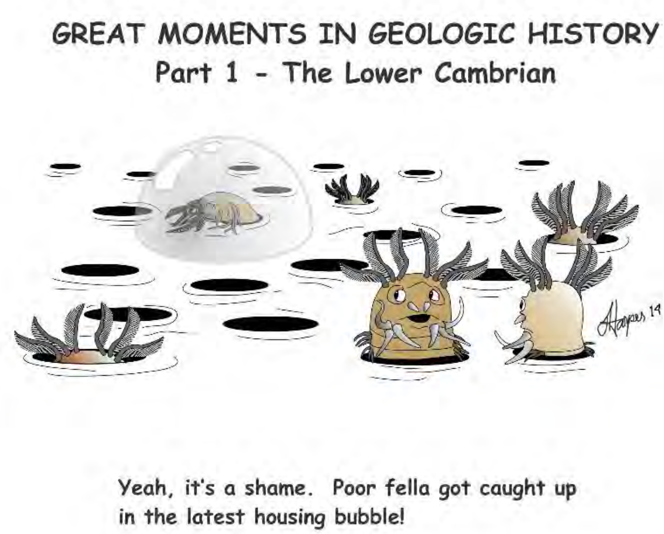

STOP S-2: ROUTE 322 BYPASS – MT NITTANY EXPRESSWAY

SMALL-SCALE FAULT-BEND FOLD IN THE APPALACHIAN VALLEY AND RIDGE

ORDOVICIAN – SALONA TO LINDEN HALL SECTION

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Observations **(40.797402°, -77.822429°)**

The folding and faulting of mountain belts like the Appalachians are rarely symmetrical in a cross sectional view of the mountain belt (i.e., one drawn perpendicular to strike of the major structures). This lack of symmetry is developed as a consequence of the mountain belt being pushed from one side rather than being caught in a vice with equal force from both sides. Two appropriate images for the Appalachian Mountains of Pennsylvania are that of a rug being pushed from one edge and snow being pushed in front of a plow. In both cases the material being pushed tends to pile up against the object doing the pushing. The technical term for one type of folding from a one-sided push is fault-related folding. Specifically, the cross section through the Nittany Mountain syncline is a fault-bend fold (Fig. S2-1). A fault bend fold has nose dipping about 65^0 and a back limb of about 25^0. Both this and the next stop are in the back limb of a fault-bend fold emerging to the NNW from the Nittany Mountain syncline.

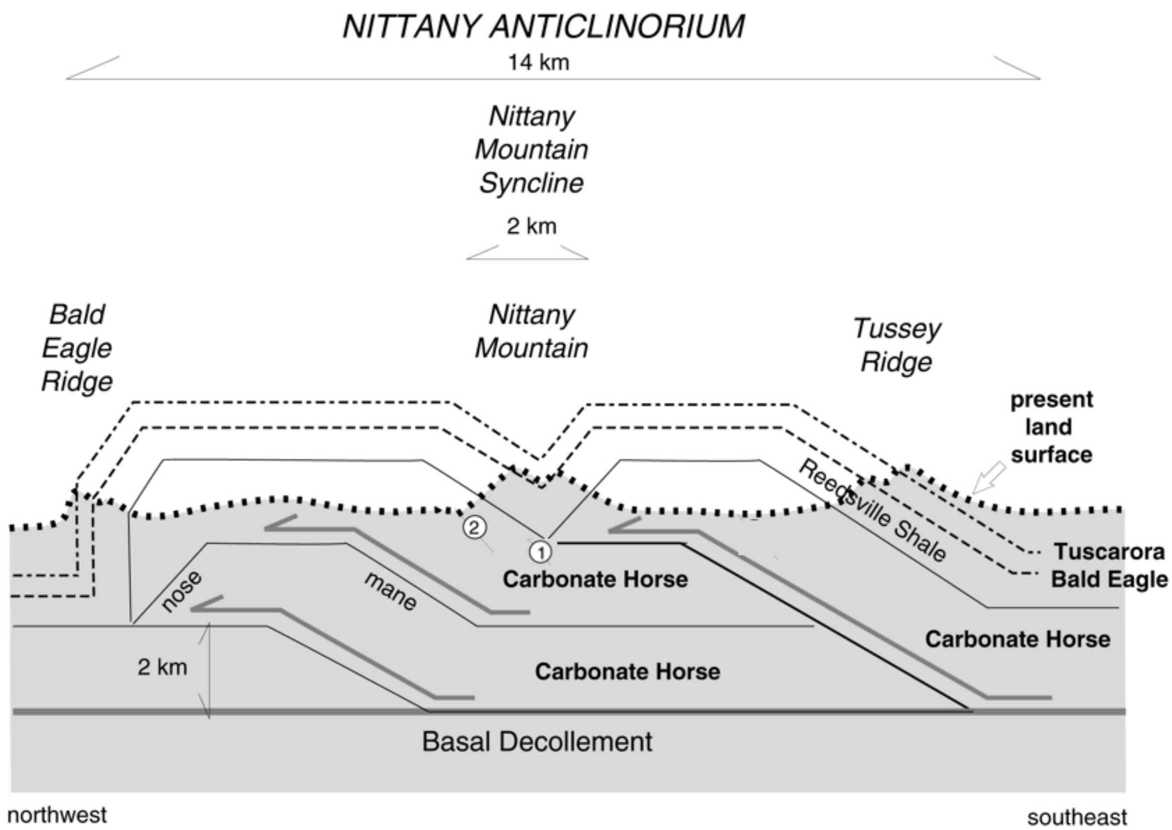

Figure S2-1. An early interpretation of the cross section through Nittany Mountain showing the locations of the two stops along the Mount Nittany Expressway. This interpretation is probably not correct because the hypothetical fault at the base of Nittany Mountain has never been found.

During the Alleghanian Orogeny the rocks of the Valley and Ridge (i.e., Nittany Valley) were compressed towards the northwest as a result of the collision of Africa and North America. In addition to the larger-scale folding expressed in the Nittany Mountain syncline, smaller-scale folding and faulting also occurred (Fig. S2-2).

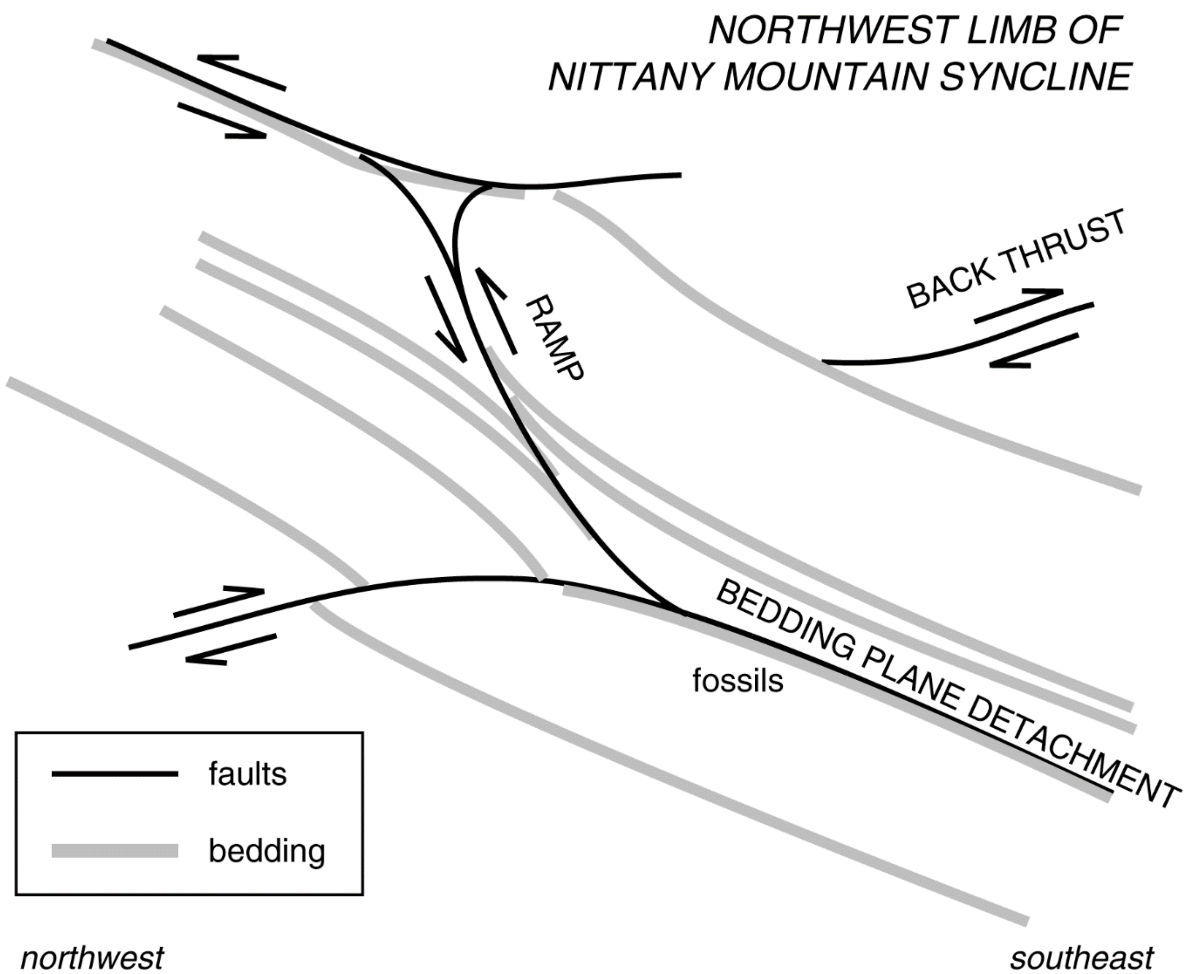

Figure S2-2. Sketch of a fault system at Stop 2.

This stop shows an example of a smaller-scale fault where limestone beds on the south side of the fault have been thrusted up over the same beds on the north side. The deformation results in the reorganization of the rocks in a way that take less room horizontally, but more room vertically (i.e., the rocks shorten and thicken). With a sharp eye you should be able to find cephalopod fossils (see the Fossils section, Figure S2-4).

Role of Bedding Planes in the Faulting Process

We stop 250 feet south of the traffic sign and walk approximately 1100 feet northward through 80 feet of rhythmite limestones/shales of the Roaring Spring and 107 feet of the New Enterprise members of the Salona Formation, through 24 feet of nodular limestones of the Rodman Member and 41 feet of borrowed micrite of the Centre Hall Member of the Nealmont Formation and into at least 64 feet of massive beds of dominantly micrites of the Linden Hall Formation. These units were the life-blood of the early steel industry in Pennsylvania.

This outcrop is a carbonate called the Linden Hall Formation. Compare the nature of bedding in the Salona and Linden Hall Formations to see that the Salona beds were somewhat thinner and the bed boundaries contained considerably more clay and shale. This outcrop illustrated the role of bedding planes in the faulting process. Here faults develop parallel to bedding and then fracture across bedding (Figures S2-2 & S2-3). Bedding-parallel faulting is common because shale is a weak material and easily fractured compared to other lithologies.

Figure S2-3. Ramp fault in Linden Hall/Nealmont/Salona section exposed at Stop 2. Fault develops parallel to bedding and then ramps up across bedding.

Note the calcite veins developed throughout the outcrop. Their spacing is attributed to strain dilation in a stress-shadow zone. Strike veins are common in the stiffer limestone beds interlayered with shale.

The stratigraphic column developed in Table 2-1 emphasizes the location of the bentonite marker horizons (refer to stratigraphic column for Oak Hall Quarry, Figure S1-1). Vertical thicknesses are marked (blue paint on the outcrop) in five-foot increments above and below the Nealmont/Salona contact 79 feet south of the road sign.

TABLE 2-1: Stratigraphy and Structure of Road-cut on Mt. Nittany Expressway

Unit thickness is given above and below the Nealmont/Salona contact, 28 feet south of Exit 26 signpost.

Distance (curb)	*Feet Vertical*	*Location*	*Distinctive Feature*	*Lithology*	*Unit*
S to N	***Salona Formation: Roaring Spring Member***				
0	176	250 feet S of Traffic Sign	Bed 320°/24°	Thin (2-10 cm) recessed interbeds	
211	150	Traffic light/signal			
262		138' 5"	Prominent break	Bentonite	B-16
300		Drain			
303	130/135	End of railing		5-25 cm coherent interbeds	
		128/130		Recessed interbeds limestone/shale	
365	123	Drain	Prominent break	Bentonite	B-15
440	115		Blocky	coherent interbeds	
440		108-114		Coherent 10-30 cm interbeds	
			Blocky	Thin (5-14 cm) recessed interbeds	
		Roaring Spring Member			
466	107' 6"	Contact	Contact: R Sp/N Ent	10 cm black shale	
518	97-100	***New Enterprise Member***	Blocky	Recessed	
521		99-107		coherent thick (15-30 cm) interbeds	
544	97-99		Prominent breaks	Two 6 cm & 8 cm shaley interbeds	
540	95				
548-570		100-105	Rusty solution channel	Cohesive thick 20 -30 cm interbeds	
570	88			Black Shale	
572-590	876			Brown weathering	
600/620	84/85		Blocky beds (330°/30°)	Brown weathering	
603	83/84	Spike: Millbrig	Prominent break	25 cm Black Shale and bentonite	B-14
630	78-83			coherent 10-30 cm interbeds	
	69-83			thick 20 - 40 cm interbeds	
	62-67			coherent 10-15 cm interbeds	
693	61.5	Wt calcite vein 155°/60°	Prominent break	13 cm black shale bed	
733	55-60	261" south of traffic sign	ramp fault	coherent thick (15-30 cm) interbeds	
725-740			Solution channel	Brown weathering/travertine	
760	50		Small rock fall		
?	44-50			Mainly thin 10-15 cm coherent interbeds	
775	43		Prominent break	Bentonite	B-13
794	35-43			coherent thick (15-70 cm) interbeds	
823	30-35	170 ft south of traffic sign	ramp faults	coherent thick (15-30 cm) interbeds	
830	25-30	Brown weathering	blocky: well jointed	thick; 25-50 cm interbeds	
856	19	Dieke	Prominent break	B-12 bentonite	B-12
	16-17		blocky: well jointed	20+40 cm vfg limestone beds	
866	15' 6"		Prominent break	B-11 bentonite and shale (18 cm)	B-11
890	10		*Cephlapods*	Competent 10-30 cm interbeds	
	7.5-15			Competent 20-50 cm lmstn; 3-10 cm shaley	
			Break	5cm shale bed	
900	4.5 to 7	Drain at 5'	Start dm-scale rhythmites	Nodular 10-15 cm thick wavy beds	
		1.4 to 4		35 cm blocky limestone	
	1' 3"	***New EnterpriseMbr***	Prominent break	2 to 3 cm shale/bentonite	B-10
915	zero	Contact	Prominent break	**SALONA/NEALMONT**	
		Rodman Member		Thin, wavy & nodular interbeds 2-5 cm	
950	10		Prominent break	*Sowerbyella* in fallen rock (Salona)	
973	15		bioclastic beds (B010°/20°)		
994	24	Sign post (Exit 26)			
997	24		Contact: Centre Hall Mbr	Large cephlapod in fallen rock	
1010	24-29			nodular	
1020	29-35			massive	
1025	35'6"		Prominent break	bentonite?	B-7?
1045	35-52		Massive beds 3 - 7 ft		
	52-58			Thinly bedded (2-10cm)	
1110	60	***Center Hall Mbr***	Bioclastic/coherent beds	Thin wavy interbeds in 60 cm 1 m units	
1120	63' 6"	126 " north of sign post	Contact	**NEALMONT/LINDEN Hall**	

Distance (curb)	Feet Vertical	Location	Distinctive Feature	Lithology	Unit
	70/75	***Linden Hall***	Massive 2-6 ft	Massive reticulated calcilutite	
1130	70		Calcite vein/joint (143°/83°)		
1156	76		Prominent break	bentonite?	B-6?
1190	85		Calcite vein/joint (330°/80°)	Massive reticulated calcilutite	
1220	97		Prominent break	B-6 bentonite	B-5?
				Massive reticulated calcilutite	
1249	105				
1284	115	End of outcrop	Bed 020°/18°	Massive micrite	

The massive beds of micrite at the northern end of the road-cut, some with thin wavy interbeds, are assigned to the underlying Linden Hall Formation. Contrast the weathered-back nature of argillaceous limestone interbeds in Salona rhythmites with their more competent appearance in the quarry wall. The blocky habit of the limestone interbeds reflects J1 strike joints (240°/88°) perpendicular to dip, and J2 joints approximately coincident with the dip section (140°/90°) and calcite veins oriented 135°/72°

Fossils

Figure S2-4a. Orthocone cephalopod.

Figure S2-5b. Orthocone cephalopod (center) showing septa. Other fossils are gastropods and brachiopods.

Figure S2-6c. Strophomenid brachiopods.

Figure S2-7d. Stromatoporoid in the Linden Hall

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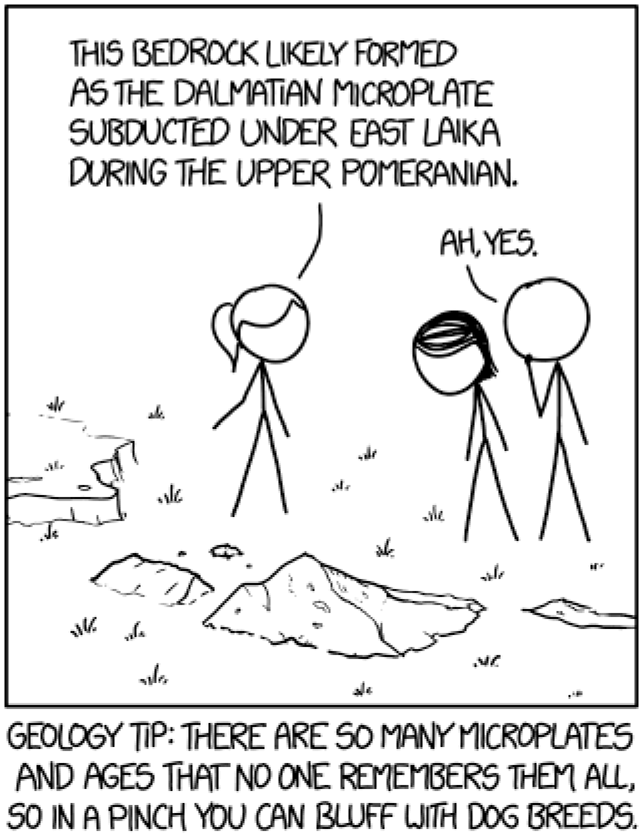
Srivastava, D.C., and Engelder, T., 1990. Crack-propagation sequence and pore-fluid conditions during fault-bend folding in the Appalachian Valley and Ridge, central Pennsylvania, Geological Society of America Bulletin, 102 (1): 116-128.



FUN FACT – BEEHIVE OVEN

Abandoned 1850's beehive ovens: Kelly Station, PA (http://www.birdsoutsidemywindow.org/category/hiking/page/2/) Kate St. John 2008

STOP S-3: ROUTE 322 BYPASS – MT NITTANY EXPRESSWAY

JOINT DEVELOPMENT WITHIN A LARGE FAULT-BEND FOLD OF THE APPALACHIAN VALLEY AND RIDGE: ORDOVICIAN – LOYSBURG TO BELLEFONTE SECTION

STOP LEADERS – DAVID P. "DUFF" GOLD[1], CHARLES E. MILLER, JR. [2], TERRY ENGELDER[3]

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Structure **(40.809032°, -77.824734°)**

Fractures in the Bellefonte dolomite and Axemann limestone in the Nittany anticlinorium include five distinct types, which can be identified, on the basis of their orientation, filling, size, and present aperture, as bedding-parallel veins, strike veins, cross-fold veins, cross-fold joints, and late-formed vertical joints (Srivastava and Engelder, 1989). Fracture orientation data are plotted in lower-hemisphere projection within which general joint sets are identified (Figure S3-1). When bedding is rotated to horizontal, both strike veins and cross-fold joints are orthogonal to the major structural trend of the Nittany anticlinorium (that is, N57°E). These structures are pre-folding, as indicated by the lack of local congruence with the nose of the Nittany Mountain syncline and general orthogonality with bedding (Figure S3-1). Strike veins are in many cases restricted to one bed and are normal to the bed regardless of the dip of that bed. Two sets of cross-fold joints are present, with one open and the other filled. Both cut and hence postdate the strike veins (Srivastava and Engelder, 1989). The presence of more than one cross-fold joint set is common in the Valley and Ridge as well as in the Appalachian Plateau. As the beds of the Nittany syncline rotated about their fold axis, the cross-fold joints were tilted, depending on the attitude of the bed relative to the nose of the Nittany Mountain syncline (Figure S3-1).

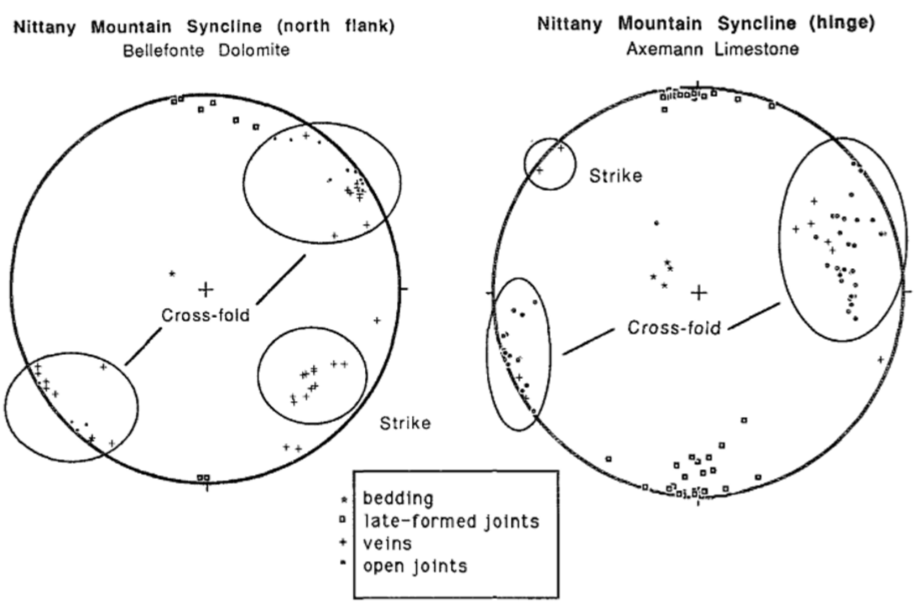


Figure S3-1. Lower-hemisphere equal-area projections of poles to fractures in the Nittany anticlinorium in the vicinity of State College, Pennsylvania. Ellipses indicate grouping of data and have no statistical significance.

Dating of fractures is based on cross-cutting relationships. The strike veins are found in the elastically stiffer beds which in the case of the Loysburg are dolomite beds. The strike veins are characterized by a plumose morphology indicating an initial propagation as a joint which was later coated with an insoluble residue and then filled (Figure S3-2). Cross-fold veins cut the strike veins indicating that the cross-fold veins formed later (Figure S3-2). The last joint to develop is vertical and independent of the strike of bedding. These late-formed joints are classified as Neotectonic as they propagate parallel to the contemporary tectonic stress field (Figure S3-1).

Figure S3-2. Left - Photograph of stylolitic strike vein showing the occurrence of insoluble residues at both the contacts of vein with the wall rock. Right - Field photograph showing overprinting of cross-fold veins (CFV) on pre-existing strike fracture (SF) coated with later developed dark colored insoluble residue. Vein-fill is developed in between the surfaces of cross-fold joints but no the insoluble residue is present.

Regional maps of contemporary tectonic stress are divided into three stress regimes based on the relative magnitude of the maximum (S_{Hmax}) and minimum (S_{hmin}) horizontal stresses and vertical (S_v) stress. These stress regimes are named after Anderson's (1951) three fault systems with the formation of a specific system (that is, thrust, strike-slip, or normal faulting) depending on the orientation of principal stress axes (σ_1, σ_2, σ_3). The regional state of stress for thrust faulting in foreland environments such as the Appalachian Valley and Ridge should conform with the stress state was recognized by Anderson (1951) where $S_{Hmax} \approx \sigma_1$, $S_{hmin} \approx \sigma_2$, $S_v \approx \sigma_3$ (Figure S3-2). Indeed, calcite-twin strain analysis of rocks on the Appalachian Plateau shows a horizontal compression and vertical extension as might be expected for $S_{Hmax} \approx \sigma_1$, $S_{hmin} \approx \sigma_2$, $S_v \approx \sigma_3$ in a thrust fault terrain. Because veins and joints propagate normal to σ_3, the stress state for thrust faulting is compatible with propagation of horizontal joints and veins. The examination of joint systems in foreland settings such as the Appalachian Plateau, however, leaves the initial impression that cross-fold joints and veins are the most prominent. Propagation of CFV is indicative of either a strike-slip ($S_{Hmax} \approx \sigma_1$, $S_v \approx \sigma_2$, $S_{hmin} \approx \sigma_3$) or normal ($S_v \approx \sigma_1$, $S_{Hmin} \approx \sigma_2$, $S_{hmin} \approx \sigma_3$) fault regime. A paradox during foreland deformation is that the stress state favoring the propagation of CFV is not compatible with that stress state favoring overthrust tectonics. Our analysis of crack-driving pressures based on fluid-inclusion trapping pressures offers a solution to this paradox.

The local stress state compatible with the propagation of SV during fault-bend folding is different from the regional stress state (Figure S3-3). Although beds passed through fixed hinges of the fault-bend fold, bending forced a local stress field on the dolomite beds where σ_3 was horizontal and in the direction of the regional compression. With the development of ramps during the progression of the thrust tectonics, rocks of the Bellefonte and Loysburg Formations passed through the kink planes of fault-bend folds. Based on their present position in the fourth horse back from the Allegheny Front (see Figure S3-3), these carbonates first passed through a synform at the base of a ramp. The distribution of strike veins in the Loysburg suggests that each pair of limestone-dolomite beds acted as a discrete unit during folding with a neutral surface at the contact between the limestone. The Valley and Ridge is an oroclinal bend. Stretching around that oroclinal bend is the mechanism that enabled the propagation of cross fold veins.

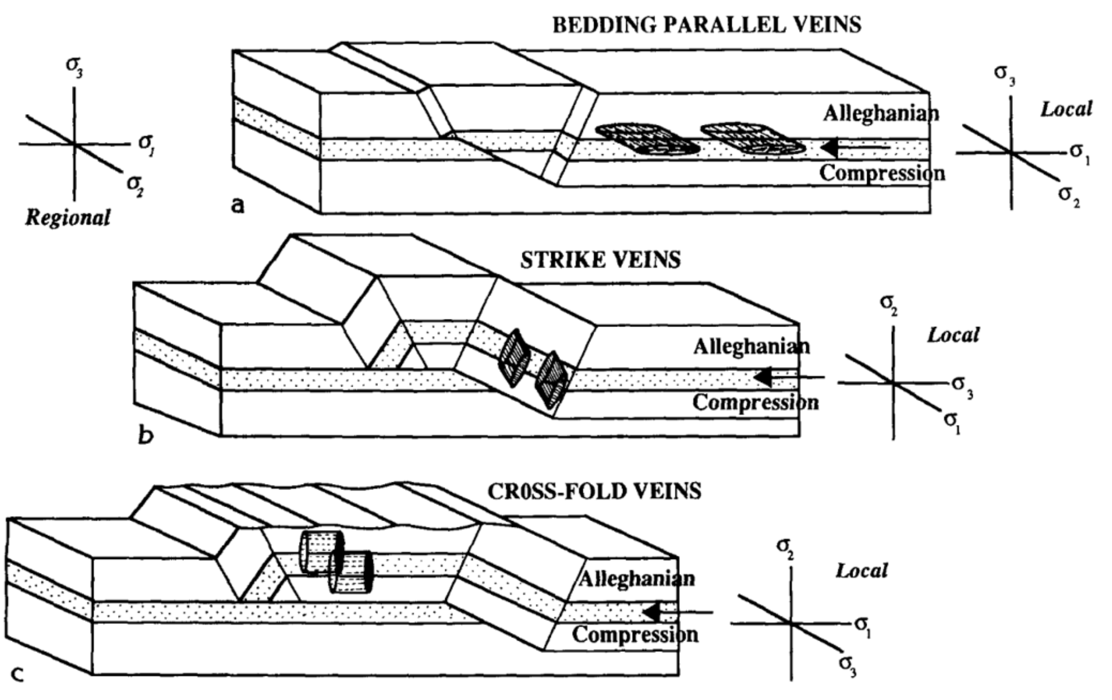


Figure S3-3. Schematic model showing progressive development of bedding-parallel, strike, and cross-fold veins during three successive stages of fault-bend folding in Bellefonte and Loysburg Formations (after Srivastava and Engelder, 1990). The late-formed (Neotectonic) joints are not shown in this schematic.

In the Valley and Ridge province of central Pennsylvania, the carbonate beds of Bellefonte and Loysburg Formations during fault-bend folding have recorded the imprints of four successive phases of brittle fracturing with Neotectonic joints being the last phase.

Table 3-1. Road-bank log of pertinent mesoscopic scale depositional and structural features

Road bed	Flag	bed #	Feature/structure	Comment	Attitude		
Blue		White			Joint 1	Joint 2	Joint 3
2400		95		Start of traverse			
2352	A	94	Large stromatolite on J1		J1 180/77		
2324			Plumose pattern stylolite and joint J2		St 240/60	J2 128/90	
2300	B	92	3 joint sets: blocky	gf-blocky; small vugs.	J1 190/80	J2 130/90	J3 080/73
2225	C	87/86	Channel	Disconformity			
2100	D	86/84	Mega-stylolite (symmetrical): conglomerate	Rip-up-clast cong., 2 ft above marker			
2085		84t	Mega-stylolites; vugs	27" dololutite with vugs			
1985	E	84b	Neotectonic joint	Massive dololutite	J3 092/90		
1916	E	84b	Neotectonic joint	Massive dololutite	J3 092/90		
1895	E	84b	Vugs: neotectonic joint	Massive dololutite	J3 080/90		
1852	F	83	Mound; 6 ft along base	Thin platy silty dololutite			
1838		83	Early and neotectonic joints		J1 200/81	J3 090/85	
1767	G	84	Low mound; tectonic stylolite	Massive, over platy silty dolostone	St 230/69		
1750		80	Tectonic stylolite		St 230/68		
1706	H	83/	Small mud mound				
1690	I	82	Mud mound in silty layers				
1606	J Road sign	80	5-ft thick bed; tectonic stylolite	5 ft thin laminae dololutites	St 220/68		
1537	K	80	6-ft thick bed; tectonic stylolite	5 ft thin laminae dololutites	St 223/73		
1385		80/79	Mega-stylolite in bed 79				
1342	L IV	78	2 tectonic stylolites in overlying bed	Tiger stripe limestone	St 232/68		
1296	M	78	Neotectonic joint	Tiger stripe limestone	J3 080.86		
1234	M	78/77	Neotectonic joint	Tiger stripe limestone	J3 084/88		
1191	N	77	Tectonic stylolite		St 220/69		
1180	Road sign						
1137	O III	76/75		12 " thick tiger stripe limestone	J3 080/90		
1086		73	Mega-stylolite				
1082	P						
1050	Q		Mega-stylolite		J245/75		
992	R II	70	Stromatolites/vugs in limestone	48" tiger stripe (algal?) vuggy			
955	S	70/69	Shale; mega-stylolite; conglomerate	Rip-up-clast cong., calcite veins	J1 200/83	J2 130/90	cv 310/85
							cv 150/75
900			Rusty stain from stylolite	Pyrite; insoluble residue			
816	T	64/63/62	Shale \dolostone\limestone	Tiger stripe bioturbated	J1 200/68	J2 133/90	St 232/72
				Bellefonte Fm. Tea Creek Mbr			
743	U		Mega-stylolite (symmetrical); vugs	Massive dololutite			
650	V	57/56	Mega-stylolite (symmetrical); vugs	Large (10-30 cm) vugs			
500		49					
400					J1 200/75	J2 130/90	J 105/90
388		43			J1 190/78		J 110/90
381	W		Stromatolite in loose boulder				
300		42					
200		37			J 110/60		
				Tea Creek Mbr	J 295/71		
150	X	32	Shale.Hardgrounds.Dolarenite; qtz grs.	Dale Summit Mbr (32 " thick)	cv 184/75	cv 200/81	
			5-10 cm shale below asymmetrical stylolite	Rusty stain; pyrite blebs			
125	Y	31	Channel; base of Dale Summit sandstone	Vugs at ground level: Coffee Run Mbr	B020/20	J 180/85	J 200/75
100		27/26	Thin symmetrical mega-stylolite				
64	Z	21	Channel				
60	AA	20	Thin stringers of bedded black chert				
57	BB	19	Black chert nodules cut by joint		B030/27	J 110/90	J 198/60
30	CC	13/12	Cm -scale clastic dikes	High pore-pressure interval			
0		1, 2, 3		End of traverse			

LOWER AND MIDDLE ORDOVICIAN STRATIGRAPHY ALONG THE MT. NITTANY EXPRESSWAY AT STATE COLLEGE, PA

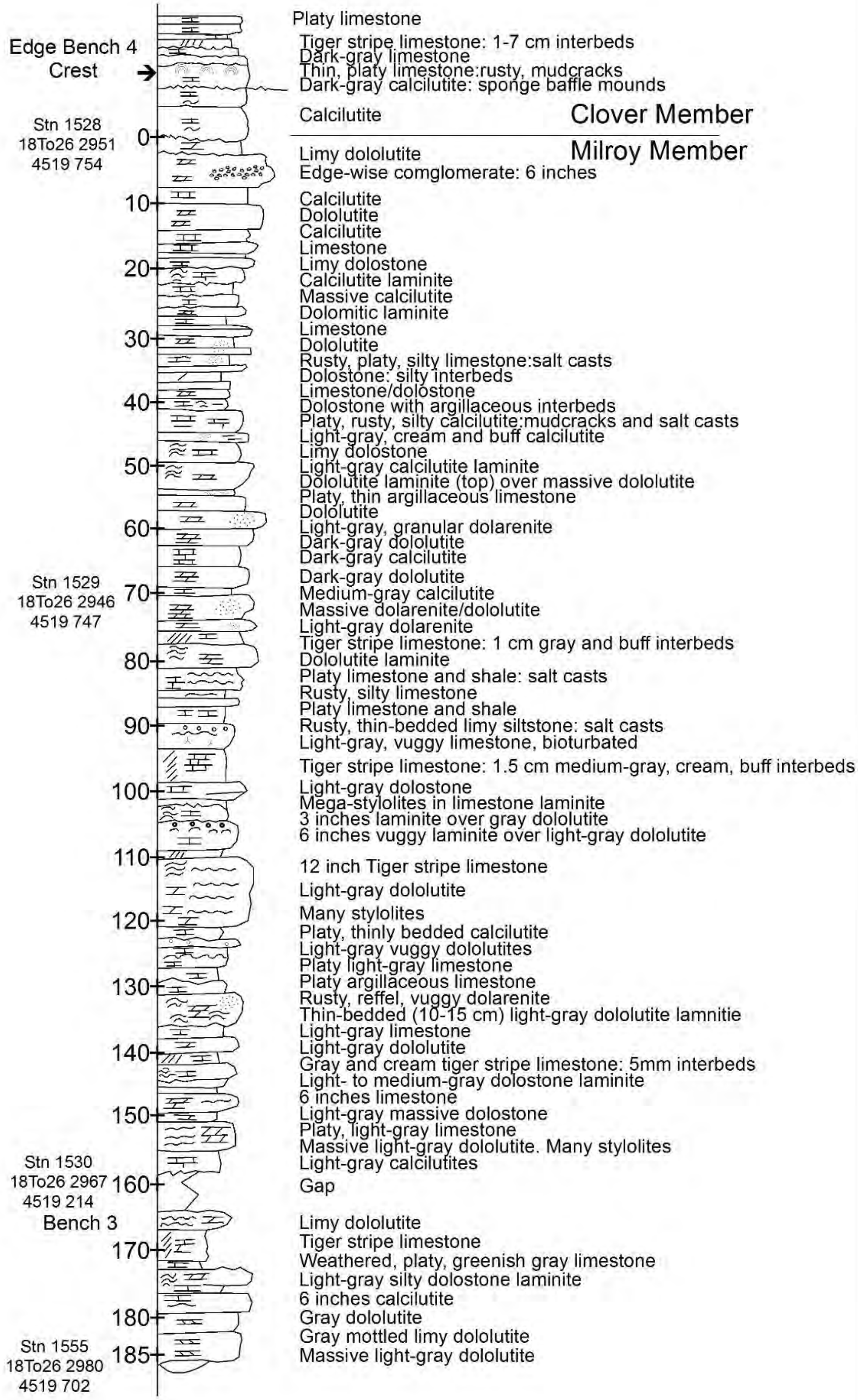
Shallowing-upward carbonate cycles in the Loysburg

The road-cut exposes 290 feet of lower and Middle Ordovician carbonate stratigraphy that includes the 194 feet of the Bellefonte Formation, and 93 feet of the Milroy Member of the Loysburg Formation. Alternating limestones (darker) and dolomites (lighter) form six sets of shallowing-upward carbonate cycles (Figure S3-4). These cycles are conspicuous, even to the casual observer. This stop is the best local exposure for viewing shallowing-upward carbonate cycles (parasequences). A broad tidal-flat setting is envisaged for the Loysburg strata exposed in the road-cut. Note primary depositional features, cm-scale layering in four "tiger stripe" limestone beds, as well as superimposed diagenetic (bedding stylolites) and tectonic (cross-strike stylolites and joints) structures.

Blue paint markers represent distance in feet from the north end along the base of the cut. Individual beds are numbered in white paint; a circled white number means a sample location. These are coded to the stratigraphic log (Table 3-1). Compare to Figure S3-5 from the Oak Hall quarry. Start at marker 2400 feet (blue painted numbers every 100 feet), and work down section from 93 feet of Milroy Member above the base of the Loysburg, through 194 feet of the Bellefonte Formation , which includes the Tea Creek, Dale Summit and Coffee Run Members. Flag in cairn marks the stations.

Figure S3-4. Shallowing-upward carbonate cycles in the Milroy Member of the Loysburg Formation. Lighter and darker strata are dolomites and limestones, respectively.

Figure S3-5. Modified stratigraphic column of Upper Milroy and Lower Clover Members of the Loysburg Formation exposed in benches three and four working faces in Oak Hall Quarry.



STATION DESCRIPTIONS

Please DO NOT HAMMER on the roadcut. We use these examples with others!

At Stop 3, the stations begin at the stratigraphic top of the roadcut in the Milroy Member of the Loysburg. Successive stations progress to lower stratigraphic levels, ending in the Coffee Run Member of the Bellefonte. Six Loysburg stations and one Bellefonte, showcasing different stratigraphic features, are pictured and described below. The first and last stations described below are highlighted in bold on Table 1. Approximately 15 stations at this roadcut outcrop are marked with flags in cairns.

Station

This station exposes stromatolites (Figure S3-6) in the Milroy Member of the Loysburg. Stromatolites are blue-green algae (cyanobacteria). These form when calcium carbonate deposits on a mucilaginous surface of the algae, preserving the organism as a fossil. Stromatolites are one of the oldest fossils, ranging back 3.5 billion years (Taylor and Taylor, 1993). They were responsible for producing much of Earth's early oxygen, enabling aerobic organisms to evolve (Biello, 2009).

Figure S3-6. Intertidal stromatolites at Station 1 in the Milroy Member of the Loysburg

Stromatolite morphologies reflect their distribution in modern tidal flats (Figure S3-7). Supratidal forms consist of laterally-linked hemispheroids with continuous laminae (LLH). Intertidal stromatolites develop larger, more distinct domes or hemispheroids forming columns or club-like "cabbage heads" (SH, LLH-SH). Subtidal forms (SS) are diminutive in comparison, consisting of discrete spheroids. The stromatolites, here, are interpreted as intertidal, based on a variety of sedimentary observations in the Loysburg. Height of intertidal stromatolites (SH, LLH-SH) has been considered as a paleotidal indicator (Cloud, 1968).

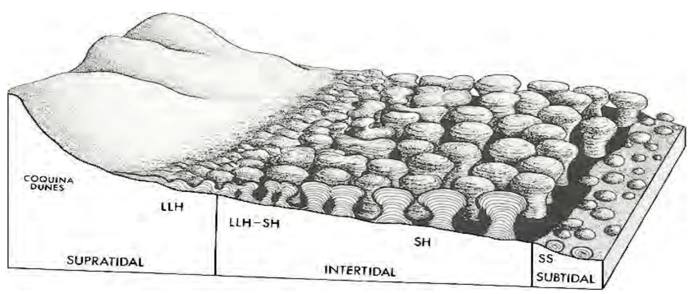


Figure S3-7. Generalized stromatolite distribution on carbonate tidal flats. (Anstey and Chase, 1974; used with permission.)

Station

This station represents an unconformity in the Milroy Member of the Loysburg (Figure S3-8). There are four major types of unconformities (Figure S3-9).

An angular unconformity is a discontinuity between dipping and horizontal strata. An erosion period separates the two sets of strata.

A disconformity is an erosion surface within essentially parallel strata.

A paraconformity represents missing strata between essentially parallel layers. It is not obvious that erosion is responsible for the missing section. Instead, the section may be missing due to non-deposition.

A nonconformity is an erosion surface over igneous or metamorphic rock.

The type of unconformity at Station 2 is a disconformity. Strata above and below the erosion surface are essentially parallel and the erosion surface is obvious.

Figure S3-8. Disconformity in the Milroy Member of the Loysburg Formation. The geology hammer is 11 inches long.

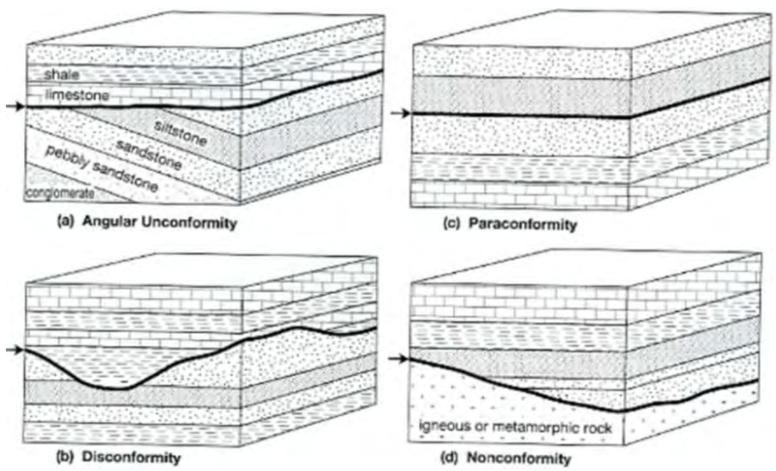


Figure S3-9. Four major types of unconformities. (From Kaushikmitra5.wordpress.com)

Station

At this station, desiccation cracks on a float block in the Milroy Member of the Loysburg are seen (Figure S3-10). Desiccation cracks should not be confused with burrows in hardgrounds (also found here), or syneresis cracks in the subtidal zone. The latter have not been documented in carbonates (Shinn, 1983). The Loysburg consists of carbonate tidal flat deposits and presence of desiccation cracks is consistent with this interpretation. The cracks probably formed in the intertidal or supratidal zones of the tidal flats, most likely the latter. During high tides, the lowermost part of the supratidal zone receives splashing water from waves in the intertidal zone. Other than the splashing, supratidal zones are subaerially exposed except during precipitation events, storm surges, and spring tides. Desiccation cracks can also form in the subtidal zone. However, this is a high-energy zone due to waves and diurnal tides. These factors make the subtidal zone less optimal for preserving desiccation cracks.

Figure S3-10. Mudcracks in the Milroy Member of the Loysburg Formation. The pen is 5.7 inches long.

Station

At this station, a rare sub-vertical, cross bedding, symmetrical stylolite is exposed in the Milroy Member of the Loysburg (Figure S3-11). A distinction is made between bed-parallel and sub-vertical stylolites. The former are due to sediment compaction during deposition and the latter due to lateral compression from tectonics.

The implication is these two types of stylolites are not the same age. The bedding-parallel stylolites at this roadcut are Lower–Middle Ordovician while sub-vertical stylolites, here, are Permian–Pennsylvanian. The latter record a change in the local stress field from structural compression during the Appalachian Orogeny and later NE-SW (contemporary) compression (Doden, et al, undated).

Figure S3-11. Sub-vertical stylolite in the Loysburg Formation. The pen is 5.7 inches long

Station

A four-inch amplitude, symmetrical stylolite in the Milroy Member of the Loysburg (Figure S3-12) is shown here. Stylolites are secondary diagenetic structures resulting from differential pressure solution perpendicular to the principal stress direction. They mostly occur in carbonate rocks and look similar to skull sutures, having serrated edges interconnecting on opposite sides. Stylolization removes rock material, decreasing total rock volume by as much as 50 to 75 percent. These estimates are based on analyses of insoluble residues resulting from stylolization. Insoluble residues consist of clay, silt, silica, mica, oxides of iron and manganese, and organic carbonaceous residues (hydrocarbons). Stylolite amplitudes indicate the minimum thickness of the dissolved material (Bathurst, 1971). In addition to reducing total rock volume, stylolization also reduces rock porosity. This is particularly noteworthy in the petroleum industry where the percent of porosity is important in a potential producing zone. This roadcut has numerous examples of high amplitude, or megastylolites. It is one of the best locations in the State College area for seeing stylolites with such amplitudes. They occur, here, in both the Bellefonte and Loysburg Formations.

Figure S3-12. High-amplitude (mega) stylolite in the Milroy Member of the Loysburg. The geology hammer is 11 inches long.

Station

This station exposes breccias with hydrodynamic implications, within a stratum in the Milroy Member of the Loysburg (Figure S3-13). The section-of-interest extends laterally approximately 30 feet. Breccias began

Figure S3-13. Intraformational breccias/rip-up clasts. (1) Asymmetrical pebble showing a sloping stoss side that includes an erosion scour in contrast to a steep lee side. (2) Sediment draping (yellow dashed lines) over the pebble in (1), indicating flow from right to left. Red arrows point to numerous small erosion channels or scours. The white arrow points to hydrodynamically oriented intraformational clasts.

as shriveled mudcracks, eroded and transported into a lower zone on the tidal flat. Their angularity attests to short transport distances – probably from the supratidal to subtidal zones. Tidal-flat deposits commonly show changing duration, velocity, and direction of flowing water, sometimes within the same layer.

Station

Wagner (1966) defines the base of the Loysburg as the first limestone following the persistent dololutites of the Bellefonte. The basal portion of the Milroy member of the Loysburg is noted for its "tiger" stripes. (Figure S3-14). This contact marks a transition from dolomite deposition of the Bellefonte to alternating dolomite and limestone of the Loysburg. Thin alternating bands of limestone or limestone and dolostone create this appearance.

Figure S3-14. "Tiger Stripes" in the lower Loysburg are marker beds for that section of the formation.

Station

A 3.7-inch-long specimen of faulted black chert in the Coffee Run Member of the Bellefonte Dolomite is exposed (Figure S3-15). The fault is discontinuous below the chert. Above the chert, the fault transitions into a fracture. These observations suggest the mechanism for faulting of the chert is not tectonics but rather soft-sediment deformation or slumping (Folk, 1952) due to differential compaction. This occurred during deposition, prior to lithification. The specimen is part of a discontinuous bedding-parallel chert layer extending approximately six feet.

Figure S3-15. Faulted black chert; Coffee Run Member of the Bellefonte Dolomite. The faulting is due to soft-sediment deformation.

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STOP S/E-4: STRAT/ENG LUNCH: MILLBROOK NATURE CENTER AND MARSH

STOP LEADER – RICHARD PARIZEK[1]

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(40.813376°, -77.838310°)

This former dairy farm including cropland, pastures and extensive meadows has been transformed into a unique, nature center. Boardwalks allow easy access to areas otherwise difficult to access while also ecologically fragile. It is open year-round and changes with the season.

Thompson Run originates from Thompson Spring just above the Duck Pond and below Penn State's sewage treatment plant. It joins Slab Cabin Run where it is accessible by boardwalk. During dry seasons, Slab Cabin low flows are noticeably less than Thompson Run despite its greater drainage area. State College Borough withdraws groundwater from Thomas and Harter well fields located in the Slab Cabin drainage. Effluent from these wells is returned to Spring Creek below its confluence near UAJA treatment plant.

Urban runoff has altered both channels. Sediment and debris have accumulated in Thompson Run whereas Slab Cabin has become incised deeper into its flood plain. Figure H5-1 provides the geologic setting, including fracture traces, tear faults and possible thrust fault, test and production wells, Hamill and John Bathgate Springs. Not shown are overburden deposits of residual soil and alluvium that blanket carbonate rocks except for small and scattered natural bedrock outcrops.

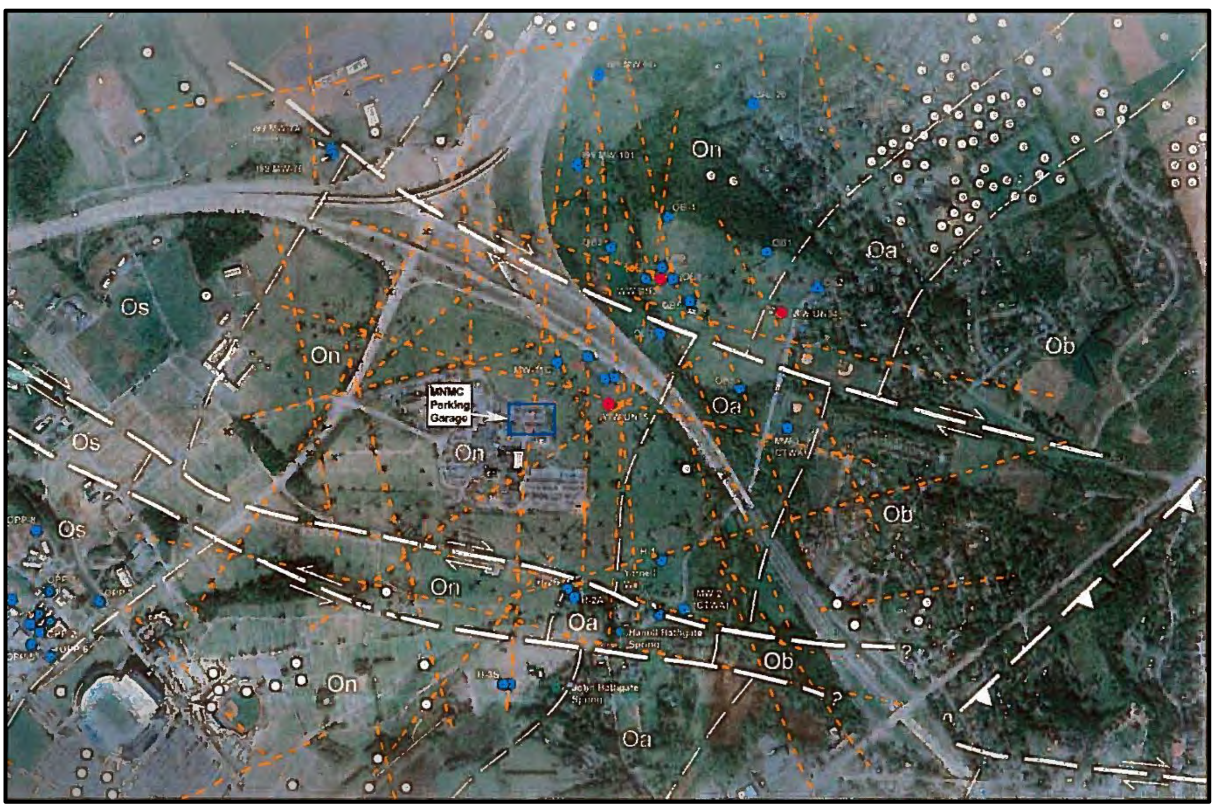

Figure H5-1. Geologic map of the Millbrook Nature Center and Marsh (From Gold, Doden and Parizek, 2016).

A discontinuous Pleistocene terrace exists along Thomas and Slab Cabin runs and Spring Creek within the vicinity of the Nature Center. It has a frost wedged disturbed soil profile indicating that it predates Pennsylvania's last glaciation. Remnants appear near the Thompson and Bathgate springs. Their water table and solution channels are still graded to these terrace remnants.

Shallow channel piezometers were installed along each channel within and near the Millbrook Marsh. Thomas, Slab Cabin and Spring Creek all showed influent and effluent sections that remained nearly the same before and after University and Municipal wells were placed in service, the subject of Steele's senior thesis (1998), Figure H5-2.

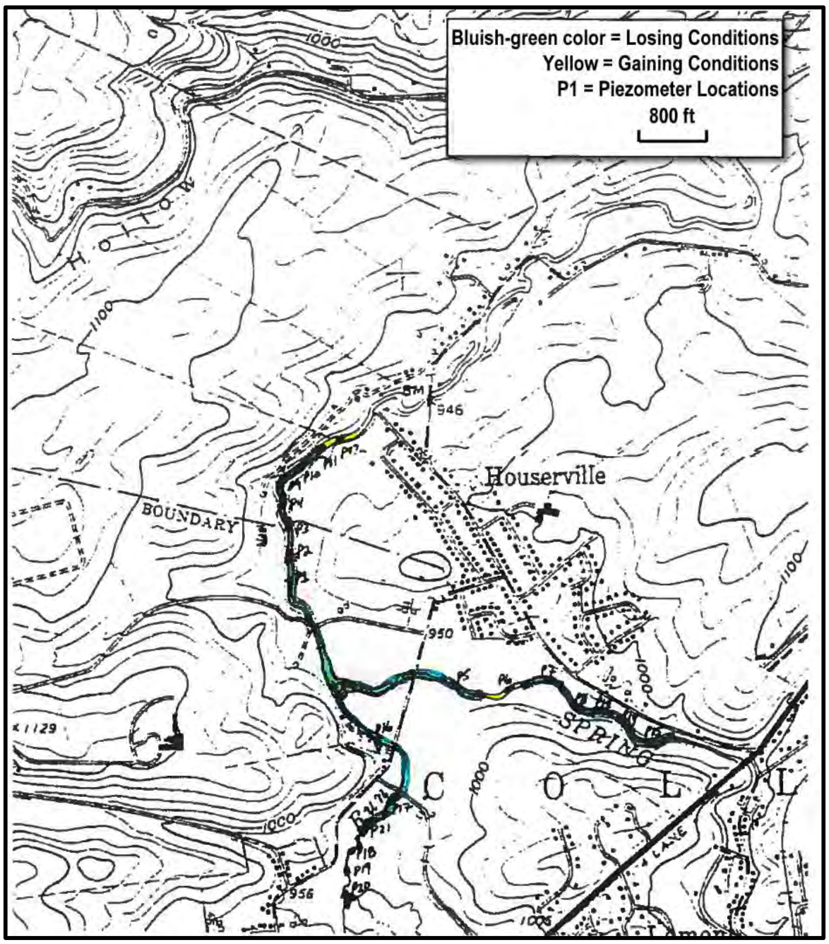

Figure H5-2. Effluent and influent conditions along Spring Creek and Slab Cabin Run during the September-October 1997 dry season (Steele, 1998).

Nested and shallow channel piezometers, stream and spring gauging stations, and bedrock observation wells were monitored extensively during the development of production well CTWA MW-1.

Major production wells include Penn State water supply wells, UN 33, 34, and 35 and College Township well MW-1. These fracture-trace intersection test sites along with 23 others near the Marsh were recommended as one of ten highly productive, potential well fields in a Centre

Regional Planning Commission study (Parizek, 1987). You passed the Alexander well field near Fox Hill Road traveling toward the University Airport, will learn about the Oak Hall site (Stop H-6), pass the Thomas -Harter Site traveling near Shingletown Gap toward Stop H-7, all recommended in 1987.

The Marsh was found to be perched before and after these four high capacity wells were placed in service. The Marsh is nourished by direct precipitation, overflow of streams during high flows together with seeps and springs largely concentrated near the southern margin of the wetland. Lowering the water table by 10, 20 or more feet will not change these sources of nourishment!

Rock V-shape barriers were set in Slab Cabin Creek with the intention of raising the water table, hence augmenting the wetland. This did not cause a rise in groundwater levels within flood plain deposits as expected because of perched channel conditions. It did improve fishery habitats by enhancing pools above and scour pools below these dams. Deep scour pools could thin protective flood plain sediments increasing risks for sinkhole development more likely under perched conditions.

Such a sinkhole opened at the Route 322 crossing of Slab Cabin Run during low flow conditions. Dams were built above the sinkhole to allow its repair (Figure H5-3).

Figure H5-3. Sinkhole within Slab Cabin Run, Route 322 bridge.

Excavation extended to more than 12 feet below Creek bottom while water was pumped around the sink. As feared, a storm event caused the deep excavation to flood. Water supply wells were immediately shut in to reduce migration of surface water that entered the void. Fortunately, the Axemann Limestone was not transmissive enough to consume the entire storm flow. Campus winter break had just started, which allowed Penn State to meet water needs from other sources. More than 10-feet of deeply weathered silty clay was exposed. It lacked sand and pebble lenses as might be expected for alluvium, contained a buried clay enriched weathered zone. Might this be proof of Williams' 1895-1930 glacial Lake Lesley I after all given its postulated 1,100- foot spillway elevation at Dix, the divide for N. Bald Eagle Creek? (See Parizek and White, 1985). Let's talk.

References

Parizek, R.R., and W.B. White, 1985, Field Trip #3. Application of Quaternary and Tertiary Geologic Factors to Environmental Problems in Central Pennsylvania, pp. 63-119. 50th Annual Field Conference of Pennsylvania Geologists. Central Pennsylvania Geology Revisited. Oct. 4-6, 1985, Bureau of Topographic and Geologic Survey. 290 pp.

Parizek, R.R., 1987. Identification of ten potential high capacity well fields in the greater State College, PA Region-Phase III Study for The Center Regional Planning Commission 110 pp.

Steele, S.W., 1998, Investigation of induced and natural streambed infiltration in the vicinity of the Pennsylvania State University's Houserville Well Field, Centre County, PA. Senior Thesis, Geosciences. The Pennsylvania State University, 63 pp.

OVERVIEW OF ENGINEERING FIELD TRIP

STOP LEADERS – ARNOLD G. DODEN[1], DAVID (DUFF) GOLD[2] AND HUBERT L. BARNES[3]

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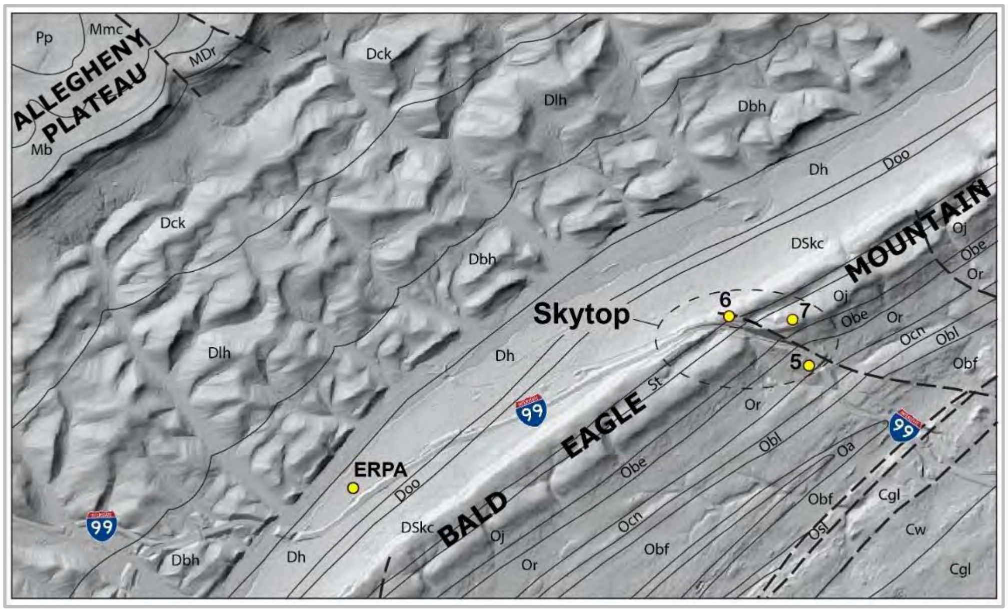
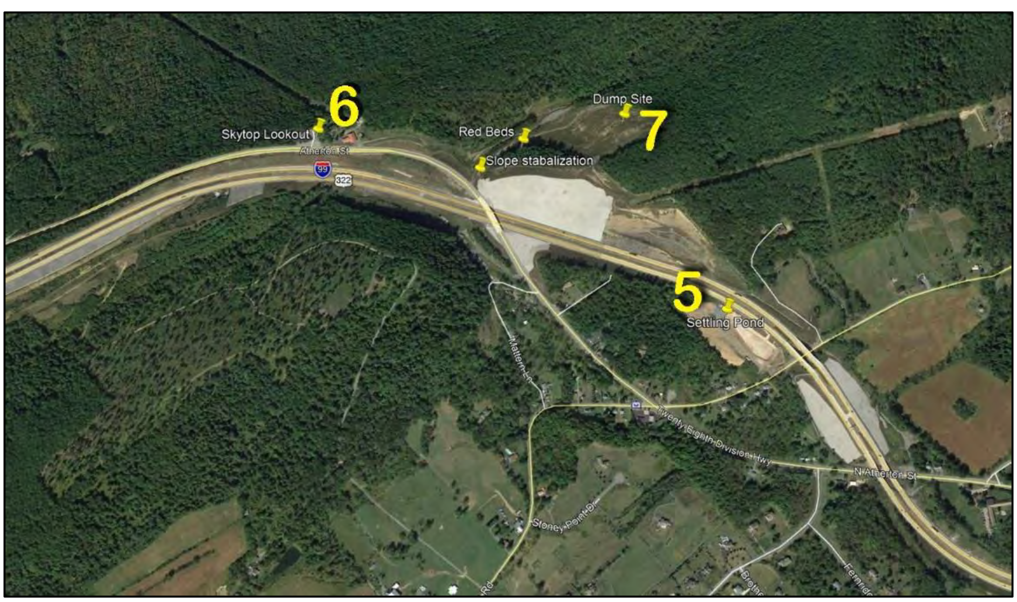


This field trip examines unintended consequences and remediation engineering employed in highway construction through the Bald Eagle Ridge wind gap at Skytop (above). These include landslide-prone cuts as well as exposing of sulfide veins in 300-foot and 900-foot sections of the roadcut. Although most outcrops are covered to prevent further acid rock drainage (ARD), remediation strategy and efforts are discussed at critical vantage points (closeup, below) for the sulfide vein system in the roadcuts as well as the sequestration of excavated material. Key features are indicated with yellow pins. Stops include settling ponds (#5), Skytop Lookout (#6) and Seibert Dump (#7), below:



ENGINEERING ROADLOG – DAY 2

		**Stop 4: Lunch – Milbrook Marsh Nature Center** **40.813376, -77.838310**
0.0	10.9	Exit Millbrook Marsh Nature Center and turn right onto Puddingtown Road
0.2	11.0	Turn left onto Orchard Road
0.8	11.8	Turn right on Park Avenue
0.2	12.0	traffic light for hospital
0.5	12.5	Pass under bridges and turn left onto I-99 S
1.2	13.7	Pass National Guard Armory on left
1.9	15.6	Woody Crest overpass
1.4	16.9	Bear right on Exit 68 towards Grays Woods Waddle, to Skytop Mountain on Rt. 322 W
0.8	17.7	Keep right at the fork, follow signs for PA-550/Waddle and merge onto N Atherton St/Grays Woods Blvd.
0.3	18.0	Road-cut to right exposes **Warrior Formation** interbedded limestones, dolostones and shale (oldest strata out-cropping in Centre County). Note low angle reverse fault cutting beds. This is one of several splays to the west correlated with the Birmingham faults exposed near Little Juniata River east of Tyrone.
0.7	18.7	Ridgemont
0.6	19.2	Turn right onto Rte 550 N
0.2	19.4	Turn left at gate to the storm water retention pond
0.1	19.5	Park near pond for Stop 6
		Stop 5: Settling Ponds **40.82958, -77.959001**
0.3	19.8	Return to Rte 322 W/Atherton St
0.4	20.2	Continue on Old Rt 322/Atherton St over the overpass of I -99. A sulfide gossan zone was exposed in the road-cut on old Rte 322 beneath and adjacent to the downhill side of the new bridge abutment. The fill north of new Rt 322 bridge contains toxic waste rock, referred to as the "S.R 3042 fill".
0.2	20.4	Disembark in the parking lot at the Skytop lookout Please avoid the chiropractor's private spaces
		Stop 6: Skytop Lookout **40.833506, -77973883**
0.2	20.6	Drive back on Old Rt 322 E to Stop #3
		Stop 7: Seibert Dump Site **40.833888, -77.968454**
0.0	20.6	Return to buses.
1.9	22.5	Head southeast on old 322/N Atherton St toward Mattern Ln
0.2	22.7	Continue onto Grays Woods Blvd
0.4	23.1	Use the right lane to take the US-322 N ramp
0.4	23.5	Merge onto I-99 N/US-322 E
0.6	24.1	Take exit 69 for U.S. 322 Business E/Atherton Street
4.8	28.9	Turn right onto Norma St
0.1	29.0	Turn left into Ramada Inn

STOP E-5: SETTLING PONDS

SINKHOLES, FISSILE SHALES AND SULFIDE VEINS IN HIGHWAY CONSTRUCTION

STOP LEADERS – ARNOLD G. DODEN[1], DAVID (DUFF) GOLD[2] AND HUBERT L. BARNES[3]

[1]GMRE, Inc., 925 West College Ave., State College, Pa 16801. [2]Emeritus, Department of Geosciences, The Pennsylvania State University, University Park, PA. [3]Emeritus Distinguished Professor of Geochemistry, Department of Geosciences, The Pennsylvania State University, University Park, PA 16802

(40.82958°, -77.959001°)

Two retention ponds were dug early in the project. The upper pond was used to neutralize ARD from the Large Cut Face (LCF) area, and the lower pond is a storm-water retention pond to capture runoff from the exposed cuts and roadbed (Figure E5-1).

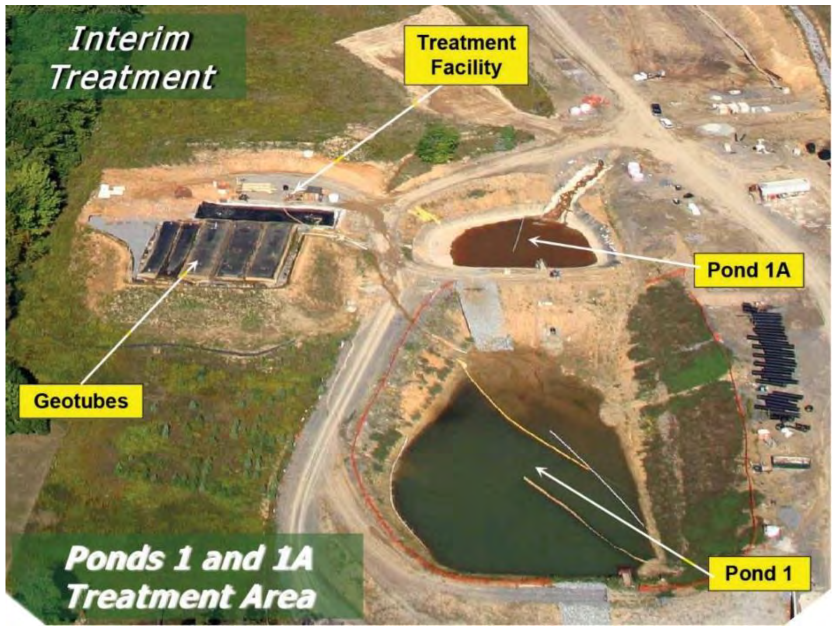


Figure E5-1. Oblique aerial view of neutralization pond (upper, 1A) and retention pond (lower, 1) during construction. *(Photograph by Skelly and Loy).*

Aerial view of SkyTop (A-12 section) shows the neutralization, and storm water retention ponds south of the Large Cut Face (Figures E5-1 & E5-2). The excavation of Reedville Shale in the

Figure E5-2. Aerial view of settling pond stop.

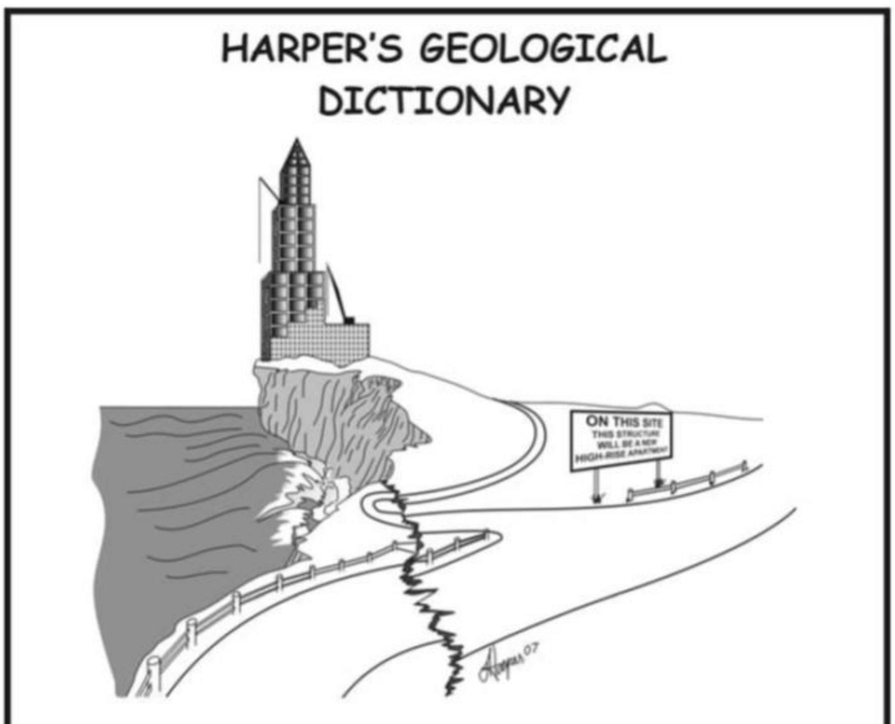
east bank served to reduce the slope of the bank as well as a source of fill. These operations were completed late spring and early summer of 2008. The bus parking area is in the Antes Black Shale. The parking area is over Antes Black Shale. The pond overlies the Coburn Limestone.

The ponds are located over the Upper Coburn bedrock (limestone and calcareous shale rhythmites). The sinkhole that developed in the retention pond was plugged for a second time during July 2015.

Approximately 60 feet of fissile black carbonaceous shales (Antes Member), uphill to the north, required an extra deep roadbed foundation.

Steeply dipping shale and siltstone (Reedsville) is exposed in the roadcuts to the north.

The dressed slope on the right effectively seals a sulfide vein system in the Bald Eagle and Lower Juniata sandstones from atmospheric degradation. This is known as the “Large Cut Face”, from which approximately 1.7 million tons averaging 5% S was excavated.



STRUCTURAL GEOLOGY - The pseudoscience that enables engineers to erect buildings, bridges, power plants, and other structures on faults, overhanging cliffs, sloping strata, 50 feet of unstable clay, etc.

STOP E-6: SKYTOP LOOKOUT

HEADWALL CRACKS, SLOW CREEP & BUTTRESSING THE TOE SLOPE IN HIGHWAY CONSTRUCTION

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[1]GMRE, Inc., 925 West College Ave., State College, Pa 16801. [2]Emeritus, Department of Geosciences, The Pennsylvania State University, University Park, PA. [3]Emeritus Distinguished Professor of Geochemistry, Department of Geosciences, The Pennsylvania State University, University Park, PA 16802

Structure (40.833506°, - 77.959001)

Assemble at the lookout (northwest end) for view of the Appalachian Plateau across the Allegheny Front – a point separating major structural and physiographic domains. You are standing on dominantly overturned beds of the Tuscarora Formation, approximately along the axis of the Catskill delta lobe. Devonian age strata are exposed dipping northwestward in the road-cuts in the valley floor. Dips shallow northward into the Mississippian strata (Burgoon Sandstone) on the horizon. Approximately 20,000 feet of stratigraphy is represented in this interval with a change in attitude from shallow southeast dips to shallow northwest dips, and the transition from the Valley and Ridge Physiographic Province to the Appalachian Plateau (Figure E6-1).

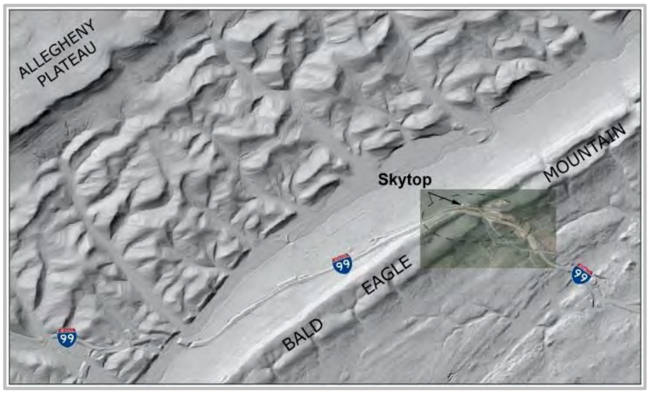
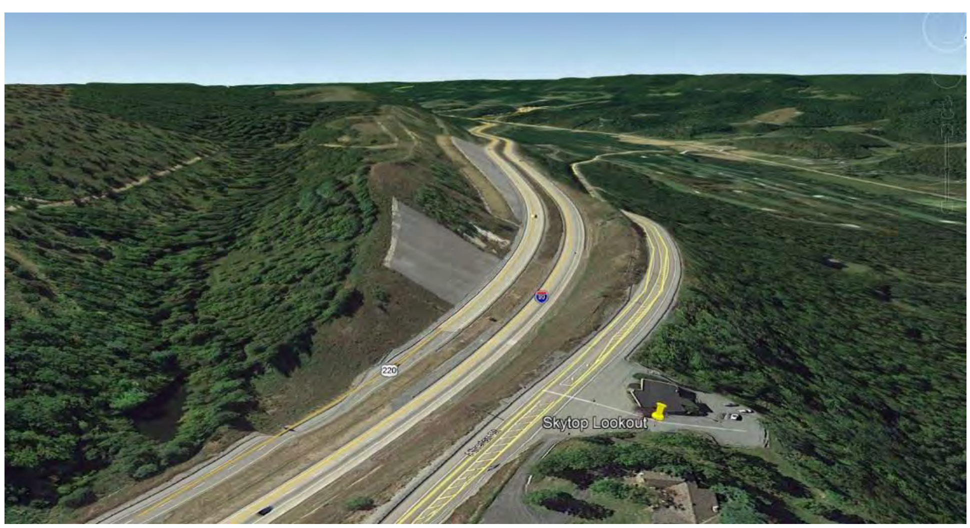


Figure E6-1. LIDAR image, with Skytop location highlighted, shows transition from Valley and Ridge Province to the Appalachian Plateau along the Allegheny Front.

Slope Instability

We will develop the Skytop construction problems from a second vantage point view 200 feet to the south near the machine shop. To the west, the large road-cut towards the road crest divide, exposing Bald Eagle and Tuscarora strata. Conspicuous in the view to the west are the differential elevations in roadbeds (Figure E6-2). During construction, the uphill slope became unstable with

Figure E6- 2. View of buttresses looking west from Skytop Lookout



slow creep (20-50 hour time scale) with slope bulges and rock-slab movement on shale interbeds in the Tuscarora on asymmetric chevron folds with steeply-inclined axial planes to the southeast. Headwall cracks (meter scale: in guidebook and Figure E6-3) developed in Tuscarora (west) and Juniata (east) strata. Remediation efforts included laying back the slope from 1:2 to 2:1 (this required an Act of Congress to alter the skyline profile) and "loading the toe" with a buttress and an elevated roadbed.

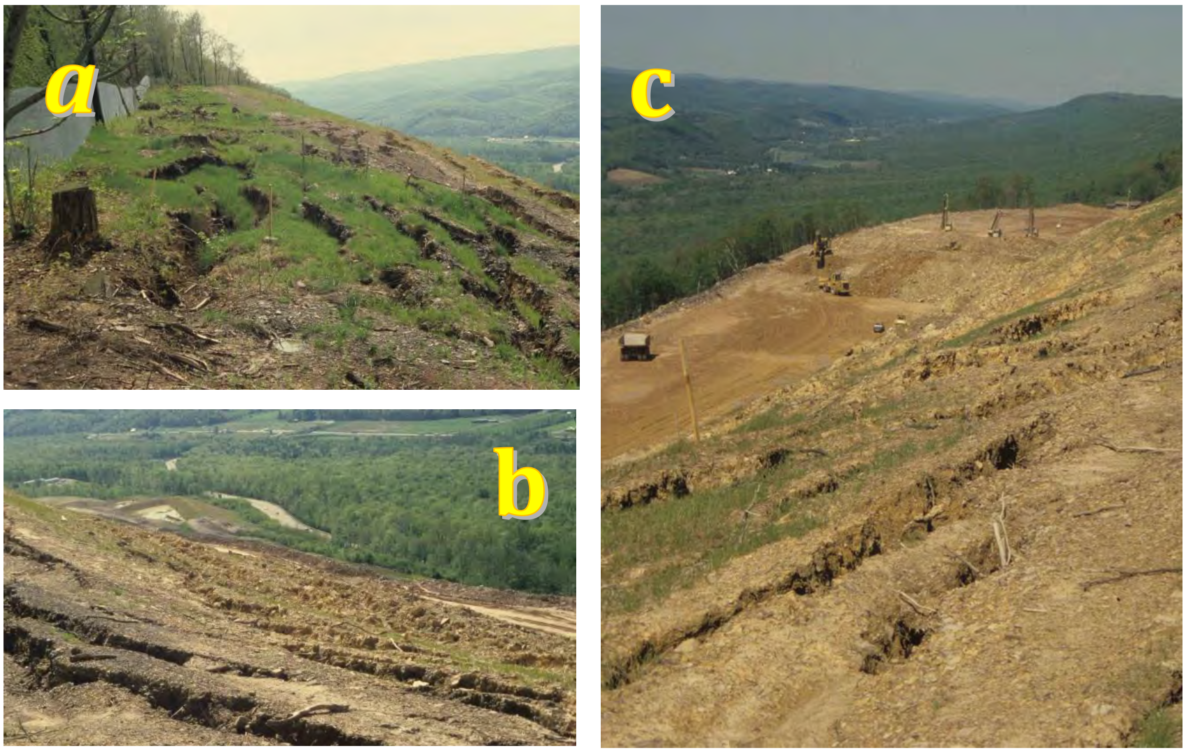


Figure E6-3. Meter scale headwall cracks at Skytop. a). Tension cracks (incipient landslides) above active excavation for I-99 at Skytop. Rt. 322 is at right center and a small segment of old Rt. 322 is just below Rt. 220. b). More tension cracks above the excavation. Old Rt. 322 is below the retention ponds and Rt. 220 is at the top of the image. c). Excavations equipment (end dumps, front-end loader, drills) excavating I-99. Note tension cracks above the excavation.

Epigenetic Veins: Mineralization and Chemistry

The view to the south towards State College captures the Large Cut Face and the canyon excavated through highly veined Bald Eagle Sandstone. Walk over to a vantage point in front of the Sky Top Machine Shop and look to the southeast (towards State College). A new two-lane bridge and a deep road-cut dominates the near view. This cut, approximately 350 feet deep, exposed a sulfide vein system in the Bald Eagle Sandstone in a zone some 600 feet wide with a clearly defined REDOX interface between the weathered oxidized products and reduced sulfide minerals. Weather related subtle color changes of the slope reflected the precipitation of transient efflorescent minerals.

Skytop had long been known as a location for sulfide veins. Pyrite veins were noted by D.P. Gold, (circa 1998) in core drilled by G.O. Hawbaker, Inc., in the old ganister workings along the ridge to west of Skytop, as well a steeply dipping gossan one (9-feet thick) exposed in a road cut along Old Route 322. The latter site was visited by many generations of Penn State geology students. This gossan was located in the western abutment of the new Route 322 Bridge (near station 882+00). The I-99 roadcuts have exposed two sulfide vein-system that are portrayed in a modified block diagram (Figure E6-4), as viewed from the south.

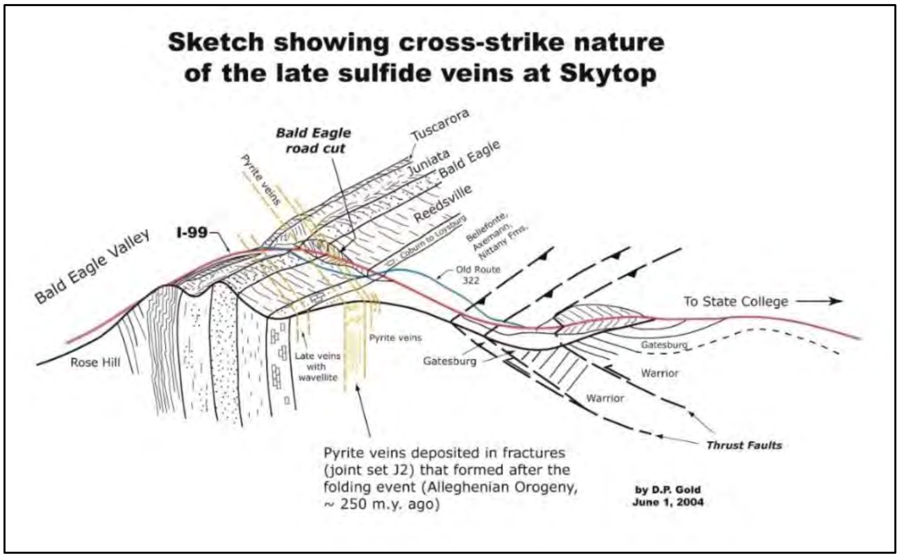


Figure E6- 4. Conceptual Isometric view (from the south) of Skytop geology and vein systems.

Although veins that transgress bedding are exposed in all the road cuts, most are concentrated in the Bald Eagle sandstones, and to a lesser extent in the Tuscarora quartzites and Juniata sandstones. These "cross-strike" veins are far less common in the over- and underlying shaley formations. The preferential development of veins in the more competent strata is attributed to the well-developed J_2 joint system in these units. Although the orientation of the veins is relatively constant, different types are distinguished by composition, thickness and alteration halos. Sulfide-bearing veins are by far the most abundant and occur as steeply dipping, cross-strike sets oriented generally SSE, essentially coincidental with the preferred orientation of the J_2 joint set (Figure E6-5). The slightly geometrical obliquity suggests there may have been two different hydrofracturing events; an early one to form the J_2 joint set and a later vein forming event.

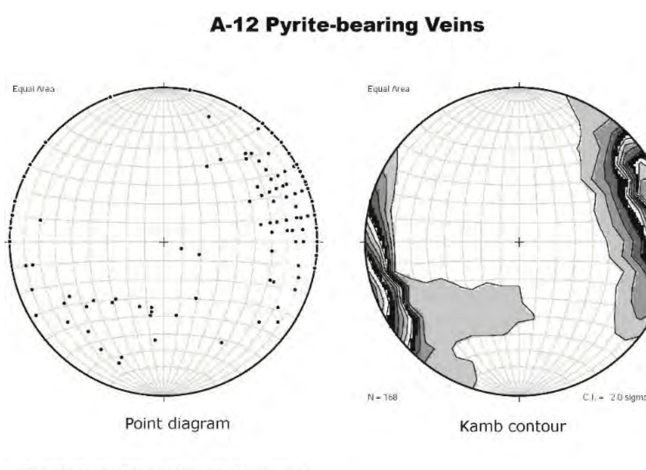


Figure E6- 5. Orientation diagram summarizing attitudes of sulfide veins.

The scenario is one of a "perfect storm" because material from the pyrite veined road-cut was used as fill for the buttress and elevated road bed as well as at 93 other sites. The remediation is discussed in the guidebook.

Another smaller sulfide vein complex (approximately 300 feet wide) was exposed in the Juniata red-beds (shale and sandstone) to the west, on the southwest side of a prominent fault underlying the small valley adjacent to the highway. This fault juxtaposed steeply dipping to overturned Juniata Redbeds (small pinnacle across Rte 322 to the west) from overturned Tuscarora sandstone beds in the I-99 road bed. The mineralized zones as well as individual sulfide veins have a have a general strike of 140°. Both these zones of sulfide mineralization have been sealed with bentonite and a geotextile mesh containing 1B limestone aggregate.

ERPA

Engineered Rock Placement Area (ERPA), located nearby, is not a stop on this field trip, but is discussed in the Guidebook, and briefly mentioned here (Figure E6-6). This is a "green field" site created and permitted in haste to sequestrate the "more easily moveable" toxic material from Skytop. The site has a footprint of 27 acres, and holds approximately 1.3 million tons of toxic waste rock mixed with 1.7 million tons of bag-house lime. This breathable repository produces approximately 300 gallons of waste water a day. Water from the Skytop settling pond is pumped over the ridge to join the effluent from ERPA at the tank, and then discharged through a passive wetland system into Bald Eagle Creek.

Figure E6-6. Engineered Rock Placement Area (ERPA)

Skytop Test Areas

Figure H6-7. Test sites adjacent to Little Cut Face (Geogrid cover to left).

Three test sites (Figure H6-7) located adjacent to the Little Cut Face (also in the vicinity, but not a stop) used for evaluating application methodologies and slurry mixes to neutralize and stabilize the slopes. Caliche is formed in test area 1.

STOP E-7: SEIBERT DUMP SITE

TOXIC WASTE ROCK FROM SULFIDE VEINED ROAD-CUT USED IN FILL, SULFIDE VEINS MEET GEOFABRIC MESH

STOP LEADERS – ARNOLD G. DODEN[1], DAVID (DUFF) GOLD[2] AND HUBERT L. BARNES[3]

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Chemistry **(40.833888°, -77.968454°)**

Disembark for the Siebert waste dump area. Outcrops of the Juniata Formation are found nearby at the west end of the Large Cut Face (Figure E7-1). Walk up the road toward the Siebert waste dump and see Juniata exposures within the road bed. These exhibit REDOX features, zones of pale green reduced rock among reddish brown oxidized rock of the Juniata Formation, indicative of reducing fluids associated with sulfide mineralization (Figure E7-2). Similar features occur along strike to the southwest, exposed in the road banks of the I-99 south-bound lane.

Figure E7-1. View looking east of Skytop and the Seibert Dump site on the north slope. The sulfide veins on the slope have been covered with geotextiles. Material from this pyrite-veined road cut was used as fill for the buttress and elevated road bed. Areas of interest (Seibert dump, Juniata redbeds, slope stabilization) are marked by the yellow "push" pins. The yellow arrow points to the Seibert dump.

The Siebert pile was one of the major unlined waste sites for an estimated 300,000 cubic yards of toxic rock. Efflorescent mineral "blooms" mainly of gypsum and melanterite, plus other unidentified sulfates, occurred in seeps from the Siebert waste dump (refer to photographs and discussion in the Guidebook). The weather sensitive "blooms" near the pond were dubbed "Duff's garden" by the construction workers (Figure E7-3).

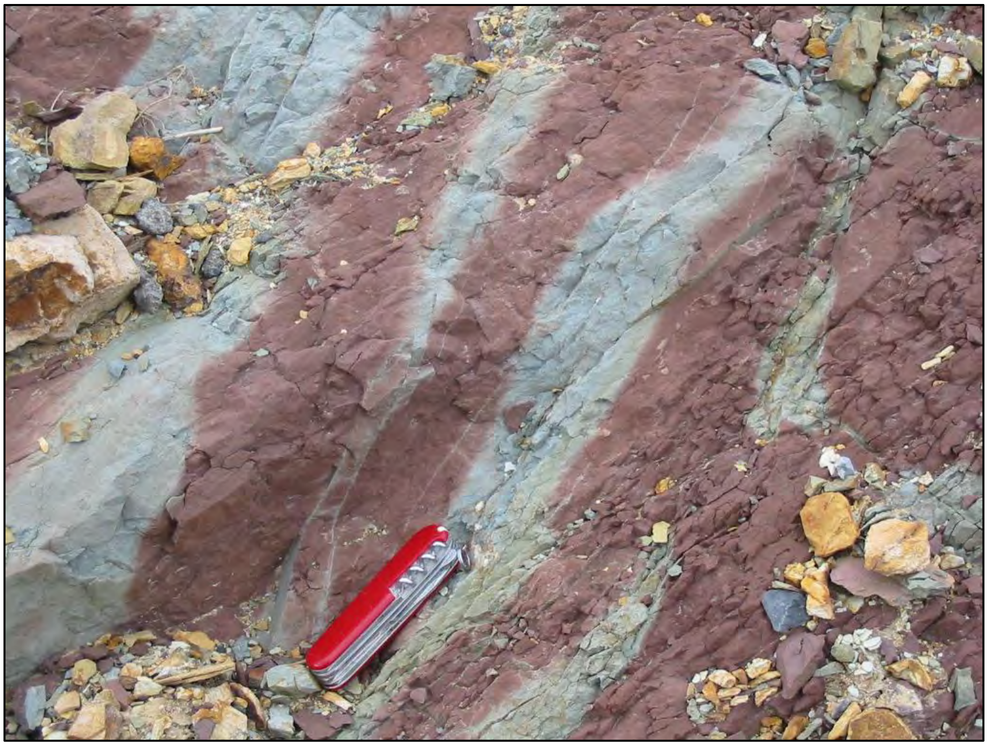

Figure E7-2. Zebra rock. Reduction halos adjacent to veins in Juniata red shale bed.

Figure E7-3. "Duff's garden". Efflorescent mineral seeps from fill at Siebert pond.

ROAD LOG: KARST HYDROGEOLOGY FIELD TRIP

NITTANY VALLEY, CENTRE COUNTY, PA

STOP LEADERS – WILLIAM B. WHITE[1], RICHARD R. PARIZEK[2] AND DAVID A. YOXTHEIMER, P.G.[3]

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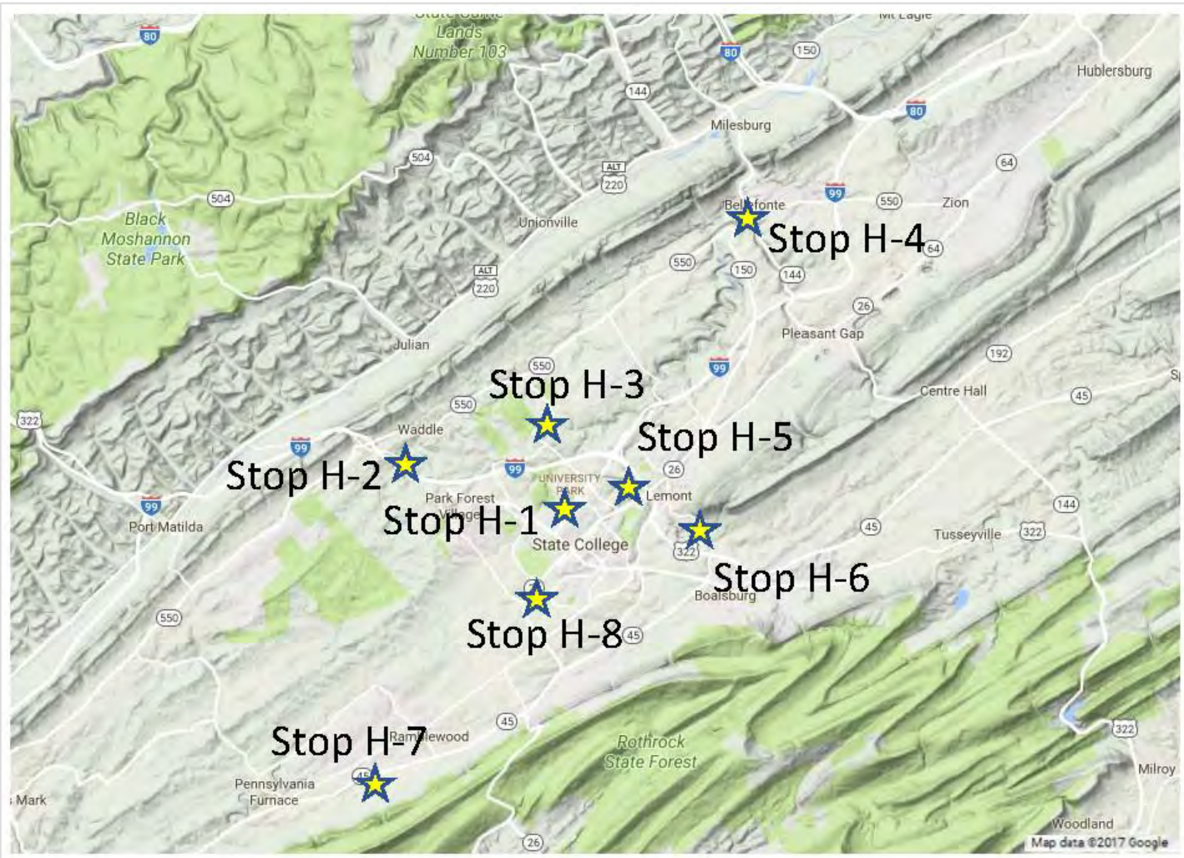
[3]HYDROGEOLOGIST AND EXTENSION ASSOCIATE, MARCELLUS CENTER FOR OUTREACH & RESEARCH (MCOR), THE PENNSYLVANIA STATE UNIVERSITY



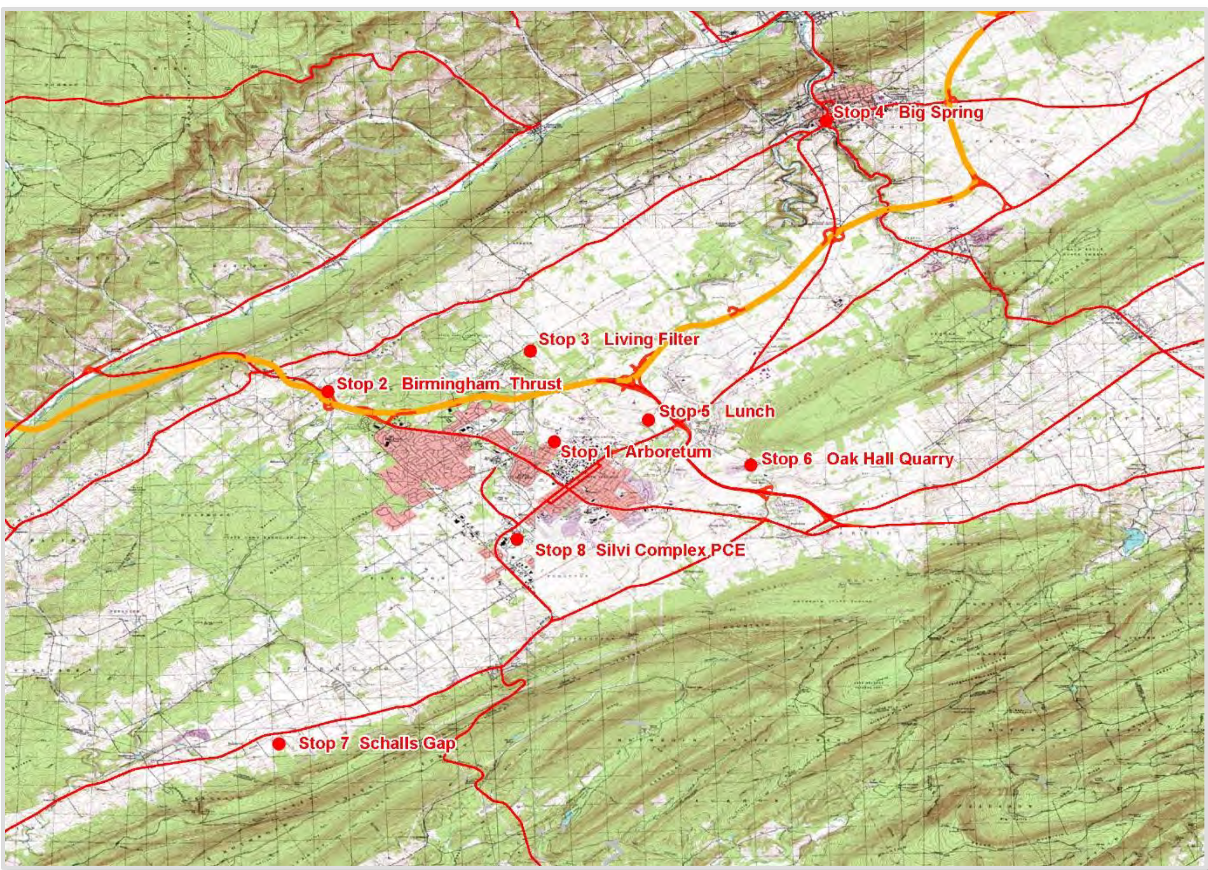
Overview of Day 2 – Karst Hydrogeology Field Trip

Representative features (terrain map, above) will be inspected that shed light on the hydrogeologic setting of Nittany Valley and similar other valleys within the Valley and Ridge, karst processes that account for differences in groundwater occurrence, movement and quality, sink development, together with land uses that have and continue to stress its environment. Examples of challenges and progress achieving sustainability goals will be featured.

An overview will be provided at the Ridge and Valley sculpture in H. O. Smith Botanic Gardens (Arboretum, Stop H-1), followed by examination of a segment of the regional Birmingham thrust fault where it displaced the Warrior Limestone, the oldest rocks exposed in Centre County (Stop H-2). Issues that gave rise to Penn State's long-running

Living Filter project, lessons learned and successes after 34 years of continuous year-round irrigation and 13 years of Research and Development will be discussed (Stop H-3). This will be followed by inspection of Bellefonte's Big Spring, review evidence for its source and protection from surface-water influences (Stop H-4). Lunch will be at the Millbrook Marsh Nature Center where evidence for the marsh's perched condition and sources of nourishment will be reviewed (Stop H-5), followed by an overlook stop at Hansom's Oak Hall Quarry (Stop H-6). Its limited pumping requirement, given its size and 50-foot depth below the water table, stand in contrast with College Township's expected future water supply well, located in Oak Hall Park. This 12-inch diameter well had a blown yield >1,500 gpm during drilling and construction. Pumping impacts on stream base flow, springs, and private wells remain to be documented.

Karst features, located along the flank of Tussey Mountain, will be inspected within the Rock Spring drainage basin (Stop H-7 at Schall's Gap). Methods used to map conduits and track the fate of farm chemicals will be reviewed, followed by an overview of a pollutant plume remediation site in State College (Stop H-8).



Karst Hydrogeology Field Trip stop names and their locations along roadways (red)

HYDROGEOLOGY ROADLOG – DAY 2

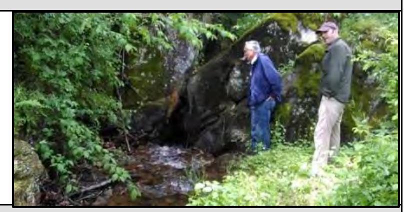
segment	cumulative	DIRECTIONS: KARST HYDROGEOLOGY FIELD TRIP – DAY 2
0.0	0.0	Depart side of Ramada Inn and turn right onto Norma St
0.1	0.1	Turn right onto S Atherton St
0.2	0.3	Turn left on University Dr. *Slab Cabin Run Tributary of Spring Creek drainage basin.*
0.7	1.0	Traffic light. Easterly Parkway. Continue straight. Walnut Springs Park on right.
1.4	2.4	Traffic light. Turn left onto Park Avenue.
0.3	2.7	Traffic light. Turn right onto Bigler Road. *Ramage Marsh L & Lutz Law Bldg R*
0.2	2.9	Turn left into Arboretum parking lot
		**Stop H-1: The Arboretum at Penn State** **40.806088, -77.868487** **Walk to pavilion for orientation**
0.1	3.0	Leave parking lot to left
0.1	3.1	Turn right onto Service Road
0.2	3.3	Turn left onto Big Hollow Road
0.2	3.5	Begin descent into Big Hollow
0.5	4.0	Aloha Lane. *Location of old fire-training site. First water wells drilled in 1930's.*
0.4	4.4	University well 24 on left
0.2	4.6	Intersection with Fox Hollow Road. Turn left. *Floods often due to urban sprawl*
0.6	5.2	Traffic light. Turn left onto Toftrees Avenue.
1.1	6.3	Intersection with Cricklewood Drive. Continue straight.
0.5	6.8	Intersection. Turn left onto Waddle Road.
0.1	6.9	Access ramp to I-99. Turn right onto Interstate. *Former sanitary landfill site.*
1.3	8.2	Take Exit 68 onto Old Route 322 *Gatesburg anticline, deepest part of GW trough*
0.7	8.9	Keep right toward Route 550
0.3	9.2	Turn right onto Curve Hill Road *Buses drop people off and go up the road to turn around*
		Stop H-2: Birmingham Thrust Fault Exposure **40.822256, -77.941483** **Exit bus. Follow trip leader around corner to roadcut. Be careful of traffic.**
0.4	9.6	*Buses return and pick people up*
0.5	10.1	Intersection with Old Route 322. Turn left.
0.8	10.9	Keep right on Business Route 322. ***Outcrop is the Warrior Limestone - oldest carbonate exposed in the area***
0.2	11.1	Continue east on I-99
1.4	12.5	Take Exit 71 to Toftrees/Woodycrest
0.3	12.8	Turn left onto Waddle Road
0.3	13.1	Turn right onto Toftrees Avenue
1.5	14.6	Intersection with Fox Hollow Road. Turn left.
0.5	15.1	Sharp right turn. Fox Hollow Road becomes Fox Hill Road.

0.3	15.4	Turn right onto Standing Stone Lane
0.2	15.6	Gate to Living Filter
0.3	15.9	**STOP H-3. The Living Filter** **40.835246, -77.876231**
0.5	16.4	Woodlot to right. Note piping system. *Monitoring Well P-5 is on your right. It served as the supply well for the Radioastronomy Building before being converted to a monitoring well. It is Parizek's second fracture-trace well and was drilled by cable tool.*
0.7	17.1	Gate. Exit the Living Filter.
0.2	17.3	Intersection with Fox Hill Road. Turn right.
0.3	17.6	*Intersection. Continue straight. Note distinct swell and swale topography developed within Gatesburg Dolomite along the Gatesburg Anticline, important in enhancing recharge. Note bright fall colors near lower flanks of Bald Eagle Mountain. These water-loving plants are developed near perched groundwater, above fragipan horizons in colluvium. Watch for similar occurrences later in the trip along Nittany and Tussey Mountain flanks.*
 1.2	18.5	Intersection. Fillmore road. Continue straight. **Alexander Well Field to left** *Parizek included this as a high-priority well field site in a regional study sponsored by the Centre Regional Planning Commission. More than 60 fracture trace intersection well sites were identified, combined with other favorable attributes that enhanced well potentials. Four test wells were drilled, proved successful, and completed as production wells for the State College Borough Authority. They are the first municipal wells to capture Penn State's reclaimed effluent applied to the Radioastronomy and Game Lands sprayfields, resulting in nearly a 98-inch annual rate of recharge. Some reclaimed effluent also is captured by Penn State Big Hollow water-supply wells.*
0.5	19.0	University Park Airport to right
0.3	19.3	First fracture-trace well located near here
0.8	20.1	T-intersection. Turn left on Rock Road.
1.1	21.2	T-intersection. Turn right onto Route 550 toward Bellefonte. 
1.4	22.6	***Con (Graymont) deep mine*** ***visible at base of Bald Eagle Mountain to left*** *It follows the vertically dipping Valentine Limestone that is nearly 70 feet thick. A block of unmined Valentine separates this mine (now idle) from the abandoned Bell Mine that extends to the northeast toward Bellefonte, below and beyond Spring Creek. The Bell Mine was nearly 960 feet deep, and despite its size, only about 700 gpm were required to control groundwater inflows. Recall, the four wells in the Alexander well field each yield in excess of 1 mgpd. The damming influence of steeply dipping limestones and thin semi-confining beds must be appreciated.*
1.9	24.5	Cross Spring Creek. Traffic light. Turn left onto Willowbank Street in Bellefonte.
0.1	24.6	Cross Logan Branch. *The importance of Bellefonte, the county seat, has to be put into proper context. Five governors who served the Commonwealth were from Bellefonte. Two other citizens of Bellefonte went on to govern other states. You might ask, why, given its remote location?*
0.1	24.7	Traffic light. Turn left onto W High St
200 ft	25.5	Turn left into parking lot
		STOP H-4. The Bellefonte Big Spring **40.908826, -77.780995**
0.1	25.6	Pull out of parking lot and turn right on W High St
0.3	25.9	Traffic light. Turn right on S Water St/Route 150, Benner Pike, toward State College
2.5	28.4	Underpass beneath I-99

		Soon you will enter Rockview Penitentiary property. Gap Run and McBride Gaps are evident along the northwestern flank of Nittany Mountain. Both mountain tributaries nourish swallow holes and conduit systems, to be discussed at STOPS 6 and 7.
3.4	31.8	Traffic light. Y at Nittany Mall. Bear right onto East College Avenue. *The ridge on your right is underlain by the Tea Creek Member of the Bellefonte Formation. Note sinkhole repairs on your left. Recently, a sinkhole developed under the railroad track which has since been repaired. The track is bowed at this location. The shoulder of Route 64 is continuing to fail nearby and awaits attention. The former Rutger-Nease chemical plant site is on your left. It is Centre County's only Super Fund Site, involving organic compounds such as Keypone and Mirex.*
1.0	32.8	Traffic light. Turn right onto Houserville Road. Spring Creek is on the left.
0.7	33.5	Intersection. Turn left onto Puddingtown Road. *You should note the Pleistocene terrace with frost-wedged soils, exposed for our 50th annual field trip (1985). A test well near the Spring Creek bridge, showed the creek to be perched >12 feet.*
0.2	33.7	***Penn State's Houserville Well field*** on right. *Note College Township's Spring Creek Park well on your left. The fracture trace intersection was near second base; hence that's where the well was drilled, much to the distress of team members and their fans who no longer could use the diamond. Disposing of >1000 gpm drilling fluids, without endangering Spring Creek and inducing sinkholes posed challenges.*
0.4	34.1	Cross Slab Cabin Run
0.6	34.7	Left into the parking lot at Millbrook Marsh
		**Stop H-5: Lunch – Millbrook Marsh** **40.813376, -77.838310**
0.1	34.8	Evidence provided of Milbrook Marsh's perched nature, TCE, PCE, and other concerns raised. Leave parking lot and turn left on Puddingtown Road
0.3	35.1	Intersection with East College Avenue. Turn left. Difficult intersection. Cross Thompson Run. Flooding is now a common occurrence due to urban sprawl.
0.3	35.4	Bear right onto Elmwood Street toward Lemont
0.5	35.9	Cross Spring Creek. Former Lemont Water Company water wells are upstream just above Branch Road bridge.
0.1	36.0	Traffic light. Continue straight on Boalsburg Road.
1.0	37.0	***Cross axis of Nittany Mountain Syncline*** *and Reedsville shale confining beds*
0.3	37.3	Pull off to right
		**STOP H-6. Oak Hall Quarry** **40.799010, -77.805194**
0.0	37.3	Continue on Boalsburg Rd.
0.3	37.6	Cross Spring Creek.
0.4	38.0	*Linden Hall Road is on your left, and Oak Hall Park and recreational facility on the hill to your left. This is the site of College Township wells OH-19 and 20. Cedar Run joins Spring Creek just below Linden Hall bridge.*
0.2	38.2	Underpass beneath Route 322 Bypass
0.7	38.9	Traffic light. Intersection with Business Route 322. Continue straight on Route 45. *Note the broad strath to your left, including Boalsburg, controlled by clastic sediments near the axis of Nittany Mountain syncline that served as a local base level of erosion. Similar straths occur approaching Milesburg and other mountain gaps.*

1.8	40.7	Shingletown. Mountain Road leads up gap to original surface water supply for State College. *Excellent hiking trails are available in the gap. The Thomas and Harter well fields are located to your right. The Borough of State College's first intentional fracture-trace intersection well was drilled in the Thomas well field during the 1960's drought where a 60-inch rainfall deficit was being recorded. Parizek recommended and oversaw the drilling and testing of fracture trace wells drilled in the area. Imagine three wells, each being pumped together at rates of 1400 gpm and being discharged in Slab Cabin Run with its flow of 135 gpm at the time.*
1.6	42.3	***Musser Gap.*** *This was the source of water supply, used for cooling and other purposes at Penn State's West Heating Plant.*
1.0	43.3	Intersection of routes 45 and 26. Turn left onto 45/26.
0.4	43.7	Cross Slab Cabin Run
0.9	44.6	*Intersection in Pine Grove Mills. Continue straight on route 45. You will soon enter the Spruce Creek drainage basin. Surface water and groundwater divides do not agree in this portion of Nittany Valley. The Spring Creek surface water basin is 145 $miles^2$, whereas its groundwater basin is more nearly 175 $miles^2$.*
2.0	46.6	***Kepler Sink on left***
2.1	48.7	Gate J of University farms. Turn left onto gravel lane.
0.3	49.0	Turn right toward red barn
0.1	49.1	Park buses

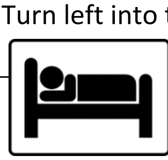
STOP H-7. Sinking stream from Schalls Gap
40.708339, -77.956121



0.0	49.1	Return to highway. You will note that isolated wooded patches and irregular tree lines indicate likely sinkholes.
0.4	49.5	Intersection with route 45. Turn right.
4.1	53.6	Intersection in Pine Grove Mills. Continue straight on routes 45/26 toward State College.
1.4	55.0	Intersection of routes 45 and 26. Keep left on route 26 toward State College.
2.5	57.5	Turn right onto Airport Road
0.4	57.9	Silvi Baseball Complex. Park buses

Stop H-8. Chlorinated Solvent Groundwater Contaminant Plume Remedial Site
40.774993, -77.880937

0.0	57.9	Return to highway
0.3	58.2	Route 26/West College Avenue. Turn right.
0.1	58.3	Traffic light. Turn right onto Blue Course Drive.
1.4	59.7	Traffic light. Turn left onto Whitehall Road.
1.8	61.5	Turn left to stay on W Whitehall Rd
0.8	62.3	Turn right onto S Atherton St
0.1	62.4	Turn right onto Norma
0.1	62.5	Turn left into the Ramada Inn



STOP H-1: THE ARBORETUM AT PENN STATE

STOP LEADER – RICHARD PARIZEK[1]

[1]EMERITUS PROFESSOR, GEOLOGY AND GEO-ENVIRONMENTAL ENGINEERING, DEPARTMENT OF GEOSCIENCES, THE PENNSYLVANIA STATE UNIVERSITY, 340 DEIKE BLDG, UNIVERSITY PARK, PA 16802

Ridge & Valley Sculpture (40.806088°, -77.868487°)

Welcome to the H.O. Smith Botanic Gardens and The Pennsylvania State University, University Park Campus. We are at the Ridge and Valley Sculpture (Figure H1-1, Station 17) for the 82nd Annual Conference of Pennsylvania Geologists.

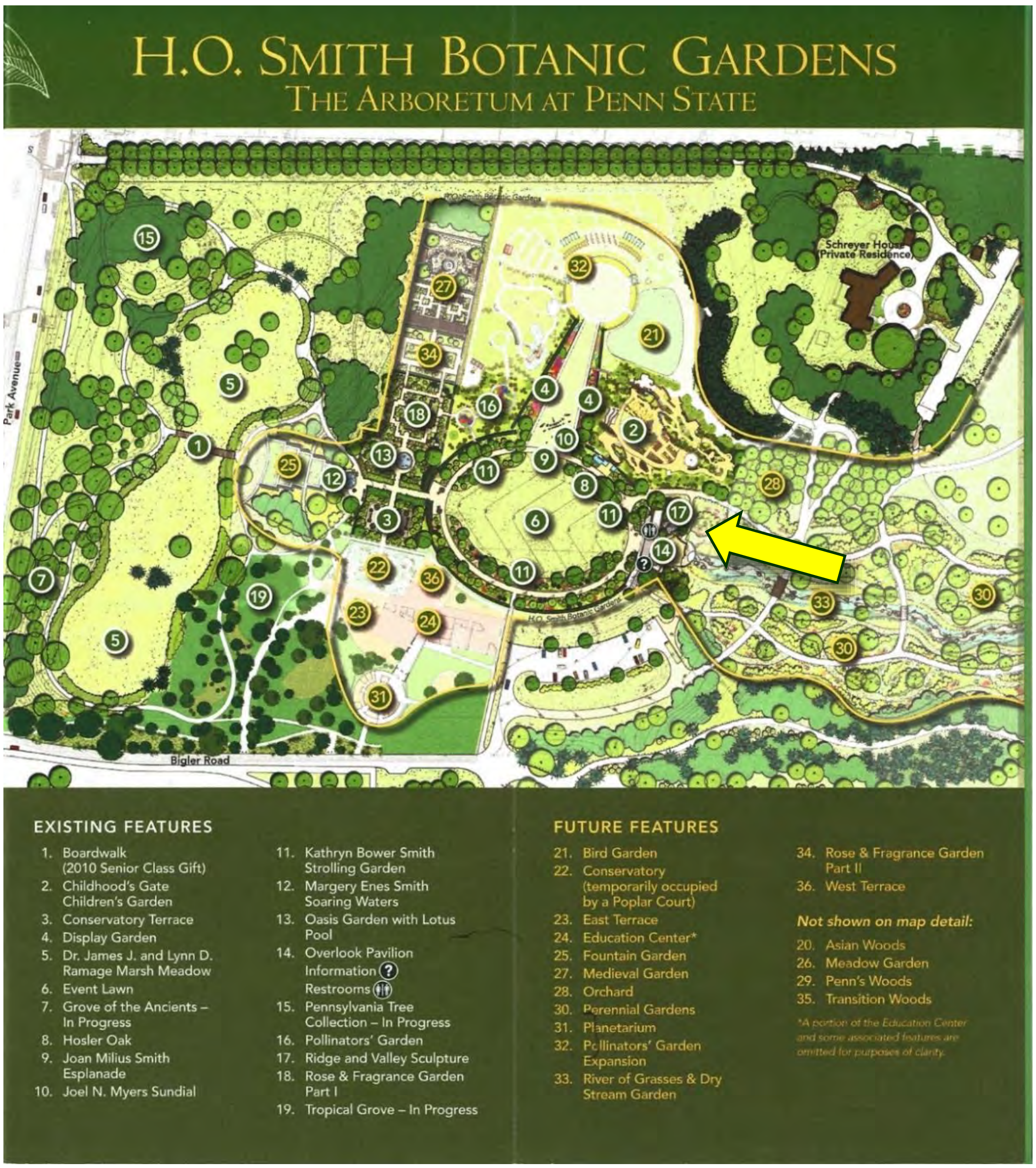


Figure H1-1. Location Map of features at the H.O. Smith Botanic Gardens. The yellow arrow points to the Ridge and Valley Sculpture at Station 17.

The Ridge and Valley Sculpture provides a useful orientation for today's trip. Shown in Figure H1-2, is a three-dimensional "map" that depicts the Spring Creek watershed surrounding Penn State University and community, depicting major features and their names.

Our view is to the west toward Bald Eagle Mountain near the center of Nittany Valley, the westernmost carbonate valley in the Ridge and Valley Province.

Figure H1-2. Ridge and Valley sculpture showing Spring Creek watershed (above, and close-up, photo top right). Local streams and waterways are depicted with runnels carved 1/4 inch deep into the stone. Nittany Valley is depicted toward the top in the bottom photo. Background in top left photo is the view toward Bald Eagle Mountain.
(Photos from www.arboretum.psu.edu accessed 09/09/2017)

Geologic Setting

Will White and I were co-leaders of the 50th Annual trip in Nittany Valley (October 4-6, 1985) and together with Dave Yoxtheimer and others, are continuing to refine the karst hydrogeologic conceptual model of Nittany Valley with application elsewhere in the Ridge and Valley Province. It remains a work in progress. Ignoring fault repeated displacements, the Spring Creek watershed is underlain by nearly 8,000 feet of Late Cambrian to Ordovician folded and faulted limestones and dolostones (refer to Day 1, Stop 1, Figures 1-1 & 1-2). Few faults were recognized during early mapping of the Bellefonte 15-minute quad, (Butts and Moore, 1936).

The valley is bounded by Bald Eagle Mountain on the northwest, Tussey Mountain on the southeast and bifurcated by Nittany Mountain splitting off Penns Valley to the northeast. Clastic rocks underlie the ridges, the highest or outer ridge supported by the Tuscarora Formation (Silurian) and the inner ridge by the Bald Eagle Sandstone. Less resistant Juniata red siltstones and shales underlie valleys between the inner and outer ridges. The Bald Eagle is breached by water gaps more often than the Tuscarora except where trunk stream exit or cross-cut ridges and valleys. Valley facing mountain slopes are underlain by the Reedsville and Antes shales grading into thin bedded shaley limestone before transitioning into thicker carbonate sequences. Thin to discontinuous sandstone lenses appear in the Dale Summit near the top of Bellefonte Dolomite and again as cyclic sandy dolomites within the Gatesburg Formation especially the Upper and Lower Sandy Members.

Residual soils blanket the carbonate strata accounting for productive farmland with exceptions of sandy droughty soils derived from the Gatesburg Dolomite. Outcrops are generally small and scattered adding difficulty to deciphering more detail structures where often numerous new thrust and tear faults have been recognized important to the hydrogeologic framework.

The thickest residual soils overlie the Gatesburg often exceeding 100 feet or more in thickness over broad areas. Mountain flanks and water gaps contain colluvium and colluvial-alluvial fans that extend out over limestones that flank these mountains. These periglacial deposits contain boulder stripes, rings, boulder fields, evidence of glacial climates. Colluvium has well developed fragipan horizons that perch shallow groundwater. Most natural sink and swallow holes and explorable caves are concentrate just below mountain flanks.

Hydrogeologic Issues in Karst

Plans for the H.O. Smith Botanic Garden called for an irrigation supply well near the Pavilion, remote from zones of fracture concentration revealed by fracture traces (Figure H1-3). Bid documents did not allow for longer supply lines.

Test wells were drilled at TH-3 and 5 (blue dots, Figure H1-3). Two flow systems were encountered: one in the Upper Stonehenge Limestone and a deeper one in the Mines Member of the Gatesburg. Water depths were generally in the range of 70 to 90 feet for the former and 240 feet for the latter. Abrupt increases in blown yields, loss in cuttings and drill fluids were encountered illustrating the importance of seemingly minor confining beds and perching zones. Wells drilled and/or cased to different depths could produce misleading interpretation of gradients and flow direction.

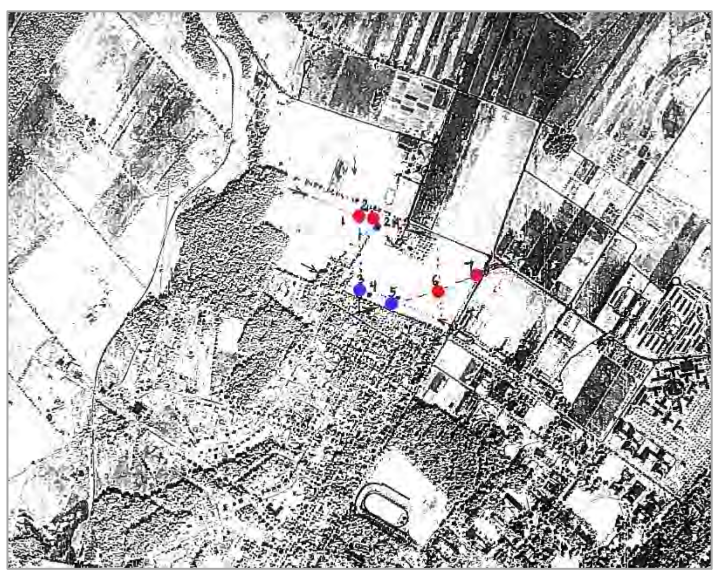


Figure H1- 3. Test wells for irrigation supply to Botanic Garden Pavilion

Figure H1-4 shows a weathered narrow zone of fracture concentration that was uncovered unexpectedly during foundation excavation for the Katz Law Building. Gentle dips toward campus are evident in the Stonehenge Limestone. This is an idle drill site for groundwater and monitoring well development that underlies the Botanic Garden.

Figure H1-4. Zone of fracture concentration with gently dipping Stonehenge Limestone, Katz Law Building.

The Ramage Marsh Meadow occupies a waterway depression enhanced by Bigler Road fill. It captures stormwater from near 2/3rds of the Garden and a portion of College Heights totaling 68 acres. One sinkhole was evident in this depression prior to development of the Garden. Five have formed and been repaired since its development caused by ponding of stormwater and piping erosion.

Sink development can be induced by various processes including void development due to undermining overburden during drilling (Figure H1-5). Such a sink developed about 25-feet from TH-5 that could have destroyed the drill rig threatening the drill crew.

Penn State has an active program to capture and retain stormwater derived from its property. Storm runoff is not to exceed storm run on. This harvesting goal is being met to enhance groundwater recharge using a variety of aggressive procedures.

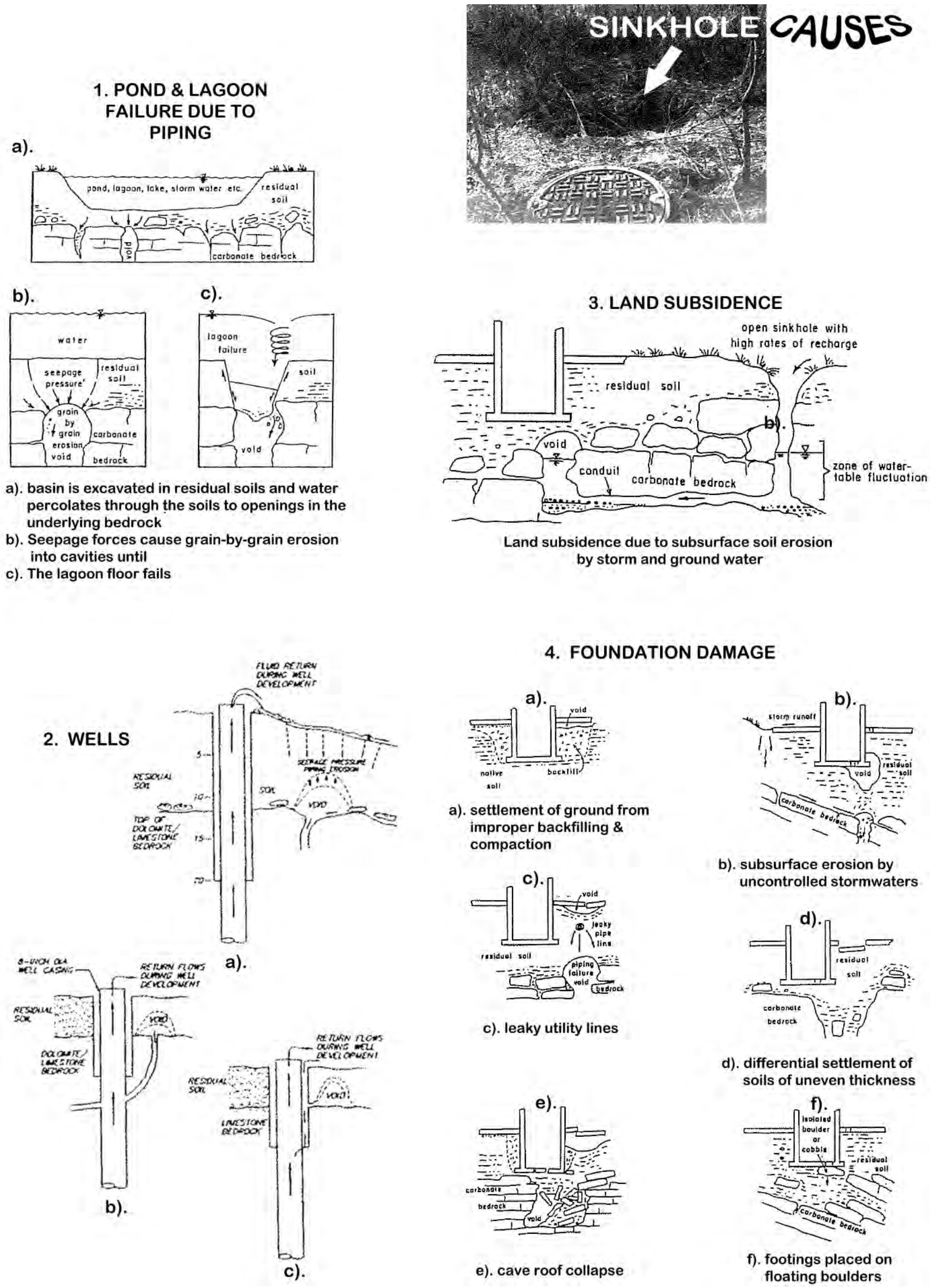


Figure H1-5. Various causes for loss ground within Nittany Valley carbonates. (after Parizek, 1971)

Spring Creek's hydrogeologic-conceptual model was captured by James McClure's iconic graphic (Figure H1-6) some regard as the ClearWater Conservancy's logo or trademark. Jim was a founding member of the Conservancy and supported by like-minded individuals, he helped organize my 1981 stormwater field trip attended by a bus load of committed people. He captured my description of hydrogeologic setting with his unique imagination and one-of-a-kind graphic style. I will always treasure our mutually enriching years of association. Jim, your memory is assured with each display of this image!

Rather than a clastic mountain barrier, the "actual tub" is confined by a transient hydraulic barrier within carbonate aquifers that extend far to the southwest. The divides of the surface water and groundwater basins differ: 175 miles^2 for groundwater and 145 miles^2 for surface water. Groundwater sub-basins exist within the Spring Creek watershed controlled by geologic features but as McClure illustrates, water will comingle over time as pumping and urbanization increases. This iconic diagram has done more to raise public awareness of water-resource issues than individual lectures, field trips and publications. However, through persistence, years of efforts by many committed individuals, the Centre Region is served by a highly informed, sophisticated public. The region's future is and will continue to be in good hands.

Figure H1-6. We are all in the same bathtub. (James McClure, 1981).

Reference

Parizek, R.R., White, W.B., and Langmuir, D., 1971, Hydrogeology and geochemistry of folded and faulted rocks of the central Appalachian type and related land use problems: The Pennsylvania State University College of Earth and Mineral Sciences Circular 82, 210 p.

STOP H-2: BIRMINGHAM THRUST FAULT EXPOSURE

OLD ROUTE 322 & CURVE HILL RD NORTH OF STATE COLLEGE, PA

DAVID A. YOXTHEIMER, P.G.[3]

[3]HYDROGEOLOGIST AND EXTENSION ASSOCIATE, MARCELLUS CENTER FOR OUTREACH & RESEARCH (MCOR), THE PENNSYLVANIA STATE UNIVERSITY

Description **(40.822256°, -77.941483°)**

This stop shows an exposure of a splay of the Birmingham Thrust fault along Route 322 just north of State College within Nittany Valley and the Spring Creek watershed. Nittany Valley is underlain by 6,000 to 8,000 ft of interbedded limestone, dolomite, and sandstone of Cambrian, Ordovician, Silurian, and Devonian age. The strata are folded into anticlines and synclines, and numerous normal, thrust, and strike-slip faults have offset the rocks in several places as shown in Figures H2-1 and H2-2.

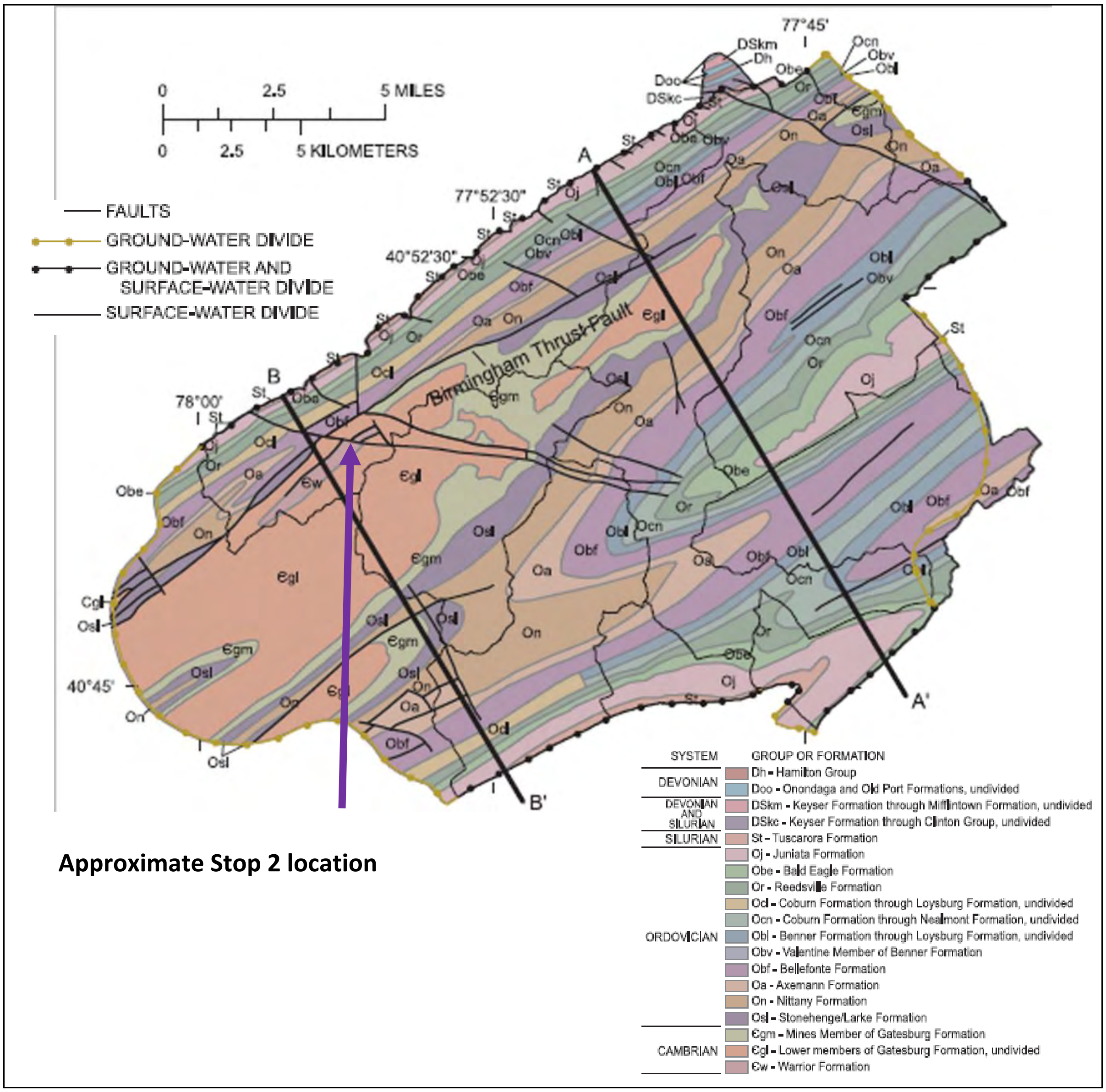


Figure H2-1. Geologic map of the Spring Creek watershed showing the Birmingham Thrust Fault (Fulton et al, 2005).

Geologic sections across the Spring Creek watershed show lithologic control on the topography of the basin. The resistant quartzite of the Tuscarora Formation and the sandstone of the Bald Eagle Formation form the double ridges of Bald Eagle Mountain and the less-resistant Juniata Formation underlies the small valleys between the double ridges. The Nittany and Penns Valleys formed on anticlines underlain by less resistant carbonate rocks of Cambrian and Ordovician age.

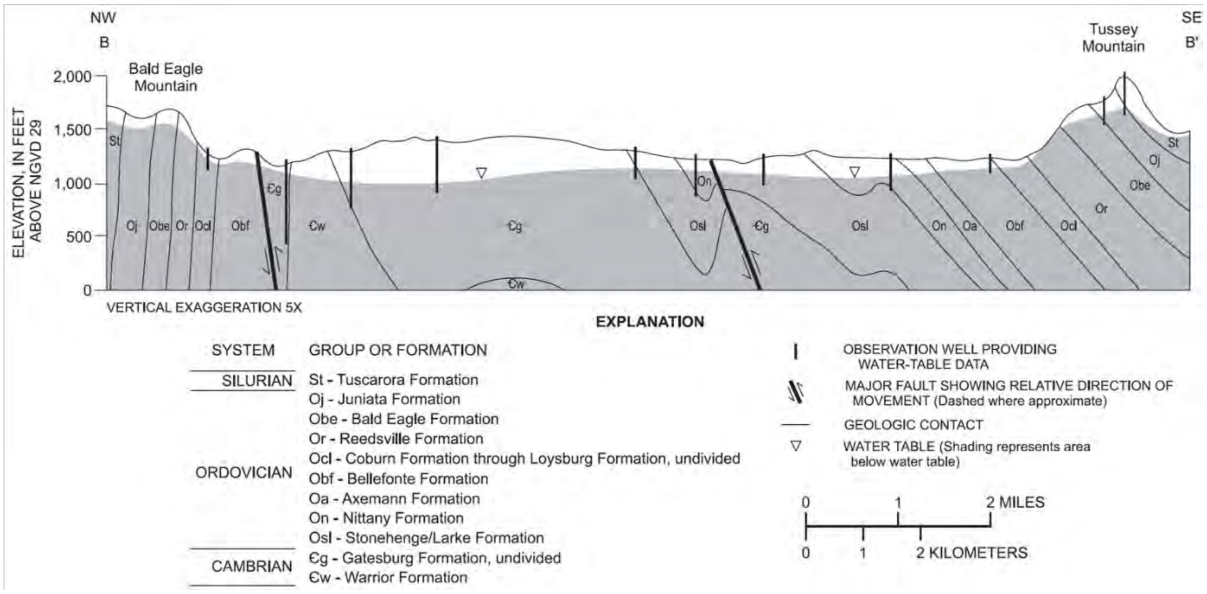


Figure H2-2. Geologic section and generalized water table through line B-B', Spring Creek Basin and adjacent area as shown on Figure H2-1.

The Birmingham Thrust Fault is the major fault extending through much of Nittany Valley. As shown in Figure H2-3, the Cambrian-age Warrior Limestone (hanging wall) has been thrust upward toward the northwest and is juxtaposed with the Cambrian Gatesburg Formation (foot wall).

Figure H2-3.

Picture of a splay of the Birmingham thrust fault along Route 322 just north of State College, PA

(looking northeast)

The Warrior Formation consists of blue, impure limestone and dolomite with thin sandy partings while the Gatesburg Formation consists of dolomite and interbedded orthoquartzite and sandy dolomite (Fulton et al, 2005). A geologic map shows the fault's southwest/northeast path with a southeasterly dip through the Spring Creek watershed until its termination near Bellefonte (Fulton, 2005). Note the location of the exposure on the map and the presence of northwest/southeast oriented tear faults near the stop.

The Birmingham Thrust fault acts as transmissive feature, which regionally directs groundwater flow through the Spring Creek watershed. As shown in Figure H2-4, the fault extends beyond the Spring Creek basin and into the adjacent Spruce Creek basin. The fault combined with northeast plunging bedrock redirects groundwater from the Spruce Creek basin into the Spring Creek basin, thus extending the groundwater drainage basin approximately 29 miles beyond the surface water drainage, a phenomenon known as groundwater piracy.

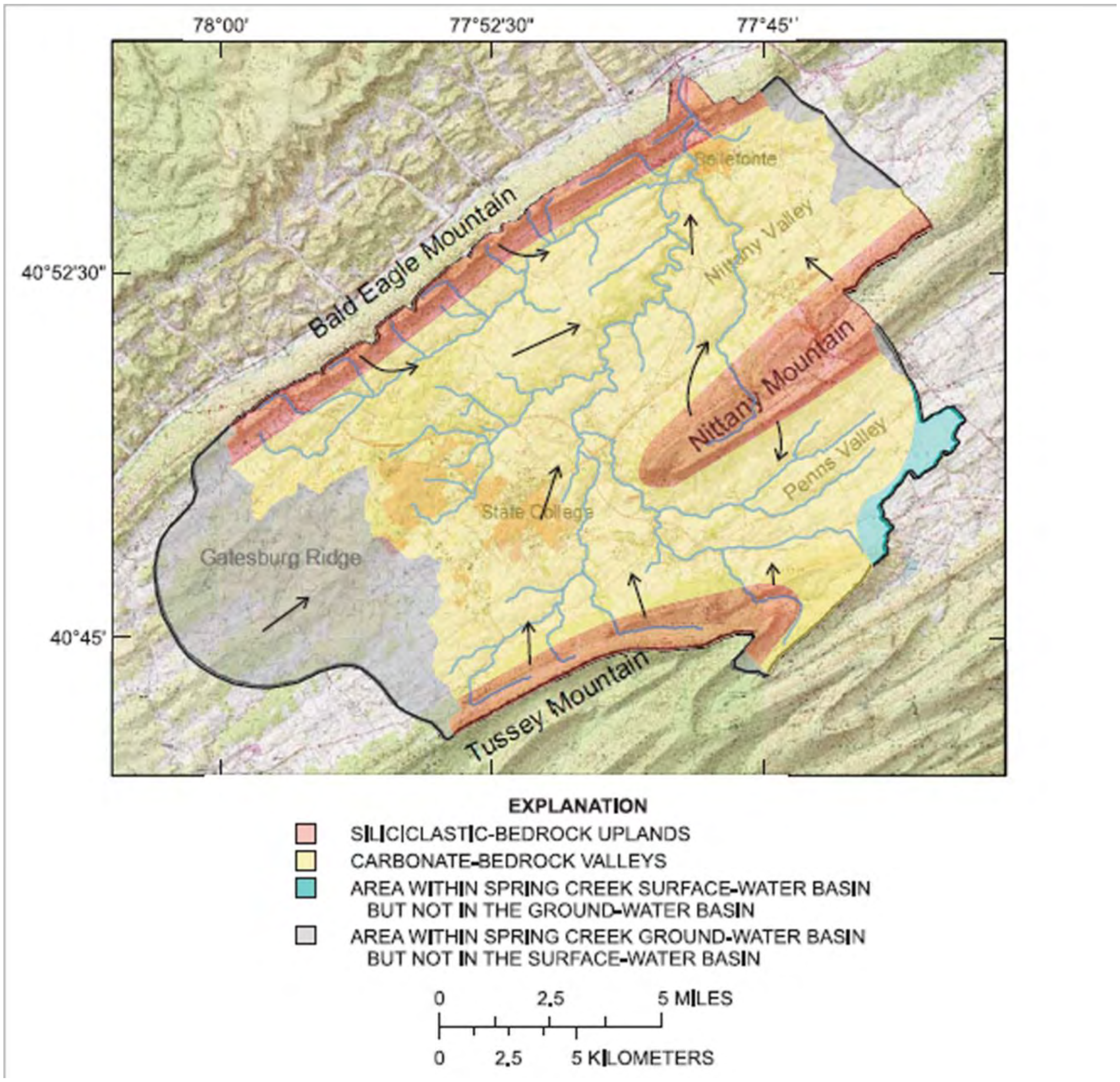
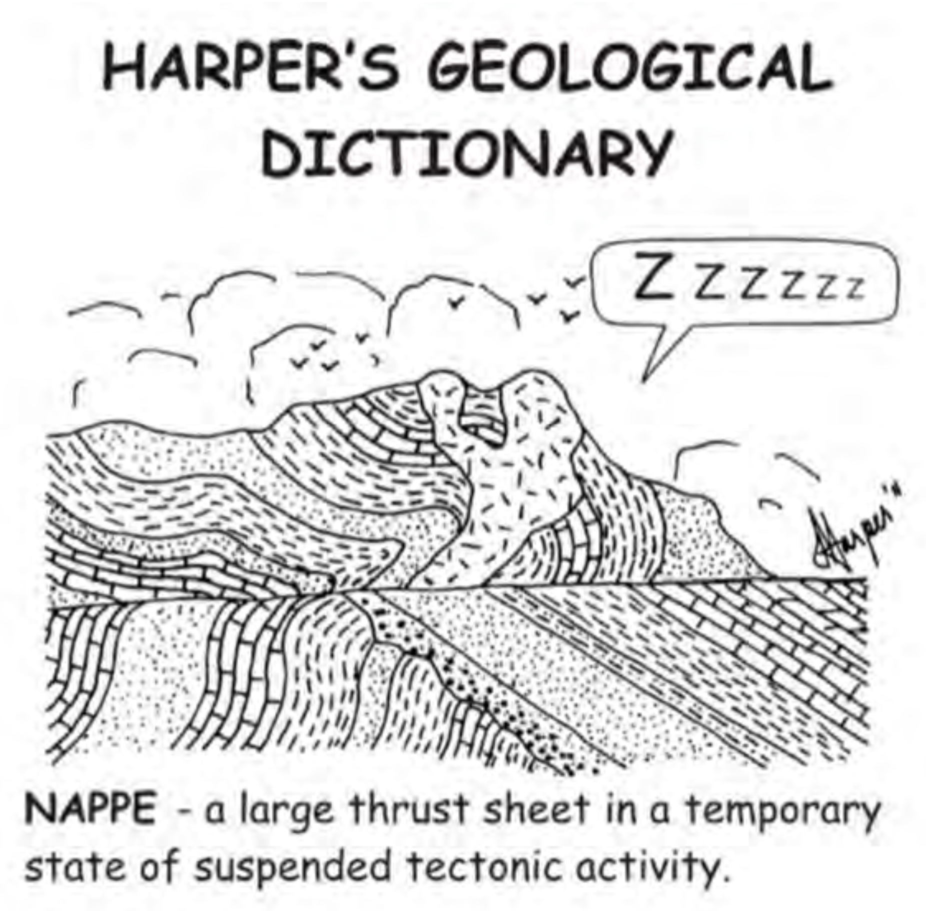


Figure H2-4. Map of the Spring Creek watershed showing the approximate location of the Birmingham thrust fault (Fulton et al, 2005).

References

Fulton, J.W., Koerkle, E.H., McAuley, S.D., Hoffman, S.A., and Zarr, L.F., 2005, Hydrogeologic setting and conceptual hydrologic model of the Spring Creek Basin, Centre County, Pennsylvania, June 2005: U.S. Geological Survey Scientific Investigations Report 2005-5091, 83 p.



STOP H-3: PENN STATE'S LIVING FILTER SYSTEM – 54 YEARS & CONTINUING

STOP LEADER – RICHARD R. PARIZEK[1]

[1]EMERITUS PROFESSOR, GEOLOGY & GEO-ENVIRONMENTAL ENGINEERING, DEPARTMENT OF GEOSCIENCES, THE PENNSYLVANIA STATE UNIVERSITY, 340 DEIKE BLDG, UNIVERSITY PARK, PA 16802

(40.835246°, -77.876231°)

In the late 1950s, a Penn State University researcher dumped cyanide in a lab sink, resulting in an extensive fish kill in Thompson Run, extending into Slab Cabin Run and Spring Creek, all cold-water fisheries. Later, smaller fish losses occurred from time to time that were shown to be related to diurnal depletion of O_2 (Metcaff-Eddie). The student population was about 16,500, when I arrived (1961). It was growing at a 1,000 to 1,500 annual rate, resulting in an organic and nutrient overload at Penn State's sewage treatment plant. The hybrid plant had dural trickling filter and activated sludge treatment processes not adequate to remove nutrient loadings. Phosphorous was a builder in the formulation of detergents at a time when soap suds billowed across Route 26 from below the Duck Pond's waterfall downstream of the Penn State sewage treatment plant.

President E. Walker and Vice President E. F. Osborn issued an appeal to the Penn State community for suggestions on how best to address the problem urged by a cease-and desist order issued by the Water Quality Board. Metcaff-Eddie recommended construction of a bypass line extending to N. Bald Eagle Creek at Milesburg. This would have protected Spring Creek, two important Commonwealth fish hatcheries and more. It would have laid ground work for a truly regional sewage system. Other suggestions included: injecting effluent into the Gatesburg Dolomite about 2500 feet below the treatment plant, disposal within Scotia ore pits to sorb nitrate and phosphorous, banning detergents, freezing the student enrollment at 25,000, etc. Land application was suggested, given the nutrients involved and experiences at a New Jersey food-processing plant where process waters were applied to the land.

An inter-disciplinary committee was formed in late fall 1961 to investigate options. I am its only living or active member of this original committee (1961-1976). Nutrients in secondary effluent were not unlike fertilizers applied to crops (Table 3-1). Routinely, liquid sludge was being applied to playfields, grass lots, and cropland during this period. The wastewater renovation and conservation cycle concept was developed (Figure H3-1), and the committee was given three years to demonstrate this treatment option with the understanding that it would be implemented, if successful.

Two sites were considered for characterization: Game Lands 176 and the Radioastronomy Site. Both were expected to contain more than 20 feet of well-drained residual soil, somewhat remote from wells and springs and a deep water table.

Test boring and geophysical surveys were conducted to establish soil thickness, texture, and mineralogy. Core borings were drilled to establish bedrock lithology, structure, and to define the water table. Geological and soil mapping was undertaken, including a regional well and spring inventory, to provide the first ever water table maps of the area. A far more complex geological setting began to emerge later to include the entire Spring Creek drainage basis, as mapping projects were undertaken by Parizek's graduate students. Monthly baseline groundwater monitoring was undertaken (including more than 50 wells and springs) a full year in advance of application of the first effluent in April 1963. Faculty and students moved portable irrigation lines from plot to plot that first growing season, given limited funds and equipment.

Table 3-1. Composite Samples of Secondary Effluent

COMPOSITION OF SEWAGE EFFLUENT	
SUBSTANCE	**CONCENTRATION (mg/l)**
Turbidity (Jackson Unit)	12.0
Residue	
Total	360.0
Fixed	220.0
Suspended Residue	
Total	40.0
Fixed	0.0
Biochemical Oxygen Demand (BOD)	7.2
Ph	7.2
Alkalinity	113.0
Chloride	36.0
Ammonia as N	0.3
Nitrite as N	0.2
Nitrate as N	2.2
Apparent ABS	2.4
Orthophosphate as P	7.7
Potassium as K	14.1
Calcium as Ca	32.6
Magnesium as Mg	18.7
Sodium as Na	47.0

Composition determined by the Pennsylvania Department of Health for July 28-30, 1964, except for values of K, Ca, Mg and Na, which are based on analyses made at The Pennsylvania State University of 23 weekly samples collected during June to December 1963.

Monitoring efforts included precipitation, interception by trees, soil moisture movement and quality using neutron logging, pan, trench and later, pressure vacuum lysimeters, wells screened in perched groundwater lenses, local and regional groundwater accessible in wells and springs. Crop and forest responses were measured together with wildlife species, their abundance and in some cases their health.

The first winter irrigation experiments in 1964/65 were at the rates of 4- and 6-inches per week, which proved to be excessive. These experiments were conducted in the Game Lands more remote from wells and springs and containing excessively thick residual soils and deep water table (up to 300 feet).

Later, a 2-inch per week effluent irrigation rate was adopted, having experimented with 1-, 2-, 4-, and 6-inch rates. Only 20 percent of Penn State's secondary effluent was applied during this R&D period, which was extended until 1976 to allow policies and procedures to be developed an adopted by PA DER, later DEP, to regulate land application systems. By 1983, 100 percent (up to 4 mgpd) of Penn State's effluent was applied to areas expanded at the original research sites, given the success of R&D efforts. Sewage from the Borough of State College was included in this treatment process. Now, all Borough sewage is treated by the University Area Joint Authority plant at Houserville.

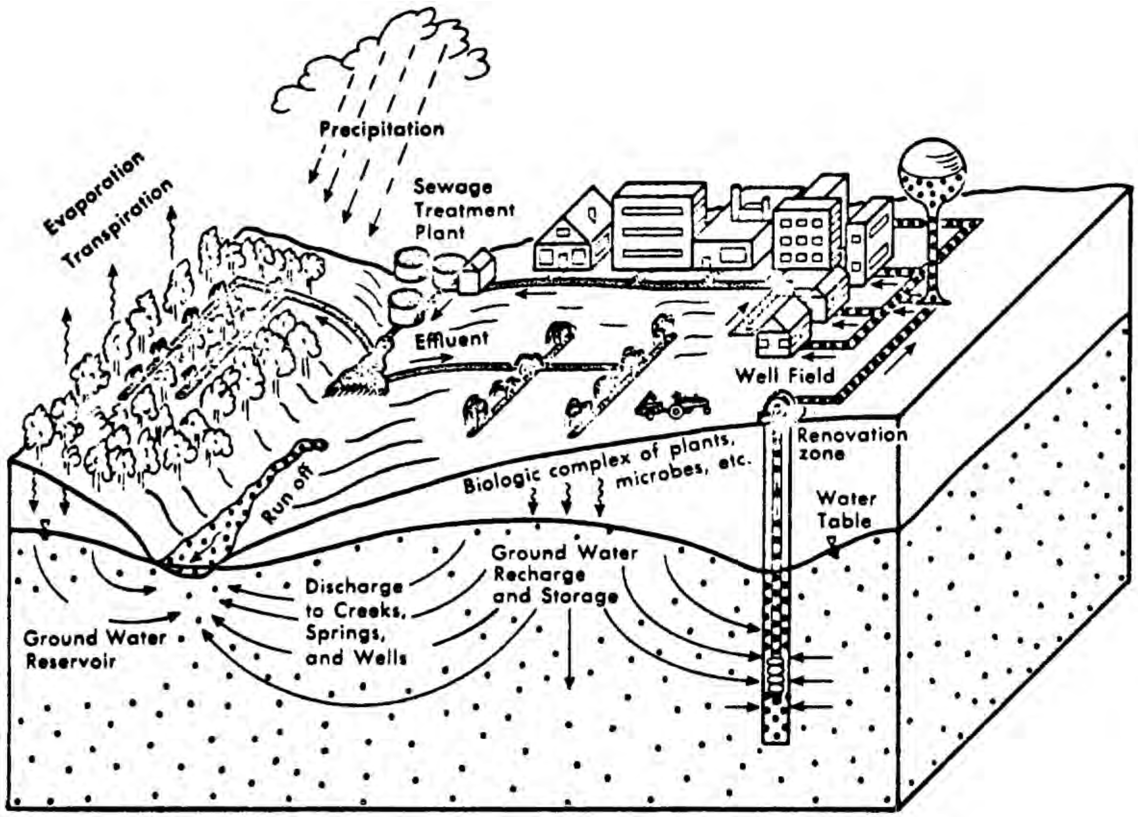


Figure H3-1. Penn State's wastewater renovation and conservation cycle concept (Parizek et al., 1967, 1971).

Figures H3-2 and H3-3, however, showed that the nitrogen loadings were exceeding uptake rates, resulting in increases in nitrate concentrations in on-site monitoring wells. Routine application of effluent was not adequate without watchful updates and modification of the nutrient management practices.

An oversight committee was reconstituted to advise the Office of Physical Plant in 1990, as the original committee had been disbanded, following successful R&D efforts. Their efforts have led to the lowering of nitrate in on-site monitoring wells so as not to exceed 9 mg/l during three consecutive sampling periods. Fortunately, PA DEP allowed Penn State to operate the sprayfields in good faith with expectation that over time, nitrate concentrations would decline as pore waters enriched in nitrate were slowly flushed from thick residual soils and unsaturated bedrock. Inspection of Figures H3-2 and H3-3 shows that this has been accomplished.

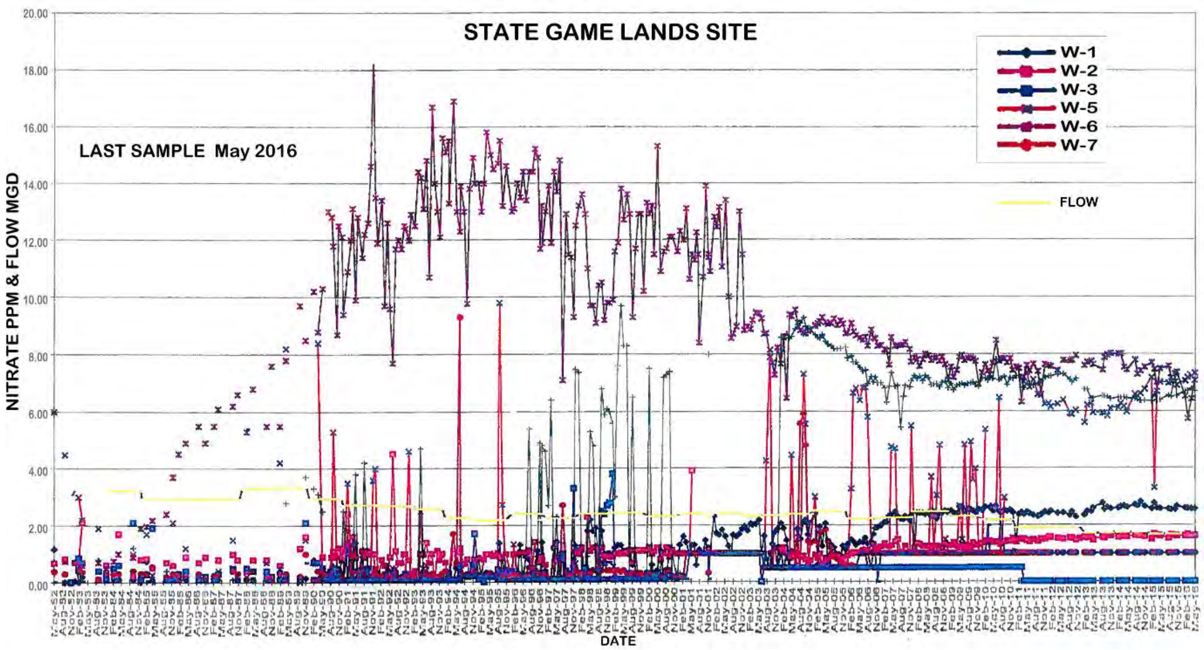


Figure H3-2. Nitrate concentrations within on-site Game Lands monitoring wells – May 1982 through May 2016 (Waste Water Management Committee, 2017).

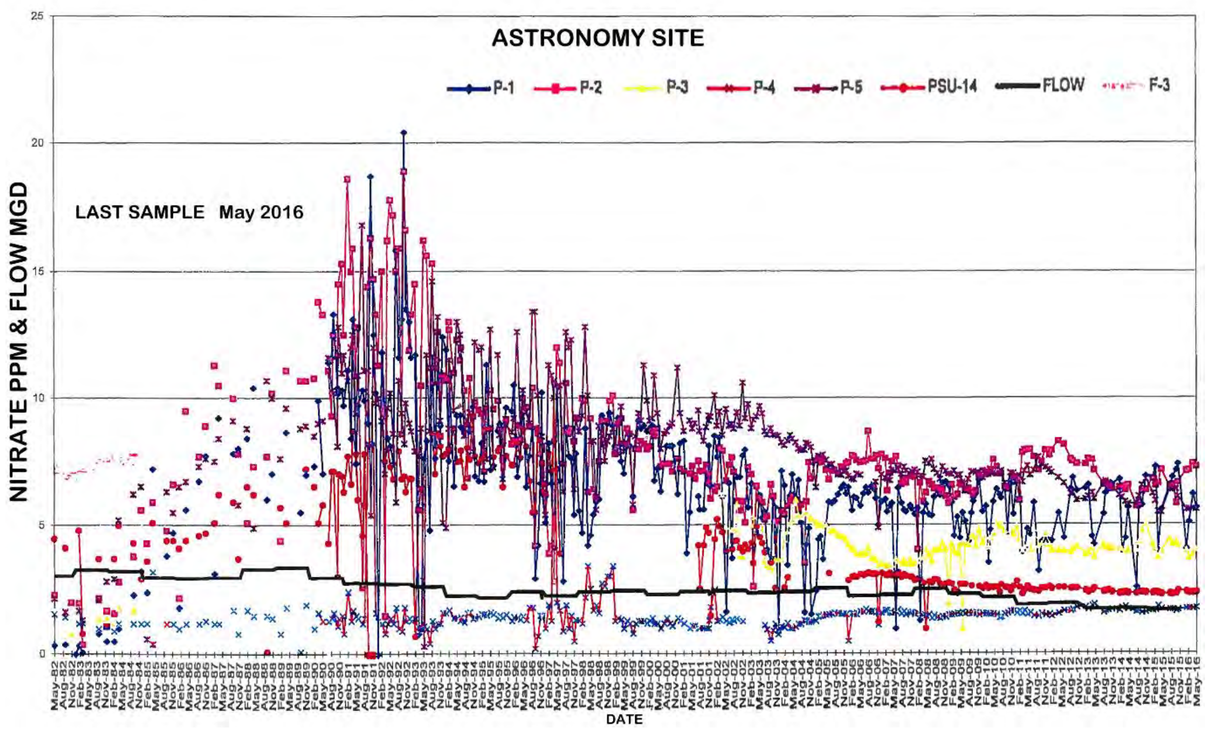


Figure H3-3. Nitrate concentrations within on-site Radioastronomy monitoring wells – May 1982 through May 2016 (Waste Water Management Committee, 2017)

A numerical groundwater flow and transport model was developed for the fracture-flow dominated carbonate aquifers in the event that interceptor wells might be required to control growing Nitrate plumes. Emergent issues include efforts to restore and maintain cropland infiltration rates, selective planting of water-tolerant trees suitable for game propagation and biomass production, control of herbaceous vegetation and deer browse allowing seedling growth within clear cuts, quantification of nutrient removal during overland flow and within natural and enhanced wetlands, fate and transport of health care products and pharmaceuticals.

Penn State researchers have demonstrated that it is possible to achieve a high degree of additional treatment of secondary effluent using year-round irrigation without relying on 120 days of storage during the non-growing season, as required by PADEP. However, detention depressions must be present to prevent excessive overland flow and trespass. Karst terrains provide detention storage but are disqualified if depressions are regarded as "sinkholes". We have induced sinkholes at our sprayfields and have a management plan for their early detection and repair using inverse filter designs. Closed depressions underlain by 10's of feet of residual soil by contrast take millions of years to develop and should not be regarded as sinkholes when considering land application and other sensitive projects.

The Waste Water Management Committee meets monthly and continues to address project management concerns, conducts original research, supervises student research projects and is engaged in outreach. How much longer can we continue to add up to 104 inches of effluent annually without adversely altering the chemical-physical properties of the soil renovation medium? What is the fate of emergent chemicals within the treatment system including treatment plant processes, overland flow, wetlands, vadose zone, and underlying water table? How can we maintain favorable infiltration rates? How to maintain productive forests and sustain wildlife? Can we extract waste heat from effluent without disrupting winter operations? What consequences are to be expected by adding water treatment plant salts to the effluent stream? What more can be done to remove metals that will allow beneficial reuse of biosolids and more?

Table 3-2 shows that up to 98 inches of recharge is being achieved annually under sprayfield footprints. This is a significant volume of "new water" being added to Penn State's sustainability ledger without concerns for thermal pollution as for streams that receive effluent at other sewage treatment sites. Reclaimed effluent is a valuable "new source of water" that will be needed to meet water resource sustainability goals within the Spring Creek watershed.

The Living Filter Project has much to celebrate. Dozens of undergraduate and graduate students have gained hands on experiences in the field and laboratory that let to receipt of advanced degrees and gainful employment. Thousands of visitors have toured the facilities starting in 1963. EPA requires that recycling of effluent be considered as an option when planning new treatment facilities.

The fracture trace-method of groundwater prospecting was first tested during site hydrogeologic characterization investigations and the selection of monitoring well sites for the Living Filter Project followed concurrently by completion of the first high capacity public water supply wells using the technique. The cost of test drilling when exploring for groundwater has been greatly reduced. More test wells are successful and fewer are needed. Pumping lift costs are less given reduced pumping lift costs. Nearly a billion gallons of reclaimed water is added to recharge as a result of the project. Vacuum lysimeters were first modified to allow extraction of vadoze water from significant depth. The list of accomplishments goes on.

Table 3-2. Annual Recharge Rates at Living Filter Sites Given Precipitation and Evapotranspiration

CLIMATOLOGICAL SUMMARY OF STATE COLLEGE, PENNSYLVANIA
30 YEARS RECORD 1982 TO 1989

	PRECIP. inches	MEAN TEMP °F	PRECIP. inches	MEAN TEMP °F	CALC. PE inches	RECHARGE inches
January	2.83	28.2	2.95	26.4	0.10	9.85
February	2.59	29.3	3.45	28.3	0.01	10.44
March	3.40	36.7	3.84	36.0	0.34	10.50
April	3.47	48.3	2.85	47.4	1.56	8.28
May	4.07	59.6	4.22	58.6	3.34	7.88
June	4.04	67.8	4.45	66.6	4.60	6.85
July	3.79	71.9	3.49	71.8	5.51	4.98
August	3.55	70.0	3.37	69.4	4.76	5.61
September	2.88	63.1	2.50	61.6	3018	6.32
October	2.89	52.5	2.29	50.9	1.73	7.57
November	2.73	40.9	4.05	40.6	0.59	10.47
December	2.66	30.2	2.77	31.4	0.13	9.64
Year	**38.8**	**49.9**	**40.20**	**49.1**	**25.90**	**98.40**

Total Monthly Precipitation in Inches for State College, Pennsylvania from 1982 to 1989.
Climatological summary for the period 1982 to 1989 compared with the 30 year record.
98.4 inches temperate rain forest
10 inches average recharge rate for this area

(from Duffy, 1991)

At present, Penn State is the only Commonwealth year-round land application system using sprinkler irrigation without storage. Yes, we irrigate in the dead of winter and infiltration still occurs within soils protected by frozen effluent and snow pack (Figure H3-4). Other year-round projects are possible but require appropriate site conditions and careful management. Storing three or four months of effluent is costly and requires more land for irrigation during growing seasons.

Figure H3-4. Irrigation occurs year-round, in winter as well as summer.

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Parizek, R.R., White, W.B., and Langmuir, D., 1971, Hydrogeology and geochemistry of folded and faulted rocks of the central Appalachian type and related land use problems: The Pennsylvania State University College of Earth and Mineral Sciences Circular 82, 210 p.

STOP H-4: THE BELLEFONTE BIG SPRING

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Background (40.908826°, -77.780995°)

The town of Bellefonte was sited at a large spring upwelling from a pool above the level of nearby Spring Creek. Big Spring has the largest discharge of any spring in the Spring Creek drainage, 19 million gallons/day (29 cubic feet/second) per the Bellefonte Water Authority. The water always remains clear and the flow and chemistry varies little with season or with storm events. The spring provides the water supply for Bellefonte, Milesburg, and for a bottled water company in Milesburg. The Borough has always been a bit touchy about sharing the water and a substantial fraction of the discharge flows off into Spring Creek.

The spring pool is directly beside a busy highway and is Bellefonte's sole water supply. A truck turnover or chemical spill on the nearby road could contaminate the spring, although it would probably flush itself quickly. Water upwells at various locations on the bottom of the pool, so that contamination would not penetrate the subsurface. However, the risk was considered too great and the Pennsylvania Department of Environment al Protection required Bellefonte to cover the spring for protection. There is no longer an open spring pool. Because of security concerns for public water supplies, it is no longer possible to walk around the spring pool, although it can be observed from the fence.

Both the feeder system beneath the spring and the recharge area for the spring are an enigma. The Bellefonte Water Authority specifies the contributing area as 24,621 acres of which the land use distribution is said to be 61% forested, 32% agricultural, and 6.2% developed (quoted from the Water Authority's website). The exact boundaries of the recharge area are not at all obvious and neither are the routes by which water travels from the recharge area to the spring. There are some hard data although not as many as we would like.

The discharge of the spring is unaffected by the behavior of nearby Spring Creek and there is no evidence for any connection. There are deep mines in the Valentine Limestone along the flank of Bald Eagle Ridge half a mile to the west. These reached depths of 1000 feet and extended under Spring Creek along strike east and west for a total distance of about four miles. Big Spring was not affected by any of the mining activity.

The temperature of the spring is nearly constant, winter and summer. The mean temperature is 10.37 °C with a standard deviation of 0.19 °C. The slight temperature rise of a few tenths of a degree in the summer may be no more than the warming of the spring pool rather than a temperature change in the feed water below. This temperature is the seasonal average for central Pennsylvania and suggests that there is no geothermal component to the spring water.

Water Chemistry

The water chemistry provides a clue (Figure H4-1). The water is of very high quality. Nitrate concentrations (in 1984) were 4 mg/L as NO_3^- (0.9 mg/L as N) and remained essentially constant throughout a year of sampling, the lowest value observed in any central Pennsylvania limestone spring. The dominant dissolved species in carbonate waters are Ca and Mg, usually expressed together as the "hardness" of the water, given as mg/L $CaCO_3$. The equilibrium concentrations of these ions are determined by the concentration of dissolved CO_2 and vary considerably between water sources (Figure H4-1). The CO_2 pressure in the water can be calculated from the pH and bicarbonate concentration in the water. The saturation index which indicates the deviation of the carbonate chemistry from equilibrium can also be calculated.

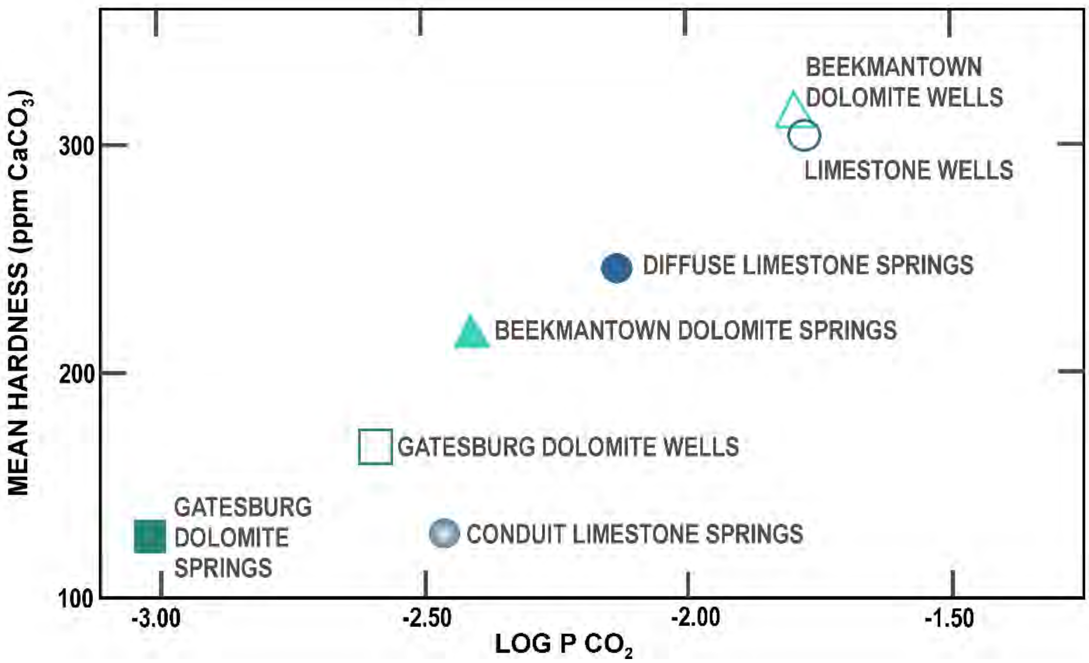


Figure H4-1. Relationship between mean hardness and mean CO_2 pressure for springs and wells from the central Pennsylvania area. Each data point represents the mean of tens up to a hundred samples for each water type. Note that hardness is on a linear scale while CO_2 pressure is on a logarithmic scale. After Harmon et al. (1973).

The chemistry for Big Spring is given in Figures H4-2, H4-3 and H4-4. Surprisingly, the hardness is low for a carbonate spring, about half that of the other springs. The hardness is also nearly constant with a mean value of 126 mg/L and a standard deviation of 1.8 mg/L. However, the water is very close to chemical equilibrium with the carbonate host rock, i.e. the saturation index is close to zero. The low near-equilibrium hardness is because the dissolved carbon dioxide level is only about a factor of two or three above the atmospheric background rather the ten to twenty times background found in most of the other springs. This suggests that the source of recharge is an area of organic-poor soils. The candidate catchment is known as the "Barrens" and lies to the southwest along Gatesburg Ridge. The sandy soils of the Gatesburg formation support scrub forest, make poor cropland, and are also weak sources of CO_2. The near-constant chemistry does imply that the flow path from recharge source to Big Spring is long and slow so that all seasonal and storm fluctuations are averaged out.

Big Spring lies at the downstream end of the Spring Creek Basin near where Spring Creek leaves the valley through Milesburg Gap. There is a major lineament here that may provide the structural pathway for the water in Big Spring to reach the surface. The deep flowpath that crosses under various surface streams may be the result of artesian flow confined below the thrust plate of the Birmingham Fault which is oriented along strike near Big Spring.

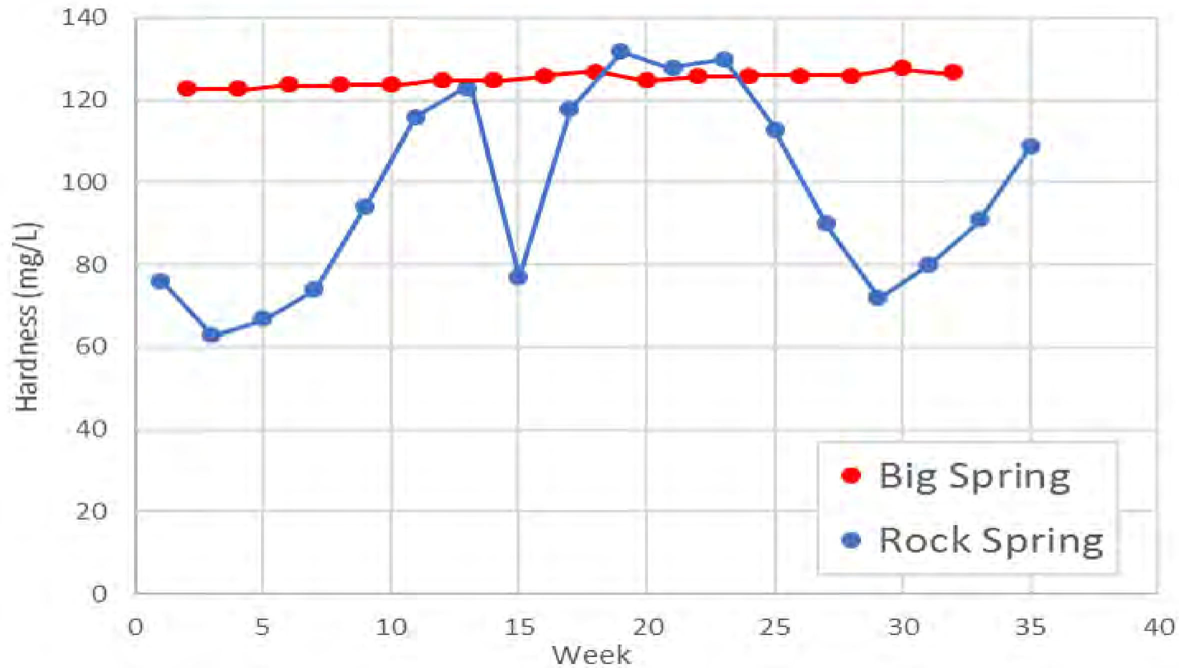


Figure H4-2. By-weekly hardness measurements from Big Spring and Rock Spring beginning April 10, 1967.

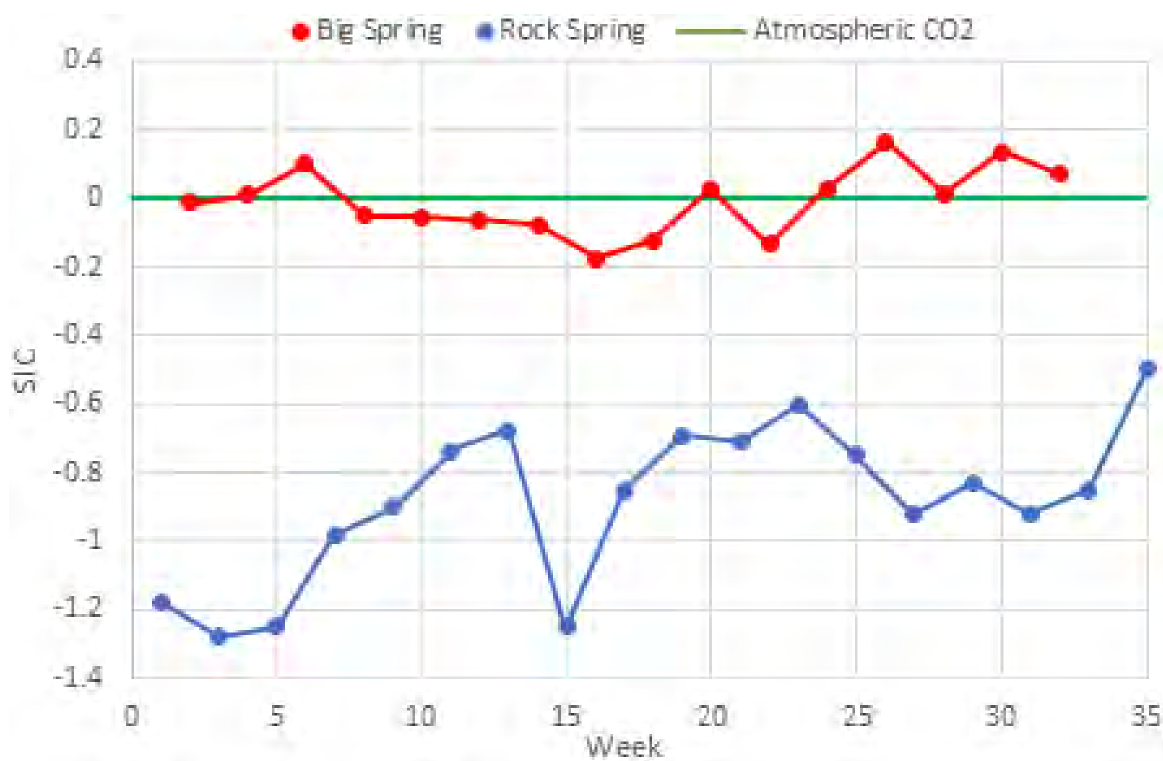


Figure H4-3. Calculated saturation indices for the same period.

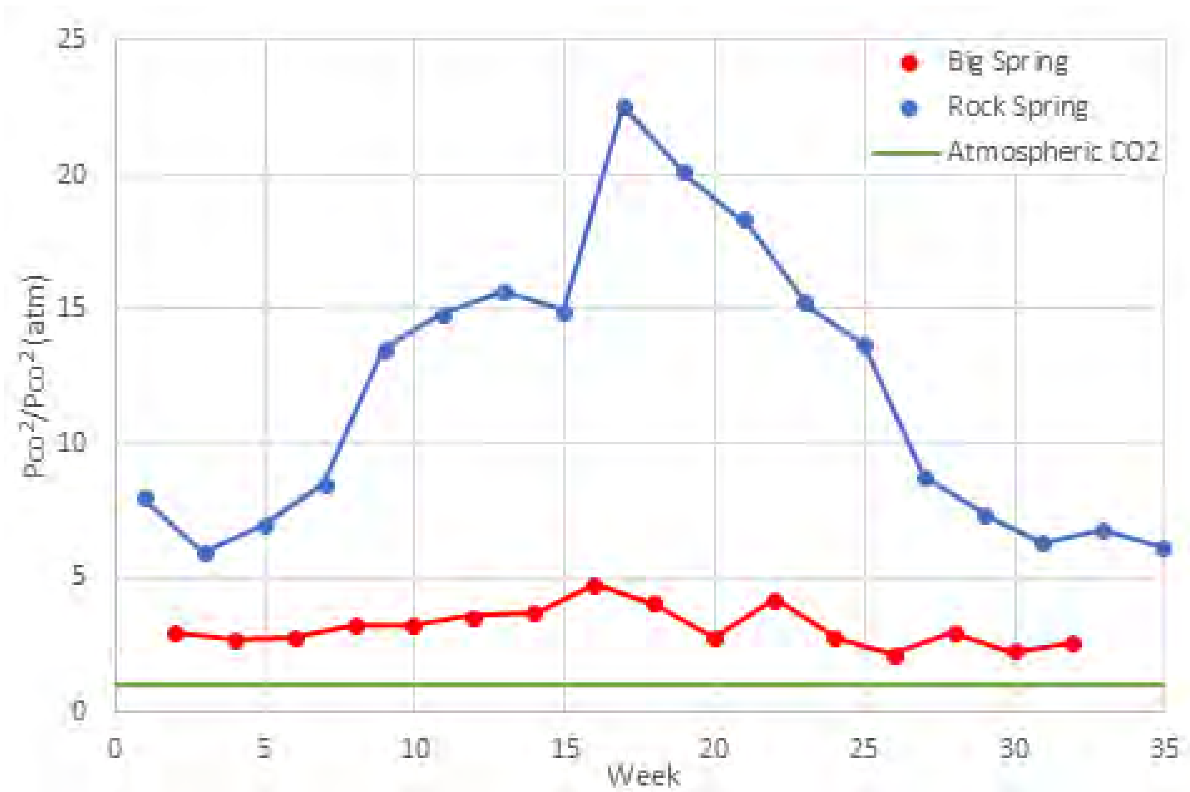


Figure H4-4. Calculated CO_2 partial pressures expressed as a ratio to the CO_2 partial pressure in the atmosphere. The green horizontal line represents the atmospheric background. Primary data from Shuster (1970).

The Big Spring Protection Project

Over the years, various beliefs have been expressed regarding the source of Big Spring. Lake Erie often was mentioned as its source, given the spring's significant discharge. This was used as an objection to Project KETCH, and AEC plowshare program to detonate a nuclear device in the Sproule State Forest. If set off below 2000 feet or so, it would create a void, resulting in breakdown and formation of a rubble chimney in which to store natural gas. Surely, this would disrupt the "veins connecting Big Spring with Lake Erie" despite elevation conflicts. This joint venture between Columbia Gas and AEC was cancelled. Later, however, a gas stimulation experiment was undertaken in western Colorado along with cratering and other experiments elsewhere.

Until the mid-1960s, Bellefonte's water supply was not chlorinated despite health risks. Years later, water was fluoridated but recently was to be discontinued because of cost concerns. PA DEP considered Big Spring to be under surface water influence. If so, this source of public drinking water would have to be abandoned or filtered to meet Safe Drinking Water Standards. No one could deny that the presence of aquatic plants, trout, snails, ducks, dust, leaves, and other debris existed within its pool. DEP proposed to obtain a filtered water sample to be analyzed for surface water indicators to justify issuing an order to begin filtration.

All hydrogeological and monitoring evidence indicated that the source of this water was regional, and although it did not show geothermal influence, it had to follow deep pathways to its emergence within the pool. The plan was to prove that water entering the pool was free of surface water indicators and, if so, protect the pool to eliminate obvious surface influences.

Traverses were made by boat to measure head changes and temperatures in piezometer set at shallow depth, observe turbidity and aquatic plants to identify groundwater inflow points to the pool. Its average depth was more than 8 feet. More active groundwater inflow areas represented a small portion of the total pool (Figure H4-5).

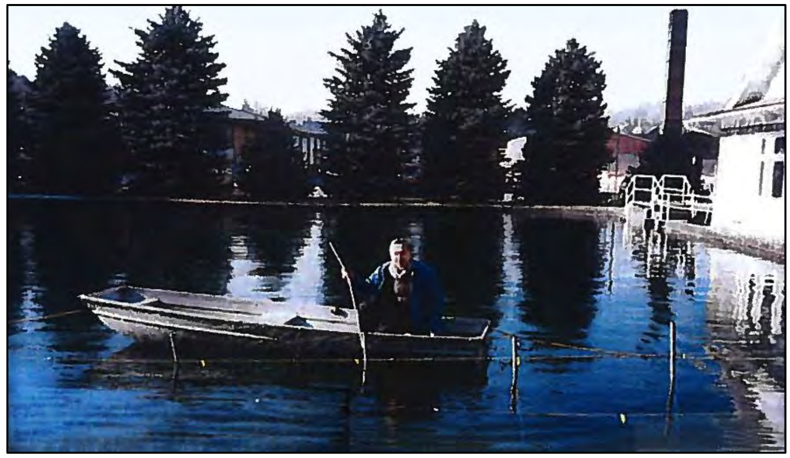
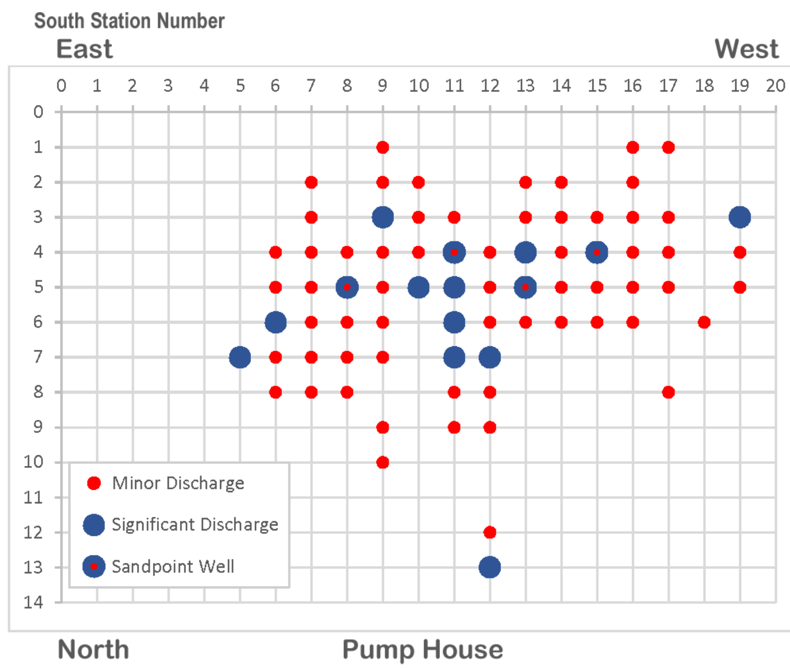


Figure H4-5. Above: locating groundwater inflow areas within the pool of Bellefonte Spring. Measurements were made along gridline traverses. Below: Areas of concentrated inflow to Big Spring (From Parizek, 2013).



Four sandpoint screens were driven into spring bottom sediments at selected locations (Figure H4-5). PVC pipe extended from each sandpoint to the spillway next to the pump house.

Pipes were combined to integrate water samples allowing daily sampling of required constituents such as temperature, pH, conductivity, total and e-coli bacteria. Flows were recorded in Spring Creek and precipitation measured daily. This followed DEP protocols. DEP personnel judged this effort to be fruitless, a delay tactic and, about one month into the monitoring program, arrived to take a filter sample. By good fortune, Parizek spotted an algal strand nearly 5 inches long enter and break up within the filter medium that otherwise would have documented surface water influences. This fragile algal strand could not have passed through spring bottom sediments. The white connecting PVC pipes were shown to be translucent, allowing enough light to enter the pipes to support algal growth! These pipes were replaced with black PVC, tested in advance with film and shown to be opaque.

Months later, filter samples were taken and found to be free of all surface-water indicators. This occurred after the required minimum rainfall event that correlated with stream flow and minor charges in pool behavior. The challenge remaining was how to rid the pool of living organisms and isolate it from shallow underflow, surface runoff, and airborne sources of contamination.

Figure H4-5 shows the sandpoint target options, and Figure H4-6 shows engineered barriers that were constructed. The original retaining wall was in disrepair, undermined in places and falling into the pool. The sidewalk around this wall was broken in many places and contained water directly connected to the pool. The land surface southeast of the pool sloped directly toward this wall and sidewalk, allowing stormflow influences.

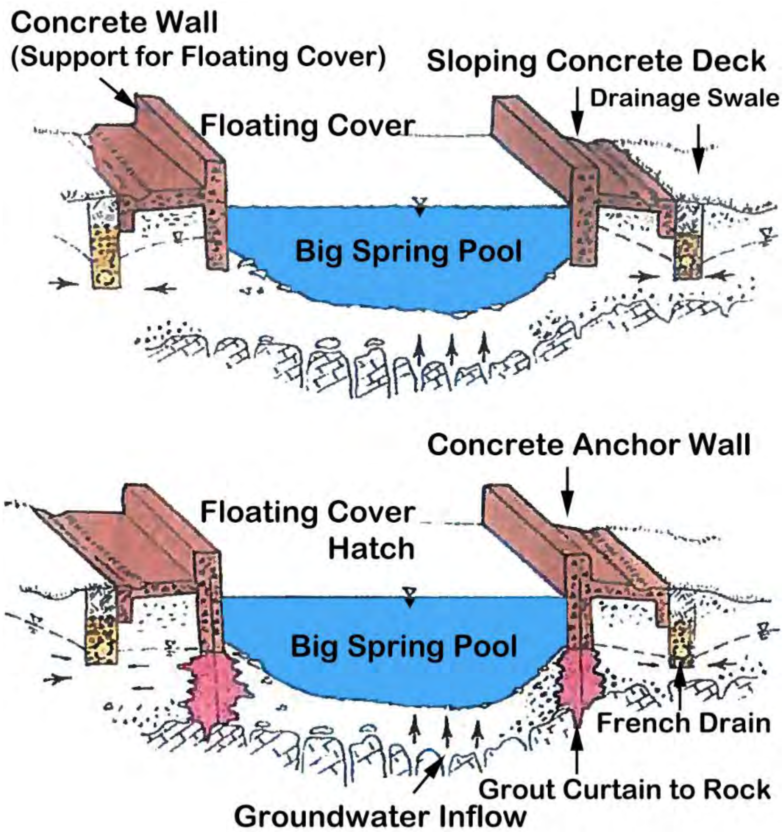


Figure H4-6. Elements of the Big Spring Protection project (From Parizek, 2013).

Gasoline stations, a sewer main, and laterals extended along the highway immediately adjacent to the spring. A cleanup effort already was in progress at a nearby fueling station south of the spring. Flowing water could be observed in storm drains nearby, and accidental highway spills posed a high risk. An open invitation was presented to terrorists due to the exposed nature of the pool.

Borings were drilled to establish thickness of overburden. A new retaining wall was needed to prevent stormwater entry and to support a floating cover. How to support the retaining wall? Driving sheet piles next to the spring pool used continuously to supply water to Bellefonte and the Corning Ashi Glass plant would raise turbidity to unacceptable levels. Trenching to construct a wall below the water table might encounter uncontrollable flows of water. Pressure grouting was sure to cause difficult to control breakouts into the pool.

Jet grouting was selected and used around most of the pool with a short section of sheet piles because of site access limitations. The foundation of the pump house served as a dam, hence did not have to be treated. Most of this portion of the pool was in an influent state.

Soil temperature surveys were used to confirm the existence of a water-tight jet grout curtain, where required, and to explore for shallow lateral sources of groundwater nourishment that might be cut off by the curtain. This was a major concern of Water Authority members. Temperature anomalies were discovered in the curtain at several locations. The grouting crew shut down grouting operations whenever grout began to appear in the pool. In some cases, they did not return to complete the column. These were located by the temperature survey and completed.

Note that a French drain was provided around much of the pool (Figure H4-6) again raising concern of Authority members. This reversed the gradient so that water would leak out rather than into the pool should a seal not be complete or were to fail. Further, it would intercept shallow pollutants such as gasoline, heating oil, etc., concentrated near the water table that enter groundwater.

The floating cover stock to be provided was tested to avoid the white PVC pipe problem that might have resulted in a costly filtration order. Sure enough, it was not opaque, as specified, and might have resulted in failure providing an energy source that could stimulate aquatic life. Attention to detail and observations matters.

A hatch is provided to allow access and inspection of the pool. Floating air vents are provided because gas bubbles were always observed at some groundwater inflow points. The hope was that once light was eliminated, all organisms would starve and much of their remains might eventually be flushed from the pool. More than a year was allowed before a filter sample was taken by DEP. Chemical treatment to sterilize the pool was out of the question and would have caused extensive fish kills in Spring Creek starting at the spring's spillway.

It passed the test. Many are now thankful, following 9/11, that the Bellefonte Spring is secure and no longer exposed. Others, however, miss seeing the pool. They suggest that the spring should have been covered with a glass dome, which would bring compliance back to square one.

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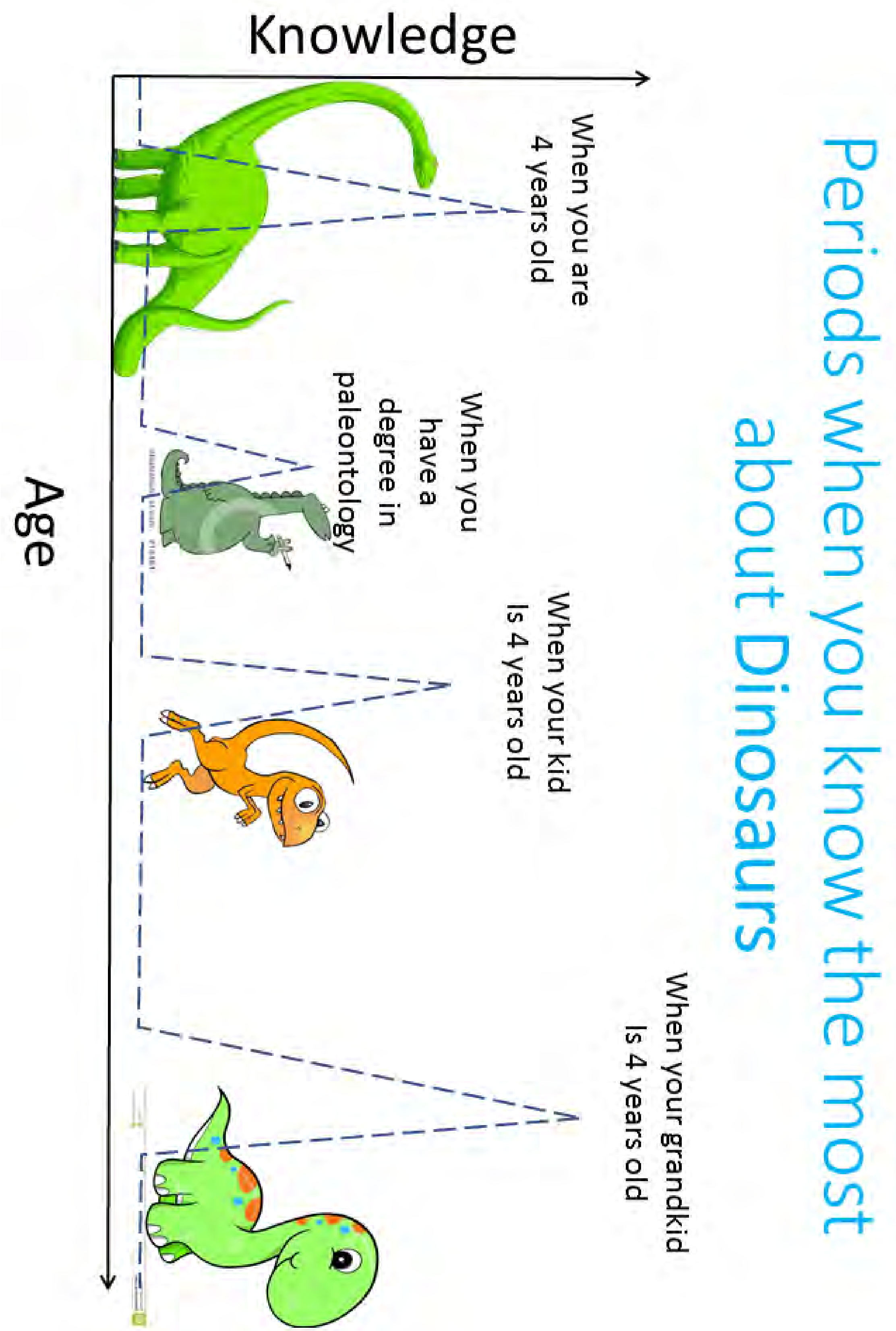
Periods when you know the most about Dinosaurs
Knowledge
Age
When you are 4 years old
When you have a degree in paleontology
When your kid Is 4 years old
When your grandkid Is 4 years old

STOP H-5: HYDRO LUNCH: MILLBROOK NATURE CENTER AND MARSH

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(40.813376°, -77.838310°)

This former dairy farm including cropland, pastures and extensive meadows has been transformed into a unique, nature center. Boardwalks allow easy access to areas otherwise difficult to access while also ecologically fragile. It is open year-round and changes with the season.

Thompson Run originates from Thompson Spring just above the Duck Pond and below Penn State's sewage treatment plant. It joins Slab Cabin Run where it is accessible by boardwalk. During dry seasons, Slab Cabin low flows are noticeably less than Thompson Run despite its greater drainage area. State College Borough withdraws groundwater from Thomas and Harter well fields located in the Slab Cabin drainage. Effluent from these wells is returned to Spring Creek below its confluence near UAJA treatment plant.

Urban runoff has altered both channels. Sediment and debris have accumulated in Thompson Run whereas Slab Cabin has become incised deeper into its flood plain. Figure H5-1 provides the geologic setting, including fracture traces, tear faults and possible thrust fault, test and production wells, Hamill and John Bathgate Springs. Not shown are overburden deposits of residual soil and alluvium that blanket carbonate rocks except for small and scattered natural bedrock outcrops.

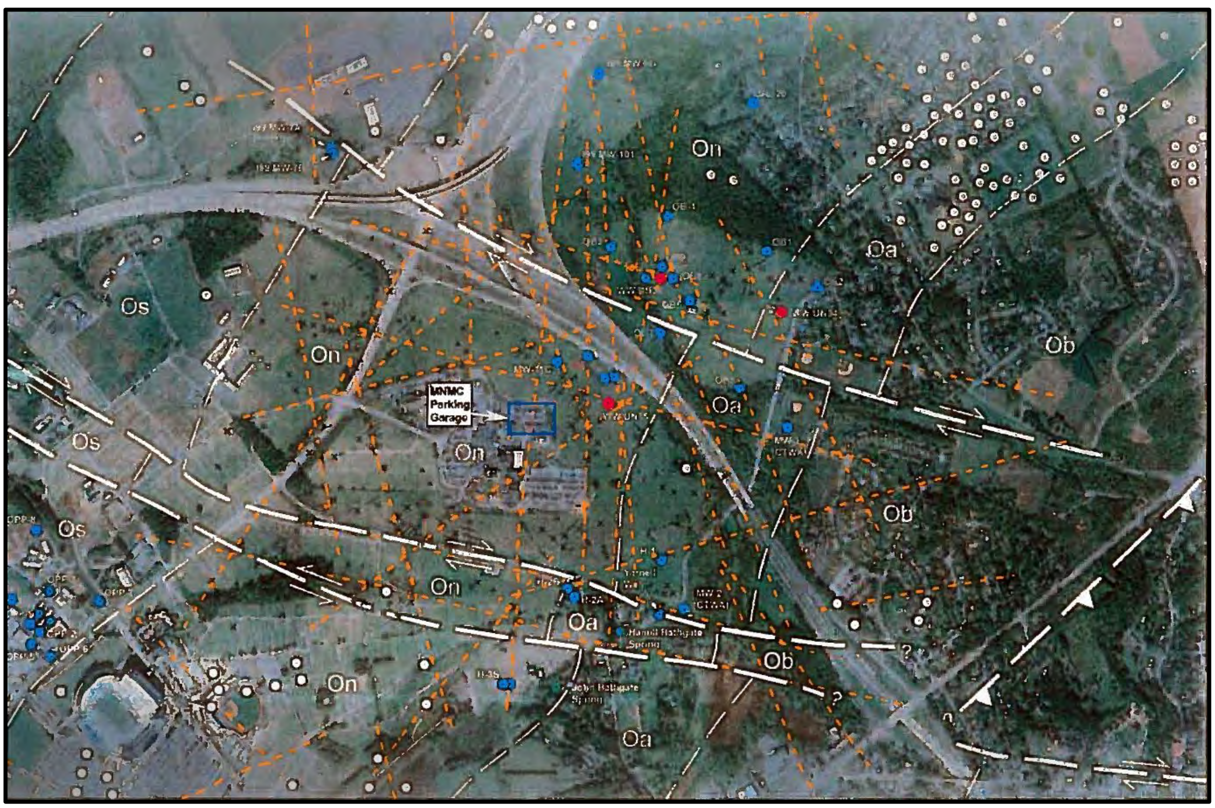

Figure H5-1. Geologic map of the Millbrook Nature Center and Marsh (From Gold, Doden and Parizek, 2016).

A discontinuous Pleistocene terrace exists along Thomas and Slab Cabin runs and Spring Creek within the vicinity of the Nature Center. It has a frost wedged disturbed soil profile indicating that it predates Pennsylvania's last glaciation. Remnants appear near the Thompson and Bathgate springs. Their water table and solution channels are still graded to these terrace remnants.

Shallow channel piezometers were installed along each channel within and near the Millbrook Marsh. Thomas, Slab Cabin and Spring Creek all showed influent and effluent sections that remained nearly the same before and after University and Municipal wells were placed in service, the subject of Steele's senior thesis (1998), Figure H5-2.

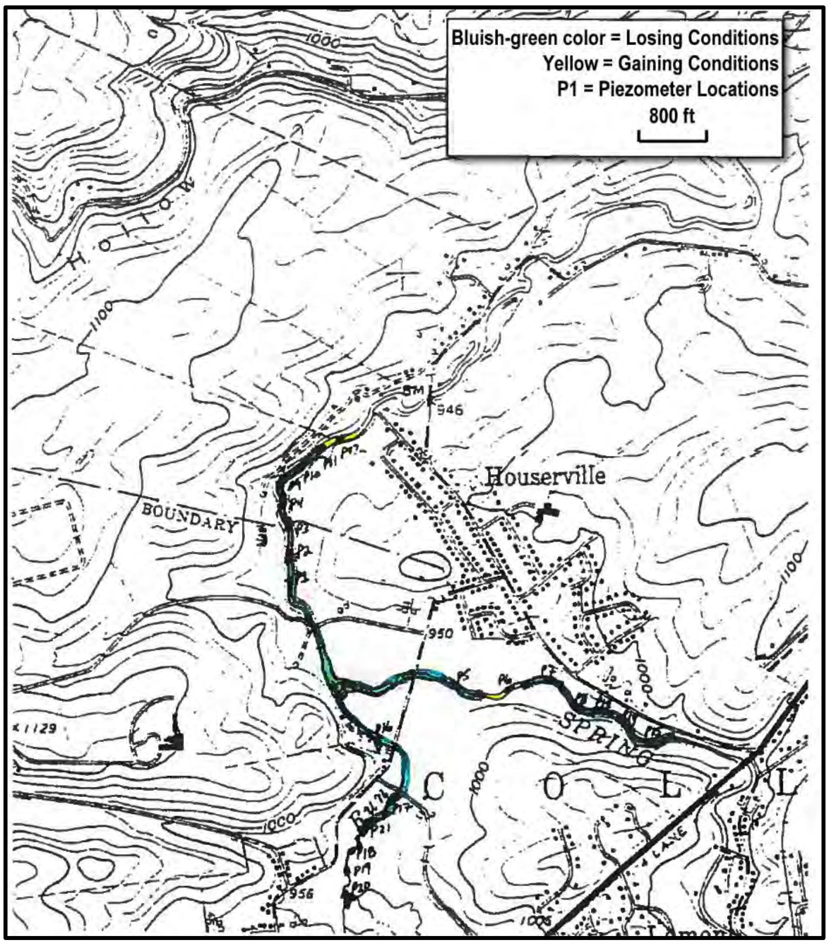

Figure H5-2. Effluent and influent conditions along Spring Creek and Slab Cabin Run during the September-October 1997 dry season (Steele, 1998).

Nested and shallow channel piezometers, stream and spring gauging stations, and bedrock observation wells were monitored extensively during the development of production well CTWA MW-1.

Major production wells include Penn State water supply wells, UN 33, 34, and 35 and College Township well MW-1. These fracture-trace intersection test sites along with 23 others near the Marsh were recommended as one of ten highly productive, potential well fields in a Centre

Regional Planning Commission study (Parizek, 1987). You passed the Alexander well field near Fox Hill Road traveling toward the University Airport, will learn about the Oak Hall site (Stop H-6), pass the Thomas -Harter Site traveling near Shingletown Gap toward Stop H-7, all recommended in 1987.

The Marsh was found to be perched before and after these four high capacity wells were placed in service. The Marsh is nourished by direct precipitation, overflow of streams during high flows together with seeps and springs largely concentrated near the southern margin of the wetland. Lowering the water table by 10, 20 or more feet will not change these sources of nourishment!

Rock V-shape barriers were set in Slab Cabin Creek with the intention of raising the water table, hence augmenting the wetland. This did not cause a rise in groundwater levels within flood plain deposits as expected because of perched channel conditions. It did improve fishery habitats by enhancing pools above and scour pools below these dams. Deep scour pools could thin protective flood plain sediments increasing risks for sinkhole development more likely under perched conditions.

Such a sinkhole opened at the Route 322 crossing of Slab Cabin Run during low flow conditions. Dams were built above the sinkhole to allow its repair (Figure H5-3).

Figure H5-3. Sinkhole within Slab Cabin Run, Route 322 bridge.

Excavation extended to more than 12 feet below Creek bottom while water was pumped around the sink. As feared, a storm event caused the deep excavation to flood. Water supply wells were immediately shut in to reduce migration of surface water that entered the void. Fortunately, the Axemann Limestone was not transmissive enough to consume the entire storm flow. Campus winter break had just started, which allowed Penn State to meet water needs from other sources. More than 10-feet of deeply weathered silty clay was exposed. It lacked sand and pebble lenses as might be expected for alluvium, contained a buried clay enriched weathered zone. Might this be proof of Williams' 1895-1930 glacial Lake Lesley I after all given its postulated 1,100- foot spillway elevation at Dix, the divide for N. Bald Eagle Creek? (See Parizek and White, 1985). Let's talk.

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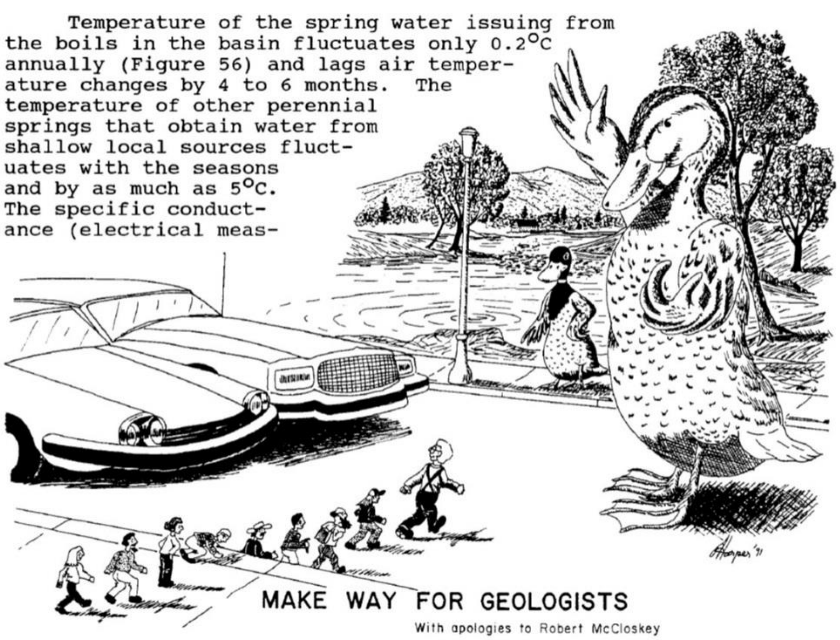

STOP H-6: OAK HALL QUARRY

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Hydrogeology (40.799010°, -77.805194°)

Figure H6-1 shows the view of the quarry from the pull-off along the road. The far wall of the quarry provides a spectacular view of the upper Ordovician carbonate stratigraphy. However, for a hydrogeology field trip, the importance of the quarry is not the exposure of the strata. Think of it as a well – a very large well. The quarry has been cut deeply below the level of Spring Creek, the base-level stream for the area. One might expect the quarry to have major water problems but, in fact, the pumping rate is low, little more than the accumulated rainwater. Where are the high capacity solution conduits that might carry water into the quarry?

Figure H6-1. View of Oak Hall Quarry from the pull-off along the road.

There is a cave, Oak Hall Cave, located to the right, down over the bank at creek level (Figure H6-2). The cave entrance is a spring mouth about 30 feet southeast of spring Creek. It is a very wet and muddy cave which averages about 1.5 feet high with 6 inches of mud and water with a foot of airspace. The cave extends to the floor of the abandoned quarry on the other side of the road but any exit is blocked by breakdown. The cave may continue where the stream that crosses the floor of the abandoned quarry resurges. Oak Hall Cave is in the Benner and Snyder Limestones which here dip 57° NW and strike N 70°E.

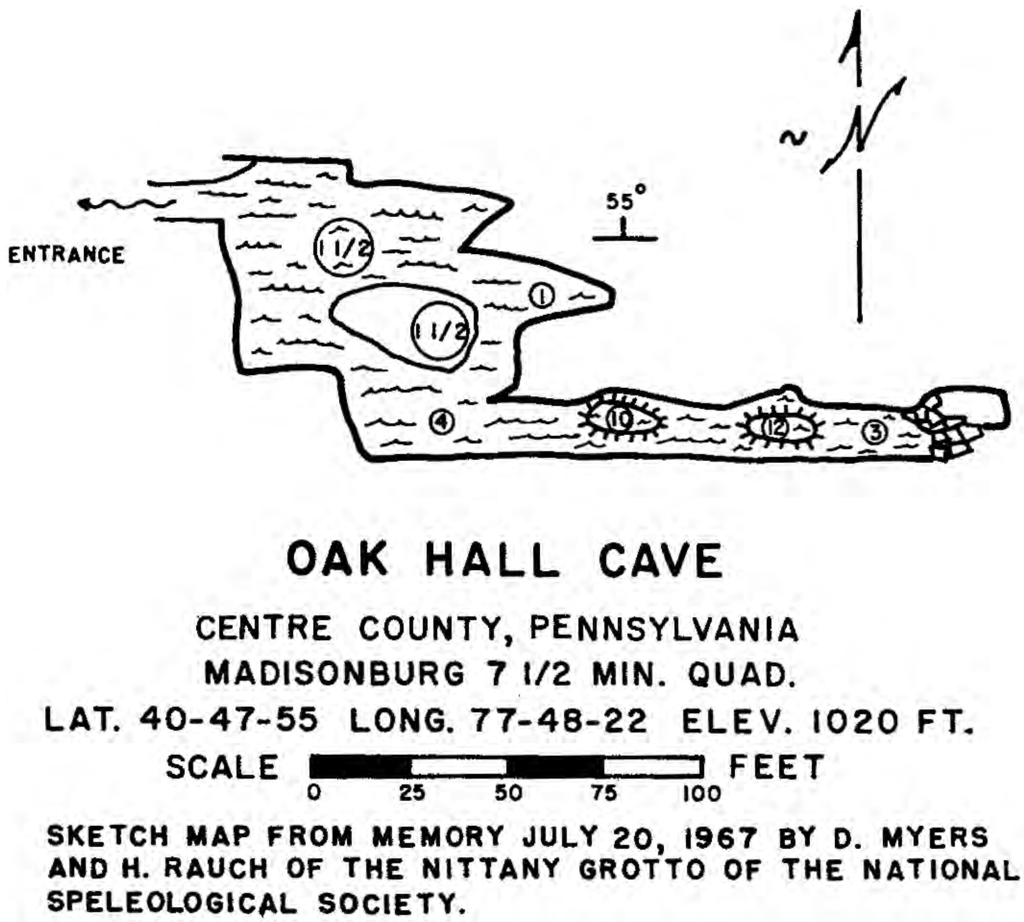

Figure H6-2. Map of Oak Hall Cave. Taken from Mid-Appalachian Region Bulletin 11 (1979)

In the late 1960s, Henry Rauch launched an ambitious project as part of his PhD dissertation at Penn State. The question was: If percolating ground water has a choice, does it dissolve some carbonate rocks in preference to others? All carbonate rocks will dissolve in slightly acid groundwater but some dissolve more quickly than others. Rauch probed this question by measuring the volumes (not length - volume) of all caves in the Nittany Valley area more than 100 feet in length, 43 caves in all. He found that 42 of the caves were in the Trenton/Black River Formations and one in the Axemann Limestone. No caves were found the in the dolomite. (There is now an exception: Ruth Cave near Spruce Creek is a large cave in the Beekmantown Dolomite.). Also, there were no caves in the shaly Salona and Coburn Formations.

The limestone/dolomite influence on karst development has been seen in many localities. There are fewer caves in dolomite and surface features such as sinkholes tend to be more subdued in dolomite. Sometimes, it has been said that dolomite is less soluble than limestone. This is not true, at least in a thermodynamic sense. The equilibrium solubility of dolomite is almost identical to that of calcite (Figure H6-3). The different behavior of limestone and dolomite arises from the kinetics of the dissolution process. Limestone dissolves faster than dolomite and, thus, over an equal time span, more limestone will have dissolved than dolomite.

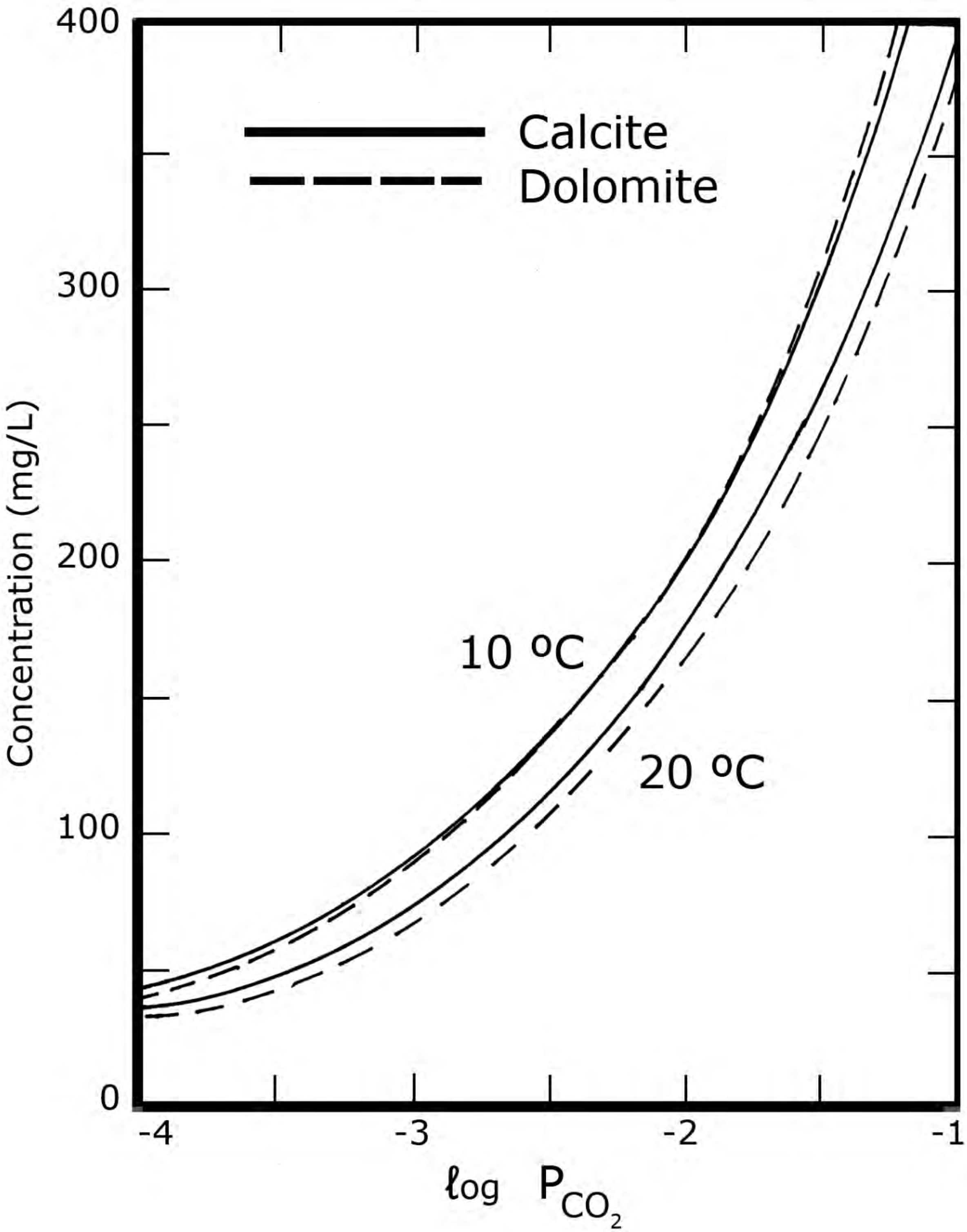

Figure H6-3. Calculated solubility curves for calcite and dolomite as a function of carbon dioxide partial pressure. To compare solubilities on an equal-molar basis, calcite is $CaCO_3$ while dolomite is written $Ca_{1/2}Mg_{1/2}CO_3$

The results of Rauch's investigation of cave distribution revealed considerable detail is the distribution of solution cavities among the available carbonate units (Figure H6-4). The black shale interbeds in the Coburn and Salona Formations thin and disappear lower in the section and gives way to more massive and purer limestones. Within these purer limestones, cave development was mainly in the Nealmont, the Oak Hall, and the Grazier Limestones. A comparison with the lithologic and chemical characteristics of the rocks suggested that a good cave-forming limestone should be pure but not too pure. High Al is bad (probably indicating more clay minerals), high Si (sand grains and silicified fossils) does not matter much. Some Mg is good, 4-5%, but too much Mg (i.e. dolomite) is bad. Fine-grained limestones (micrites) dissolve more effectively than coarse grained limestones (sparites).

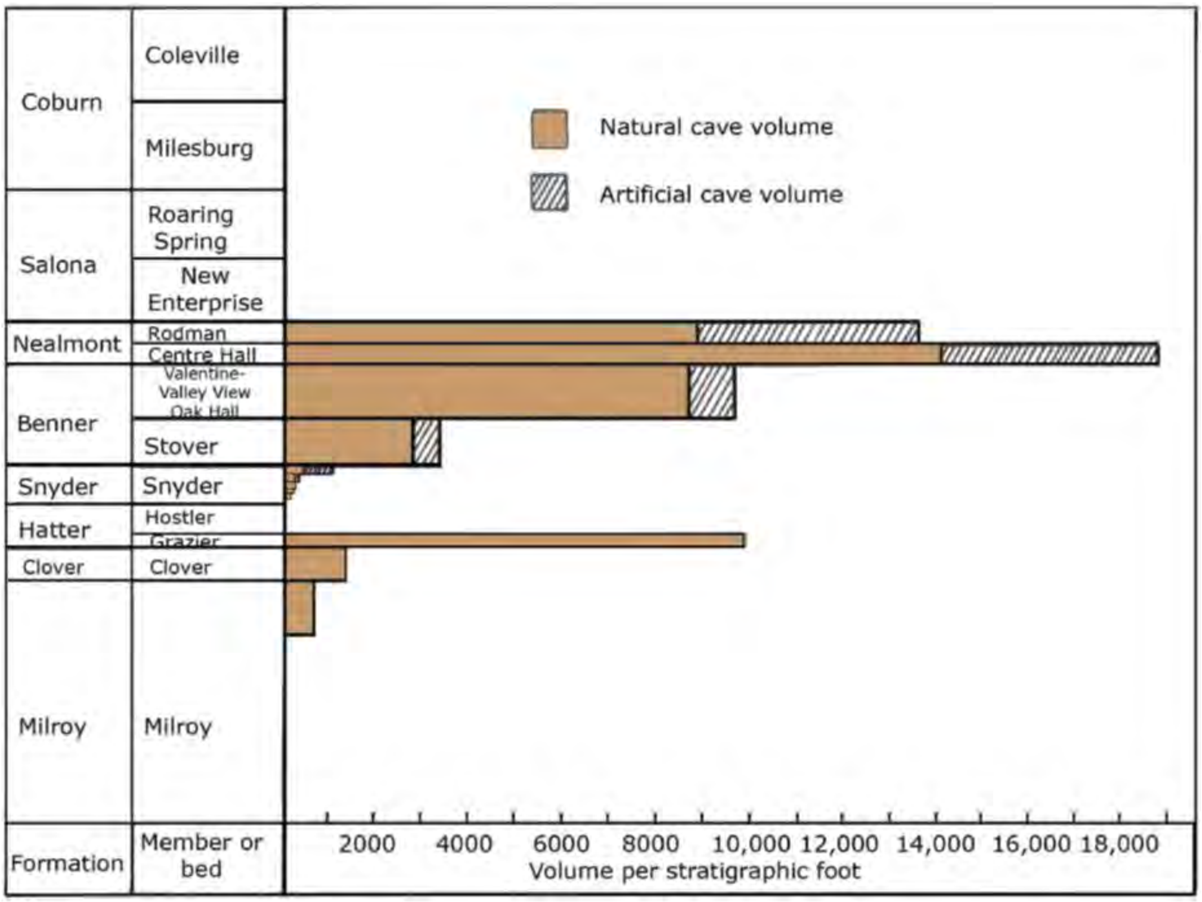

Figure H6-4. Distribution of cave volume among the units of the Trenton/Black River group of Ordovician carbonates. "Artificial Cave" means caves with artificial entrances – entrances in quarries and highway cuts (from Rauch and White, 1970).

Regarding development of solution pathways, the mass of carbonate rock in Nittany Valley is, in fact, very heterogeneous. The peculiar hydrologic behavior observed at Big Spring and at the Oak Hall Quarry is to be expected. Ground water flow in these heterogeneous carbonates tends to be localized along fractures and solution conduits. Some units are sufficiently impermeable to act as groundwater dams thus saving Oak Hall Quarry a great deal of pumping.

Limestone has been extracted from this area for more than 100 years. Hanson Aggregates, PALLC, the current owners, have extended the quarry 50 feet below Spring Creek within limestone strata known to contain most of the commercial and explorable caves in Central

Pennsylvania. Today dewatering requirements are minimal and permitted at 0.72 mgd. An application to extend the quarry to a depth of 250 feet is in review. This would involve 50-foot lifts and 25-foot setback benches to achieve its final depth. The quarry is shown in Figure 3E including the current water table configuration.

Resident concerns include disturbances such as blasting, truck traffic, dust, noise, and drawdown interferences within nearby wells. Increased induced streambed infiltration losses in base flow and sink development are environmental concerns together with alterations of the cold water fishery.

Drawdown interferences to date appear to be minor (Figure H6-5) despite the normally productive limestone formations involved. Steeply dipping beds, thin metabentonites, shale partings all impede flow across bedding but do not preclude drawdown in the direction of bedding. Boreholes have encountered poorly productive limestone consistent with the rather limited cone of depression shown in Figure H6-5. Further, the Oak Hall Spring continues to flow on the east side of Spring Creek only a short distance from the existing open pit.

Figure H6-5. Geology and water table for the Oak Hall Quarry Area.

Figure H6-6, by contrast, shows the expected rather extensive area of pumping influence for the College Township Water Authority proposed well (OH-20) located within Oak Hall Park. This fracture trace intersection well had a blown yield of >1,500 gpm during test drilling and well construction. Its high yield potential stands in contrast to Oak Hall Quarry dewatering requirements: bore-hole diameter measured at 12-inches vs. quarry in acres!

The expected area of pumping influence was computed assuming an average annual rate of recharge. The OH-20 potential contributing groundwater basin area is far greater and sustains flows of Cedar Run and Spring Creek. Some surface water is likely to be captured by induced streambed infiltration. In this event, the cone of depression will be smaller than shown. Its asymmetric shape is predicted based upon dipping strata together with their stratigraphic strike.

High transmissivities predict a shallow but extensive cone of depression constrained by more steeply dipping strata.

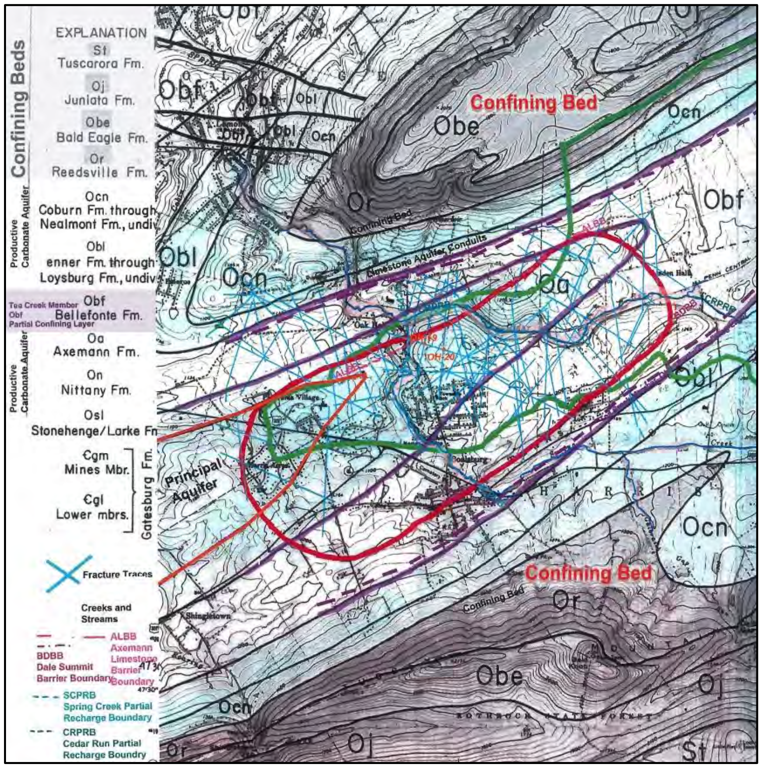

Figure H6-6. Estimated area of capture to sustain a 1,250 gpm pumping rate under draught conditions (From R.R. Parizek and K.A. Parizek, 2017).

Many favorable hydrogeologic attributes were considered when selecting this prospect site. Access to public land allowing wellhead protection requirements to be met, few nearby farm, or domestic or municipal wells, fracture trace intersection well sites, anticlinal crest/low dipping strata, Nittany Dolomite target aquifer, adequate soil cover to reduce water quality concerns, non-threatening land use activities, service area requiring water, and favorable recharge rates.

Shallow channel piezometers were set along Cedar Run and Spring Creek for pump testing of the Oak Hall Park recreational facility water supply well OH-19. This well was pumped at 220 gpm rate, limited by pump capacity. Sections of both stream channels were influent before and during 48-hour constant rate test. Test pumping OH-20 at a 1,250 gpm rate will require extensive monitoring of springs, farm and domestic wells, nested piezometers, wetlands, flows of Spring Creek and Cedar Run together with the Oak Hall Park well. The outcome of these monitoring efforts will inform decisions on OH-20's allowable pumping rate, need for mitigation and flow augmentation measures should these be required. The Susquehanna Ricer Basin Commission makes this review and decision. PA DEP assumes that the water and facilities meet Safe Drinking Water Requirements.

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STOP H-7: SCHALLS GAP SINKING STREAM

STOP LEADERS – WILLIAM B. WHITE [1] AND RICHARD PARIZEK[2]

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Hydrogeology (40.708339°, -77.956121°)

The watershed divide for the Spring Creek basin is the central ridge line of Tussey Mountain, the high, unbroken, central ridge supported by the resistant Tuscarora Quartzite. Tussey Mountain is a synclinal structure so that a fore ridge is formed along the western flank supported by the Bald Eagle Sandstone. In between are small upland valleys developed on the Juniata red shale and siltstone. Runoff from this complicated catchment structure is through a sequence of water gaps in the fore ridge (Figure H7-1).

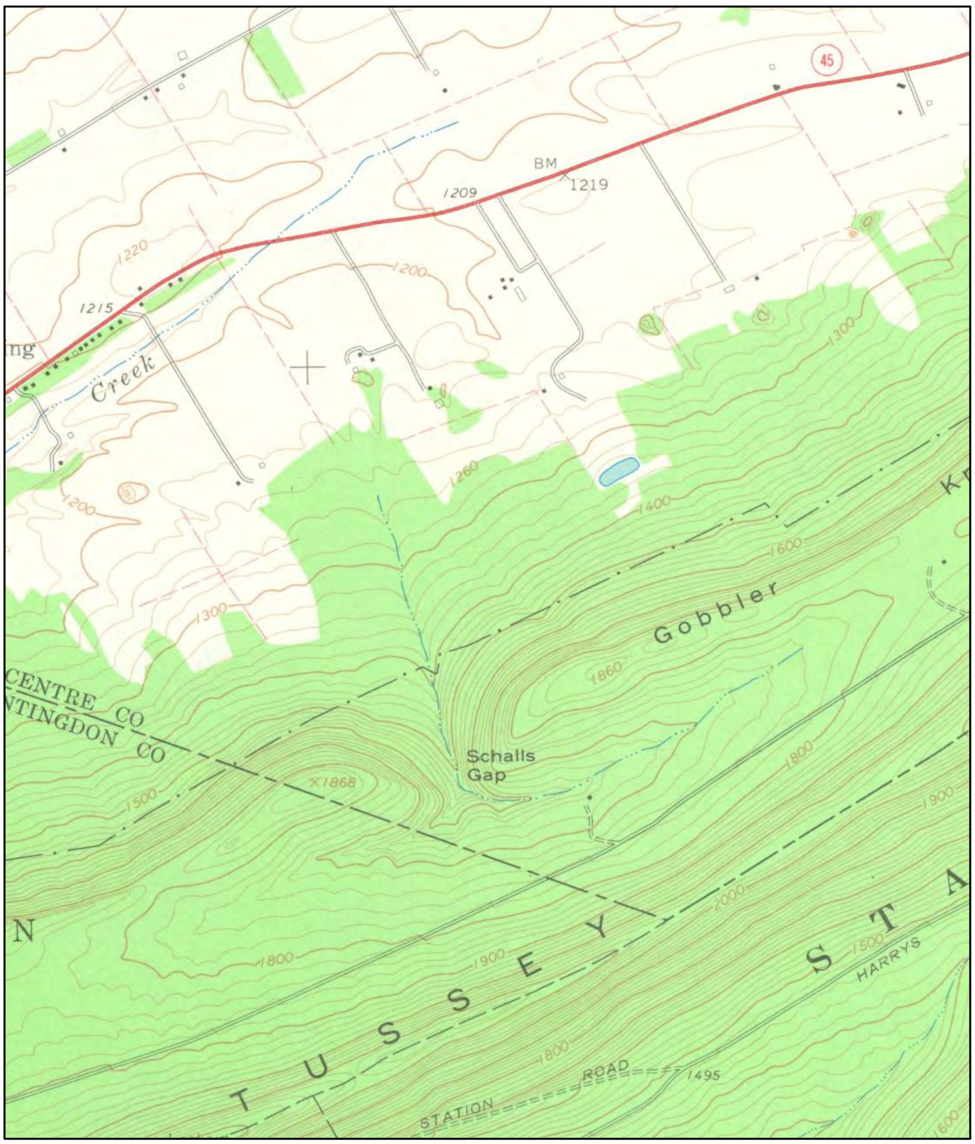


Figure H7-1. A section of the USGS Pine Grove Mills 7.5 minute quadrangle map showing Schalls Gap and its stream. Note that sinkholes, which are often in clumps of trees, often escape representation on topographic maps derived from aerial imaging.

The fate of these small gap steams when they reach the valley and the limestone contact is somewhat variable. From the northeast:

- **Galbraith Gap** (Skimont, the road to Bear Meadows) – a stream crosses the carbonates as a tributary to Spring Creek.
- **Shingletown Gap** (containing an unused surface water supply for State College) – a stream crosses the carbonates as a tributary to Slab Cabin Run.
- **Musser Gap** – the stream sinks with a dry channel extending to Slab Cabin Run under low-flow conditions.
- **Gap at Pine Grove Mills** (the headwaters of Slab Cabin Run) – the stream sinks in the village and reappears as a spring behind the Naked Egg Cafe. Flood flows overtop the sink and flow through the village.
- **Erb Gap** – the stream sinks in a deep sinkhole (Kepler Sink) immediately beside Route 45. There is no channel downstream from the sinkhole. There are several small caves in the sinkhole.
- **Schalls Gap** – the small stream sinks with no continuing surface channel.

The stream at Schalls Gap crosses the Reedsville Shale and the upper shaly units of the limestone to create a small valley incised below the floor of the valley uplands. Although such features appear on topographic maps as sinkholes, they are better described as blind valleys sloping upward upstream with the stream disappearing in a blind footwall downstream (Figure H7-2).

Figure H7-2. The sink point or swallet of the Schalls Gap stream.

There is a very broad, low surface divide for the Spring Creek Watershed shown on the topographic maps just west of Pine Grove Mills. Per Giddings (1974) the groundwater divide lies significantly west of the surface divide, about a mile west of Pine Grove Mills. Northeast of the divide, drainage is into Slab Cabin Run and from there into Spring Creek. Southwest of the divide, drainage is into Spruce Creek which heads at Rock Spring (in the village of Rock Spring). Spruce Creek flows into the Little Juniata River at the village of Spruce Creek. The streams from Erb Gap and Schalls Gap feed into a master underground conduit that extends about three miles oriented along strike from Kepler Sink to Rock Spring.

Other limestone valleys of central Pennsylvania such as Brush Valley and Sugar Valley contain these master drains feeding to big springs about which we know next to nothing. They are shallow but mostly water-filled and thus not easily accessible to exploration. Caves at the infeeder sink points are small and blocked by breakdown after short distances. None are known that connect to the master drain. In the 1980s (personal communication) a SCUBA diver entered Rock Spring and followed the master conduit for an estimated quarter of a mile which should have brought him close to the Schalls Gap in-feeder. The diver reported an undulating tube, large enough for easy diving with mostly deeper sections completely water-filled but with some shallow sections of air-filled passage. Small particulates could be seen drifting with the current in the bright beam of his dive light.

Rock Spring, like many other karst springs, is flashy and can become turbid or muddy after storms. By what may be regarded as a streak of luck, Roger Jacobson, then working on his PhD thesis at Penn State, had instrumented Rock Spring during the period that included the Hurricane Agnes storm of 1972 (Jacobson, 1973). The hydrograph clearly shows the flashy response of the spring, not greatly different from the expected response of a surface stream. The normal flow discharge of the spring is 2 to 6 cubic feet/second. Storm pulses are ten times that or higher. The Hurricane Agnes storm raised the spring discharge to a peak value of 220 cfs. The typical flashy response of conduit-fed karst springs lead to a question of how much sinking streams contribute to aquifer recharge. Of the water draining from the mountain and sinking at the limestone contact, how much would be available to wells drilled out in the valley and how much is runoff lost down the creek immediately after the storm?

The valley surface is gradually lowered by chemical denudation as the carbonate rocks are dissolved. Unlike dissection by surface streams, karst denudation lowers the surface without dissection as the dissolved rock mass is carried through fractures and sinkholes to the conduit system and the springs. Jacobson's measurements at Rock Spring allow a calculation of mass loss from the Rock Spring watershed since he measured both discharge and concentration of dissolved carbonates. The denudation, usually expressed as meters/million years, can also be expressed simply as the volume of rock lost per unit area per unit time. Figure H7-3 shows a comparison between Rock Spring, fed by a large component of mountain runoff and Thompson Spring (in State College) fed mostly by infiltration onto carbonate rock uplands. Rock Spring shows less mass loss during low flows, but higher mass loss during storm flow. While the concentration of dissolved carbonates is diluted by storm flow, the off-setting effect of increased volume of discharge shows that the greatest amount of rock loss takes place during storms.

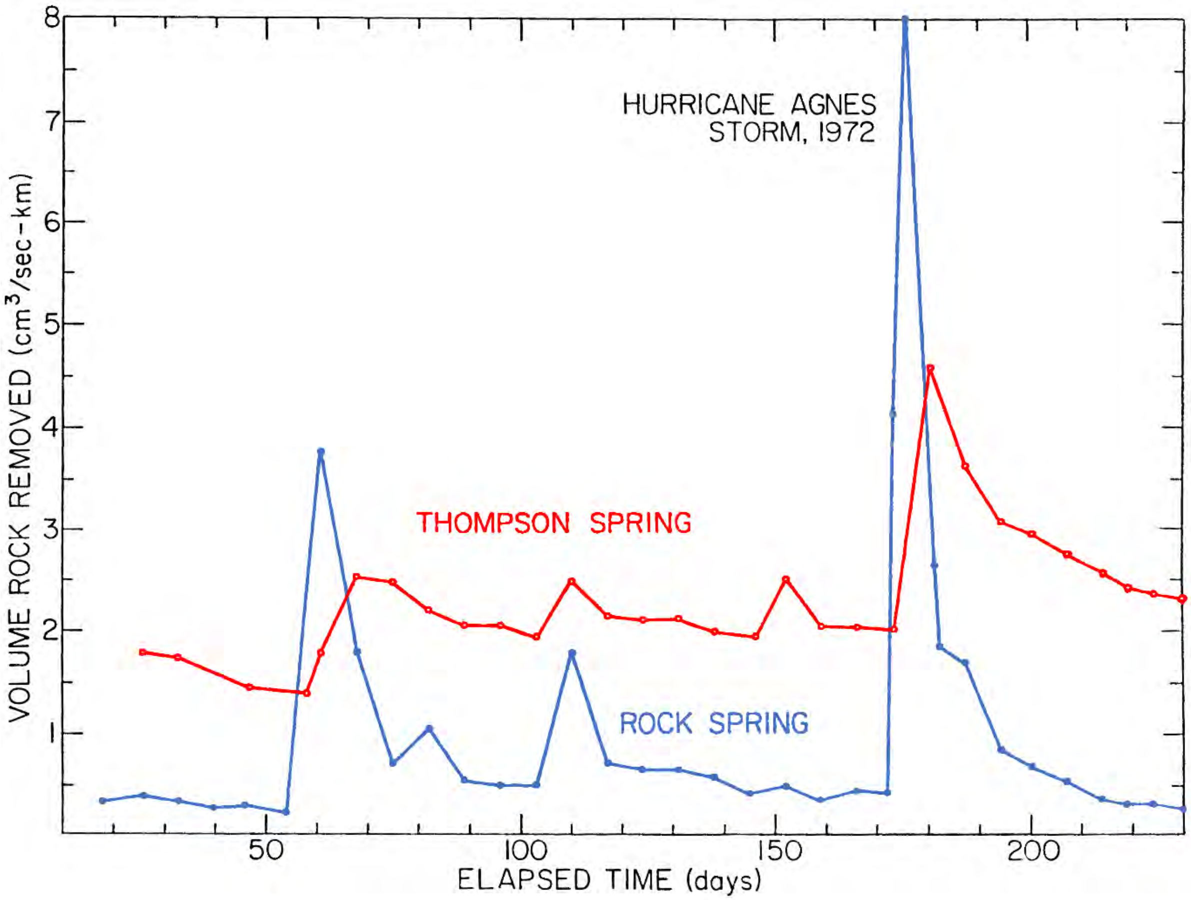


Figure H7-3. Denudation curve for the Rock Spring and Thompson Spring watersheds calculated from Jacobson's (1973) data.

There is also an effect of storm flow on pollution transport in karst aquifers. Much of the Rock Spring watershed is used by the Penn State College of Agriculture for their experimental farms. Kristen Underwood measured the release of nitrates and pesticides at Rock Spring over a water year (Underwood, 1994). Both nitrate release (Figure H7-4) and the concentration of atrazine (Figure H7-5) spike during storm runoff showing that these agents are carried rapidly into the subsurface and flushed down the conduit by storm flow.

The flashy response of karst drainage systems requires that monitoring for water quality take account of contaminant releases. Random or quarterly sampling may produce a very misleading assessment of contaminant threats.

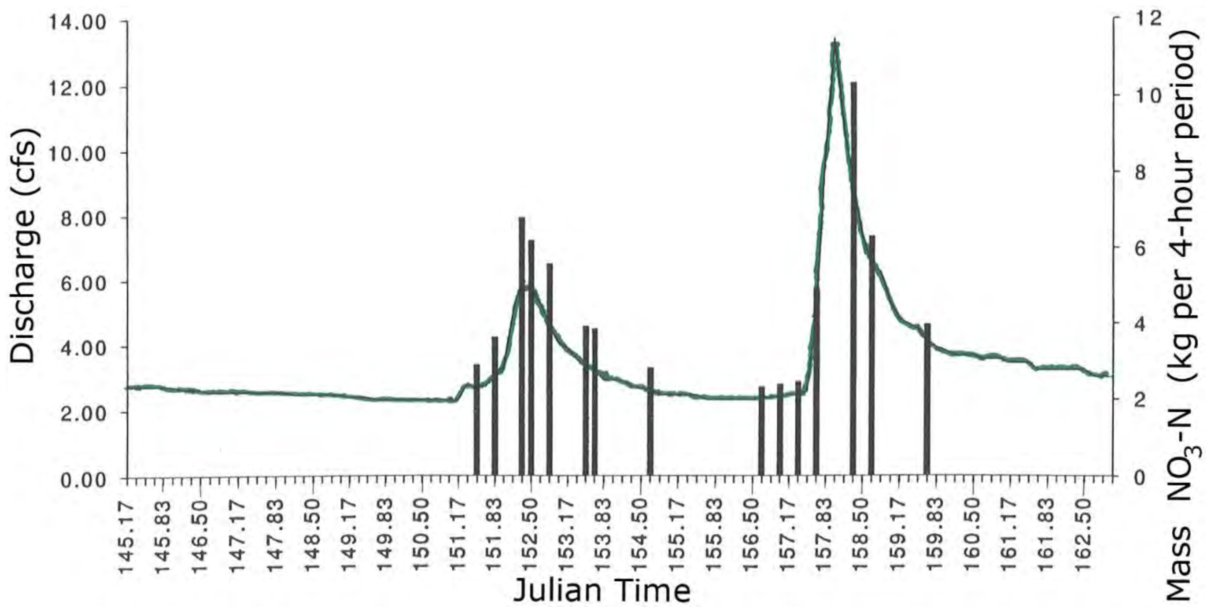


Figure H7-4. Chemograph for nitrate release from Rock Spring. Adapted from Underwood (1994).

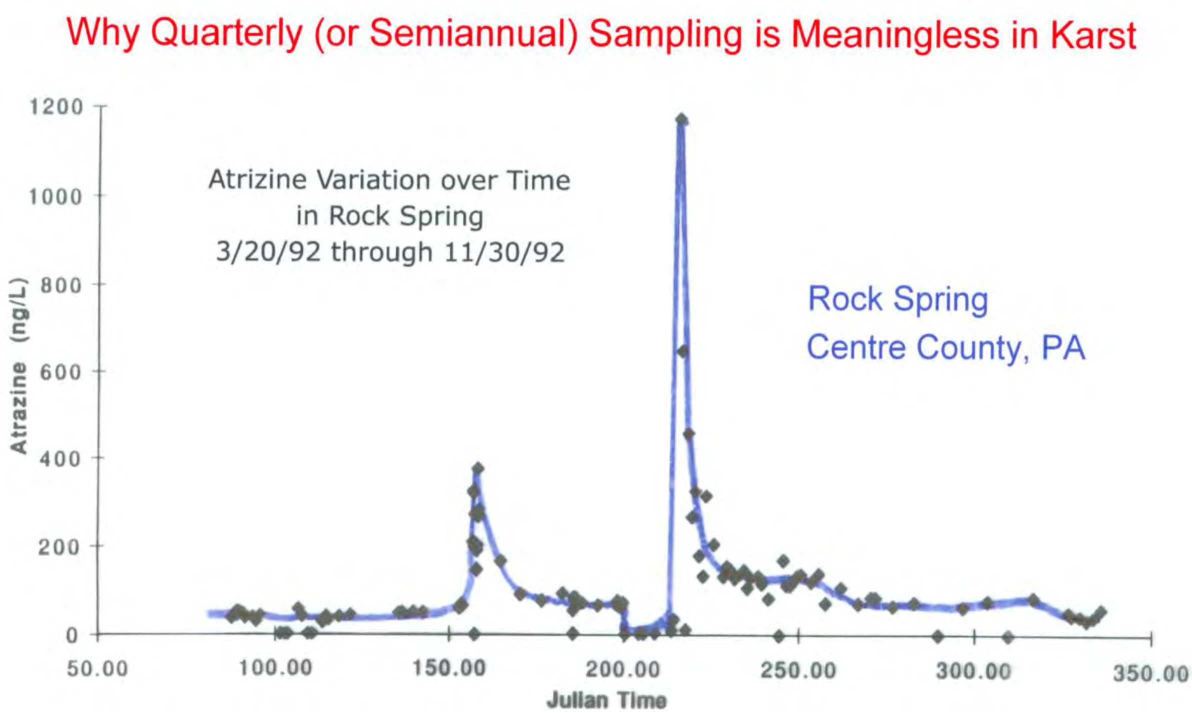


Figure H7-5. Chemograph for atrazine in Rock Spring. Adapted from Underwood (1994).

The hydrogeology and environmental geology of the Rock Spring drainage basin, including portions of the Spring Creek watershed extending westward toward Stormstown, was mapped as part of F. Hunter's M. S. thesis (1977). He was not appraised of a significant lineament that was revealed on recent satellite images: referred to as the McAleys-Port Matilda lineament. Features that reveal this lineament appear wider than the lineament that is believed to control Big Spring (STOP H-4). Gold and Parizek consider it to represent a domain boundary not unlike but smaller than the Mount Union-Tyrone lineament: a deep-seated zone of differential movement and decoupling of strata during Ridge and Valley structural deformation. Figure H7-6 shows Hunter's structural map. It contains 7 times more structural features when compared to the same stratigraphic units a short additional distance away on either side of the lineament along strike. The intent was not to bias his interpretation, attempting to resolve observations made at outcrops. Knowledge of this lineament could have colored its interpretation.

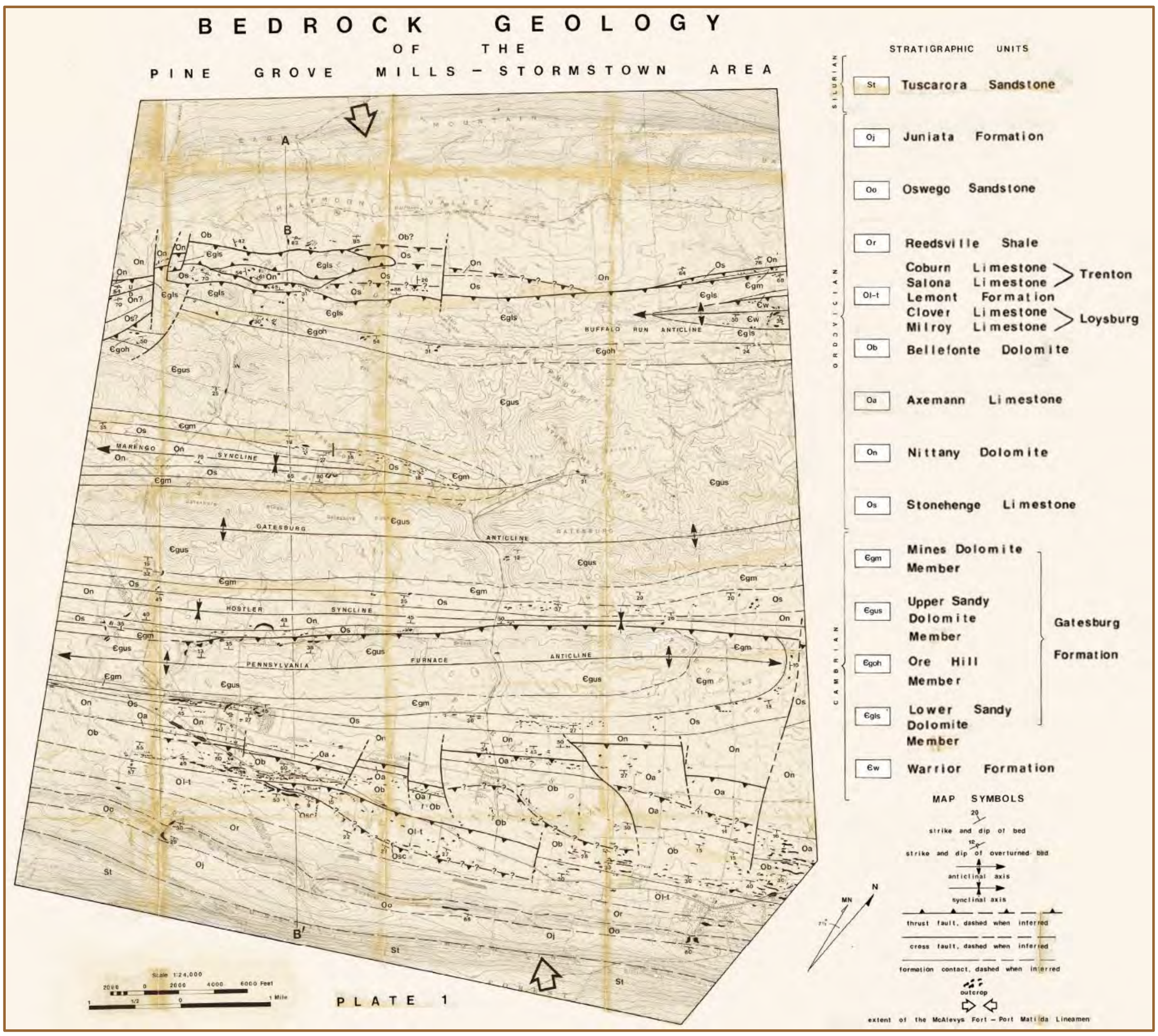
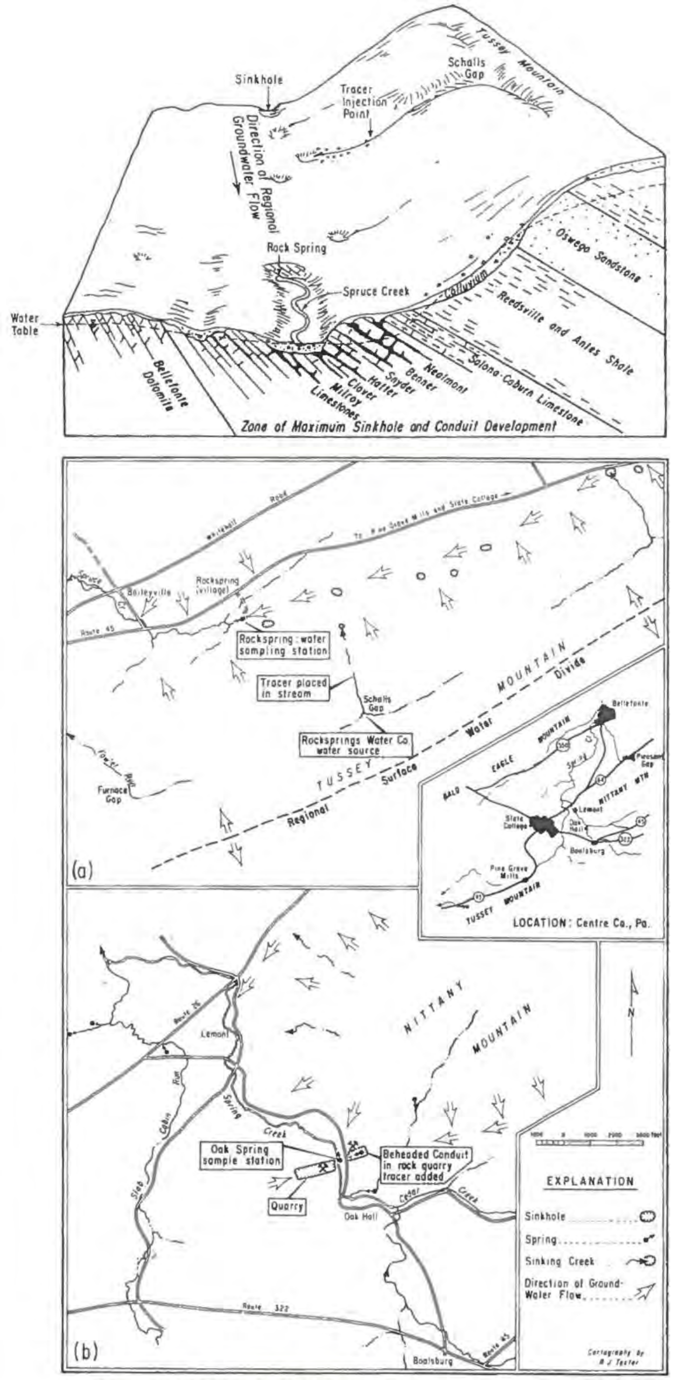


Figure H7-6. Geologic map of the Rock Spring drainage basin (From Hunter, 1977).

It is not apparent how this structural feature might have influenced the hydrogeologic setting but it is associated with water gaps, gaps and sags in ridge tops, sink and swallow holes. The water table configuration shows drainage is influenced by conduits that nourish Rock Spring. Tracer experiments included in Underwood's M.S. thesis and conducted by Smotzer et al. (1974) show conduit control (Figure H7-7).

It is instructive to evaluate merits and limitations of geophysical techniques when tested against known features. Whittemore (1971) for example, conducted VLF electro magnetometer surveys across lower portions of Rock Springs watershed near Rock Spring. Systematic patterns in in-phase and quadrature values for positive and negative polarities where apparent. Similar patterns appeared on adjacent profiles moving away from Rock Spring. They parallel stratigraphic strike and are consistent with bedding plane controlled conduit development expected within steeply dipping strata. Contrast between limestone and shaley limestone were apparent in the transition between limestone and shales of the Salona-Coburn Formations.



Location of Rock Spring (a) and Oak Spring (b) discharge points showing tracer input point and their relationship to regional groundwater flow systems.

Figure H7-7. Tracer experiments conducted for Oak Hall Spring and Rock Spring using post-activation analysis of Bromine (Schmotzer et al., 1974).

Temperature profiles were established in the vicinity of Miller Cave using one-meter deep equally spaced drill holes (Ebaugh, 1973). Pipes were set in boreholes to a standard depth. Heat flow theory was used to compute the magnitude of temperature anomaly expected given timing of the annual solar sine wave v geothermal gradient, depth of observation, diffusive properties of soil and limestone, perturbations expected for cavities of various size and depth. Seasonal water temperature anomalies were far greater than those predicted by theory but none the less faithfully delineated voids. It is important however, to know the reasons for favorable predictions. In this case, concentrations of vadose water were infiltrating into fracture networks above Millers Cave greatly magnifying the seasonal geothermal signal. It was the seasonal concentration of seepage not the cave that accounted for temperatures. The fracture network however, was connected to the cave.

Other geophysical methods were evaluated in this same general area by graduate students in the former Department of Geology and Geophysics, now Geosciences.

During Friday's stop at the Overlook on Tussey Mountain, Parizek showed how excess storm water from Schalls and other gaps could be captured, piped beyond these conduit zones for recharge within central valley carbonate aquifers. Injection wells would be the most efficient means of artificial recharge with little disturbance of surface property. However, recharge basins might be attractive to address quality concerns. This passive system would require construction of a small impoundment in the gap using a water skimming design that would accept inflows to a transmission line only when storm flows exceeded a given value. The system would cease to operate following a predetermined water stage-value. This water would continue to maintain aquatic ecosystems that extend into swallow holes and beyond.

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STOP H-8: API TECH FACILITY NEAR SILVI BASEBALL COMPLEX

CHLORINATED SOLVENT GROUNDWATER CONTAMINANT PLUME REMEDIAL SITE

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Description **(40.774993°, -77.880937°)**

Site H-8 is an active manufacturing facility (former MuRata Electronics site, now API Technologies) where the historic use of chlorinated solvents resulted in a groundwater contaminant plume of tetrachloroethylene, trichloroethylene, and associated degradation products. The site is underlain by the Nittany Dolomite, which is one of the principal groundwater supply target formations in the region. Typical depths to groundwater at the site are between 30-70 feet below ground. The site sits near the head of the watershed and historic mapping of groundwater flow in this vicinity is toward the north/northeast (Giddings, 1976 and Taylor, 1997). Groundwater contaminants were discovered in several downgradient private wells during the 1980s, which led to the site investigation to delineate the extent of chlorinated solvents at this site. Figure H8-1 below shows the approximate extent of the groundwater contaminant plume along with several key wells involved with the site's groundwater remediation system.

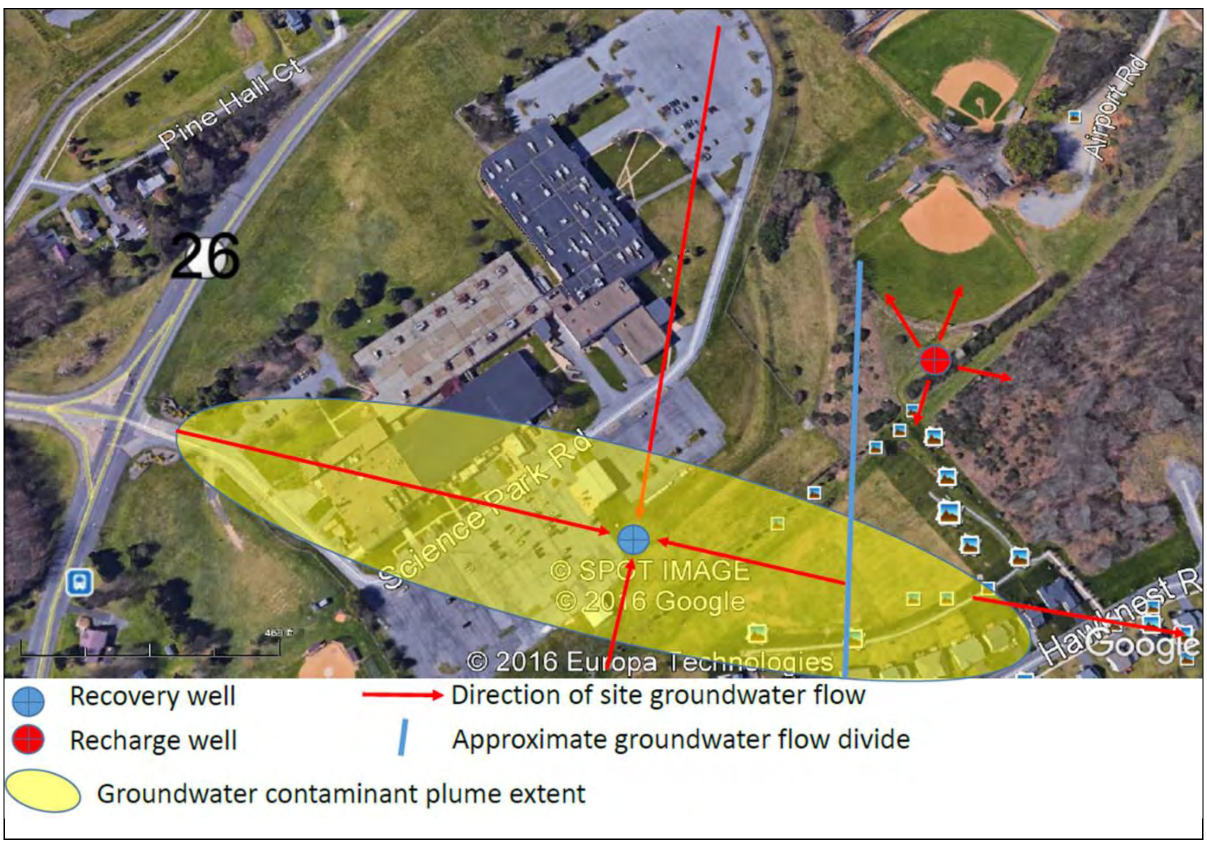

Figure H8-1. Site map showing the former MuRata Electronics facility near State College along with the estimated extent of the groundwater contaminant plume and associated remedial wells.

A recovery well was installed in 1994 using fracture trace analysis in order to intercept the highest concentrations of contaminants in a more highly transmissive zone of the aquifer. The recovery well was installed to a depth of 227 feet below ground and completed as an open rock borehole between 158-227 feet below grade. Figure H8-1 shows the location of the recovery well, which was installed as part of the groundwater pump and treat system. The recovery well did intercept the highest concentrations of PCE and TCE groundwater at the site (approximately 500-1,000 ug/L). Initially the well was tested at a rate of 244 gallons per minute and an existing sinkhole on the site was used to recharge the aquifer with treated groundwater. Contaminated groundwater continues to be recovered and treated using granular activated carbon. Ultimately a groundwater recharge well (Class V injection well) was installed to better control the plume by creating a groundwater mound along the eastern portion of the site. The groundwater recovery system is typically operated at a rate of 100 gallons per minute, which creates a capture zone that encompasses the majority of the groundwater plume. Contaminant concentrations have decreased in site recovery and monitoring wells, but still do not meet the target remediation levels of 5 ug/L for both tetrachloroethylene and trichloroethylene, therefore the remediation system presently continues to operate. The system does achieve the goal of containing the plume primarily on the site's property, therefore preventing future migration of contaminants in groundwater. To date the system has pumped over a trillion gallons of groundwater and several tons of volatile organic compounds have been recovered.

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