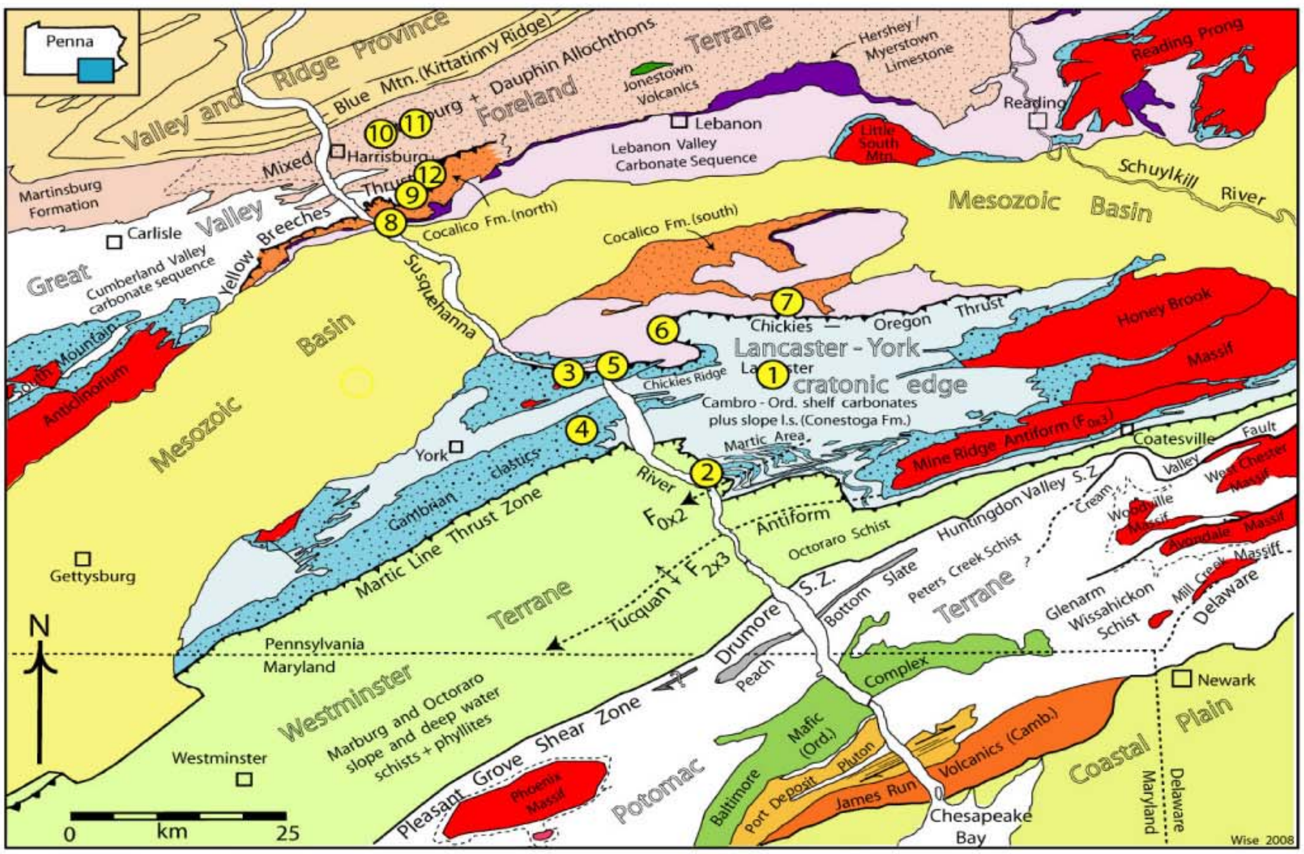
GUIDEBOOK

Tectonics of the Susquehanna Piedmont

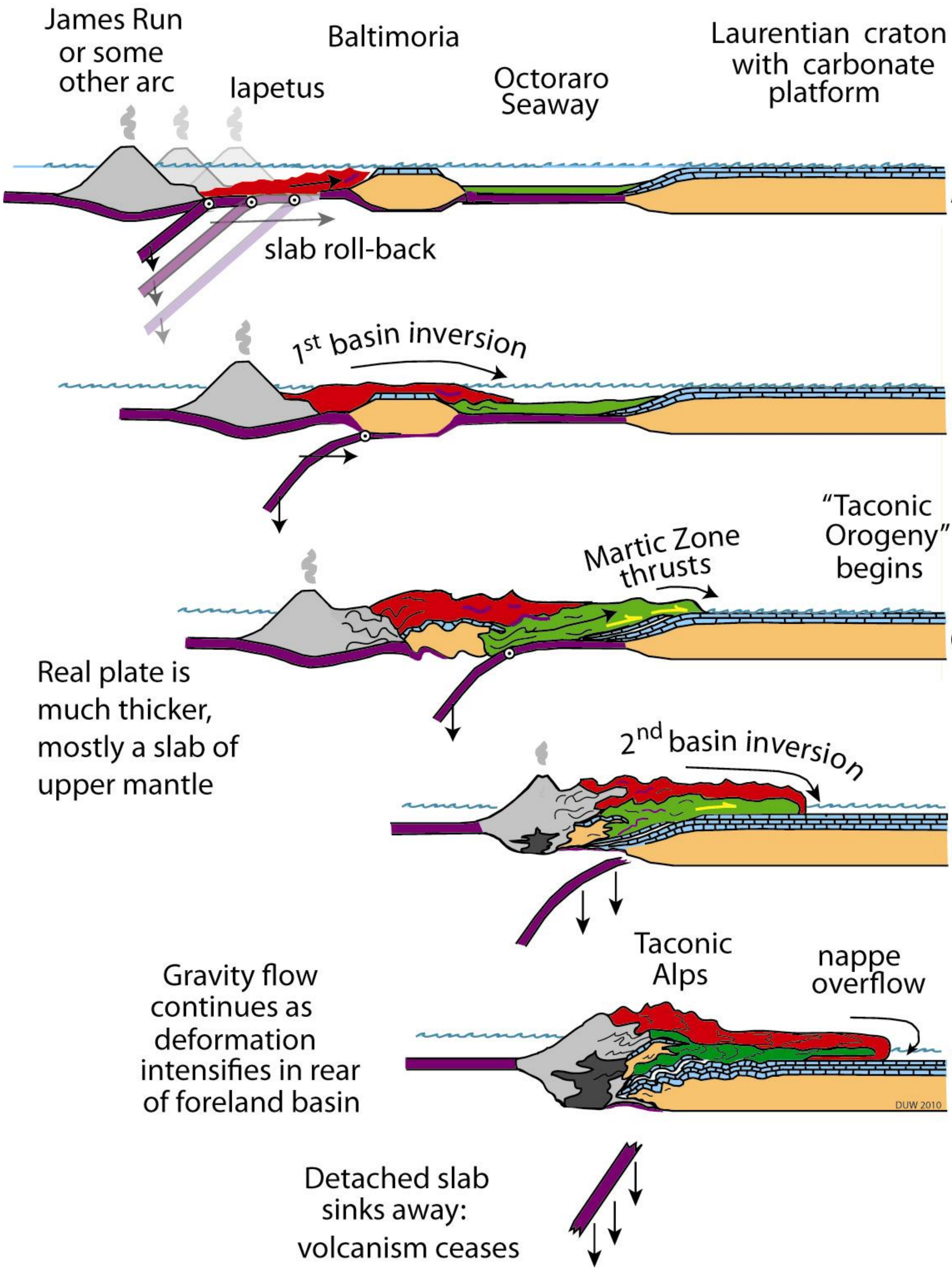


in Lancaster, Dauphin, and York Counties

75th Field Conference of Pennsylvania Geologists

September 24, 25, 2010
Lancaster, Pa.

Organized and hosted by the Pennsylvania Geological Survey


James Run
or some
other arc
Baltimoria
Iapetus
Octoraro
Seaway
Laurentian craton
with carbonate
platform
A
slab roll-back
1st basin inversion
B
Martic Zone
thrusts
"Taconic
Orogeny"
begins
C
Real plate is
much thicker,
mostly a slab of
upper mantle
2nd basin inversion
D
Taconic
Alps
nappe
overflow
Gravity flow
continues as
deformation
intensifies in rear
of foreland basin
E
DUW 2010
Detached slab
sinks away:
volcanism ceases

Tectonics of the Susquehanna Piedmont

in Lancaster, Dauphin and York Counties, Pa.

2010 Guidebook

75th Field Conference of Pennsylvania Geologists

Chair: George E. W. Love
Vice-Chair: Tom G. Whitfield
Secretary: Jamie Kostelnik
Secretary -Treasurer, Emeritus: Gary M. Fleeger

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Robert C. Smith II
Roger D. K. Thomas
Donald U. Wise

September 24-25, 2010
Lancaster, Pa.

Organized and hosted by the Pennsylvania Geological Survey

SOME TECTONIC AND STRUCTURAL PROBLEMS OF THE APPALACHIAN PIEDMONT ALONG THE SUSQUEHANNA RIVER

By: O. P. Bricker
C. A. Hopson
M. E. Kauffman
D. M. Lapham
D. B. McLaughlin
D. U. Wise

Edited by: D. U. Wise and M. E. Kauffman

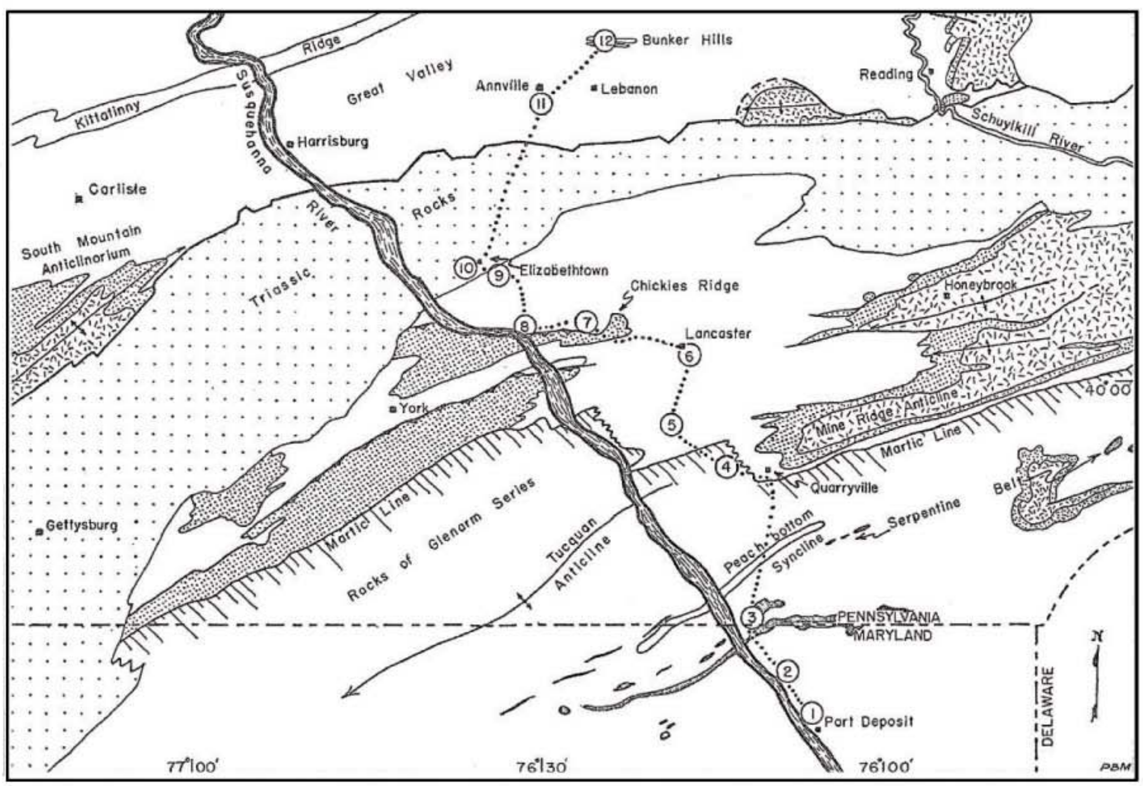
25th FIELD CONFERENCE OF PENNSYLVANIA GEOLOGISTS
Ocrober 22-23, 1960

Hosts: Department of Geology
Franklin and Marshall College
Lancaster, Pennsylvania

1960

This guidebook is available on line at the FCOPG web-site

(As are other past field trip guidebooks)



Dedication of this 2010 Tectonics Symposium and Guidebook

Geologic mapping of this region by George Stose, Florence Bascom, Anna Jonas (Stose), and Elenora Bliss (Knopf) in the 1900s through the 1930s allowed them to develop tectonic syntheses and interpretations of the Susquehanna Piedmont far ahead of their times. Their tectonic syntheses and maps were radical. In an era when even the existence of great overthrusts was hotly debated, many geologists found such models beyond belief. The idea that the Martic Zone involved a great overthrust was bad enough; making the entire Reading Prong a completely allochthonous thrust sheet bordered on geologic insanity. Since then revolutions in geologic thinking and methods have elevated those early outrageous models to the status of (almost) proven facts.

Had Stose not been the map editor of the USGS, most of these tectonic syntheses probably would never have been published. He started as a field assistant in the last days of Powell's tenure and was honored in the 1950s for 75 continuous years of service with the USGS, maturing his thinking during those years. Today we should recognize the pioneering efforts of those early field geologists. Their work, quadrangle by quadrangle, stratigraphic unit by unit, is still easily recognizable within today's stratigraphic names and modern geologic maps. Their ideas have also withstood the test of time. Not only did they see and interpret far more geology of the overall region than their predecessors ever did nor their successors likely ever will; they also integrated those myriad details into imaginative tectonic sketches, texts and maps still well-worth detailed study. In putting together some of the data and ideas in this volume, I have again read much of their work and have been repeatedly surprised at the advanced level of much of their thinking. There is far more in those works than first meets the eye.

When this conference had its first of 75 trips in 1931 (four years were missed during WWII) such tectonic models really were near the lunatic fringe. When Ernst Cloos led a Field Conference trip in 1949 to the famous New Providence Railroad cut where Wissahickon Schist rests on Conestoga Limestone, even he was unwilling to apply either "thrust" or "unconformity" to that contact despite his superb mapping that showed five underlying stratigraphic repetitions that he was willing to call "thrusts." However by the 1960 field trip many of those previously "outrageous" tectonic ideas and models of the early workers were beginning to be more widely accepted. Now as this conference, a half century later, tries to make sense of a host of new field observations, radiometric and fossil dates, petrology, geochemical signatures, geophysics, structural fabrics and plate models, many of those early "outrageous" ideas appear prophetic. The problems now focus on how plate tectonic processes created the complex Susquehanna orogenic salient by jamming and overprinting a succession of mountain systems into a rifted corner of the North American craton.

At the diamond anniversary field trip of this conference and the golden anniversary of the "Tectonic Cross-section of the Piedmont" 1960 field trip, it seems appropriate to dedicate a tectonically-oriented guidebook to those pioneers who laid the map, stratigraphic, and tectonic foundations upon which we build our modern, and possibly "outrageous" tectonic syntheses.

Don Wise, September, 2010

Group Photo of the 2009 Field Conference of Pennsylvania Geologists at the Drake Well (STOP 6)
Photo by Yuriy Neboga

History of the Field Conference of Pennsylvania Geologists

The 75th Field Conference seems a good occasion for a brief look in the mirror. This short history is slightly modified and updated from a history written for the 50th Field Conference in 1985 and included in a commemorative reproduction of the first Field Conference Guidebook distributed at that meeting.

The history of the Field Conference of Pennsylvania Geologists is told through the road logs, stop descriptions, receptions, and informal talks that became the pattern of each of the trips. This pattern was established in 1931 by C.A. Bonine, graduate of Lehigh University and Professor of Geology at The State College of Pennsylvania, who was the organizer and originator of the Field Conference. Bonine's desire to "become better acquainted with the other geologists located or working in Pennsylvania" became a major objective of the Conference. This objective has been well met at the subsequent meetings of the Conference, as it has guided geologists to share their knowledge and to look at new interpretations of geological phenomena throughout our Commonwealth.

Of the several field conferences held annually in the northeastern U.S. (see web sites at http://fcopg.org/negeotrips/), the Field Conference of Pennsylvania Geologists is a "johnny-come-lately." The first of these conferences was held in 1901, led by William Morris Davis, to become what is now the New England Intercollegiate Field Conference. The New York Geological Association held their first field trip in 1924, and not to be outdone, what we now call Quaternary geologists held their first meeting as the Friends of the Pleistocene (the original, now called NE to distinguish from several other regional FOPs). All have followed the same organizational pattern of minimizing bureaucracy and maximizing visits and discussion at "the outcrop."

The success of the Conference is the result, for the most part, of the willing volunteer efforts of geologists of the colleges and universities of Pennsylvania and our nearby states, the Pennsylvania Geological Survey and nearby State Geological Surveys, the U.S. Geological Survey, and geologists from our industrial mineral and fossil fuel companies, as well as many other individual geologists. Some 347 geologists have been leaders on at least one trip, and a number have been leaders for several. From the beginning, these geologists have prepared detailed road logs and carefully written stop descriptions published as the guidebook for each trip, and have provided able instruction at each stop to explain Pennsylvania's complex geology in the most current interpretation.

Meetings have been held each year since 1931, with the exception of 1942 to 1945, which was due to limitation on travel during World War II, and in 1957, when 18 months elapsed between the October, 1956 meeting in New Jersey and the Spring 1958 meeting in Maryland's South Mountain.

Officers

At the second meeting, hosted by Lehigh University, bylaws were adopted which included the appointment of a permanent Secretary-Treasurer "who must be a member of the Pennsylvania Geological Survey" so as to provide continuity of scheduling, and maintaining records and finances. These bylaws continued in force until 1978 when the Conference incorporated as a Pennsylvania domestic non-profit corporation. The new corporate bylaws created an Executive Committee composed of a Chairman, a Secretary-Treasurer, and the Local Committee Chairman; the first two officers must be members of the Pennsylvania Geological Survey, again to provide continuity.

Dr. Bradford Willard was the first officer and continued as Secretary-Treasurer until 1935. Dr. Lawrence Whitcomb was the Conference officer in 1936 for the sixth annual meeting, conducted by Lehigh University geologists. The sixth conference is significant as the only combined conference held with the New York State Geological Association. Dr. Arthur B. Cleaves assumed the permanent office during 1937 and 1938 and was then replaced by longtime Pennsylvania Geological Survey member Marchant N. Shaffner, who remained in this office for nearly two decades. He was followed by Alan Geyer and Donald Hoskins, who became Secretary-Treasurer in 1967. Upon incorporation in 1978, Arthur Socolow was elected Chairman at the annual meeting of the Conference. In 1986 William D. Sevon was elected Chairman when Socolow retired from the Pennsylvania Geological Survey. In 1997, Donald Hoskins ended his tenure as Secretary-Treasurer to become Chairman. Gary M. Fleeger succeeded him as the first new Secretary-Treasurer in 30 years. At Donald Hoskins' announced retirement in 2000, William Kochanov was elected to complete Hoskins' term as Chairman.

In 2004, the by-laws were amended to increase the number of officers to four current or retired members of the Pennsylvania Geological Survey- Chairman, Vice Chairman, Secretary, and Treasurer. The term of office was reduced to two years. The intent is that each officer will serve in each position for two years, for a total term of service of eight years. The officers elected in 2004 were William Kochanov (Chairman), John Harper (Vice Chairman), Gary Fleeger (Secretary), and Lynn Goodling (Treasurer).

In 2006, John Harper became Chairman, Jaime Kostelnik, Vice Chairman, William Bragonier, Secretary, and Lynn Goodling remained the Treasurer.

2008's officers are George Love (Chairman), Tom Whitfield (Vice Chairman), Jaime Kostelnik (Secretary, after Bragonier wussed out after only 2 years), and Lynn Goodling (Treasurer).

Transportation

Field trips during the first 25 years of the Conference were largely by individual auto, usually with State Police escorts. Minutes of the fifth meeting in Philadelphia state "Despite the size of the party [86] and the necessity of moving a motorcade of 25-30 cars through the thickly settled Philadelphia district, the trip was handled without difficulty, thanks to a trained escort of the Pennsylvania State Highway Patrol." Private cars were used until the middle 1950s when buses were chosen for some of the individual trips in 1954, 1955, and 1959. In 1960, for the 25th conference, a caravan of some 45 vehicles traversed Lancaster County. Students in the lead vehicle had flags and were dropped off at each intersection to hold traffic as the caravan moved through, then were picked up by a following vehicle only to begin the process over again at each stop. Since the meeting of 1963, buses have been used in preference to individual cars because of logistical problems as Conference attendance grew. With the one exception in 1967 when one of the buses was struck while parked, no serious accidents have occurred.

Times have changed Field Conference traditions. One tradition of the Field Conference for many years was beer at lunch and at an afternoon refreshment break. Gradually, the amount of beer consumed was reduced and the amount of water and soda increased, until, in the 1990s, more soda and water were consumed than beer. Also, by the 1990s, many of the lunch stops, usually public facilities such at state parks, disallowed alcoholic beverages. By the late 1990s, liability concerns and the cost or availability of insurance eliminated the serving of beer during the field trips. New officers, pledging to bring beer back to the Field Conference soon learned that it was beyond their control.

Time of year

Until 1956, the conferences were held in late May and early June, usually over the Memorial Day weekend. In 1956, the meeting was held in late September. The next two meetings in 1958 and 1959 were held in May. Following those years, the Conference has met consistently in the Fall in order to avoid difficulties of scheduling around college graduation days. Since 1963, the Conference has usually met on the Thursday, Friday, and Saturday of the first weekend in October.

Attendance

Attendance on the trips started with 45 in 1931, gradually growing to 99 in 1936, and then fluctuating in the low to middle 100s until 1967, when a record 183 attended. This figure was exceeded in 1981 when, for three years in succession, over 200 attended with the record being 343 in 1985, the 50th anniversary trip. In recent years, the attendance has usually been between 100 and 150.

Starting in 1990, CEUs (continuing education units) could be earned by teachers and others for attending the Field Conference. Now that as of 2010 continuing education is required of registered geologists, these CEUs will help PGs meet the requirements.

Subjects of the Conferences

Subjects of the Conferences have usually centered on the research interests of the host organizations. Areas visited on more than one occasion have been Centre County, the Philadelphia and Pittsburgh areas, the Harrisburg-York-Gettysburg area, Lancaster County, the Allentown-Bethlehem-Easton area, the Wyoming-Lackawanna Valley, and along our major highways and rivers where outcrops are more prevalent. Areas that have not often been visited are the northern tier of counties and southwestern Pennsylvania, with several counties having never been traversed. The record of the Conference shows that revisits to areas of former trips are productive, as the dynamics of geology require the application of new interpretations to old and familiar outcrops.

Host organizations

Host organizations vary widely. Early trips were hosted by one institution, but most have been hosted by multiple organizations. Credit for these through the 75th Field Conference in 2010 goes to (number of conferences in parentheses):

Pennsylvania Geological Survey (43), Pennsylvania State University and its predecessor, State College (9), Lehigh University (5), New Jersey Geological Survey (5), Bloomsburg University (4), U.S. Geological Survey (4), Bryn Mawr College (4), Pittsburgh Geological Society (4), Franklin and Marshall College (3), University of Pittsburgh (3), Carnegie Institute of Technology (2), Dickinson College (2), Edinboro State College (2), Lock Haven University (2), Lafayette College (2), Maryland Geological Survey (3), Mercyhurst College (2), Slippery Rock University (2), University of Pittsburgh- Johnstown (2), West Chester University (2).West Virginia Geological Survey (2), Academy of Natural Sciences of Philadelphia, Anthracite Heritage Museum, J.E. Baker Company, Carnegie Museum of Pittsburgh, Concord College, Delaware County Christian School, Delaware Geological Survey, East Tennessee State University, Eastern Industries, Eckley Miners' Village, Elizabethtown College, Everhart Museum, Excalibur Group, LLCGeorge Washington University, Hobart and William Smith Colleges, Johns Hopkins University, Juniata College, Lafarge Corporation, LaSalle College, Luzerne County Community College, Mansfield State College, Millersville University, Mountain Research, LLCNational Park Service, National Science Foundation, New Enterprise Stone & Lime Co. New Jersey Division of Water Resources, New York State Museum, Ohio State University, Ohio Wesleyan College, PA DEP Bureau of Watershed Management, Princeton University, Ricketts Glen State Park, Rider College, Rutgers University, Spitzenburg Hoch Ergiehunganstalt, SUNY College at Fredonia, Susquehanna County Historical Society, Susquehanna University, Tethys Consultants, Inc., University of North Carolina, University of Pennsylvania, University of Pittsburgh- Bradford, Villanova University, and the Virginia Geological Survey.

Support

Logistical and occasionally financial support of the Conference has been given cheerfully by industry and a few individuals from the early years. Conference records show that the Gulf Research and Development Corporation of Pittsburgh hosted the first complimentary smoker at the fourth annual conference held in 1935 in Pittsburgh. Support to the Conference over these many years has been provided by:

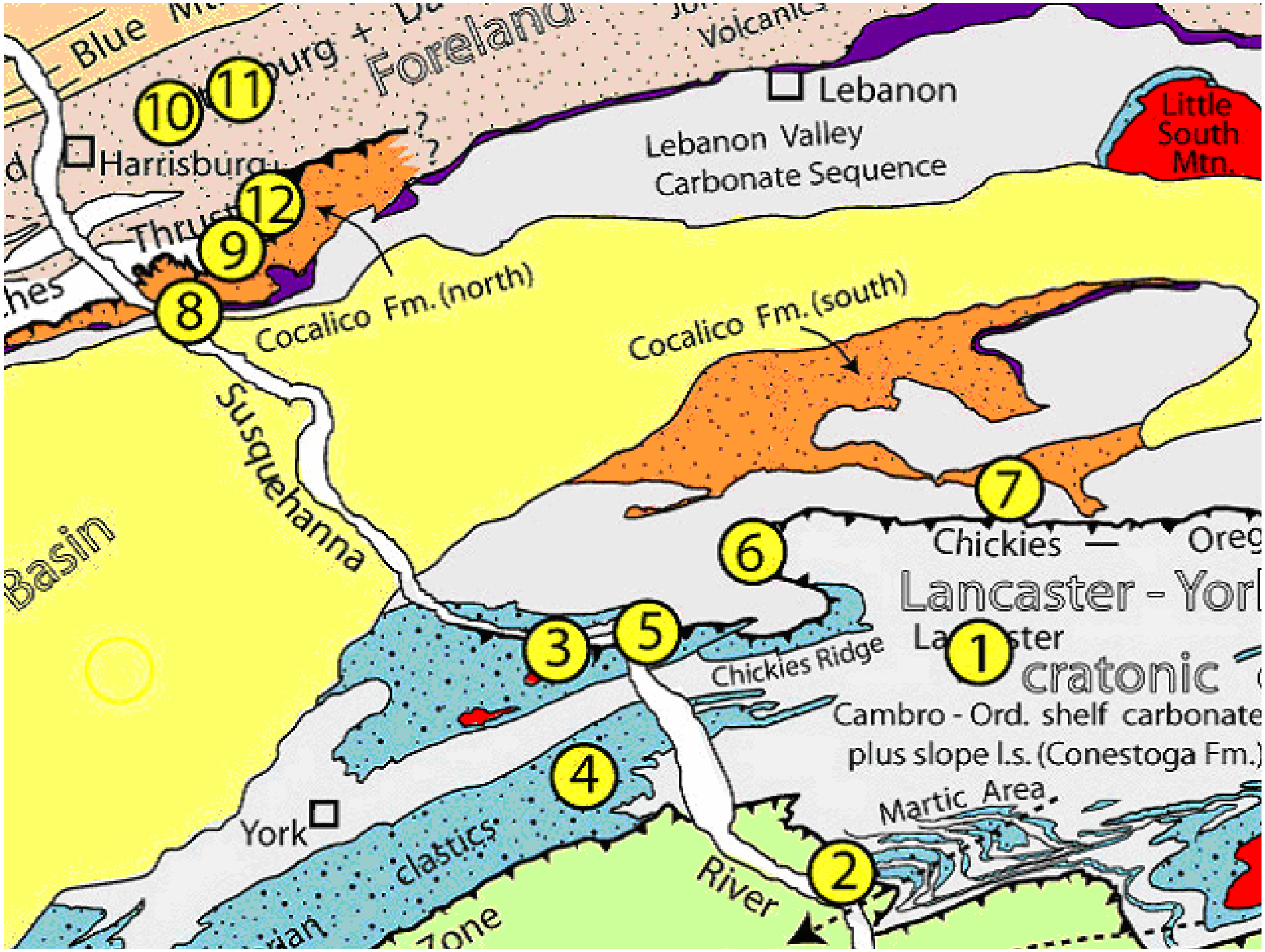
A.B. Crichton, Aero Service Corporation, Allegheny Minerals Corp., Alpha Portland Cement, Atlantic Refining Company, the J.E. Baker Company, Michael Baker Associates, Benatec Associates, Benders Quarry Company, Bendix Field Engineering Corporation, Bethlehem Steel Company, Brockway Glass, Calcite Quarry Company, Ceco Associates, Inc.,

Chevron Resources Company, Cummings Riter Consultants, D'Appolonia, Datum Products, DLZ Construction, Dunn Geoscience Corporation, Dupont Corporation, Ecoscience, Eichelbergers, Inc., Mrs. Marion Escallon, Eshenaur's Quarry Company, Fairway Laboratories, Inc.GAF Corporation, J.T. Galey, Geomechanics, Geo-Technical Services, Inc., Gannett-Fleming, Inc., Geo-Graphics, Etc., Geoscience Engineering Co. Inc., Groundwater & Environmental Services, Inc., GTS Technologies, Inc., Carlyle Gray & Associates, Mr. Ben Greeley, Harrisburg Area Geological Society, HDR, Hotel Easton, Hudson Coal Company, Hydro-Geo Services, Inc., Ingersoll-Rand Company, International Exploration Company, Kendall Oil Refinery, Key Environmental, L. Robert Kimball and Associates, Lafarge Corporation, Lehigh Navigation Coal Company, SMC Martin, Inc., H.E. Millard Lime and Stone, Mountain Research, Inc., New Enterprise Stone & Lime Co., New Jersey Zinc Company, Northeastern Environmental Associates, Samuel T. Pees and Associates, Inc., Pennsylvania Bluestone Association, Pennsylvania Drilling Company, Pennsylvania Oil Producers Association, Peoples Natural Gas Company, Petroleum Reclamation Company, Philadelphia Clay Company, Philadelphia and Reading Coal Company, Pennsylvania Drilling Company, Philadelphia Geological Society, Pittsburgh Association of Petroleum Geologists, Pittsburgh Geological Society, Mr. Jack Purvis, Quaker State Refining Company, Reading Railroad, Rebor Sand and Coal Company, Sheetz, Showalter's Quarry Company, Snyder Brothers Coal Co., South Penn Oil Company, State Aggregates, Inc., Sun Oil Company, Tethys Geotechnical Consultants, Thomasville Lime and Stone Company, United Natural Gas, Wellsboro Chamber of Commerce, Wolf's Head Oil Company, and R.E. Wright Associates.

Past Field Conferences

Guidebooks from recent Field Conferences are available at http://fcopg.org. Out of print guidebooks are also available there on a DVD.

Table of Contents



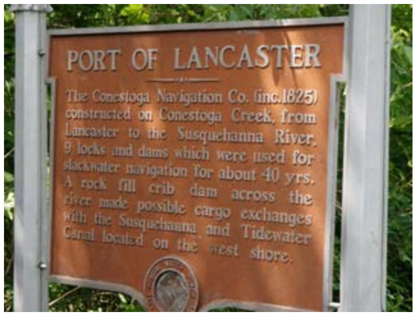
Stop locations for the
75th Field Conference of Pennsylvania Geologists

Day 1

Interval Mileage	Cumulative Mileage	Description
0.00	0.00	Start on Vine St. Turn right on South Queen. .Southern Market is on the left, one of five markets that used to serve Lancaster. Central and Eastern markets are still active.
0.10	0.10	Turn right on East King, Annie Bailey's pub on right
0.20	0.30	Turn left on North Lime. Lancaster Museum of Art and Musser Park on right. Note Triassic sandstone spheres at entrance to the museum
0.40	0.70	Turn right on East Lemon
0.10	0.80	Turn left on New Holland. Cap and Cork restaurant/bar on right, next to Science Factory
1.20	2.00	**STOP 1 Burle Industries site**- exit bus and walk to south where outcrops are located. Reboard bus promptly.
1.00	3.00	Turn left on New Holland
0.10	3.10	Turn left on N Plum
0.60	3.70	Turn right on E Walnut St----------------->
1.40	5.10	Turn left on N. Prince St- note Pho and Billiards shop. This is Gallery Row where many art galleries are located. On the left is the Lancaster Historical Trust which is in the same building visited by Lewis and Clark. Connie and Davids locally made ice cream on left. Worth it. Next to that, Prince St. Café open late on Friday evenings. Fulton Opera house on right. This is the site of the Paxton Boys' massacre of Native Americans who were under the governor's protective custody. Benjamin Franklin wrote that the Conestogas would have been safe among any other people on earth, no matter how primitive, except "the CHRISTIAN WHITE SAVAGES of Peckstang and Donegall!"
5.20	10.30	Turn right on New Danville Pike
3.60	13.90	Silver Mine Road/Main St
0.40	14.30	Turn left on River Road
0.20	14.50	Turn right on Powerhouse Rd. to parking lot

Interval Mileage | **Cumulative Mileage** | **Description**

STOP 2 Safe Harbor

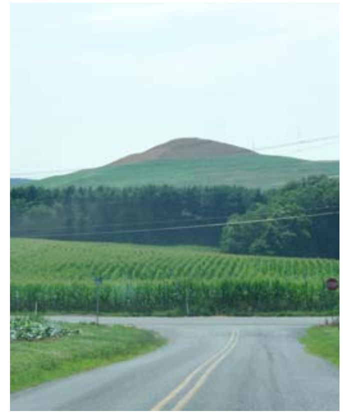


Gravity in effect in this region.

0.30	14.80	Take Powerhouse Rd to River Road
0.70	15.50	Turn left on River Rd.

Safe Harbor Village- two blocks of suburbia in the idle of the woods. Company town.

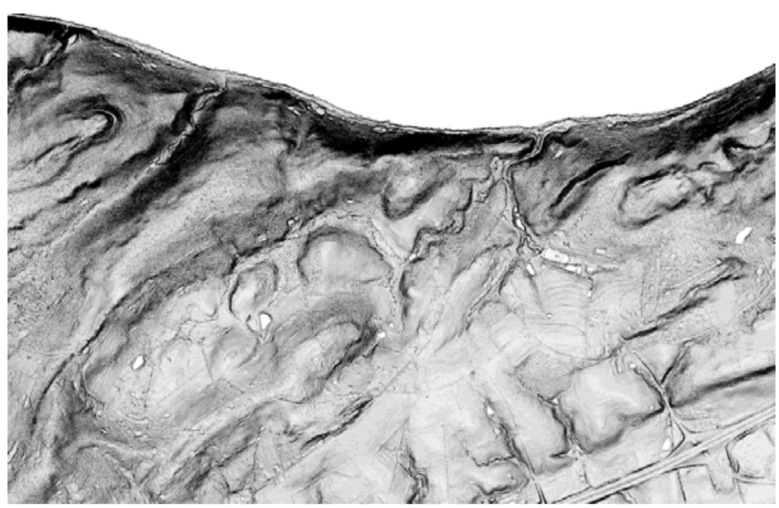
Interval Mileage	Cumulative Mileage	Description
2.80	18.30	Turn left, cross bridge
0.70	19.00	Turn right - continue on River Road
2.90	21.90	Turn left at Letort Road (stay on River Road) Turkey Hill and the landfill are ahead on left
2.60	24.50	Turn left at Herr St-stay on Water Street



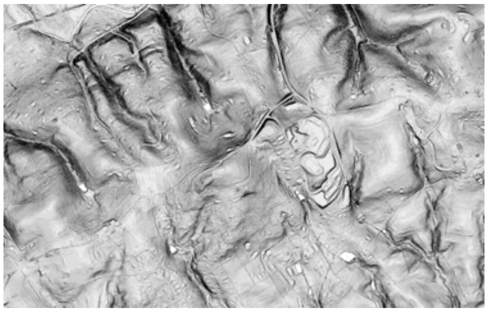
Frey Farm Landfill

Charcoal burn locations on extreme right of photo

1.00	25.50	Continue on S Front (no turn-just a name change)
0.20	25.70	Turn right on Locust
0.60	26.30	Turn left on N 3rd St
2.40	28.70	Turn right onto Rt 30
0.20	28.90	Exit on right at Wrightsville Exit
0.40	29.30	Turn right on Cool Springs Rd
0.90	30.20	Turn left at Dark Hollow Rd
0.40	30.60	Turn right on Accomac Rd
		STOP 3 Accomac Inn- once considered to be part of Maryland (1722)



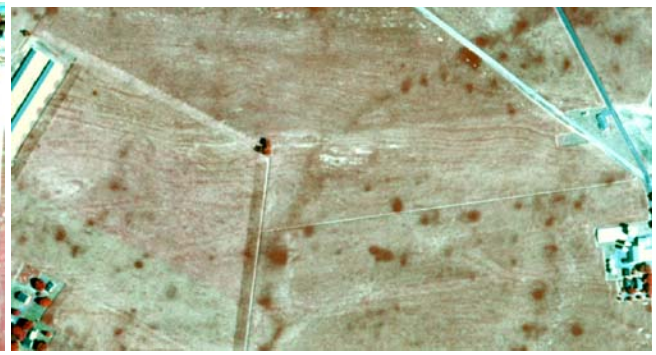
Interval Mileage	Cumulative Mileage	Description
0.40	31.00	Turn right on Accomac Rd
0.90	31.90	Turn left at Dark Hollow Rd
1.20	33.10	Turn right on Cool Springs Rd
1.50	34.60	Cross Rt 30 stay on State Rt 2011
0.60	35.20	Turn right on Mt Pisgah Rd. La Casa de David is on the right with world's largest stack of fake rocks. Left into Park
0.40	35.60	Turn left into Park
		STOP 4 Lunch - Sam Lewis State Park - note joyous effect of Sam Lewis State Park



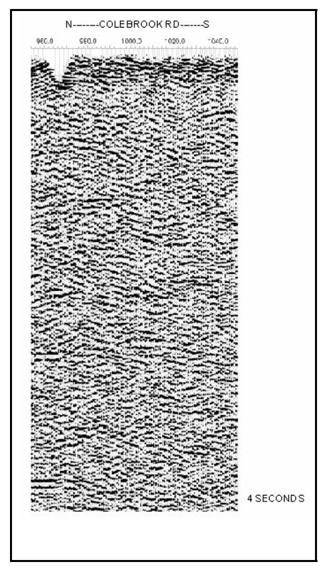
Interval Mileage	Cumulative Mileage	Description
0.50	36.10	Turn right out of park on Mt Pisgah Rd
1.50	37.60	Turn left on Cool Creek
0.70	38.30	Turn right on 462/Hellam St
1.50	39.80	Bear right to enter bridge. The bridge foundations on the left remain from the bridge burned by citizens on the eve of the Battle of Gettysburg, who feared the Confederates would cross and pillage Lancaster. The Union army encouraged citizens to do the burning because if the army burned the bridge, the government would be required to pay for the loss
2.10	41.90	Turn left on 441 (note mural on right depicting the famous Columbia Watch and Clock Museum)
0.10	42.00	Turn left on third St. Follow Rt 441. Mural on right depicting the famous Columbia Watch and Clock Museum
6.20	48.20	Turn left across traffic onto Old Furnace Rd. Turn around. Turn right onto 441 and pull off to right at outbuildings
		STOP 5 Chickies Rock------------------------>
1.50	49.70	Continue south on 441
0.10	49.80	Turn right at Cedar St to enter Rt 30
2.90	52.70	Merge on to Rt 30
0.30	53.00	Turn right on Prospect Rd exit

Interval Mileage	Cumulative Mileage	Description
4.00	57.00	Turn left on Prospect Rd------>
0.20	57.20	Turn right on Quarry Rd
		STOP 6 Prospect Quarry
0.10	57.30	Northwest on Quarry Rd
0.70	58.00	Turn right on Prospect Rd
2.00	60.00	Continue on Spooky Nook Rd

0.90	60.90	Turn left on Landisville Rd



1.60	62.50	Turn right on S. Colebrook--------------------------->
0.50	63.00	Turn right on 722



3.30	66.30	Turn left-merge onto 283 E
0.01	66.31	Take Fruitville Pike exit
0.30	66.61	Turn right on Prince St
1.10	67.71	Turn left on King
1.20	68.91	Turn right on S Duke
0.20	69.11	Turn right on E Vine
		Return to Hotel

STOP #1: CONESTOGA LIMESTONE AT BURLE INDUSTRIAL PARK

(A Cambrian carbonate slope deposit on the sinking edge of the craton)

Donald U. Wise, Dept. of Geosciences, Univ. of Massachusetts at Amherst

Location: **NO HAMMERS!!! (And please don't trample the plants!)**

Outcrops are 2in the front yard of Burle Industrial Pak on New Holland Ave, Route 23 (in the NE sector of Lancaster) about 1/3 mile SW of the intersection with Bypass Route 30.

Onlap Relationships: Note that on the tectonic map the location of this stop is far inboard or north of the Martic thrust zone that separated the Latest Precambrian- Earliest Cambrian edge of the craton from the deep water Octoraro Seaway to the south. The rather lengthy caption to Figure 1 describes facies relationships associated with this rifted corner.

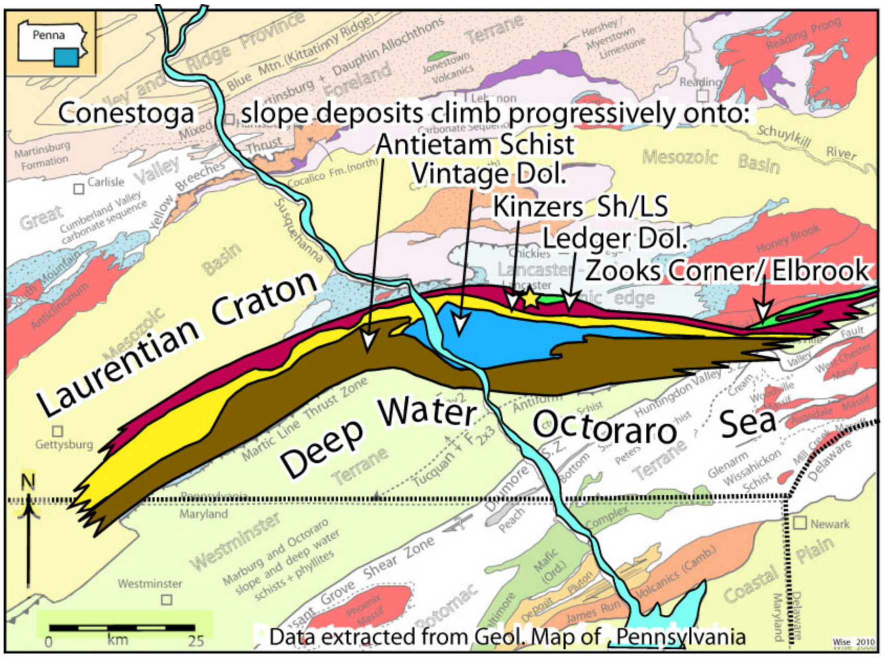


Figure 1. The Susquehanna corner of the Laurentian craton. *Opening of the Latest Precambrian Iaptian Ocean included a major transform fault offsetting the cratonic margin in the region of the present Susquehanna River (Rankin, 1975, Thomas, 1976). The original corner angle was probably near 90º but its transform limb east of the river may have been thrust northward and rotated by about 30 - 45º. Cooling of the hot mantle beneath the original transform may have initiated a protracted period of sinking of part of that edge with a resulting change in trend of the shoreline.*

The Antietam Schist / Quartzite, youngest of the Chilhowee clastics, probably graded downslope into deep-water clastics of the Octoraro Seaway. Later carbonate debris from shallow water deposits on the craton were transported downslope as the oldest part of the Conestoga Formation to interfinger with and cover the Antietam. Sinking continued and platform carbonates continued to accumulate to allow the Conestoga slope deposits to continue their northward and up-stratigraphic climb. The Conestoga progressively covered Vintage Dolomite, Kinzers Shale (in this area), Ledger Dolomite, and Zooks Corner/Elbrook Dolomite. During this onlap, a number of platform carbonate masses broke loose as submarine landslides to form breccia olistostromes within the Conestoga, one to be seen at this stop.

Wise, D.U. (2010) Stop #1: Conestoga Limestone at Burle Industrial Park, *in* Wise, D.U and Gary M Fleeger, eds., Tectonics of the Pennsylvania Piedmont along the Susquehanna River, 75th Annual Field Conference of Pennsylvania Geologists, Lancaster, PA, p. 7 – 12.

Continued sinking: Cooling mantle and sinking of the edge continued through the Cambrian and much of the Ordovician to accumulate another ~ 3 km of Cambrian Conococheague and Beekmantown Group carbonates.

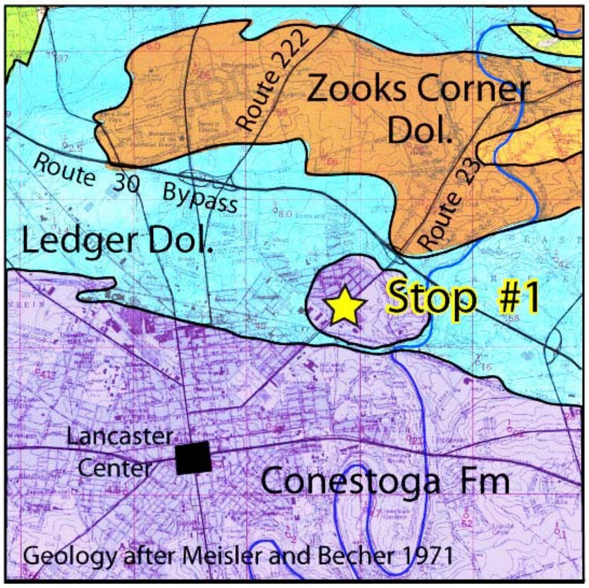


Figure 2. Location of Stop #1 as a submarine slope collapse, here preserved as an outlier of Conestoga Fm. over Ledger Dolomite. *This location (star) is an area of relatively thin Conestoga over Ledger Dolomite, an anomalous area separated from the main Conestoga area to the south by a narrow zone of complex younger fault and fold structures.*

The stop includes exposures of a breccia mass with some apparent Ledger blocks. Nearby quarries at the eastern edge of the outlier have breccia masses that include apparent Ledger blocks up to 5 feet in maximum dimension. Excavations for a new school next to McCaskey High School, about a half mile south in the main Conestoga area, encountered a wide variety of breccia types and interbedded Conestoga lithologies. The contractors used desk-sized blocks of these breccias to build a cyclopian wall behind the athletic field, a visit to which can form a separate olistostrome field trip in its own right.

The evidence is far from conclusive, but a reasonable interpretation would make this anomalous outlier of the Conestoga Fm. part of a massive submarine collapse of the edge of the carbonate platform while the Conestoga Limestone was overlapping the Ledger Fm. Many additional faults and olistostromes, such as the ones at McCaskey High School, were probably a result of headward expansion of the collapsing edge. Lowered elevation within the collapse area has preserved this anomalous area from subsequent erosion.

Outcrops. The Conestoga Formation crops out as a series of low outcrops in front of the Burle Industrial Park**. (Again: Please, no Hammers, no trampled flowers or shrubs!)** At first glance in map view these structures may seem chaotic (Figure 3) with fold axes plunging in both directions at a variety of azimuths while beds thicken and thin, pinch out, etc. until one realizes that most folds plunge more or less consistently toward the southwest. A series of down-plunge sketches of the crops with an "eye-ball averaged" attempt to project their axes into a commonplane results in the much simpler picture of Figure 4. This shows that a stratigraphy totaling about 50 feet is represented in the outcrops. Within it is an upward transition from rather massive and somewhat dolomitic beds in the north to more flaggy, organic rich blue-gray limestones in the central area to breccia masses in the south (Figure 4). More complete lithologic descriptions by R. Thomas are in the following section.

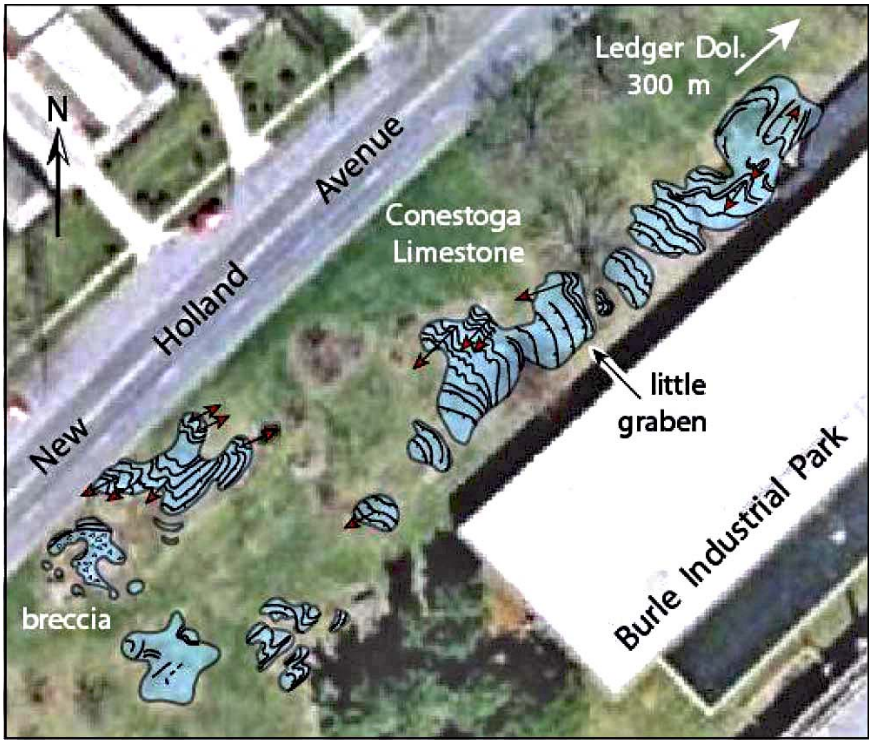


Figure 3. Bedding traces on Conestoga Limestone outcrops at Burle Industrial Park. *Dip directions are indicated by tick marks on bedding traces while arrows show trend and plunge of the most prominent fold axes. (Base image from Google Earth.)*

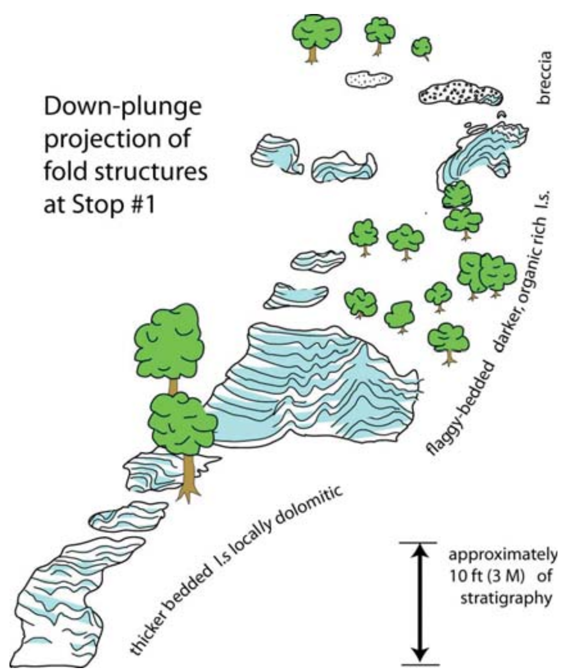


Figure 4. Down-plunge projection of outcrops of Figure 3.

<u>Sequence of structural events</u>. Five major structural events can be separated from overprint and superposition relationships in the outcrop (Figure 5). The most important location at which to separate the early elements is in a meter-scale graben (location indicated on Figure 3 and illustrated on Figure 5, upper right).

<u>Event 1</u>. <u>Centimeter-scale veinlets indicative of N15E-S15W extension</u>. (see net Figure 6). These are locally developed in and around the small graben but the beds in which they occur are cut by the graben. They are more resistant to weathering than the host limestone causing them to stand out in small relief. Some are developed in the basal part of thin limestone beds suggesting mechanical differences arising from graded bedding. Others are developed at different levels suggesting other causes than graded bedding or cryptic bedding. Their orientation sub-parallel with the trends of the old shoreline (Figure 1) is appropriate to early minor gravity extension toward the adjacent edge of the carbonate platform.

<u>Event 2</u>. <u>Graben extension in an E-W direction.</u> Symmetrical distribution of dips of the opposing faults with respect to the tilted bedding (Photo on Figure 5 and net on Figure 6) indicates the graben formed prior to tilting. Offset of veinlet-hosting beds from graben shoulders to its trough shows veinlet extension preceded E-W graben extension. Contrasting asymmetry of the conjugate faults, the left showing some drape and the right showing a relatively clean break, suggests the active extension was toward the west. A local reorientation of the stress field during landslide collapse is a reasonable but otherwise unsupported guess for this relationship.

<u>Event 3</u>. <u>Emplacement of breccia masses.</u> These masses of angular blocks, some of Ledger-like appearance with dimensions reaching two feet, are quite angular and locally are set in a finer grained matrix. Their parent fault scarp cannot have been far away. Their basal contact with the bedded Conestoga is structurally complex. Dark limestones with cm-scale bedding and/or fracture spacing form a disrupted and broken zone just below the breccia. Emplacement of the breccia was not a completely gentle process. (See Thomas article for further discussion).

<u>Event #4.</u> <u>NNW-trending tectonic transport lineations of calcite and minor quartz (Taconic).</u> These lineations are concentrated mostly on bedding surfaces that were subsequently disrupted by younger folding. Similar features occur throughout the region in association with Taconic tectonic transport (Figure 7). East of the Susquehanna, the trends are consistently about N30W. Similar smearing-type transport patterns will be seen at Stops #3 and #6. The Taconic-age (Late Ordovician) folds of the Martic zone, the Accomac anticline and older axes within the Lebanon Valley nappes are perpendicular to this direction. On the other arm of the cratonic corner (Figure 1) beyond the city of York, the transport direction changes to N60W or approximately normal to the Blue Ridge edge of the craton.

When these lineations formed, this area was covered by at least an additional 10,000 foot (3 km) thickness of the Conococheague and Beekmantown carbonates plus unknown thicknesses of Cocalico foreland debris, the whole further thickened by flow folding and nappe formation. The pile could easily have been 3 miles thick as the Lebanon Valley nappes passed overhead with associated weakening and easy flowage of calcite within these beds. Presence of water and local pressure solution also would have aided the flowage and provided dissolved material to help form these mineral lineations. At this location, most lineations have slightly different trends (about N15W, net on Figure 6) from typical regional orientations of N30W (Figure 7). Whether this results from subsequent refolding or a local statistical variation is uncertain. The lineations are typical of Taconic movement indicators that occur throughout the region.

Event #5. Regional folding with overturning toward the N50W direction. Again, the transport direction is slightly atypical of regional Taconic transport, probably as a result of later refolding and strain. These are neither similar nor concentric folds but complex, doubly plunging features. Elements of two periods of folding seem to be present but neither time nor talent has been available to separate them.

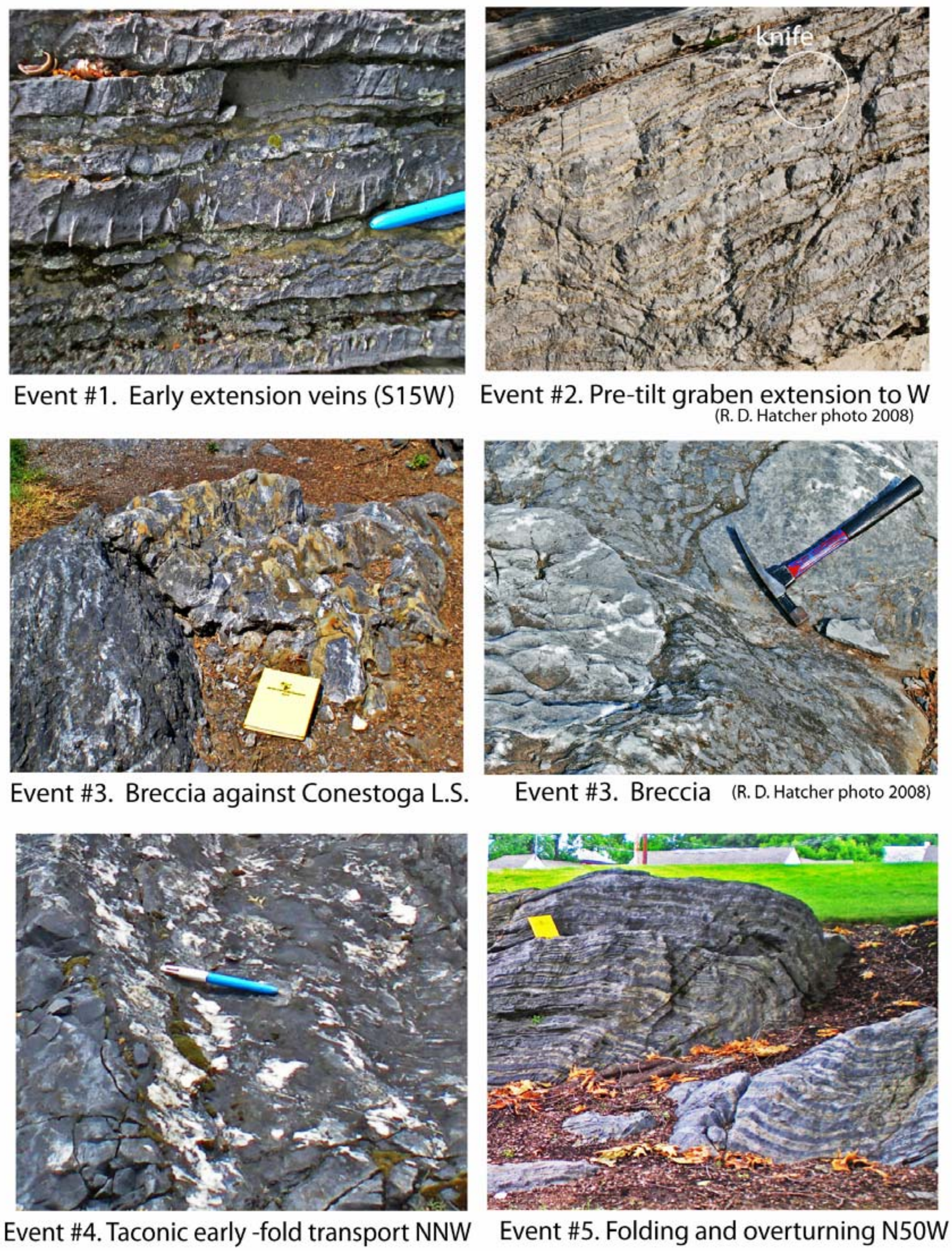


Figure 5. Stequence of structural events in the Stop #1 outcrops

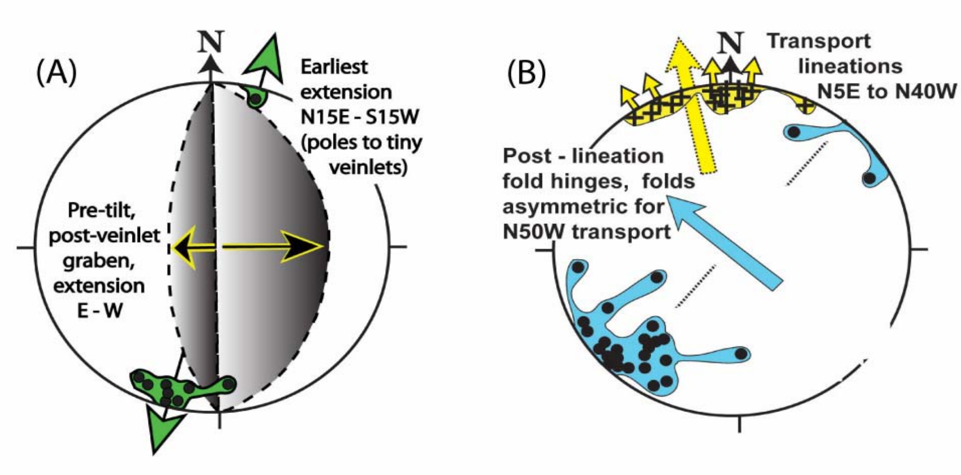


Figure 6. Equal area plots of tectonic elements at Stop #1

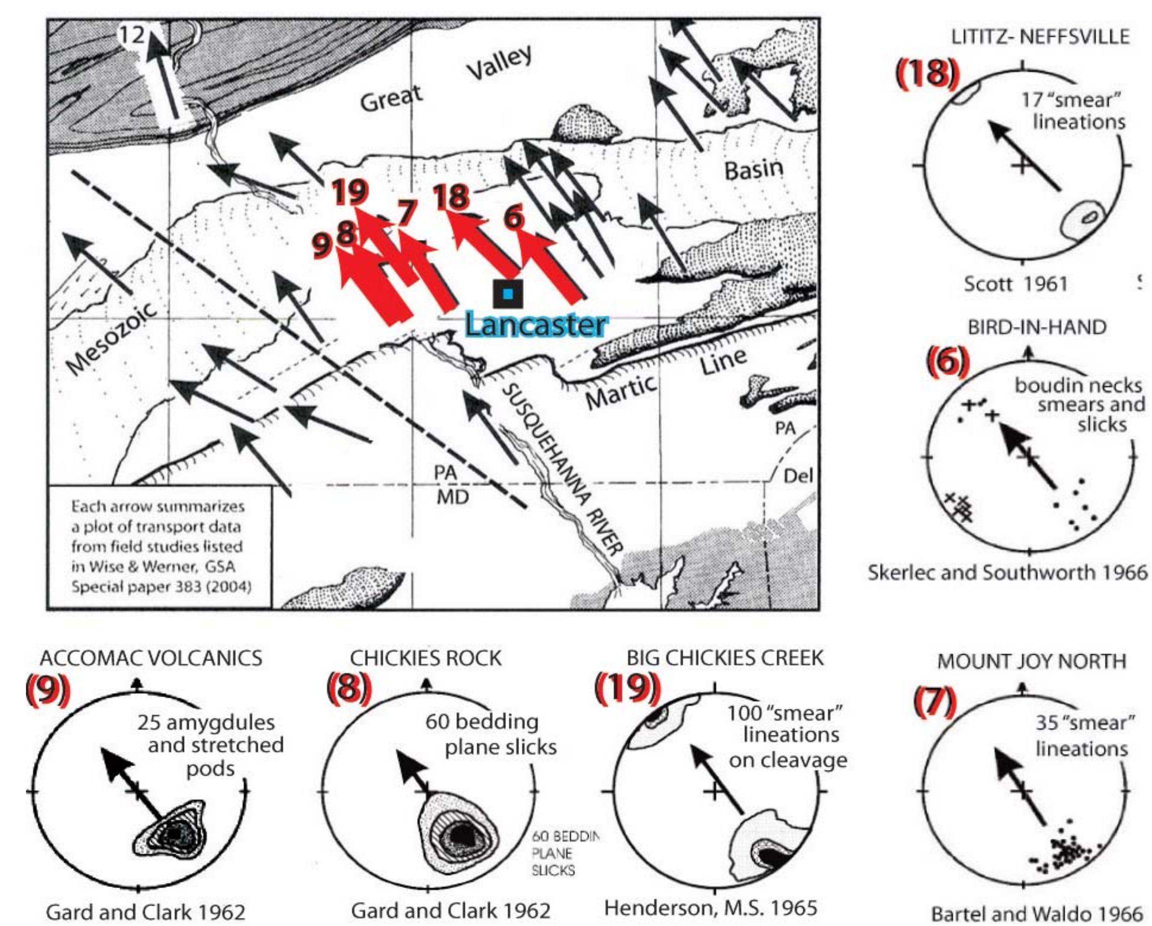


Figure 7. Dominant N30W tectonic transport in the Lancaster area. Data from senior theses of Franklin and Marshall College students. Each area was about 3x3 miles.

STOP #1A: LITHOLOGY OF THE CONESTOGA LIMESTONE AT BURLE INDUSTRIAL PARK

Roger Thomas and Carol deWet, Franklin and Marshall College

Sedimentary sequence, environment of deposition. In Early to Middle Cambrian time, the edge of the continental shelf of Laurentia bordering the Iapetus Ocean passed through what is now the city of Lancaster, defining the future trend of the Appalachian fold belt in Pennsylvania. North of the city, Cambrian strata record nearshore and open-shelf depositional environments. To the south, the Conestoga Formation accumulated on the continental slope, interfingering upslope with the Vintage, Kinzers and Ledger formations (Rogers, 1968; Brezinski *et al*. in press) and probably also including considerably younger strata away from the shelf margin.

This outcrop illustrates the relationship between the Conestoga Formation and the adjacent shelf. The lowest part of the exposed section, originally fairly thick-bedded (10-20 cm) limestone, has been dolomitized. A thin bed of sedimentary breccia, with clasts up to 2 cm across, occurs 1.5 m up from the base. Higher up the strata, also dolomitized, are more regularly bedded and less thick (4-7 cm). The transition from these beds to limestone occurs both up-section and laterally to the SW. Tight, SW-plunging folds in the overlying beds are deflected and phase out against the rigid and partially brecciated dolomite. The Conestoga Formation is rarely dolomitized. Here, its diagenesis reflects proximity to the action of processes that caused dolomitization of the overlying Ledger Formation.

The main, mid-section of the outcrop consists of classic rhythmically bedded dark gray silty limestone and buff-colored limy mudstone (Figure 1A). Where less carbonate is present, the thin shaly beds are phyllitic. The limestone is strikingly uniform in texture, very fine grained, with no sign of graded bedding. At the middle of the outcrop, as many as 10 ribbon-banded couplets occur within 20 cm of strata. Higher up, the rock is more coarsely bedded and the thickness of the beds is less uniform, laterally.

At the SW end of the outcrop, close to the road, bedded limestone grades up and laterally into an olistostrome, of which no more than 2 m is exposed. Limestone immediately below the sedimentary breccia is not well exposed. It is relatively massive, including scattered clasts. Immediately to the east of the olistostrome, rhythmically bedded limestone reappears above it, here deformed by small folds that plunge to the east. The olistostrome includes three types of clasts:

(1) Angular to subangular blocks of white limestone. Some exhibit a dark\light mottled color-pattern, somewhat like *Stromatactis* but without the characteristic flat bases (Figure 1B). There are no signs of relict ooids or other sedimentary structures. Some of the blocks are quite large, more than 0.5 m across. These clasts were derived from the Ledger Formation.

(2) Subangular to well rounded clasts of dark gray limestone. Very variable in shape and not notably tabular, they range from 3-4 mm to 15 cm in maximum dimension (Figure 1C). These clasts are penecontemporaneous, derived from beds of the Conestoga Formation itself that that were initially deposited further up-slope.

(3) Tabular clasts of lighter gray limestone with quartz grains scattered uniformly throughout the rock (Figure 1D). These clasts range up to 10 cm in length. They are infrequent, concentrated in one area. They are inferred also to have been derived from within the Conestoga Formation, which exhibits this lithology at some localities.

Thomas, R. and de Wett, C. (2010) STOP #1A: Lithology of the Conestoga Limestone at Burle Industrial Park, *in* Wise, D.U and Gary M Fleeger, eds., Tectonics of the Pennsylvania Piedmont along the Susquehanna River, 75th Annual Field Conference of Pennsylvania Geologists, Lancaster, PA, p. 13 – 15.

The angularity of clasts derived from the Ledger Formation indicates that it was well lithified and brittle, presumably already dolomitized, when the blocks broke away and slipped downslope. If so, the clasts, now consisting entirely of recrystallized calcite (Frey, 1999) have been dedolomitized (cf. Arienzo, 2008). Trace element analysis has shown these clasts to be enriched in Fe^{+2} and Sr^{+2} relative to microbialites and grainstones from the Ledger Formation, but lower in these elements than the muddy Conestoga matrix (Frey, 1999) with which they partially equilibrated. Concentrations of Mg^{+2} reported from the white limestone clasts range up to five times the highest values observed in the Conestoga matrix (Frey, 1999), consistent with their prior incarnation as dolomite.

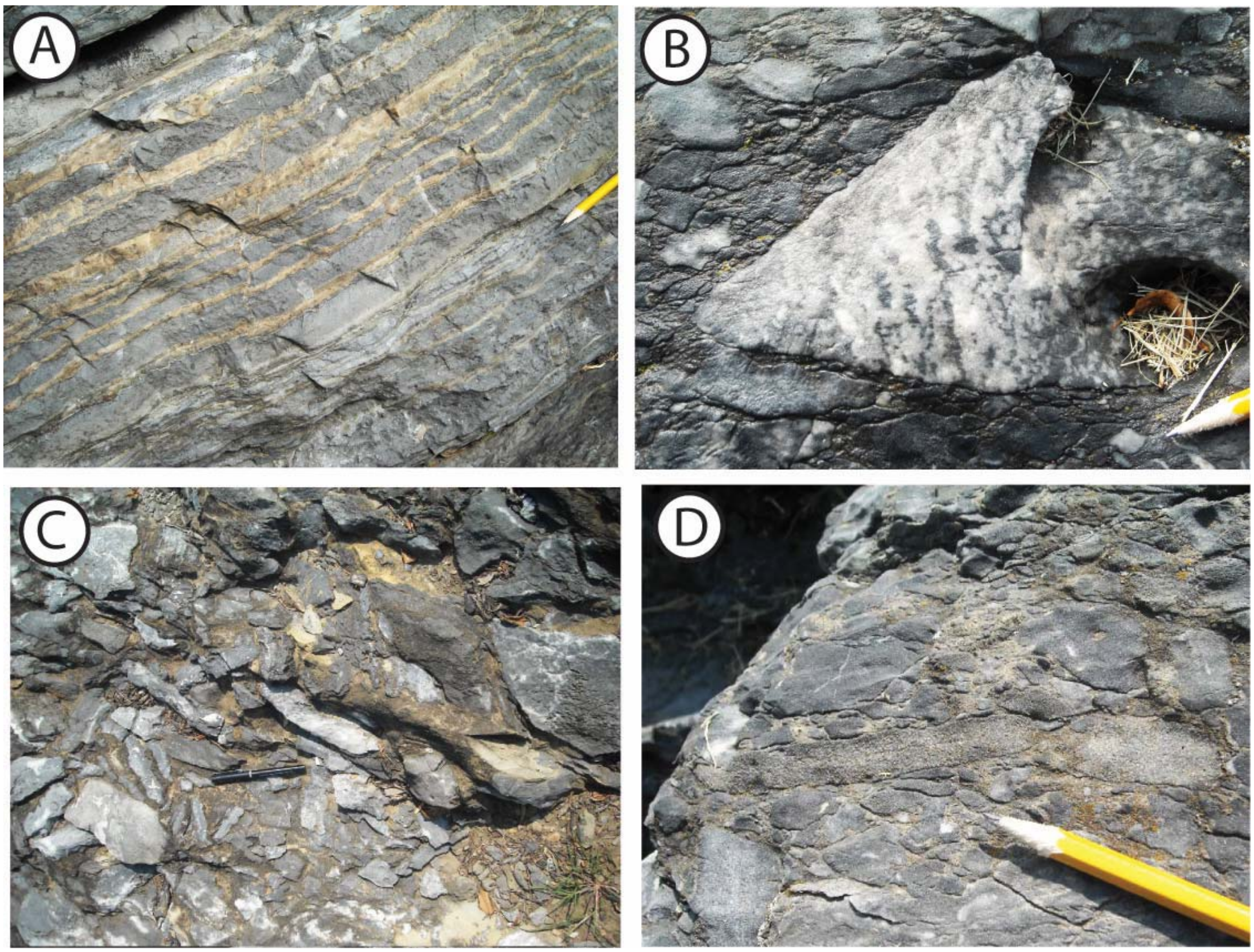


Figure 1. Lithology of the Conestoga Formation at Burle Industrial Park, Lancaster
A: Rhythmically bedded limestone and calcareous shale
B: Angular clast derived from Ledger Formation with striking mottled texture
C: Chaotic breccia of Conestoga limestone mixed with some Ledger clasts
D: Flat-pebble clast with disseminated quartz grains

These observations illustrate the dynamic relationship between sediments that accumulated to form the Ledger Formation, as the first phase of development of the Great American (carbonate) Bank along this margin of the continental shelf (Read, 1989; de Wet *et al.* 1999; Brezinski *et al*. in press), and deeper water facies of the Conestoga Formation. Two principal modes of contribution of carbonate sediment to the continental slope are represented. Under stable conditions, periodic downslope flows of fine carbonate sediment gave rise to rhythmically bedded limestone and calcareous shale. From time to time, progradation of bank-edge carbonates led to destabilization of the shelf-edge (de Wet *et al.* 1999), collapse, and resulting formation of the olistostromes.

Relationships among the Kinzers, Ledger and Conestoga formations vary along the Cambrian shelf margin from York County, through Lancaster, and further to the east (Taylor and Durika, 1990; Brezinski *et al*. in press). In York County, the Kinzers Formation includes massive olistostromes that accumulated adjacent to a steep shelf-margin. Around Lancaster, bedded limestones in the upper part of the Kinzers grade up into more varied, deeper water strata that are not readily differentiable from facies of the Conestoga Formation. In the York area, the Ledger is represented by well developed oolite shoals and microbialite reefs (de Wet *et al.* 1999), whereas these facies are much less evident in Lancaster County. This may simply reflect differential development of facies along the continental shelf. Alternatively, the Ledger Formation may be defined more by its diagenesis than by its original sedimentary architecture.

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STOP #2: MARTIC CONTACT AT SAFE HARBOR DAM

Donald U. Wise, University of Massachusetts at Amherst

Location A: Access road to Safe Harbor Dam. The busses will stop in a wide area of the public park just short of the "canyon" leading to the bridge entrance to the dam.

Location B: The bridge over the mouth of the Conestoga Creek at the far end of the "canyon" exposures provides fisherman and others access to the Susquehanna shoreline and to the fishing pools at the base of the dam. After location A and a look at the schist exposures, the group will reassemble just across the bridge for morning refreshments followed by Frank Pazzaglia's discussion of the river gorge and its relationship to the emerging field of neo-tectonics and its insights into geomorphology and uplift of the region. **See following section for Pazzaglia's brief notes with his more complete discussion and references on neotectonics in the symposium proceedings.**

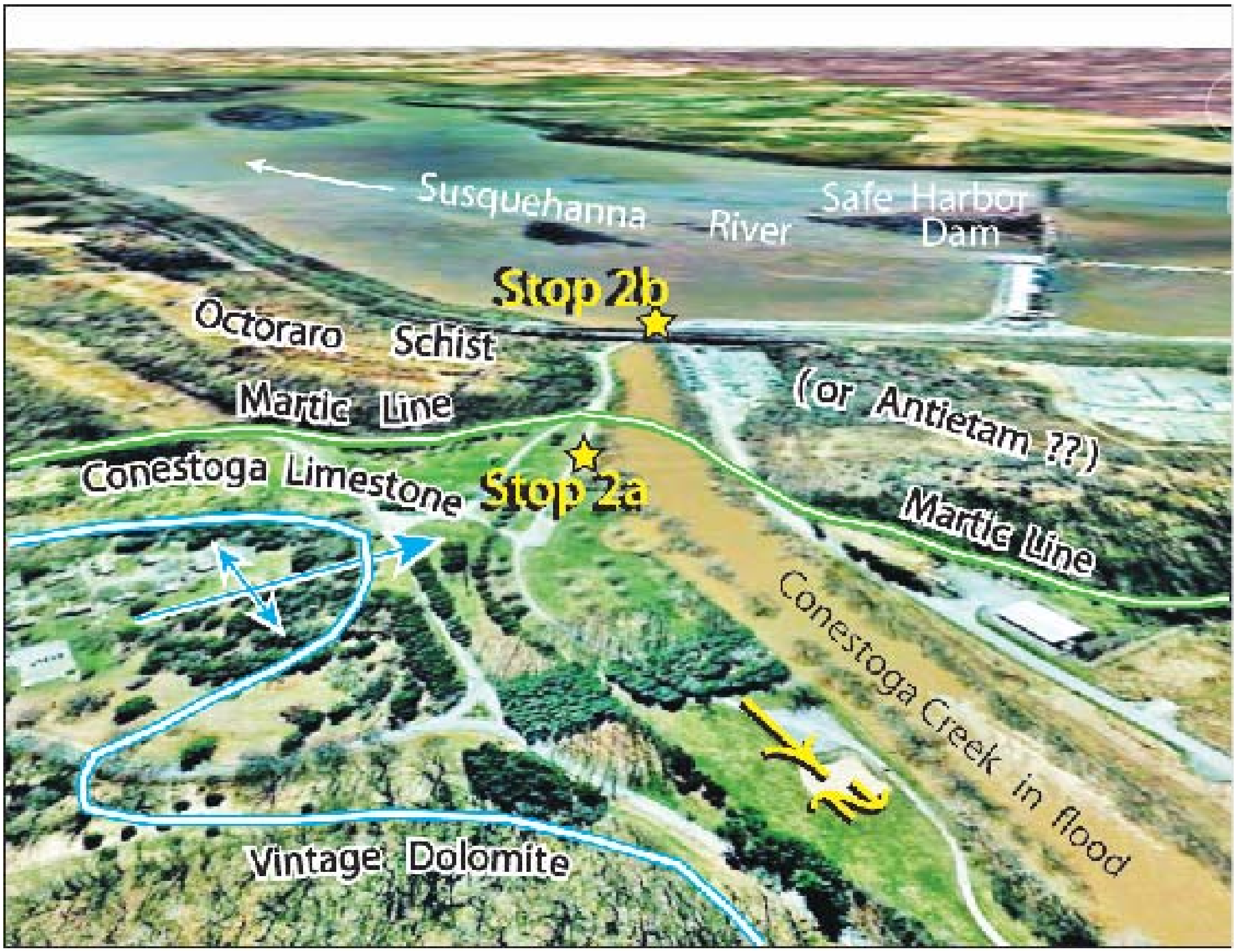

Figure 1. Oblique view southwest across the Safe Harbor area (Google Earth image)

Wise, D.U. (2010) STOP #2: Martic contact at Safe Harbor Dam, *in* Wise, D.U and Gary M Fleeger, eds., Tectonics of the Pennsylvania Piedmont along the Susquehanna River, 75th Annual Field Conference of Pennsylvania Geologists, Lancaster, PA, p. 17 – 24.

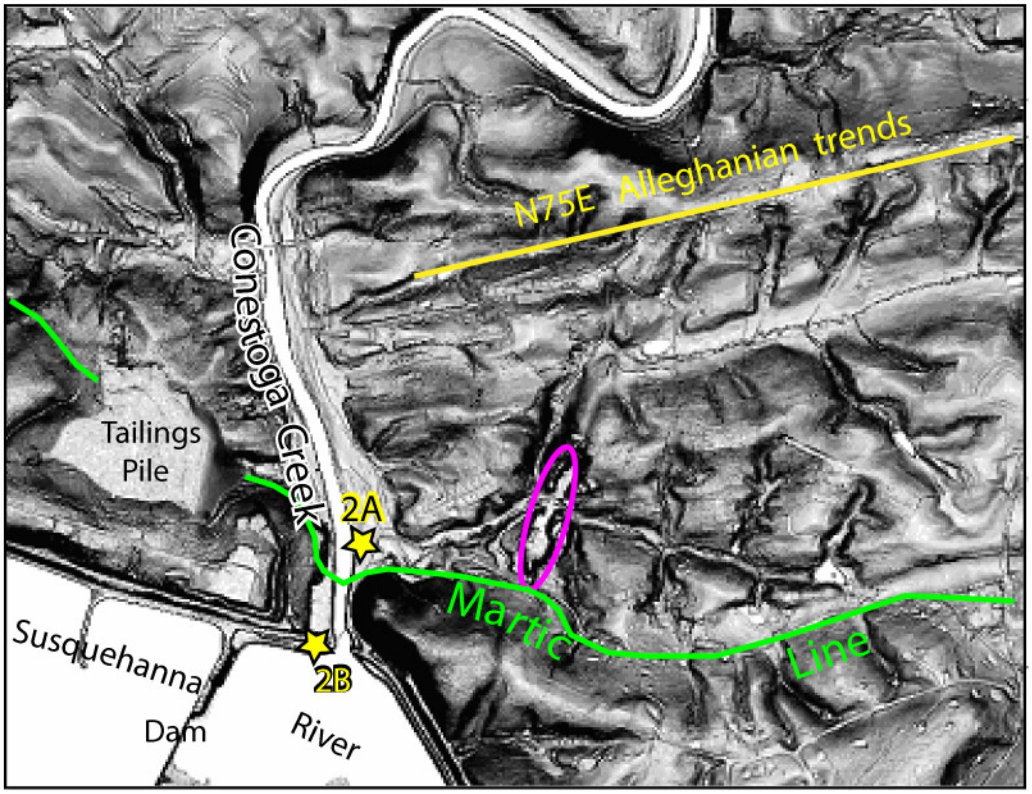

__Figure 2 LIDAR topography of Safe Harbor Area__. (Image courtesy of Jay Parrish). Stops 2A and 2B are on either side of the Martic Line. The hill just to the NE of 2A is Antietam Schist with a fold nose of Vintage Dolomite plunging toward the stop. Both are part of an early E-W trending fold at the lip of a Taconic thrust sheet. The N75W topographic grain follows the younger Alleghanian overprint but the N60E trending schistosity and folds are not prominent in the topography. The pink ellipse is Safe Harbor Quarry from which the Jurassic Safe Harbor basaltic dike was used for concrete to build the dam. Cloos (1941) has a detailed map of the quarry showing the folded thrusts in its walls. In the topography, valleys parallel to the quarry and dike suggest other fractures were formed in the Jurassic but not filled with dike material. The giant tailings pile remains from the "Susquehanna Navy's" dredging the river floor for placer coal. This was separated here and shipped by train to the Conowingo Dam to burn for power generation.

Geologic Setting: The Conestoga Creek, just to our west, flows nearly due south to cut a "canyon" through an Octoraro (Antietam?) schist septum to reach the Susquehanna.

1) We stand in a broad open area underlain by Conestoga Limestone (Figs. 1 and 2).
2) The more resistant schist underlies the uplands to our immediate southwest and continues as the hills across the creek just beyond the terrace with all the electrical equipment.
3) This overlying unit is the former "Wissahickon" Schist, now "Octoraro" Schist and possibly the "Antietam" Schist.
4) *The infamous and much debated "**Martic Thrust**" contact* of schist over limestone follows this line. The name Martic is associated with Marticville and Martic Township that lie a few miles to our east. The Martic Forge Inn and long-forgotten Martic Forge are about 3 miles to our SE.
5) The small wooded hill immediately to our east is formed by the Vintage Dolomite, slightly more resistant than the Conestoga. The hill behind it is the much more resistant Antietam Schist, its differential resistance to erosion obvious on Figure 2. Both are part of the nose of a small anticline that plunges westward under the Conestoga Limestone on which we stand.

The fold, like many nearby, is a brow fold rolled over on the leading edge of a Taconic-age thrust sheet.

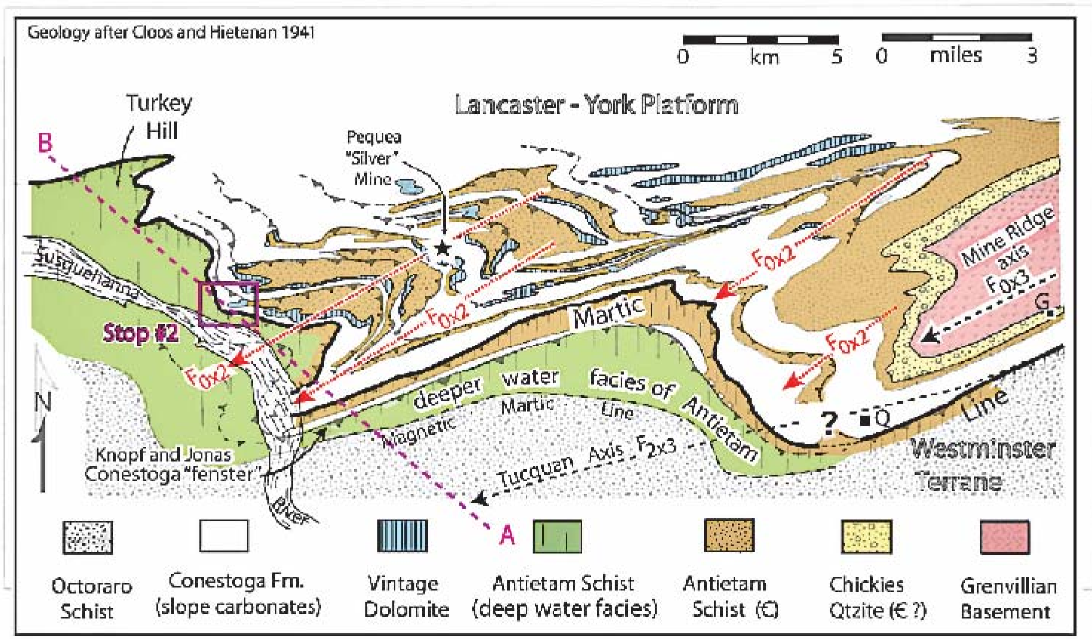

***Figure 3. Multiple folding of imbricate thrust sheets in the Martic Zone**. (Mapping after Cloos and Hietenan, 1941; interpretations after Wise, 1970, and Wise and Ganis, 2009.) This terminology utilizes a double subscript numbering system, the first number being the s-surface being folded; the second is the number in the deformation sequence. For example, the fold axis of bedding (S_0) in the Antietam sheets by the main Taconic deformation (D_2) is marked F_{0x2} whereas the axis of the Tucquan Antiform, formed by folding of the main cleavage (S_2) by Mine Ridge Alleghanian basement deformation (D_3) is marked F_{2x3}, etc.*

The Martic Problem: The purpose of this stop is to provide a brief introduction to Martic Problem. The "problem" began with Knopf and Jonas's 1929 mapping showing schists on the projection of the west-plunging nose of Mine Ridge's crystalline basement (Figure 3) rest on the Conestoga Limestone. The schists were then thought to be of Precambrian age whereas the Conestoga was then dated as Ordovician. In an era when even the existence of such structures was debatable, they proposed a regional-scale "Martic Thrust" as the cause of this age anomaly of old over young. On the basis of topography they interpreted several valleys south of the thrust line (Figure 3) as fensters of Conestoga Formation exposed by erosion through the thrust. There are no known exposures of Conestoga or anything else in these valleys, causing Cloos to leave the Conestoga areas off his map. However, their pronounced erosional relief, remarkable linearity, and parallelism with linear valleys of Conestoga on the other side of the line strongly suggest that the Knopf and Jonas interpretation of underlying Conestoga Limestone was correct. However, the overall geometry makes their "fenster" interpretation almost impossible. Miller (1935) raised objections to thrusting by suggesting the relationships were nothing more than the metamorphosed equivalents of the Martinsburg and Beekmantown units of the Great Valley while Mackin (1935) supported the thrust using structural and down-plunge projection arguments.

In more recent time, as great overthrusts became widely recognized elsewhere and multiple fold studies began to unscramble deformations of the imbricate sheets, the Martic Thrust model has been generally accepted. Knopf and Jonas's Wissahickon Schist that once extended to Philadelphia has been split into several components, the one in this area being Latest Precambrian to Cambrian Octoraro Schist (Blackmer, 2010). The Antietam and Conestoga Formations are now recognized as Cambrian slope deposits that came off the Lancaster-York carbonate platform into the adjacent Octoraro Seaway. The "Precambrian Wissahickon Schist" in this area could be called either Octoraro or Antietam Schist. (See discussions in the proceedings volume by Blackmer and by Taylor, 2010).. The old "fensters" now appear to be small remnants of Conestoga Formation riding on the back of another imbricate thrust slice that happens to have the famous Martic Thrust as its base.

The superposed main folding and schistosity are now dated as Taconic by the recent monazite date from the Pequea Mine where mineralization was localized along a F_{0x2} fold hinge. (Location on Figure 3, for Williams and Jercinovic's dating as reported in Wise and Ganis, 2009). After eighty years, most of the original questions about the "Martic Problem" appear to have reasonable answers - but as this trip will show, a new set has replaced them.

At this stop, the unexposed Martic Line will be crossed in passing from limestone valley into schist upland. Outcrops of the Octoraro Schist can be examined along with their multiple cleavages, dominated by the main S_2 or Taconic schistosity. Locally, lunch-box sized isoclinal fold noses are associated with this schistosity. A few of these folds deform slightly older, sub-parallel S_1 quartz veins produced by metamorphic expulsion of local excess silica as the rocks passed through early stages of greenschist metamorphism.

Multiple Folding: By 1944, Stose and Stose had recognized the existence of two major deformations in the area, an older one that produced the main schistosity and a younger one that deformed it into the broad Tucquan Antiform that lies a few miles to our south. Details of these deformations and fold systems along the river were defined by Freedman, et al., (1964) and extended through the Martic area by Wise (1970) as shown in Figures 3 and 4. Their terminology is explained in the caption to Figure 3.

For the discussion at this stop, we should note that the small F_{0x1} fold of Vintage Dolomite (Figure 1) is the rolled, leading edge of one of the early imbricate thrust sheets (Figure 3). The map-scale folding of the Martic line near this stop is an F_{0x2} feature whereas the associated schistosity evident in the road cuts is a second generation F_{2x2} structure. The north dips are younger than either as explained in the caption to Figure 4.

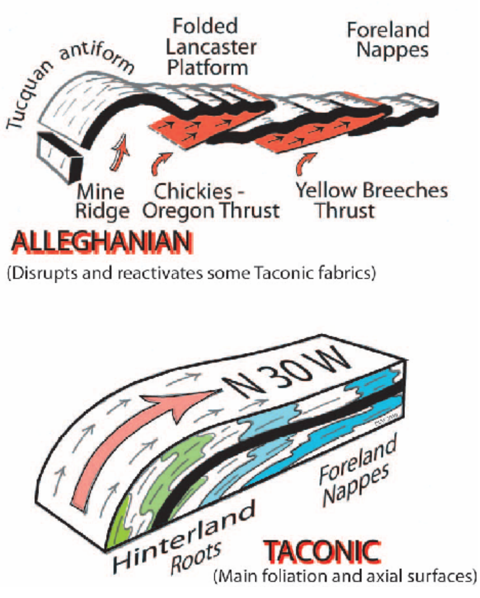

Figure 4. Cartoons of tectonic features of the two major orogenic events affecting the Susquehanna Region. *In the upper panel, the black sheet represents the deformed black surface that is shown as a Taconic axial zone in the lower panel. Note that for this location, the originally near-recumbent Taconic-age fold surfaces were tilted into significant north dips on the north limb of the Alleghanian Tucquan Antiform*

Enigmatic Folds of the Martic Contact at Safe Harbor and Turkey Hill. Steven Schamel (1963) mapped the Safe Harbor area for his Senior Thesis at Franklin and Marshall College. That work included measurements of bedding and schistosity that show several overprinted fold patterns (The maps and plots of Figure 5 are extracted from his thesis).

A) Equal area plots of those bedding measurements show a girdle for folds that plunge S85W at small angles. The nose of one of these folds lies in the woods just to our east (Figure 1).

B) For the main schistosity, the equal area plot shows a N63E strike, axial planar to large-scale, gently west-plunging map-scale folds of the Martic contact.

C) This schistosity lies oblique to the Martic Line as best shown at the south edge of Figure 5. The N75E topographic grain of the LIDAR image is probably a reflection of the younger Alleghanian-age folds and their associated S_3 schistosity.

At first glance, the cross-section of Safe Harbor folds on Figure 5 seems normal, showing simple synclines with younger schist in their cores. The false note is that the asymmetry of the folds and north dips of their axial planar cleavage suggest the folds formed by south-directed transport contrary to regional tectonic patterns. Cloos (1941) among others interpreted this as a puzzling reversal in direction of tectonic transport. An "Aha !" moment comes when one realizes these really are the noses of Taconic anticlinal lobes that were once recumbent with northward transport but are now rotated to north dipping axial surfaces across the Tucquan Antiform (Figures 3 and 4). Suddenly, all the elements of fold pattern, tectonic transport and cleavage dips seem to make sense... but then the enigma appears.

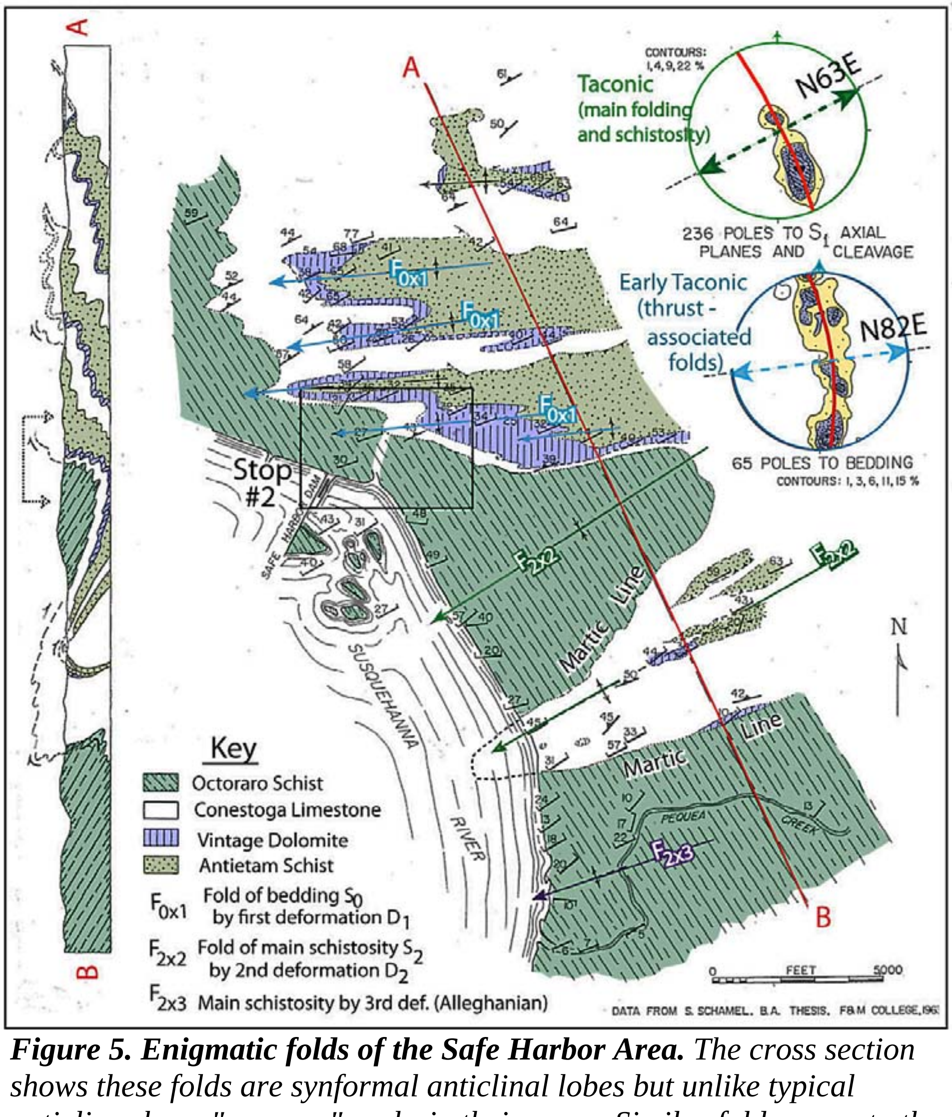

Figure 5. Enigmatic folds of the Safe Harbor Area. *The cross section shows these folds are synformal anticlinal lobes but unlike typical anticlines have "younger" rocks in their cores. Similar folds occur to the north; the most prominent is at Turkey Hill (Figure 3).*

If these really are anticlinal lobes, how can they have the youngest, highest thrust sheets in their cores?

The cartoon sequence of Figure 6 and its caption present one model to explain the enigma. The model is based on the well-known characteristic of near-surface, strong limestones rapidly losing most of their strength to become very ductile at burial depths of about two km (Robertson, 1960). The first Taconic arrivals of the deep-water contents of the adjacent Octoraro Basin onto the submarine slopes of the Cambro-Ordovician platform were probably weak, water-rich, clastic masses. As the Octoraro source basin closed behind them, these masses were driven up the lower slopes of the platform. Here they produced a zone of imbricate thrusts by detaching and carrying along slabs of the slope deposits. The detachment and transport process was aided by Hubbert and Rubey's (1959) excess fluid pressures acting on the Harpers Phyllite that lies just below the detached Antietam sheets.

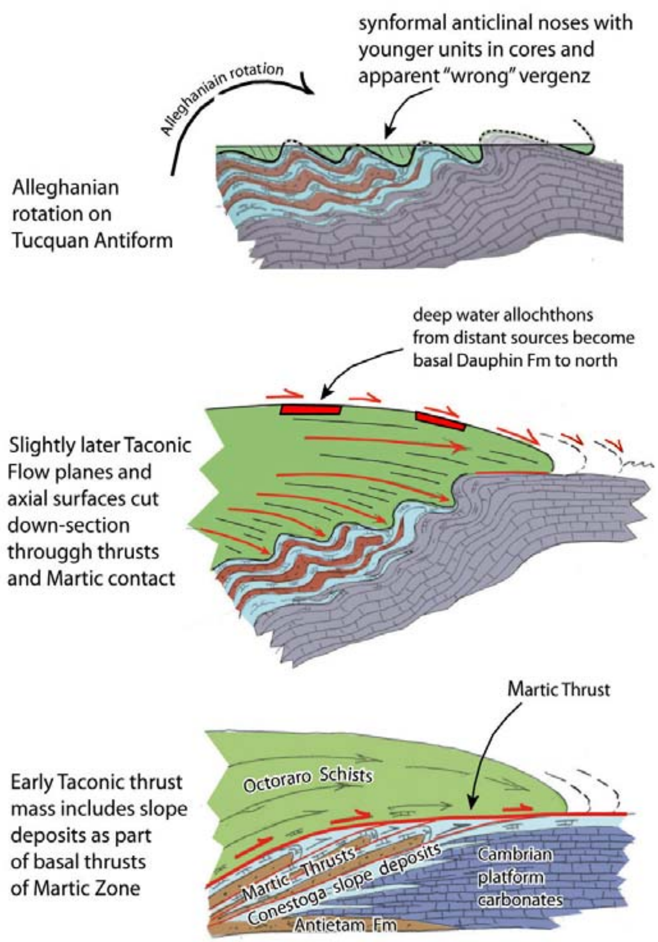

Figure 6. Model to explain the enigmatic Safe Harbor and Turkey Hill folds. *Following early-stage Taconic imbricate thrusting of the Martic Zone, the overriding schist mass continued to increase in thickness. Deeper burial caused underlying carbonates to become more ductile and for some flow lines to deflect downward and pass through the imbricate stratigraphy. These formed outward-advancing anticlinal lobes with younger cores. Later Alleghanian deformation rotated these folds past recumbency. Subsequent erosion has left them as folds with anomalous age relationships.*

As the weak mass of clastic sediments and future schists continued to thicken and increase total lithostatic loads on underlying rocks, the carbonates became increasingly ductile (Robertson, 1960). Upper parts of what was once a strong floor for the overriding clastics became part of the northward flowing mass. Along the platform edge, flow planes cut down-section through the thrust slices to produce *anticlinal noses with younger rocks in their cores*. With Alleghanian tilting across the Tucquan Antiform, these became the folds with enigmatic age relationships.

Nappe mechanics. Mechanisms has never been too clear by which deep-water distal sedimentary materials were transported far inland to be emplaced as the initial Dauphin Formation on the foreland basin carbonate floor (Ganis and Wise, 2008). In the Martic Zone, only proximal schists are thrust directly onto the carbonates with very little stratigraphic omission whereas farther north a variety of distal deep water lithologies rest on upper Beekmantown units or their slightly younger Myerstown or Annville limestones. As a result, most stratigraphies from Jonas and Stose in the Lancaster Quadrangle (1930) to Stose and Stose in York County (1944) to Meisler and Becher in the Lancaster Area (1971) have interpreted an erosional unconformity at the base of Martinsburg / Cocalico flysch.

Such interpretations were plausible so long as the red units at the base of these formations were believed to be volcanic sediments (authors cited above). With the Ganis, et al. (2001) recognition of these as allochthons from distant deep sea sources, many with ages older than the units upon which they rest, the unconformity models became untenable. Some kind of a regional thrust or transport mechanism had to bring them across the proximal basins, the Martic zone, and some of the adjacent carbonate platform. Furthermore, the fact that the allochthons only begin to appear well north of the Martic Zone (first stop, second day), this mechanism must get them across the Martic edge of the platform with no sign of their passage, and that during the supposedly actively growing, early stages of the eventual Taconic Alps.

The middle panel of Figure 6 suggests a solution. The distant allochthons of the Great Valley's future Dauphin Formation rode across the platform edge as the most distal and highest parts of the overriding mass. The mass moved forward into the flooded and still sinking foreland basin, mostly in caterpillar tread mode but locally with thrust removal of some underlying carbonate units. With suitable distance of travel to the north, caterpillar action finally moved these "passengers" to the "front of the bus," to become the basal allochthons of the foreland. With continued sinking of the basin, flysch of the Cocalico / Martinsburg Formation was deposited as a thick fill across them. Finally, like the carbonates of the platform edge, continuing burial by sedimentation and tectonic overflow of additional masses began to weaken the underlying carbonates them to flow forward as part of the overriding mass.

In effect, this weakening caused the entire foreland basin to resemble a giant "cold bottom" glacier, attached at its base but flowing progressively at higher levels for greater and greater distances. This set of mechanisms produced a very wide orogenic belt with little or no basement involvement, a process that had to be driven largely by gravity in its distal parts. Ganis and Wise (2008) liken it to the modern Apennine orogeny of Italy with its far-travelled allochthonous blocks. Here it consisted of a 15 to 20 my event of slow but steady pushing of weak contents of several offshore basins onto the craton where they could flow for a vast distance across that flooded surface. More regional discussion of these aspects of the Taconic Orogeny appears in the proceedings volume (Wise).

Please proceed southward along the cuts to look at exposures of the Octoraro - Antietam (?) Schist, the main S_2 cleavage dipping to the north from rotation past recumbency, and S_3 cleavage, weakly developed here but quite prominent in many areas to the south. **Refreshments await beyond the bridge**.

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STOP 2: ACTIVE TECTONICS OF THE PENNSYLVANIA PIEDMONT (SAFE HARBOR SHORELINE)

Frank J. Pazzaglia, Lehigh University

The Safe Harbor area affords the field trip the opportunity to observe the gorge of the lower Susquehanna region and a venue to discuss active tectonics of the Appalachians. The idea that the Appalachians, an orogen well into its decay phase, has experienced active tectonics is not a new idea. Beginning with Davis (1889), a persistent idea is that the Appalachian landscape preserves an erosional stratigraphy that is directly related to impulsive rock uplift, followed by long periods of erosional decay. A new generation of process-based studies and integration of geologic, geomorphic, and thermochronometric data that was not available to Davis and his contemporaries allows us to test the predictions made by episodic rock uplift and speculate on the possible mechanics driving it.

In an old, decaying orogen like the Appalachians, rock uplift does not occur because of horizontal shortening, accomplished by faults that thicken the crustal column; rather, erosion of the crustal column slowly consumes a formerly thickened crustal root which drives isostatic uplift of rocks. There are seismogenic faults in decaying orogens like the Appalachians, but they tend to be concentrated on crustal- or lithospheric-scale zones of weakness, indicating differential response to isostatic or dynamic forces rather than crustal thickening. Isostasy returns only 80% of what is consumed by erosion so the net effect of erosional thinning of the crust is subsidence. Any increase in mean elevation of an isostatically compensated crustal column must be driven by epeirogenic processes, such as lithospheric flexure or dynamic flow of the sub-lithospheric mantle. These epeirogenic processes can be episodic and influenced by surficial processes, such as the redistribution of surface loads by erosion and deposition. We will use a comprehensive knowledge of erosion and incision rates in space and time to document unsteadiness in landscape evolution consistent with these epeirogenic processes.

For the Piedmont and the Appalachians in general there are six key observables that must be reconciled to explain its post-orogenic (post-Triassic) evolution. First, the metamorphic core of the range currently lies at the lowest mean elevation, and much of it is below sea level, covered by a coastal plain. What is commonly referred to as “the Appalachians” are really what is left of the former Appalachian foreland, now topographically inverted. Second, a long-term record of unroofing exists in the form of siliciclastic sediments in Atlantic margin shelf-slope basins. These sediments argue for unsteady exhumation driven by epeirogeny, climate, or both (Pazzaglia and Brandon, 1996) although there is some ambiguity regarding the precise provenance of the basin material. The most recent pulse of sediment delivered to the shelf-slope basins arrived in the middle Miocene and high sediment rates persist through the Quaternary. Third, the longitudinal profiles of Atlantic slope rivers increase in gradient towards the Atlantic, forming a zone of seemingly anomalous rapids (Fall Zone) near the coast. Furthermore, the rivers of the mid-Atlantic States possess knickpoints upstream of the Fall Zone of common elevation that have no apparent relation to rock-type or structure. Fourth, the divide between Atlantic slope and Ohio drainages is not a static feature; rather, it has a long-term history of unsteady translation westward. Fifth, Appalachian topography is locally rugged, with lofty, steep mountains and deep, narrow canyons. The presence of mountainous topography in a foreland that has experienced kilometers of erosion over 180 m.y. is enigmatic. Lastly, thermochronologic, river incision, and emerging cosmogenic data that are increasingly quantifying Appalachian erosion rates show surprising correspondence across long-time scales despite variable tectonic histories, eustasy, rock-type, and relief, but discordance over shorter times scales.

River gorges, like the Piedmont gorge of the lower Susquehanna, are striking evidence of disequilibria in surface processes that have different response times to changes in base level (rock uplift and eustasy) and climate. The long-term rate of river incision in the Piedmont gorge has been a slow ~9 m/m.y. over the past ~ 15 m.y.; however, that rate appears to be faster in the Quaternary than it was in the

Pazzaglia, F.J. (2010) STOP 2: Active tectonics of the Pennsylvania Piedmont (Safe Harbor shoreline), *in* Wise, D.U and Gary M Fleeger, eds., Tectonics of the Pennsylvania Piedmont along the Susquehanna River, 75th Annual Field Conference of Pennsylvania Geologists, Lancaster, PA, p. 25 – 26.

Tertiary (see Fig. 7, Pazzaglia et al, 2010). Incision over the past 100 k.y. in the Holtwood gorge has averaged ~250 m/m.y., arguing that much of the Piedmont gorge is a youthful feature. Impressive bedrock erosion features such as potholes, knickpoints, wide straths, and deeps, one of which is known from here at Safe Harbor are consistent with this interpretation. Rivers respond more rapidly to changes in base level or climate than hillslopes, which constitute most of the landscape area. For this reason, river incision rates are commonly different than measures of landscape erosion, such as suspended sediment yields, accumulation of colluvium in zero-order hollows, and cosmogenically-determined exposure and alluvium dating. A compilation of these data show that they are comparable, but slower than the Pleistocene river incision rates (see Fig. 9, Pazzaglia et al. this guidebook). Comparison of Quaternary measures of landscape erosion to data that integrate over longer time spans, such as the sediment load in the shelf-slope basin (see Fig. 4, Pazzaglia et al., this guidebook) and thermochronology (see Figs. 2 and 3, Pazzaglia et al, 2010) show that the long-term rates are indistinguishable from the Quaternary rates (see Fig. 9, Pazzaglia et al, 2010). The similar long- and short-term erosion rates may indicate that the post-orogenic history of the Appalachians has been an uneventful, slow erosional unroofing, with the attendant isostatic rebound, at ~20 m/m.y. The gorge, rapid Quaternary incision, and unsteady delivery of sediment to the shelf-slope basin suggests that this observation is a coincidence and that there has been a recent late Cenozoic increase in surface and epeirogenic processes driving Appalachian landscape change.

The elevation of Tertiary river terrace remnants in the Piedmont shows that there has been nearly 200 m of base level fall since the middle Miocene (~15 Ma) and correlative deposits on the Fall Zone indicate ~ 100 m of base level fall there. Geodynamic models that consider elastic flexure of the mid-Atlantic lithosphere under changing surface loads due to erosion and deposition (Pazzaglia and Gardner, 1994, 2000) successfully predict the broad warping of the Pennsylvania Piedmont indicated by the terrace data (see Figs 5, 6, 11 Pazzaglia et al, 2010). In these models, the Fall Zone is shown to be the exposed portion of the flexural hinge. However, the flexural model does not explain the mean elevation of these tertiary geomorphic and stratigraphic markers that lie at elevations over 100 m. A previously entertained explanation was that middle Miocene sea levels were 60-100 m higher than present, but recent eustatic reconstructions have dispelled that notion and model middle Miocene sea levels as no higher than Holocene sea level (Miller et al., 2005). New geodynamic models that consider sub-lithospheric mantle flow in response to the foundering Farallon slab beneath eastern North America predict ~100 m of lithospheric uplift in the past 30 m for the mid-Atlantic region (Moucha et al., 2008). The geomorphic and stratigraphic markers suggest that most of this uplift is concentrated in the recent portion of this 30 m.y. window.

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STOP #3: ACCOMAC VOLCANICS

Donald U. Wise, University of Massachusetts at Amherst

For petrology and regional volcanic correlations: See following article by Smith and Barnes.

Location: Parking lot of the upscale Accomac Restaurant and Inn. The location is on the York County shoreline of the Susquehanna River, one mile upstream from Chickies Rock. The winding road down through Accomac Glen is the main access to this stretch of the Susquehanna shoreline (Figure 1A).

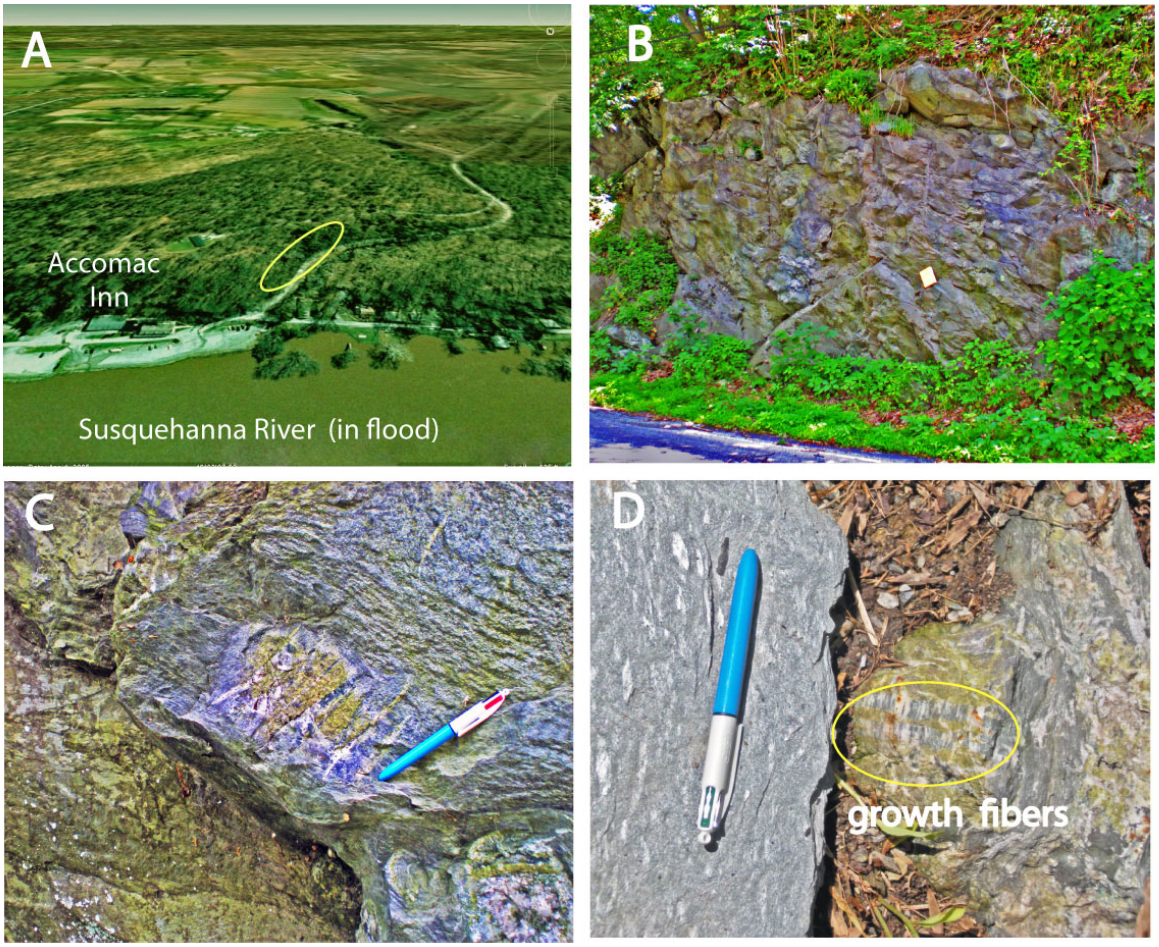

Figure 1. Accomac images. *A) Road cut location, Google earth view from the north. B) Road cut with epidote pods. Cleavage dips SE, away and to the right. C) Stretched epidote pod with quartz veins. D) Specimens with stretched amygdules and other features on left. On the right is an extension vein with quartz fibers perpendicular to it.*

Historical note and update: As noted in the dedication, geologic mapping of this region by George Stose and Anna Jonas (Stose) allowed them to develop tectonic syntheses and interpretations far ahead of their times. Some of the best of their ideas are summarized in a 1944 professional paper and Figure 2's base map.. After 66 years a few updates to their ideas are possible.

Wise, D.U. (2010) STOP #3: Accomac volcanic, *in* Wise, D.U and Gary M Fleeger, eds., Tectonics of the Pennsylvania Piedmont along the Susquehanna River, 75th Annual Field Conference of Pennsylvania Geologists, Lancaster, PA,
p. 27 – 32.

1) One significant modern difference from the S&S 1944 interpretation is a much clearer separation of N60E-trending Taconic folds such as the Accomac anticline as opposed to more E-W trending Alleghanian thrusts associated with the Chickies-Oregon thrust, Honeybrook and Mine Ridge Uplifts. Many of these potential age distinctions appear clearly in some 1944 S&S text and maps of the Hanover-York professional paper but were not emphasized. Today they are regarded as distinct chapters with different tectonic settings and style.

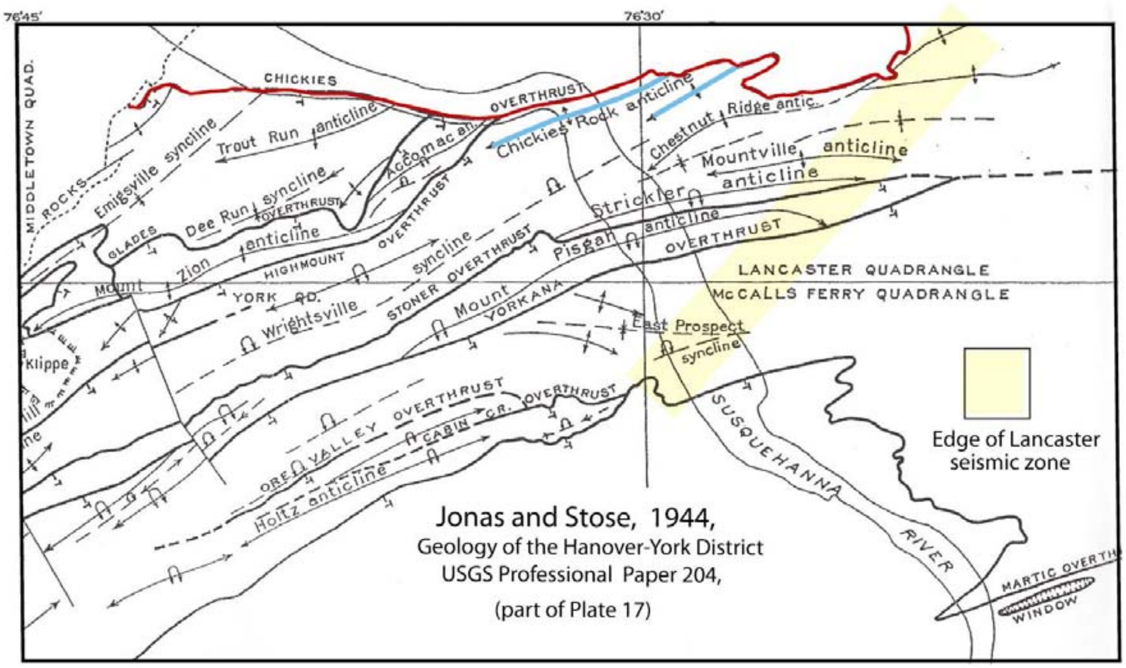

Figure 2. Stose and Stose (1944) Tectonic Map *(partial) showing the two phases of deformation (here color enhanced) around the Chickies area. The edge of the Lancaster seismic zone of Wise and Faill (2002) is highlighted in yellow, the SW end of that zone appears as several quakes in the vicinity of the East Prospect Enclave. This text and others in this guidebook hypothesize that regional changes in tectonic style are localized along this buried edge of basement.*

2) Stose and Stose (1944) had problems with the age of the Conestoga Formation. They present evidence in some detail that the Conestoga lies over as well as under other units and note that such relationships are not consistent with fossil ages. As one reads their slightly puzzled and puzzling discussions, it is tempting to smile with modern knowledge that the Conestoga interfingers with these slope deposit. Accordingly, it both overlies and underlies these units. Parts of the Conestoga are time-correlative with each of these units and regionally it is correlative with all of them. Lest one feel too self-satisfied, it would be well to remember that none of us had this obvious insight until John Rodgers pointed it out in 1968. 1970.

3) Missing formations at the base of the Martinsburg / Cocalico were recognized in Stose/Jonas and Stose's mapping but until the relatively recent work by Ganis on graptolites and Repetski on conodonts (Ganis, et al., 2001, Ganis and Wise, 2008) these were interpreted as the result of erosional removal after an uplift that preceded the Cocalico unconformity. Now these relationships are recognized as largely tectonic removals associated with massive allochthon displacements of the Cocalico-Martinsburg-Dauphin nappe complex.

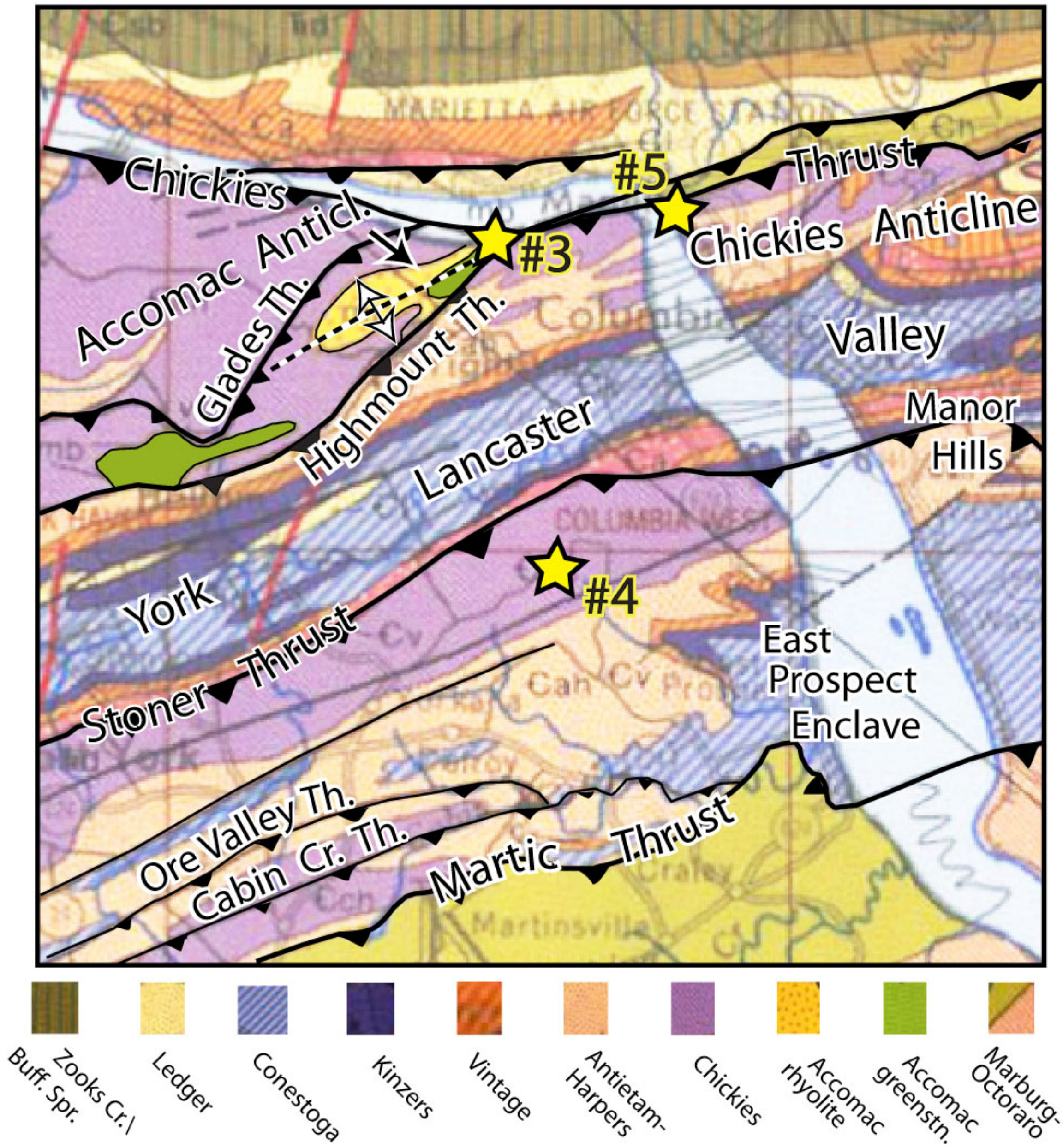

Figure 3. Geologic map of Accomac setting. *Annotations over the state geologic map base*

Structural and tectonic setting: The Hellam Hills consist mostly of a series of Taconic age, N60E trending thrusts and folds of Chickies Quartzite and its basal Hallam Conglomerate. Alleghanian age thrusting and folding of this complex along E-W trends by the Chickies Thrust produced a broad area of erosionally resistant rock. Less resistant, overlying Cambrian carbonates form the Lancaster-York Valley on the southern or upper limb of the anticlinorium whereas the same rocks in its footwall form the broad Marietta to Elizabethtown lowlands across the river to the north. This erosionally resistant mass deflects the flow of the Susquehanna River eastward for about five miles before the ridge narrows by intersection of these two trends to allow flow through the water gap at Chickies Rock. Within that five-mile-long fault- line scarp from Chickies Rock to Codorus Creek, only the Accomac Run cuts deeply enough through the ridge to provide easy access to the riverfront. Details appear in Figure 4.

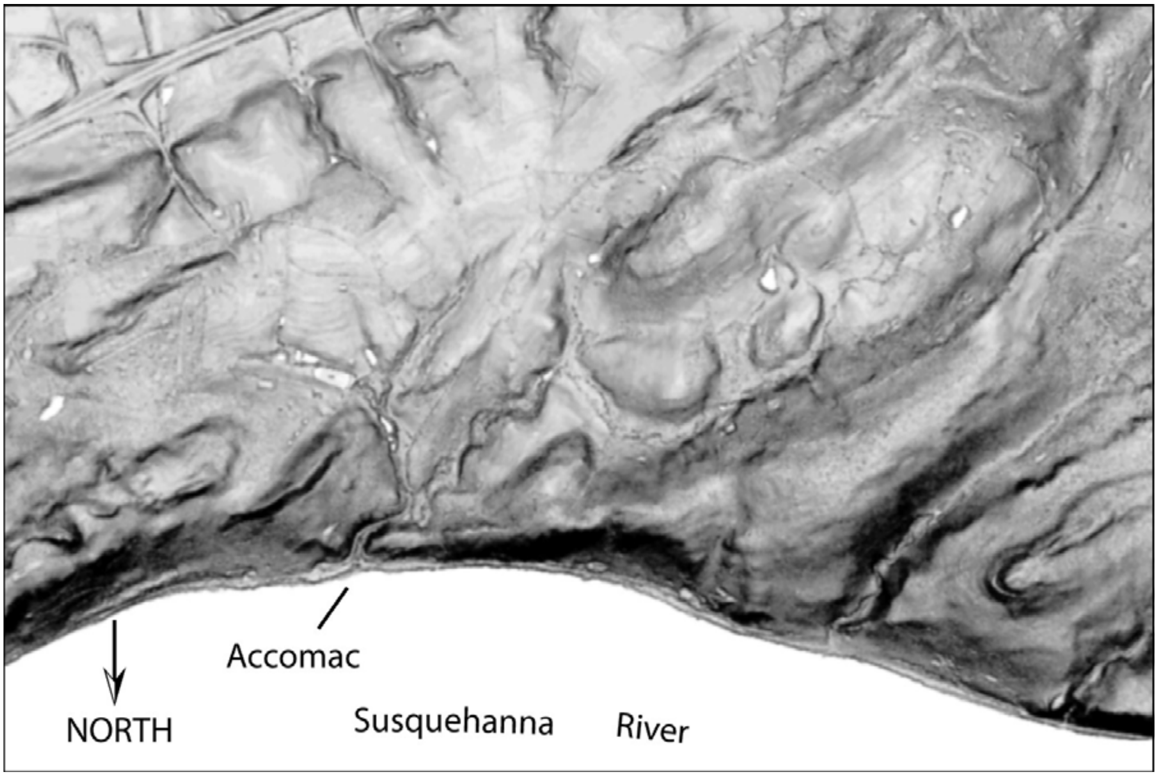

Figure 4. LIDAR image of the Accomac Area*. Note north is reversed to correspond with Figure 1A. showing NE elongated area of exposure of Precambrian volcanics surrounded by more resistant Hallam Conglomerate and Chickies Quartzite. Image courtesy of Jay Parrish.*

1) The location of the Accomac volcanics as the eastern-most exposure of Catoctin-related volcanics may be related to the locus of the Eocambrian Blue Ridge part of the rifted edge. A weakened hotter lithosphere / crust would represent a logical location for rifting with a transform fault occurring near its northern end. As suggested in Figure 5, a small area of the volcanic cover of that area would be likely to survive on the transform edge.
2) The Chickies Thrust follows the river edge, just offshore of the parking lot (Figure 1A) with scattered exposures of Ledger Dolomite appearing locally on the far shore, a stratigraphic throw of 3000 – 4000 ft (~ 1 km)
   a) The opposite shore (Jonas and Stose, Middletown Quad, 1933) also exposes Vintage Dolomite and Antietam schist/quartzite beyond a second fault that J&S interpreted as a Mesozoic normal fault largely on the basis of its straight-line outcrop.
3) The Accomac Volcanics occur as the Precambrian core of a tight anticlinal fold strongly overturned to the NW. It lies between the Glades Thrust below and Highmont Thrust above (Figures 2 and 3).
   a) The Alleghanian age Chickies thrust truncates this and all the other N60E trending Taconic structures at shallow depths beneath the shoreline
   b) Figure 6 supplements and colors Stose and Jonas's 1933 sketch of the thrust and near-recumbent geometry visible in the Susquehanna bluffs westward from Accomac Glen. Their sketch shows the river-facing cliffs as might appear from the opposite shore. The left quarter of the diagram is a new addition based on

the general data and their text discussions. As suggested in the caption, the apparent wrong displacement on the thrusts is probably an artifact of the oblique orientation of the line of exposure.

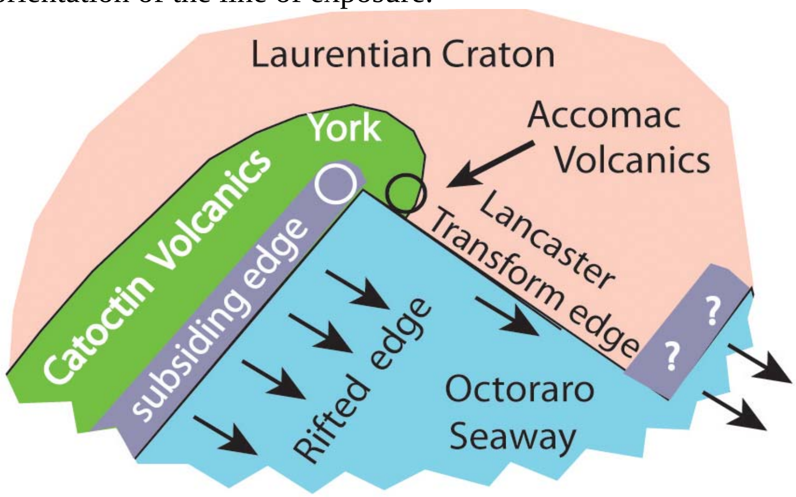

Figure 5. Suggested reason why the Accomac Volcanics *are the easternmost bits of Catoctin-related volcanics. Part of the Neoproterozoic rifting of Rankin (1976) and Thomas (1977) was localized along a zone of lithospheric weakness under the Cactoctin province. The Lancaster Transform Fault linked this rift with another one, now buried, displaced, and of uncertain location but still reflected in the chip of its edge now preserved as the Reading Prong.*

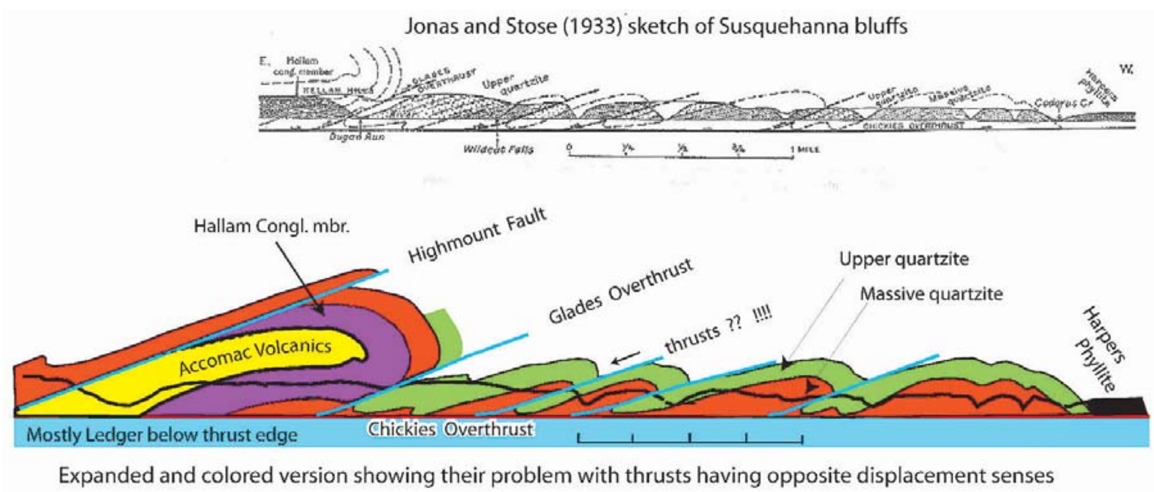

Figure 6. Jonas and Stose (1933) sketch of the Susquehanna River Bluffs *west of Accomac Glen (upper image). View is looking south. Colors and additions in Accomac area are new with this manuscript. Note the problems Stose and Stose recognized in the apparent normal fault displacement of folds that appear to be brow folds in a stack of imbricate thrusts.(The oblique E-W slice of the Chickies Thrust through a N60E trending series of folds and thrusts is probably the cause of this apparently anomalous offset.)*

Structural Fabric: The greenstone volcanics in the road cuts contain many epidotized pods, possibly remnants of pillow lavas. With diligent search and a strong imagination, some observers claim to have found remnants of bedding, especially in finer grained zones. These commonly exhibit a strong cleavage, locally with elongated amygdules and lithic fragments indicative of strong extensional strain during cleavage formation. Similar strain orientation appears in the epidote pods in the form of quartz veins perpendicular to the stretching direction, locally with fibers sub-perpendicular to the veins (Figures. 1C, D).

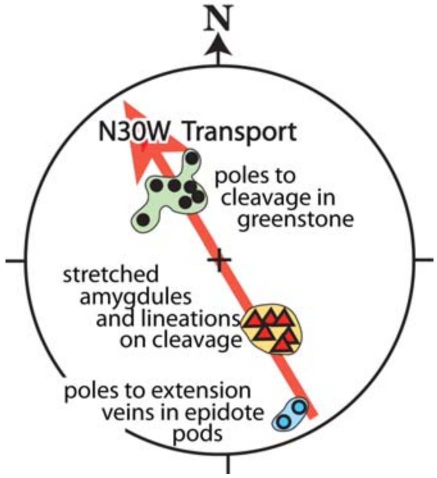

Figure 7. Petrofabric orientations at Accomac. *These fabric elements show N30W tectonic transport and structural style typical of Taconic structures of the region. (Wise, 1970, Wise and Werner, 2004)*

The equal area plot of the orientations of these features (Figure 7) shows clear N30W tectonic transport, characteristic of the Taconic deformation in the immediate Susquehanna area in and regions to the east. On a broader scale, areas to the west of this area are dominated by N60W transport normal to the Blue Ridge trends and the rift arm of the Late Precambrian corner of the craton. Stop #1 notes include a cropped figure from a regional compilation by Wise and Werner (2004) showing these motion vectors from many study areas.. That figure with net data from Clark and Gard's Franklin and Marshall College senior thesis of Accomac area shows the extension directions from this outcrop are typical of a much broader area.

More details of piracy of Taconic cleavage by Alleghanian folding along the lip of the Chickies Thrust appear in the notes for Chickies Rock, Stop #5.

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STOP # 3 SOUTH MOUNTAIN METABASALT AND CATOCTIN METARHYOLITE, ACCOMAC, YORK COUNTY, PENNSYLVANIA AND THEIR RELATIONSHIP TO VOLCANICS OF THE SOUTH MOUNTAIN ANTICLINORIUM OF ADAMS, CUMBERLAND, AND FRANKLIN COUNTIES, PENNSYLVANIA.

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1) Introduction: At Accomac, York County, the 2010 FCPG will mainly see South Mountain Metabasalt, but porphyritic Catoctin Metarhyolite occurs within walking distance to the SW. There may even be some highly sheared metarhyolite near the top of this metabasalt section. Both the metabasalt and the metarhyolite in this general area were mapped by Stose and Jonas (1939) with the metarhyolite placed stratigraphically between the metabasalt, below, and the Hellam Conglomerate of the Chickies Formation, above.

South Mountain Metabasalt is a product of the stage of rifting of the supercontinent Rodinia that began circa 600 Ma, *i.e.*, during the late Neoproterozoic. This period of rifting was successful in that it resulted in the opening of the Iapetus Ocean. The magmatic products of this rifting were a basaltic Continental Initial Rifting Tholeiite (CIRT; Smith and Barnes 2004) and a rhyolitic product that likely consists of remelted continental crust. Over perhaps a few million years, the CIRT gradually evolved toward ocean floor basalt (OFB) compositions as the continental crust was attenuated by extensional thinning and, to a lesser extent, by the melting which removed deep siliceous continental materials and brought them to the surface as rhyolites. Although there was a rift to drift transition for the basaltic magmas, there are very few intermediate compositions between the rift basalts and rift rhyolites. Isn't this also characteristic of rift bimodal volcanism?

At Accomac, we are seeing the magmatic products of the third of six dated period of extension/rifting since the ~ 1.0 Ga Grenvillian orogeny observed in the mid-Atlantic region. The magmatic products associated with these variably successful extensional events occurred at approximately 970, 735, 570, 433, 201, and 50 Ma, perhaps an irregular series. Further details are provided in the annotated table of dates in this same volume (Smith, 2010). The relationship of three of these rifting volcanics to the topography for the Battle of Gettysburg was discussed by Smith and Keen (2004).

The metabasalt and metarhyolite in the Accomac area are similar to those in the South Mountain anticlinorium of Adams, Franklin, and Cumberland counties, Pennsylvania. They are distinct from those to the southeast of the Tunnel Hill-Jacks Mountain (TH-JM) fault system which bounds the South Mountain anticlinorium on its southeast side. Below, the case will be made for geochemically dividing the volcanics. However, here it should be noted that the TH-JM fault system is an Alleghanian-age artifact that has juxtaposed two different pieces of Catoctin, *sensu lato*. David B. MacLachlan (1991) is acknowledged for making the same division based on structural differences. He, in turn, acknowledged the Appalachian tectonic map of Hatcher et al. (1989, Plate 1 dated 1990)

2) Descriptions and distinctions: The South Mountain Metabasalt at Accomac is fine-grained, mostly greenish, but locally it is bluish gray. It contains actinolite, chlorite, epidote, albite and quartz. Some units are massive and others contain abundant 1-mm to 1-cm epidote-rimmed and chlorite-filled amygdules. Still others contain abundant chlorite-epidote-quartz filled amygdules ranging from 0.2 to 0.7 cm in diameter. Metabasalt at the base of the outcrop along Accomac Road

Smith, R.C. II and J.H. Barnes. (2010) Stop # 3 South Mountain Metabasalt and Catoctin Metarhyolite, Accomac, York County, Pennsylvania and their relationship to volcanics of the South Mountain anticlinorium of Adams, Cumberland, and Franklin counties, Pennsylvania, *in* Wise, D.U and Gary M Fleeger, eds., Tectonics of the Pennsylvania Piedmont along the Susquehanna River, 75th Annual Field Conference of Pennsylvania Geologists, Lancaster, PA, p. 33 – 41.

and in the creek across the road may contain pahoehoe toes (Smith and Barnes, Pennsylvania Geological Survey, 11/3/1994). Cryptic, high-angle faults within the metabasalt are locally mineralized with copper. Elsewhere in SE Pennsylvania, geochemical equivalents of Catoctin Metabasalt, *sensu lato*, occur at other metamorphic grades and geometries. However, the easternmost recognized surface exposure of Catoctin Metarhyolite in Pennsylvania is in the Accomac area. The Rittenhouse Gap Felsite, Berks County, occurs still farther east, but is ~ 30 Ma older and has a distinct composition (Smith, 2003). The associated Tunnel Hill Metabasalt, Berks County, has an age roughly comparable to that of the felsite based on using it in a whole rock Rb/Sr isochron.

David B. MacLachlan, in his inimitable style, pointedly pointed out that there are two South Mountains. He did this largely on the basis of structures, patterns of mapped units, and the resulting topography (MacLachlan, 1991). In that article, he discusses the differences, including the Ridge and Valley style structures of the South Mountain Anticlinorium of Pennsylvania. A few months prior to Mac's article, the senior author observed the TH-JM fault and confirmed Fauth's (1978) previously noted hypothesis of Mesozoic reactivation of an Alleghanian fault. Sam I. Root and Mac then kindly confirmed Smith's observation of a Mesozoic, brittle, extensional fabric that cuts both Alleghanian cleavage and isoclinal folding.

With respect to the metabasalts, it has been noted since 1991 that "The most profound break occurs across the Tunnel Hill-Jacks Mountain fault zone, which appears to separate metabasalts of the lithologic continuation of the Blue Ridge of Maryland and Northern Virginia from Pennsylvania's more diverse volcanic, *i.e.*, NW of the TH-JM fault system" (Smith et al.,1991, p. 19). As first recognized by Smith et al. (1991), it is necessary to distinguish the South Mountain Metabasalt in the South Mountain anticinorium NW of the Tunnel Hill-Jacks Mountain (TH-JM) system of Fauth (1978) from the "true Catoctin Metabasalt" to the SE. This distinction is consistent with the structural differences across the TH-JM fault system sharply noted by David B. MacLachlan (1991). Because of *both* geochemical and structural differences, it is herein proposed that the formal name South Mountain Metabasalt be established for the metabasalts NW of the TH-JM fault system. Below, the case will also be made for generally subaerial environment for the South Mountain Metabasalt and a commonly subaqueous one for the Catoctin Metabasalt and equivalents in Pennsylvania. The type locality for the South Mountain Metabasalt is the overturned section at Stop 3 of the 56th Field Conference of Pennsylvania Geologists (See Figures 43 and 44 by S. W. Berkheiser in Smith et al., 1991), Waynesboro Reservoir, Adams County. The venerable name Catoctin Metabasalt is and should be retained for the metabasalts SE of the TH-JM fault system in the Blue Ridge of Pennsylvania, Maryland, and Virginia. Catoctin Metarhyolite remains an unequivocal name for both the metarhyolite in the South Mountain anticlinorium NW of the TH-JM and for the smaller amounts to the SE into Maryland and Virginia.

3) Where Accomac fits in: Both the metabasalt and metarhyolite at Accomac form nice vignettes of the corresponding volcanics NW of TH-JM fault system, *i.e.*, of the South Mountain Metabasalt and Catoctin Metarhyolite. In the South Mountain anticlinorium of Adams, Franklin, and Cumberland counties, South Mountain Metabasalt is associated with copious Catoctin Metarhyolite (perhaps 80% metarhyolite and 20% metabasalt at the surface to the south of the Carbaugh-Marsh fault (Root and Hoskins, 1977, and Figure 10 in Root and Smith, 1991), < ~10% metabasalt between the Carbaugh-Marsh and Shippensburg faults, and no mappable metabasalt *at the surface* to the north of the Shippensburg fault. The Catoctin Metarhyolite has been dated by Aleinikoff et al. (1995) at 564 +/- 9 Ma. Southworth et al. (2009) report 571 Ma for a lower Catoctin Metarhyolite in Virginia and 564 Ma for an upper on in Pennsylvania. The ages for the metabasalts are expected to be roughly comparable.

To the NW of the TH-JM fault system in the South Mountain anticlinorium, local enclaves of relatively undeformed South Mountain Metabasalt contain ropy pahoehoe surfaces, pahoehoe toes, vesicular cored pyroclast bombs, agglomerate-agglutinate piles (welded cow-pie bombs and spatter), larger bombs, pipe vesicles, and thin flows having highly vesicular zones beneath thicker upper chilled surfaces (Smith et al., 1991, Plates I through IV), all of which are compatible with subaerial deposition. To date, however, such relatively undeformed enclaves have not been observed at Accomac, perhaps because of proximity to the Chickies and Oregon thrust faults (or the main Taconic cleavage strain and recrystallization which appear to be lacking in the South Mountain anticlinorium). In the South Mountain anticlinorium, a few discontinuous float trains from medium-grained metadiabase feeder dikes have also been found. Based on pipe vesicle orientation, ropy pahoehoe surfaces, cleavage being less steep than bedding and in the same quadrant, relative thickness of chilled margins in thin metabasalt flows, and trapping of frothy basalt beneath upper contacts in that area, the volcanic section in the South Mountain anticlinorium of Pennsylvania is overturned. Again, structural complexity at Accomac has precluded use of such facing direction criteria.

Other metabasalt populations that are geochemically correlative to the South Mountain Metabasalt to the NW of the TH-JM fault system include: 1) Catoctin *sensu lato* Metadiabase dikes in Grenvillian terrains throughout southeastern Pennsylvania [As noted by Smith and Barnes (2004), the Grenvillian-age Brandywine massifs of Faill (1997) can be distinguished by the latter having been cut by the distinctive "older diabases" of (Bascom and Stose 1932).], 2) the White Clay Creek Amphibolite flows (Smith and Barnes, 2004), 3) Sams Creek Metabasalt of York County, 4) Fishing Creek Metabasalt Member of the Scotts Creek Formation of Lancaster County, and 5) Sams Creek Metabasalt of Maryland, type and principle reference section.

4) The venerable Catoctin Metabasalt: As noted above, the volcanics to the SE of the TH-JM fault system are both geochemically and logically equivalent to the Catoctin Metabasalt of the Catoctin Mountains of Maryland and the Blue Ridge of Virginia. Some pillows have been observed in Pennsylvania SE of the TH/JM and in correlatives such as the Glen Rock Metabasalt of York County and, yes, the remarkably undeformed "Jonestown Volcanic Complex" (Smith and Barnes, 2004, Table 3, p. 36). [However, the so-called "andesite extrusives" mapped in the Jonestown area are basaltic based on the classification of LeBas et al. (1986). Hence, the less grandiose name Jonestown Basalt is herein proposed to cover the geochemically similar extrusives and shallow dikes in the Jonestown area.] Pillows in these areas suggest a subaqueous depositional environment at those locations. Other geochemical correlatives of the true Catoctin Metabasalt which have not yet been observed to contain definitive pillows include the Holtwood Metabasalt of Lancaster County, brought to the present day surface by being near the core of the Tucquan anticline and the Pigeon Hills Metabasalt of Adams and York counties, which is the direct continuation of Catoctin Metabasalt across the Gettysburg Basin. It is likely continuous beneath the Mesozoic Gettysburg Basin.

As shown by chondrite normalized rare earth and TiO_2-Zr-Y diagrams, among others, the Catoctin Metabasalt now found to the SE of the TH-JM fault system evolved to more Ocean Floor Basalt (OFB)-like compositions (Smith and Barnes, 2004). They appear to have formed from a rift-thinned crust capable of yielding only a much smaller percentage of Catoctin Metarhyolite. The metabasalt SE of the TH-JM fault system may be slightly younger as the rift-to-drift evolution of CIRT South Mountain Metabasalt to more OFB-like Catoctin Metabasalt likely required several millions of years. Smith et al. (1991) noted that the metabasalt SE of the TH-JM fault system was “true Catoctin,” like that of the Blue Ridge of Virginia and Catoctin Mountains of Maryland, and added that the ratio of metabasalt to metarhyolite in the Pennsylvania portion to the SE of the TH-JM was ~10:1 vs. ~2:10 in the fault block to the NW. The metabasalt in the Pigeon Hills, which

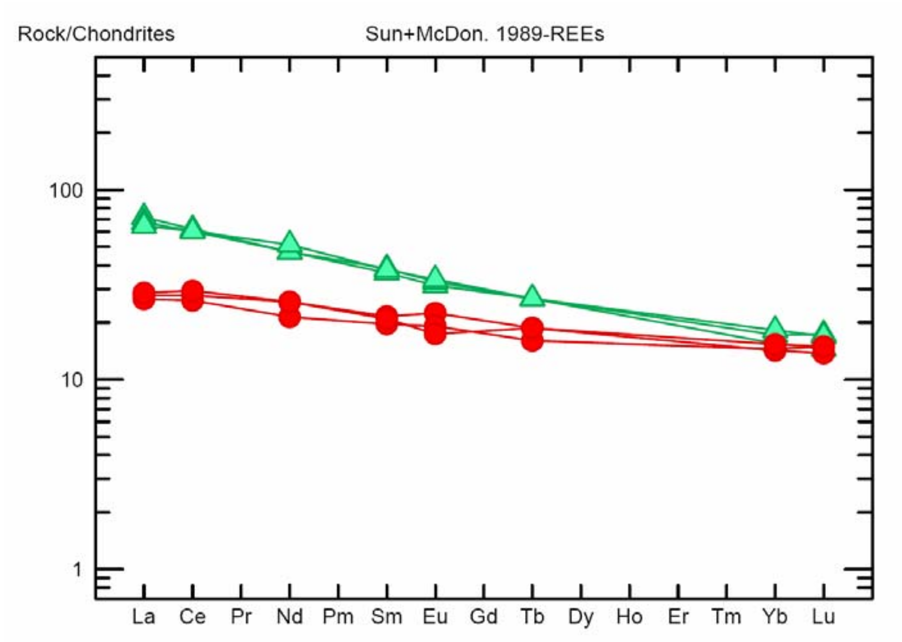

Figure 1a. Chondrite normalized rare earth elements *(CN REE, Sun and McDonough, 1989)*

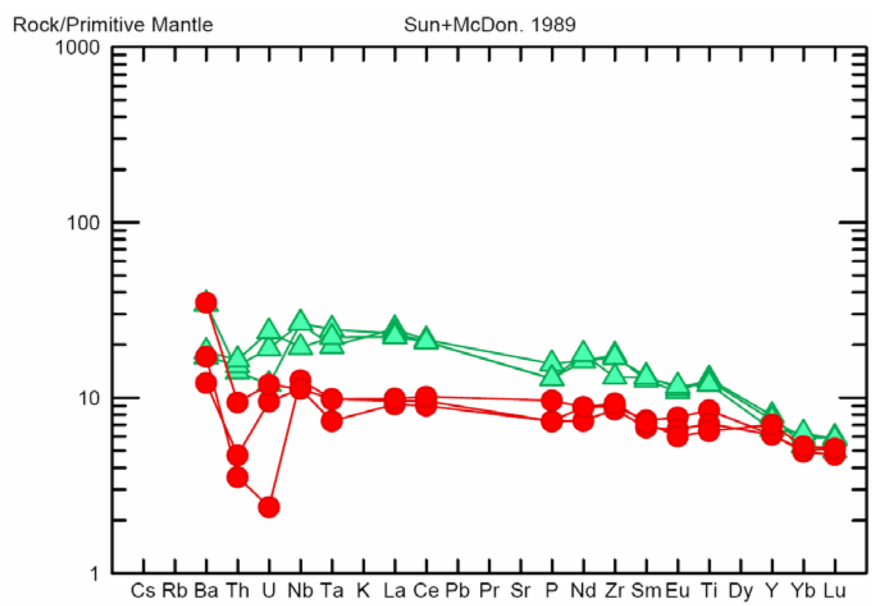

Figure 1b. Primitive mantle normalized *(Sun and McDonough, 1989)* ***plots for the medians for Accomac Metabasalt, Dikes in Grenvillian terrains, and White Clay Creek Metabasalt*** *as triangles compared with Catoctin Metabasalt SE of the Tunnel Hill-Jacks Mountain fault system, Pigeon Hills, and Jonestown Basalt as circles.*

appears to lack associated metarhyolite, is geochemically equivalent to Catoctin Metabasalt, i.e., that SE of the TH-JM fault system (Table 1).

5) Geochemical data summary: Table 1, adapted from Smith and Barnes (2004), shows the two main groupings within the Catoctin *sensu lato* Metabasalt. It also suggests the transitional nature of the rift to drift process. As noted above, the Accomac Metabasalt is part of the South Mountain Metabasalt grouping. Figures 1a and 1b show few of the differences between some Catoctin Metabasalt, *sensu lato*, groups associated with the NE vs. SW side of the Tunnel Hill-Jacks Mountain fault system.

Table 2 compares two samples of Catoctin Metarhyolite from the Accomac area with corresponding samples from the South Mountain anticlinorium. Table 3 (modified from Smith and Barnes, 2004) shows how variable other, unrelated metabasalts in the area are.

6) Neoproterozoic Rifting in the mid-Atlantic region: As noted by Smith et al. (1991, p. 5), "… the Catoctin event appears to be the most underrated geologic even in the Appalachians." It is the 3rd of 6 extensional events since Grenvillian in the mid-Atlantic region (Smith and Keen, 2004). Smith (2003) attempted to relate the various volcanics related to the opening of Iapetus and to summarize the relevant dates then available.

As noted above, the Catoctin Metabasalt of the Catoctin Mountains of Maryland and the Shenandoah of Virginia heads east at approximately Fairfield, Adams County, and reappears across the Gettysburg Basin as the geochemically equivalent Pigeon Hills Metabasalt (See MacLachlan (1991) for structure, Smith et al. (1991) and Smith and Barnes (2004) for geochemistry). On the other hand, surface exposures of volcanics of the South Mountain anticlinorium apparently end as Catoctin Metarhyolite 5 km SW of Dillsburg, York County. However, metadiabase in one portion of the Womelsdorf outlier of Berks, Lancaster, and Lebanon counties is vesicular and a few other bodies have a geometry permissive of flows rather than that of the almost ubiquitous dikes (T. V. Buckwalter's mapping in Geyer et al., 1963). The vesicular metadiabase in the Womelsdorf outlier is at least hypabyssal, if not extrusive. The main portion of the Reading Prong lies east of the Schuylkill River and has few, if any, candidates for Catoctin *sensu lato* extrusives. Indeed in that area, there appears to be a profound unconformity at the base of Hardyston Formation. Locally, major amounts of heavy minerals occur in a fossil placer bed at the base of the Hardyston and above the underlying Grenvillian gneisses. Geochemical equivalents of South Mountain Metabasalt flows don't reappear to the southeast until one is in amphibolite-grade terrain. These flows are part of the White Clay Creek Amphibolite of Delaware County, Pennsylvania, and adjacent New Castle County, Delaware (Smith and Barnes, 2004). This may seem to be a moderate distance for a correlation with the South Mountain anticlinorium, but one needs to be mindful that the Long Range Basalt dikes of Newfoundland are generally regarded as cousins to the Catoctin. The Catoctin was a *very* widespread event.

7) Suggested future work: **a.** Obtain SHRIMP ages of zircons from heavy-mineral concentrates from fossil placers at the base of the Hardyston Formation to establish the possible former presence of ~960 to ~560 Ma Neoproterozoic volcanics in the main portion of the Reading Prong. Such former presence is already hinted at by tourmaline, which is sparse in most parts of the Reading Prong except Chestnut Hill-Marble Mountain, in the fossil placer. **b.** Complete the two TiO_2 maps, begun by the present authors, for Catoctin Metarhyolite and South Mountain Metabasalt plus Catoctin Metabasalt in Pennsylvania. It already appears that TiO_2 is higher in the presumably younger metabasalt flows near the clastic cover in the South Mountain anticlinorium. Elsewhere as, in the Reading Prong near Huffs Church, Berks County, float containing a pair of Catoctin *sensu lato* Metadiabase dikes contains higher TiO_2 in the crosscutting chilled dike. **c.** Search for allochthonous areas of the ~ 735-Ma Robertson River Igneous Suite (RRIS) of Virginia (Aleinikoff et al., 1995) in the South Mountain anticlinorium of Pennsylvania and in what appear to be areas of older rifting to the east such as Chestnut Hill, Northampton County, and the sub-Chickies bimodal (?), amphibolite-facies gabbroic and granodiorite gneisses of the Honey Brook Upland. High contents of F, Ga, and Nb and plotting of structural facing directions might help recognize some members of the RRIS. Examine post-Grenvillian dikes in Laurentian terrains. To date, Rittenhouse Gap Felsite dikes having a similar high F, Ga, Nb geochemistry to the Battle Mountain Member of the RRIS have been found in Berks County, Pennsylvania, but the 602.3 +/- 2 Ma date is between those for the RRIS and Catoctin (Smith, 2003). **d.** Obtain TIMS U-Pb dates of zircons from Catoctin Metarhyolite near Accomac and "Marble Mountain metarhyolite," informal, near Easton, Northampton County. **e. Complete** interpretation of an 18+ point linear $^{143}Nd/^{144}Nd$ vs. $^{147}Sm/^{144}Nd$ isochron for the Pennsylvania's version of the Catoctin Metabasalt, *sensu lato,* begun by Ken A. Foland, Ohio State University, and the senior author.

Table 1. Medians for selected trace elements in the South Mountain Metabasalt at Accomac, York County, Pennsylvania, and correlative Catoctin Metabasal*t, sensu lato, analogs from southeastern Pennsylvania and adjacent states. In general, data in the upper 7 rows, which includes the South Mountain Metabasalt from NW of the Tunnel Hill-Jacks Mountain fault system, are similar. Those in the lower 5 rows, which include the true Catoctin Metabasalt from SE of the same fault system, are also similar. Populations are arranged by decreasing TiO_2, which in this case roughly corresponds to a rift to drift transition. "N" is the number of analyzed samples in each population. The TiO_2 data are listed in percent and others in ppm.*

	N	**TiO_2**	**Zr**	**Hf**	**Nb**	**Ta**	**Th**	**Ni**	**V**	**Y**	**La**	**Ce**
Catoctin-affinity Metadiabase dikes in Grenvillian terrains	23	2.78	210	4.3	19	0.9	1.2	40	330	36	17.0	38
South Mountain Metabasalt at Accomac, York Co.	5	2.72	190	4.6	19	1.0	1.3	60	244	32	16.0	37
White Clay Creek Amphibolite	21	2.64	150	4.1	14	0.9	1.6	66	393	30	15.4	37
South Mountain Metabasalt NW of TH-JM fault	48	2.35	157	3.6	12	0.6	0.7	80	329	36	11.5	29
Sams Creek Meta-basalt, York Co.	3	2.02	160	3.5	21	1.1	1.6	160	328	38	16.5	38
Fishing Creek Metabasalt Member of Sams Creek Formation, Lancaster Co.	7	1.94	154	3.6	21	1.1	1.7	96	223	30	14.8	33
Sams Creek Meta-basalt, MD, type and ref. section	6	1.88	146	3.0	22	1.0	1.4	126	306	32	14.2	31
Holtwood Metabasalt, Lancaster Co.	6	1.82	99	2.3	9	0.3	0.4	78	306	28	7.1	18
Glen Rock Meta-basalt, York Co.	8	1.82	107	2.6	6	0.4	0.4	104	368	36	7.0	18
Catoctin Metabasalt SE of TH-JM fault	6	1.74	105	2.4	9	0.4	0.4	110	301	28	6.6	17
Pigeon Hills Meta-basalt, Adams and York counties	6	1.54	96	2.0	8	0.2	0.2	134	312	28	6.7	16
Jonestown Basalt, Berks and Lebanon counties	7	1.40	104	2.4	8	0.4	0.8	95	270	32	6.8	18

Table 2. Selected trace element contents of two "pairs" of Catoctin Metarhyolit*e from outcrops at Accomac, York County, and the South Mountain anticlinorium, Adams, Cumberland, Franklin and York counties. The first pair may yield zircons suitable for U-Pb dating.*

Sample	**TiO_2**	**Ba**	**Ga**	**Ge**	**Hf**	**Nb**	**Ta**	**Zr**
MRACSW Accomac	.312	657	27	1.2	17.2	59.7	3.90	832
OFRRFB S. Mtn.	.310	651	17	1.9	18.8	59.8	3.99	610
MRACS Accomac	.227	99	20	0.9	21.6	66.4	4.59	862
CATMRRH S. Mtn.	.228	182	27	1.7	20.9	68.7	4.51	842

Table 3. Selected trace elements in 15 populations of metabasalts from southeastern Pennsylvania and mid-Atlantic state*s (Smith and Barnes, various) that are not known to be related to the Catoctin event. They are included for comparison with the data in Table 1 to show the larger variation between unrelated basalts, even though some of these are from continental rifting environments. "N" is the number of analyzed samples in each population. The TiO_2 data are listed in percent and others in ppm.*

	N	**TiO_2**	**Zr**	**Hf**	**Nb**	**Ta**	**Th**	**Ni**	**V**	**Y**	**La**	**Ce**
"Bald Eagle metabasalt," York County, informal	4	3.21	186	5.4	24	1.4	2.4	66	270	30	35	76
Bald Friar Metabasalt, associated with BMC	14	1.24	80	1.9	3	<0.1	0.3	102	256	30	2.5	9
Conowingo Creek Metabasalt, Lancaster County, associated with BMC	7	1.34	75	1.6	8	0.2	<0.1	114	339	12	9.9	20
Eocene basalts, Va. and W.Va.	7	2.28	151	3.8	34	1.9	2.8	68	252	26	32	60
James Run, Cecil County, Md.	5	1.45	166	4.0	6	0.5	3.6	6	117	48	14	34
Kennett Square Amphibolite, Delaware County	8	1.10	66	1.5	4	0.4	0.3	90	275	24	4.2	11
"Liberty Reservoir amphibolite," Carroll County, Md., informal, associated with BMC	5	1.20	95	2.2	4	0.3	1.1	67	264	27	5.9	16

"Nottingham County Park amphibolite," Lancaster County, informal, associated with BMC	3	1.78	16	.2	1	<.01	<0.05	35	660	14	0.8	2
"older diabase," Delaware County, High-MgO subgroup	5	0.74	67	1.3	4	<0.1	0.4	160	227	24	5.1	13
Quarryville Diabase, Lancaster County, type locality	1	0.41	59	0.9	4	<0.1	0.9	320	160	20	4.0	9
Rossville Diabase, York County, principal reference section	1	0.88	77	1.3	7	0.2	1.0	70	254	24	5.2	12
Sword Mountain Olivine Melilitite, Washington Co., Md.	8	4.06	307	4.6	106	7.8	8.4	335	297	22	72	134
Tunnel Mine Metadiabase, Berks County	5	3.70	355	7.6	54	3.4	5.9	191	217	49	62	123
"Williams Quarry metadiabase," Northampton Co., informal	3	3.51	295	5.4	91	5.4	6.6	102	189	44	67	132
York Haven Diabase, York County, type locality	1	1.12	109	2.1	11	0.3	1.6	73	220	24	8.7	18

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STOP #4: REGIONAL OVERVIEW FROM SAM LEWIS STATE PARK:

Donald U. Wise, Dept. of Geosciences, University of Massachusetts at Amherst

Agenda: Lunch and the Hellam Conglomerate outcrop followed by group picture and overview of region with associated wild-eyed arm-waving. NO HAMMERS!

Location: southwest of Wrightsville and one mile south of the town of Hellam. The park occupies the highest hilltop in the immediate area and affords magnificent views of the topography associated with the Susquehanna Region as well as all the major tectonic elements of the field trip.

Geologic setting: This topographic high is the result of differential erosional resistance of the Hellam Conglomerate with respect to its less resistant and mostly overlying Chickies *slate* facies, a major change from the *quartzite* facies in the Hellam Hills just to the north.

1) Large outcrops of the conglomerate are adjacent to the parking area.
    - a) Mostly quartz clasts in the 1-2 cm size range with only a few lithic fragments. Careful search *may* reveal a few *questionable* Accomac Volcanic pebbles.
    - b) The outcrop is highly cleaved and deformed. Bedding is difficult to detect.
    - c) Nearby large blocks of bull quartz indicate extensive vein activity was associated with the deformation.
    - d) The quartz dominance is indicative of a long-exposed, deeply weathered source area on the craton. Like so many basal unconformities the initial destruction of such a source area yields mostly quartz sands and pebbles.
    - e) The outcrops are in the core of the Mount Pisgah Anticline sandwiched between the Stoner and Yorkanna thrusts (Fig. 1 and Stop #3, Fig. 2).

2) The York-Lancaster Valley just to the north marks a very significant facies change from dominantly pure quartzites of the type locality of Chickies Rock, visible to the NE along the Susquehanna River.
    - a) The lithology on this side of the York-Lancaster valley is so different that Stose and Stose (1944) changed terminology from Chickies *Quartzite* on the north of the valley to Chickies *Formation* on the south.
    - b) The change marks a transition southward toward deeper water slope deposits of the Octoraro Seaway on the south from the cleanly washed, *Skolithus* inhabited, cross-bedded beach and platform deposits on the craton to the north.
    - c) Several significant thrusts occur between here and the Hellam Hills – Chickies Ridge. Telescoping of the unit makes the facies change appear more abrupt than originally deposited.

Geologic Map and Cross-Section: Fig. 1 is an annotated overprint of Wilshusen's 1979 map of the Greater York Area, derived mostly as an application-oriented version of Stose and Stose's 1944 USGS professional paper on the Hanover-York District.

1) The annotations on Fig. 1 are mostly from Stose and Stose, 1944 text and figures.
2) The tentative cross-section (Figure 2)may be the first ever published across this area -- with good cause.

Wise, D.U. (2010) Stop #4: Regional overview from Sam Lewis State Park, *in* Wise, D.U and Gary M Fleeger, eds., Tectonics of the Pennsylvania Piedmont along the Susquehanna River, 75th Annual Field Conference of Pennsylvania Geologists, Lancaster, PA, p. 43 – 48.

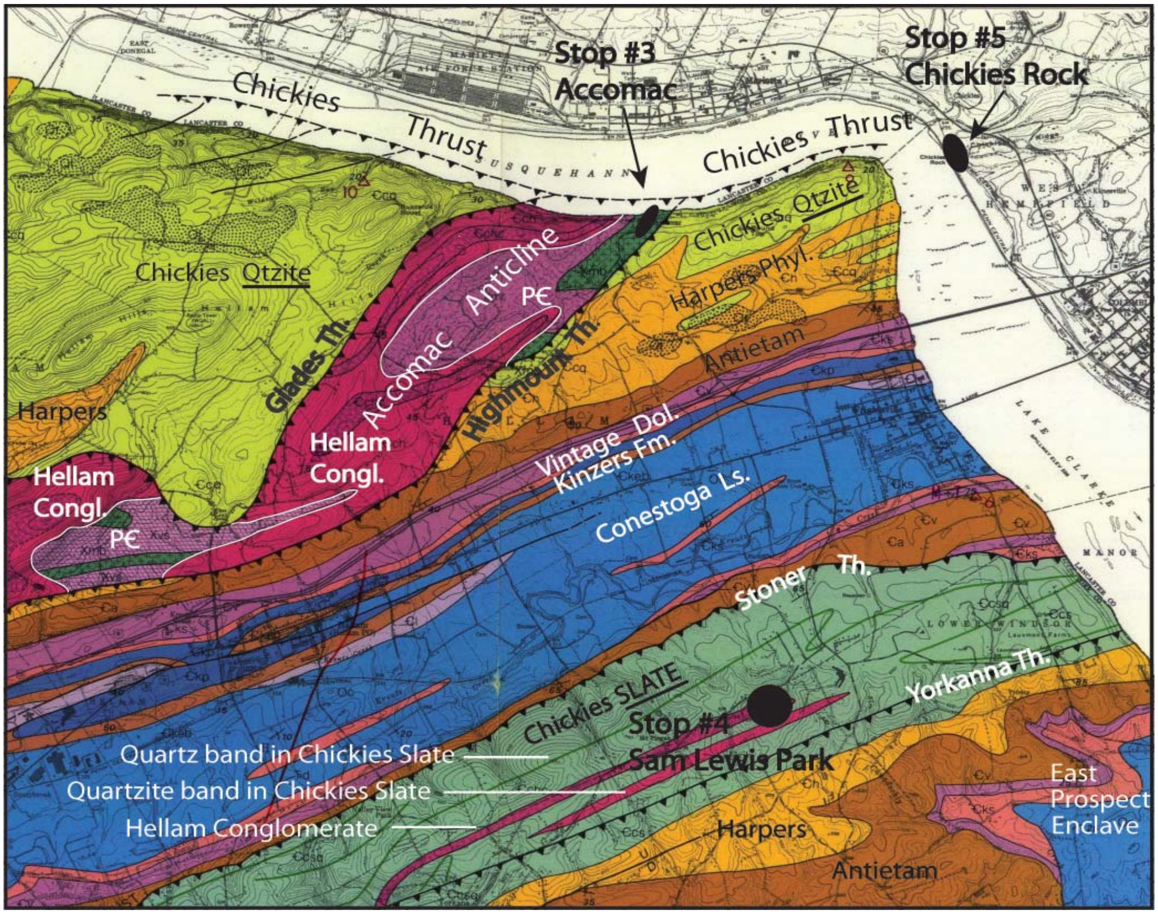

Figure 1. Geologic map of the area of Stops #3, #4, and #5*. Map from Wilshusen (1979) after mapping of Stose and Stose (1939, 1944). Stop #4 is in Hellam Conglomerate lenses in the core of the Mount Pisgah Anticline. Note the N50-60E trend of the Accomac fold is truncated by the N70E grain of the areas to the south.*

a) Apparently Stose and Stose wrestled with cross-section problems of the Accomac Anticline for years. The Stose and Jonas Middletown Quadrangle report (1933) includes the Accomac structure and Chickies Thrust near the southern edge of the quad along with a sketch profile along several miles of exposures of the quartzite cliffs facing the river east of the Accomac Valley (See Stop #3, Fig. 2). The sketch shows a series of strongly overturned, NW-facing folds in quartzite thrust sheets. However the actual displacements in the field and on the sketch are of a normal or apparently extensional sense, probably an apparent effect of the oblique trend of the younger Chickies Thrust with respect to the older fold axes and thrusts.

b) The larger problem is the Highmount Fault on the SE or right-side-up limb of the Accomac Anticline. Its relationship to the younger units of the York-Lancaster Valley just to the south indicates a normal or extensional sense of displacement. Stose and Jonas called it a "normal fault" in 1933.

c) By 1944 Stose and Jonas (Stose) had come a long way in sophistication about the structure of the area. They clearly recognized two stages of deformation. The earlier (now Taconic) phase of N60E trending folds and major metamorphism was followed by (now Alleghanian) imbrication of gently south dipping thrust sheets. Descriptions of the Highmount fault were changed in the later document to that of a younger *thrust* fault that overrides the older fold structures of the Chickies Rock system. However no cross-sections are given in support of this model … for a very understandable reason.

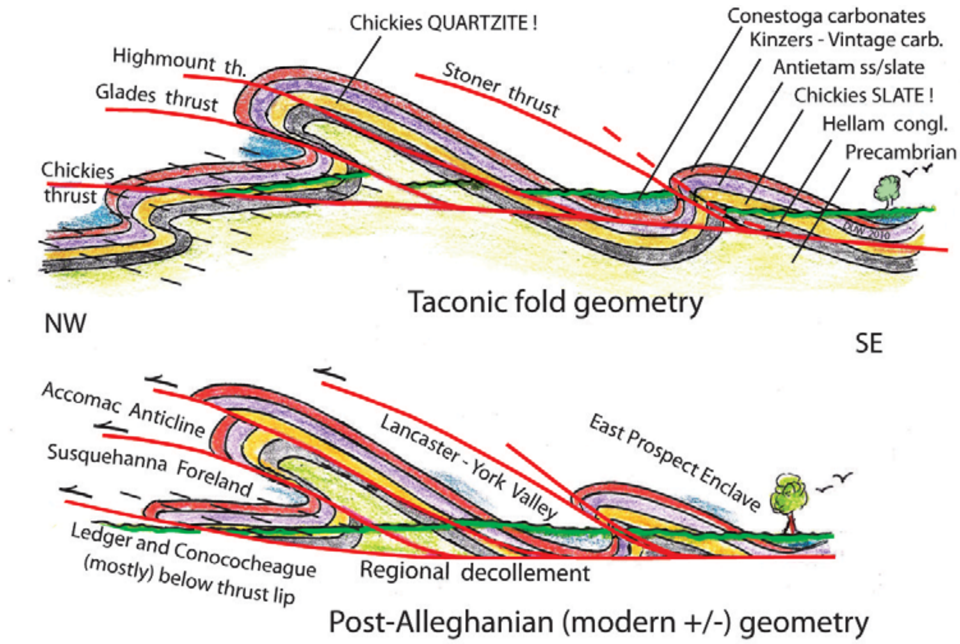

Figure 2. Generalized geologic cross-sections across Figure 1 *showing Taconic structure at the top with present erosional surfaces indicated in green. Alleghanian modifications at bottom with older erosion surfaces brought to the present single surface.*

3) In attempting to write this section, I spent a frustrating week drawing about two dozen different cross section across the area (all failures) while re-reading the Stose and Stose works. In doing so I was increasingly impressed with the remarkable structural sophistication in their work. They even drew a palinspastic reconstruction of the several thrust sheets showing where the older fold structures would fit into the pre-deformation thrust sheets. I concluded there was very good reason that their otherwise very complete professional paper did not include a cross-section.

a) The basic problem is that the Highmount fault removes section in a fashion typical of normal faulting rather than repeating it in typical thrust fashion. Even with post-Stose and Stose (S&J) knowledge that this type of omission is typical of out-of-sequence thrusts cutting down section toward their distal ends, it was still very difficult to draw a realistic before-and-after cross-section of this area.

b) Among the many difficulties is that this location includes the geographic changes in regional trends from Blue Ridge on the SW to Reading Prong trends on the NE as well as superposed overprints from Taconic to Alleghanian. It lies directly in the tight central bend of the Susquehanna "elbow."A single balanced cross section is probably impossible.

c) The before and after cartoon cross-sections of Fig. 2, are far from complete or ideal but suggest a general set of geometric relationships that may account for the structures of the area.

d) One concludes that Stose and Stose had most of the structural elements mapped and well understood, far before their time. Even with 2/3 of a century's advance in structural knowledge, these "improvements" on their work are possible only with difficulty and still not altogether satisfactory results.

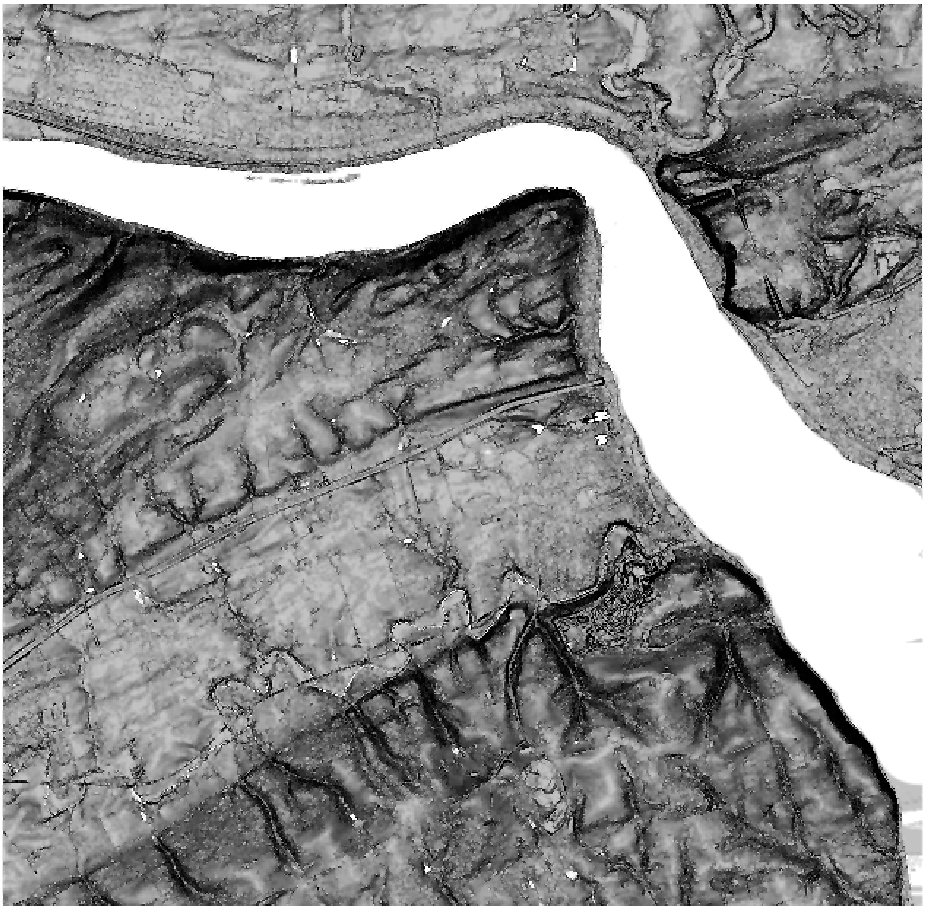

***Figure 3. LIDAR image of the field trip area**. The very well-defined edges of the Lancaster-York Valley reflect the sharp contrast in erosional resistance between the Antietam Schist and the immediately overlying Vintage Dolomite. Image courtesy of Jay Parrish.*

Views of major tectonic elements from Stop #4:

1) Lancaster city is visible off to the east in the middle distance.
   a) Beyond it on the skyline, the outline of the Honeybrook Upland may be visible in good weather.
   b) On the skyline to the right of the Honeybrook Upland is the outline of Mine Ridge
   c) Far to the left on the skyline, Little South Mountain and the end of the Reading Prong are visible in exceptionally clear weather.
2) On the northern skyline, Silurian Kittitanny Ridge is visible in good weather with the Great Valley just this side of it.
3) Immediately to our north, the Hellam Hills are visible with a gap caused by Accomac Glen and Stop #3.
4) In the middle distance to the north, the resistant diabase sills of the Mesozoic Basin form a line of hills.
   a) The diabase ridge-line can be traced eastward to become the Furnace Hills of northern Lancaster County.
   b) The commonly visible steam plume just beyond the Hellam Hills is from the cooling towers of Three Mile Island. The nuclear plant was sited on the strong foundations of the York Haven diabase sill where it crosses the Susquehanna River.

5) Just to the NE across the Susquehanna River is Chickies Rock (Fig. 1). The frontal thrust of quartzite over Ledger Dolomite lies just beyond the rock, but this side of the mouth of Chickies Creek that enters from the east.
   a) South of the rock, resistant beds of the Chickies Quartzite and Antietam quartzite continue to form steep valley walls that mark the core of the Chickies Anticlinorium.
   b) The bridge of interstate 30 crosses the river just downstream of Chickies Ridge as do old route 30 and the pilings of a covered bridge burned during the Civil War.
   c) Chickies ridge continues eastward to end just west of Lancaster city.
6) On the south flank of Chickies Ridge, the Cambrian carbonates form the Lancaster – York Valley with the town of Columbia visible on the far bank of the Susquehanna.
   a) During the Civil War, Confederate cavalry reached Wrightsville on this side of the River in an attempt to cut the main rail line that runs through Lancaster to Harrisburg. Had they succeeded, the Gettysburg story might have been different. However, the North set fire to the bridge to preclude this. The Confederates lobbed a few cannon balls across the river into Columbia, knocking the steeple off a church, before turning westward towards Gettysburg.

<u>The Lancaster Seismic Zone as the south end of the New England Province</u>:

At this stop you may be standing almost on the buried end of New England basement. In 2002, Wise and Faill suggested the Lancaster Seismic zone was caused by strains associated with a shallowly buried, westward-dipping basement sheet of the Reading Prong-Honeybrook-Mine Ridge Uplands.

1) In detail, the seismic activity ends along a reasonably distinct line from the vicinity of Reading to East Prospect, a tiny enclave of Cambrian carbonates on this side of the river just behind intervening topography to our east.
2) Four of those quakes occur close to the East Prospect enclave (Figure 4). The recent Salunga Quake, final “slow-down” "stop" of today, is on its epicenter.
3) It is proposed here that many regional structural features are related to this western edge of that strong sheet. These include the little pocket of exposures forming the East Prospect enclave, the east end termination of the Manor Hills folds, the jog in the Chickies-Oregon thrust, the Manheim end of the Lititz-Manheim nappe, and the change from gentle tilting where the Newark Basin lies on the strong sheet to the Narrow Neck in the weaker beds beyond it.
4) Within the sheet, Precambrian sutures and boundaries localized the Oregon part of that thrust along the north edge of the Honeybrook Upland.
5) The boundary between the Mine Ridge and Honeybrook massifs projects WNW as the northern boundary of the Conestoga Limestone with the successive lines of Conestoga overlap following the same trend. As the trace of the Eocambrian transform boundary, this line of the craton should have been perpendicular to the Blue Ridge trends, but instead has an oblique orientation. One hypothesis would make the Mine Ridge massif weaker and more susceptible to the Cambrian tilting, making the Lancaster corner of the old craton sink and tilt more rapidly as the shoreline of the Octoraro Seaway. Alternatively, cooling areas in the mantle that helped localize the transform may have changed the sinking pattern. It was this incline that provided the ramp to help localize the thrusting of the Martic Zone and focus the Lebanon Valley nappes northward from the Lancaster area.
6) As we look northeastward from Stop #4 toward the end of the Reading Prong, the view is essentially along the buried western edge of the southern New England sheet and the many structures that terminate it or are modified by its edge effects.

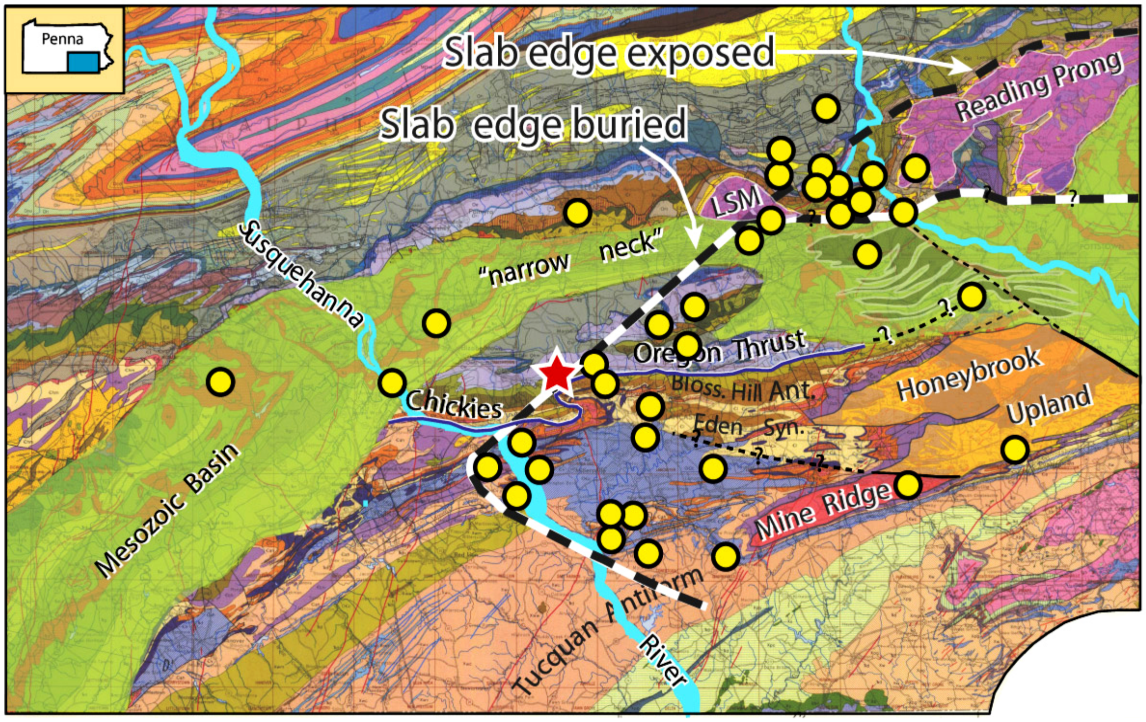

Figure 4. The Lancaster Seismic Zone *as the southernmost tip of New England. The Mine Ridge-Honeybrook Upland-Reading Prong basement massifs are outcrops of thin, west-dipping basement sheet. This basement sheet and its piggy-back Paleozoic geology is fundamentally a continuation of the geology of southern New England. The model proposed here is that in Alleghanian times, as the southern New England mega-thrust sheet peeled back the edge of the craton, it encountered the old transform edge. This caused it to end in a sharp corner which was then carried forward with the thrust sheet. The triangular Lancaster Seismic Zone is that tip, bounded on its NW by the shallowly buried thrust edge of the Reading Prong and on its SW by the old transform edge of the craton. In this model, Stop #4 lies almost above that southernmost tip of New England. The red star represents the recent Salunga earthquake which will be driven over at the end of today's trip.*

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STOP # 5: STRUCTURAL GEOLOGY AT CHICKIES ROCK

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Location and some history:

The location (Figure 1) is at Chickies Rock, Lancaster County Park. (Excessive hammer use is inadvisable). It is on the north side of Chickies Ridge, two miles north of Columbia on Rt. 441.With more time available, other visitors may wish to park in the access area along Rt. 441 about 300 meters to the south and follow an abandoned trolley line to the top of Chickies Rock for a magnificent overlook of the river (Fig. 3). Most trips with small groups can park facing south on the west side of Rt. 441 just south of Chickies Creek bridge. Follow the path west past water supply pump houses wells are in shattered Chickies Quartzite at the edge of the Chickies Thrust. Continue along path and up embankment onto abandoned RR bed, bearing left until the NW corner of Chickies Rock is visible through the trees as Sub-stop #1.

This l is the type locality of the lower Cambrian Chickies Formation. It is also the probable discovery location from which the resident ironmaster, Col. S.S. Haldeman, named the fossil "worm" tube, *Skolithos linearis, Haldeman* 1840. Superposition of the Susquehanna River drainage across Chickies Ridge created a landmark in Indian and colonial times but the present nearly vertical face and relatively fresh quartzite are the result of later undercutting and widening to make way for the Susquehanna Canal and low grade of the Pennsylvania Railroad.

Figure 1. Aerial view northward toward Chickies Rock *taken at extreme low water (D. Wise photo). The folds plunge eastward toward the rock and bluffs as shown on Fig. 3. The Chickies Thrust crosses the river north of the rock, just beyond the poorly exposed white blobs in the river. The most distant river exposures are upper Conococheague carbonates of the footwall. The active railroad line hugs the Susquehanna shoreline, its bridge visible in the mouth Chickies Creek. Good carbonate exposures occur in the creek just upstream of*

Wise, D.U. and C. de Wet (2010) Stop #5: Chickies Rock, *in* Wise, D.U and Gary M Fleeger, eds., Tectonics of the Pennsylvania Piedmont along the Susquehanna River, 75th Annual Field Conference of Pennsylvania Geologists, Lancaster, PA, p. 49 – 57.

the bridge. Placement of lower Cambrian quartzite on upper Cambrian carbonates requires at least a km of throw. Underlying Accomac volcanics from Stop #3, a mile to the west, probably provided detachment zone from basement and lubrication for the thrust.

This location was the center of a 19th century ironmaking complex. The old ironmaster, Col. S.S. Haldeman, was also an early scientist. He discovered and named *Skolithos* "worm" tubes in 1840, probably from talus blocks near north end of rock face. The creature that made tubes are still unknown and their name, *Skolithos* continues to be misspelled in general.

Remains of a large iron-making complex exist as cellar holes and still stand as many brick buildings on the flats just north of the creek. This location was ideal for ironmaking with all four major components in close proximity. Local forests were abundant for charcoal and later coal could be brought easily from the Pennsylvania fields along the Susquehanna Canal and subsequently the RR. Limestone (for flux in furnaces) was available from quarries immediately to the north. Limonite ore came from the Grub mines (residual deposits from weathered limestone trapped along the contact of Cambrian limestone/against underlying Antietam Formation, several miles to the east) or magnetite from the Cornwall mines (contact metasomatic deposit at contact of Jurassic sills into limestones, 15 miles to the NE). Water came from a small dam in Chickies Creek, 300 m to the north and/or from the river.

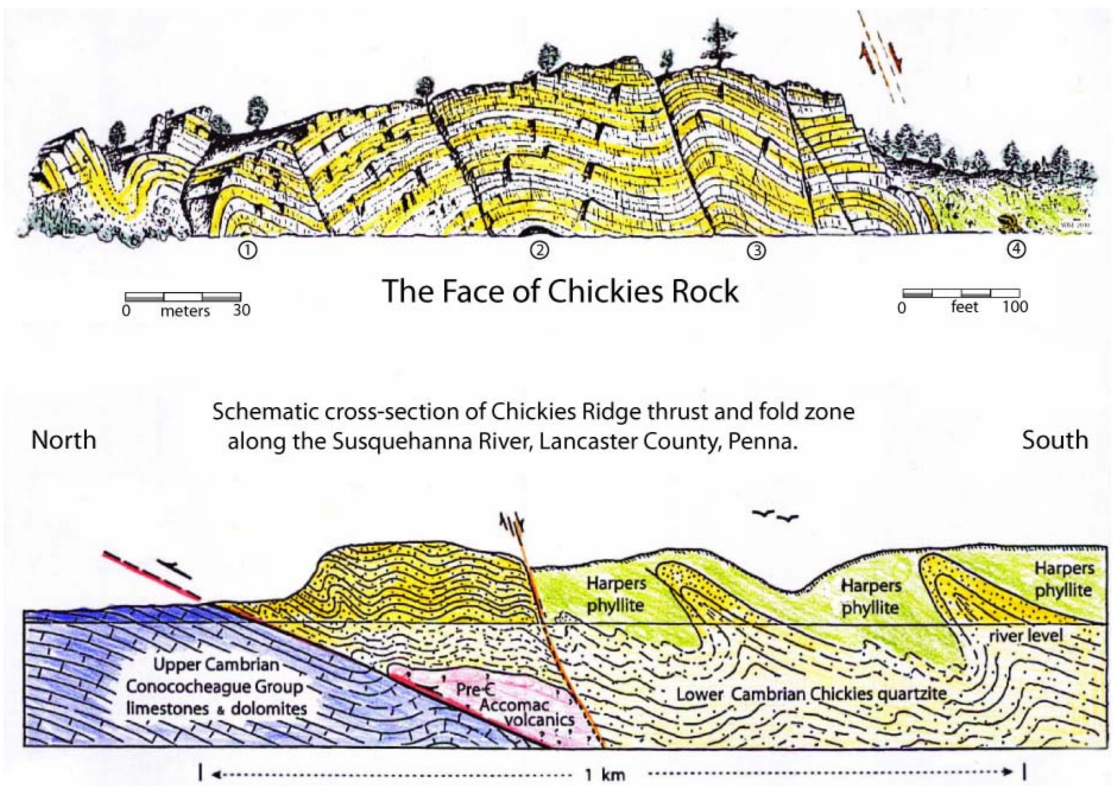


Figure 2. Chickies Rock and its setting*. (Top) Sketch of the face. Numbered locations (still bearing red paint from the 1960 trip, alas!) are described below as sub-stops with specific features to be examined. (Bottom) The rock is the leading edge of an Alleghanian age thrust fault that reactivated and pirated Taconic-age cleavage. A normal fault at its south end separates it from two large overturned folds exposed in the bluffs to the south.*

Overview of Chickies Rock Structures

Four sub-stops, indicated by numbers on Fig. 2, describe the outcrop evidence for these points.

1) Folds plunges generally east at 10-15 ° (Figures 1, 3).
2) Chickies Thrust is about 300 m (+/- 100 m) to the N with 1 to 1.5 km of throw.
   a) Throw amount is based on lowermost Cambrian quartzite being placed on upper Cambrian Conococheague limestone.
   b) Limestone is exposed at mouth of Chickies Creek and just below dam and former bridge along abandoned railbed. Dip is about 20° to S which could be same dip as Chickies thrust if it is bedding-parallel.
   c) Air photo of riverbed (Fig. 1) shows several plunging folds. Bluffs to south show two overturned folds (Fig. 2B) that can be traced into Route 441 roadcuts with changes to and from faulting on overturned limbs.
3) Just to west across river, the Accomac greenstone appears below the Cambrian unconformity at Stop #3. (South Mountain Catoctin volcanics of the Blue Ridge are generally correlative as described by Smith and Barnes for that stop.)
   a) The Accomac Valley, eroded along the volcanics in the fold core, trends about N60E, oblique to the generally E-W trend of Chickies Ridge. This oblique trend is normal to the general N30W transport of Taconian nappes and is parallel to the older F_{0x1} folds of the Martic front.
4) Taconian N30W bedding-parallel shortening is interpreted as the origin of early cleavage.
5) Examine Chickies Formation lithology and beach environment, including their resident *Skolithos* "worms or whatever."
6) "Refraction" of cleavage by bedding-plane slip on phyllitic units. The combined slip on both bedding and cleavage provided the rock ductility for the distinctive Chickies folds.
7) See the geometry of two stages of folding around non-coaxial trends that produced a corkscrew lineation. This is most easily seen on the small fold at the south end of the rock.

Main themes at this stop

1) Two stages in the structural evolution. The first was a Taconian layer-parallel shortening along ~N30W trends involving pressure solution and recrystallization aided by slip on pervasive conjugate micro-planes under low-grade metamorphic conditions. The layer-parallel shortening process flattened *Skolithos* tubes that invariably lie in the plane of cleavage. As a result the *Skolithos* remain as "paleo-plumb-bobs" to record internal rotation of the rock fabric.
2) The second stage was an Alleghanian-age thrusting and wrinkling of the quartzite on the lip of the north-directed Chickies thrust. This reactivated the older cleavage by cross-linking some of its older fabric planes into more E-W striking multi-millimeter spaced cleavage on which dip-parallel, deck-of-cards slippage produced external rotation of bedding surfaces by progressive small-scale displacements. As a result, bedding can have *external* rotation of as much as 90 º while *internal* rotation of rock fabric on which slippage occurred was only half as much as shown by cleavage dips and associated *Skolithus* plunge.
3) Plunging fold mechanics. At this location a system of plunging folds was generated with *external plunge* rotation but no sympathetic internal rotation of its *Skolithus* fabric. *Skolithos* retain simple down-dip orientations on the cleavage planes independent of the plunge of their host folds.

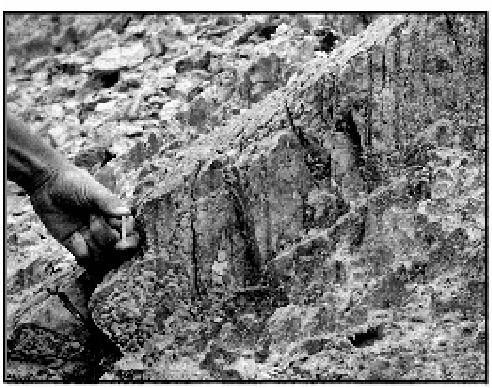
a) The along-strike fold geometry represents *external rotation of fold hinges* similar to the *external rotation of bedding dips*. Differences along the hinge line in total amount of slip on spaced cleavage planes causes the hinge to warp into plunging folds while underlying mechanisms of strictly dip-slip, *Skolithos*-parallel motion on the cleavage planes caused *no internal rotation* of the rock fabric.

b) Careful hand-lens examination of some *Skolithus* tubes will show this displacement on tiny sericite grains, their mica flakes oriented into micro-slickenlines parallel to the tubes.

<u>Sub-Stop #1: Big Asymmetric Anticline</u> (Location circled as 1 on Fig. 2- top)

1) Find bedding on vertical north face. Find ripple marks on it.

Figure 3. Low water view of folded Chickies Quartzite looking west from the top of Chickies Rock.



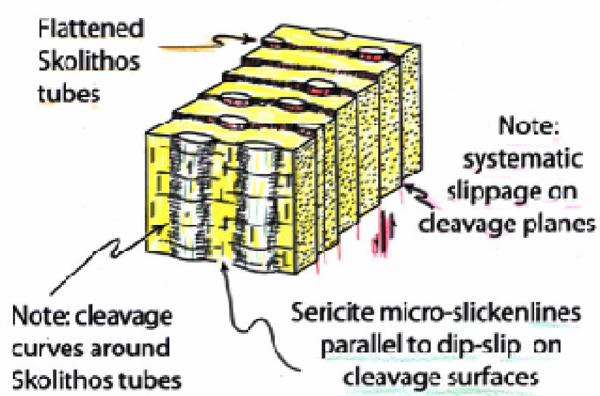


Figure 4. Skolithus and cleavage. *Skolithus tubes invariably lie in the plane of cleavage. Their coating of silky sericite allows them to weather differentially. With extreme weathering, as in the left photo from the Oyster Point Quarry, a few rare tubes can be lifted free of the matrix. Cleavage in the photo is vertical, passing backwards and to the right, parallel to the trend of the fold axis that contains the left-dipping bed. In detail, spaced cleavage planes are micro-fault packets with sericite alignments indicative of slip parallel to the Skolithus. Hence, part of*

the fold mechanism involved deck-of-cards slip parallel to Skolithus within the cleavage planes.

2) Find cleavage. (Fig. 4) and cleavage / bedding intersections. (Remember the old structure class mantra: c/b intersections are parallel to larger scale fold axes). Do not confuse with ripple marks of the old beach. These are also present here.

3) Find *Skolithos* tubes in plane of cleavage. (Most easily seen on nearby talus blocks)
   - a) Problem: How can bedding be vertical while internal structure as indicated by cleavage and paleo-plumb-bob *Skolithos* rotated only by about 45° ?
   - b) Deck-of –cards slip on innumerable cleavage planes (Figure 4, right). Bedding is merely a passive indicator of cumulative slip, *an external rotation*)
   - c) Note: *Skolithos* are flattened in plane of cleavage
   - d) Look at *Skolithos* to see micro-slickenlines of sericite from dip-slip on cleavage

4) Walk around to main face and try to trace bedding (over the big asymmetric fold)
   - a) Note cleavage fans the fold but does not rotate nearly as much as bedding. (*Again: internal versus external rotation*).

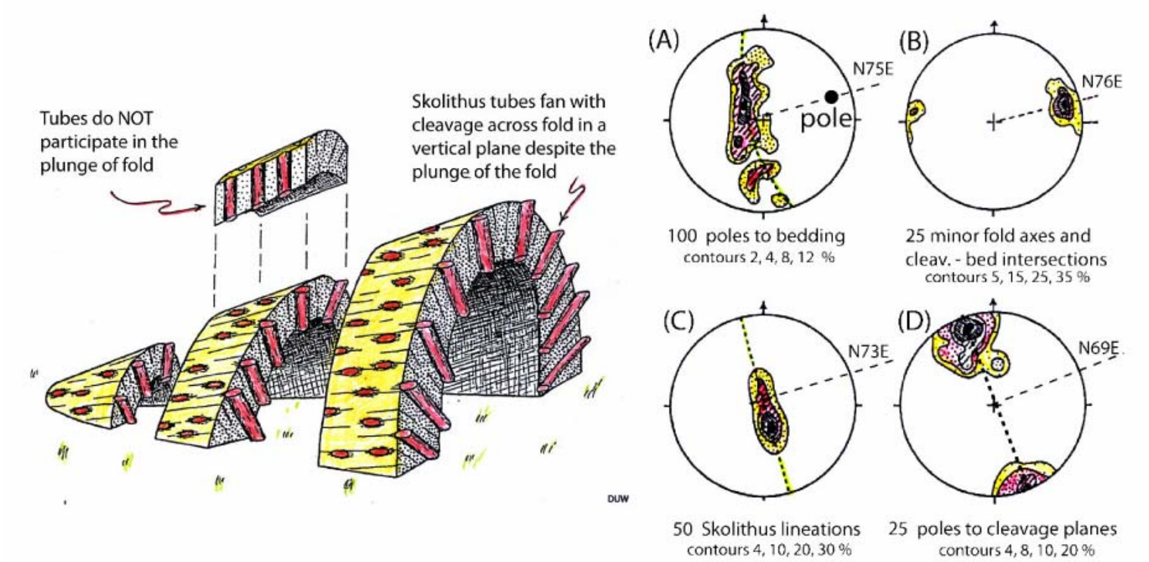


***Figure 5. Skolithus, cleavage and plunging folds**. Equal area, lower hemisphere nets A) and B) show N75E plunging folds. The pole to the curving girdle in A) has the same orientation as the fold indicators in B). Orientations of folds indicated by C) and D) are similar but non-plunging. The Skolithus girdle in C) does not curve but fans along with cleavage in a vertical plane normal to the fold hinges.*

5) Universal stage plots of poles to mica c-axis orientations are shown on Fig. 6
   - a) Oriented samples were taken around this fold from locations indicated.
   - b) Mica plates are oriented generally parallel to megascopic cleavage but show a double maximum. In thin section these micro-slip planes wrap around the quartz grains.
   - c) Suggestion of a Prandtl compressed cell with flattening perpendicular to cleavage accommodated by slip on conjugate micro-fault planes of low dihedral angle.
   - d) Quartz C-axis fabric (not illustrated) has scarcity of grains with axes lying in plane of cleavage. True of large, strained, survivor quartz grains as well as new, small, equi-dimensional unstrained grains. Suggestion: grains with prism faces lying in plane of cleavage were selectively strained and destroyed or had difficulty in nucleating as new crystals.

e) Cleavage formation involved pressure solution and extensive recrystallization of both mica and quartz.

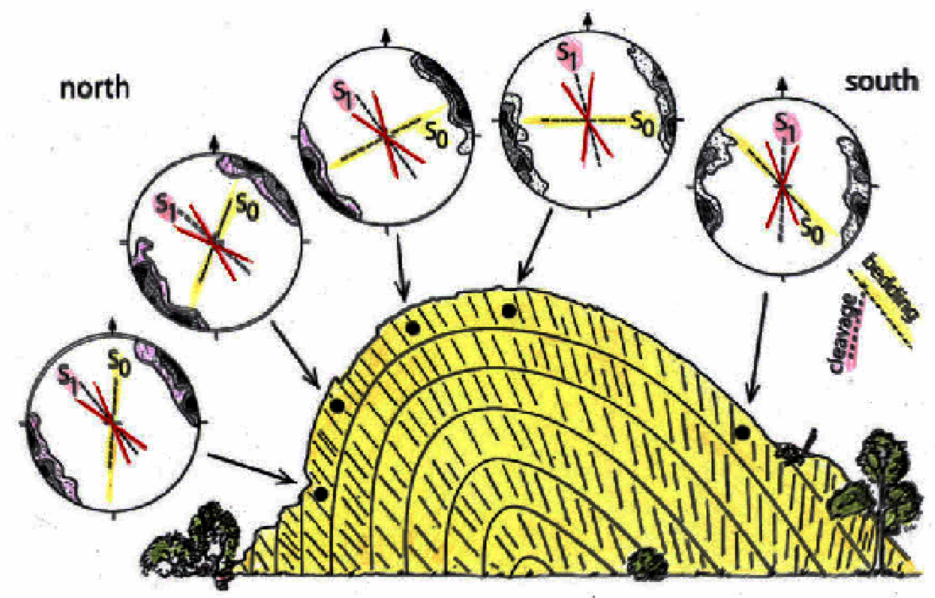


Figure 6. Poles to muscovite grains in thin sections from the Chickies Anticline*.* *The grains are strongly oriented sub-parallel with cleavage, but all show double maxima indicating they are really oriented along conjugate shear planes. A model is suggested wherein flattening normal to cleavage and elongation parallel to it was accomplished by slip on these conjugate planes.*

Figure 7. The "walk-in" anticline at Chickies Rock*, location 2 on Fig. 2*. Cleavage and *Skolithus* fan the fold but *Skolithus* show no rotation indicative of the plunging fold in which they occur. Hinge line here, like bedding, is a feature of external rotation. Cleavage-controlled, dip-parallel displacement rotated bedding and varied in its cumulative amount along the hinge line. The result was external rotation of the hinge into a plunging geometry with no associated rotation of the internal fabric.

Sub-Stop #2: Walk-in Anticline. (Location 2 in circle on Fig. 2 top)

1) Small fold plunging to the East.

   a) Note fanning of cleavage across roof of fold. *Skolithos* also fan with cleavage.

b) Note bedding / cleavage line of intersection is parallel to fold hinge. (Remember the structure textbook mantra about c/b orientations?)

2) Look at bedding plane slickenlines on roof. Note they are oblique to fold axis and to bedding/cleavage intersection (see nets on Fig. 5). Transport was oblique and non-coaxial.

3) Mystery problem for students:

a) Skolithos fan in the vertical plane but the fold plunges at a moderate angle. (See equal area nets of Fig. 5). Why didn't anyone tell the *Skolithos* they were part of a plunging fold?

b) Answer: Compression oblique to older cleavage caused differing degrees of displacement along the trend of the fold and hence differing amounts of dip-slip motion on cleavages along that fold hinge (see Fig. 8). Just as bedding is a passive indicator of external rotation *across* the fold, the hinge is a passive indicator of differential vertical displacement *along* its strike, all motion being dip slip in a plane at right angles to the overall structure.

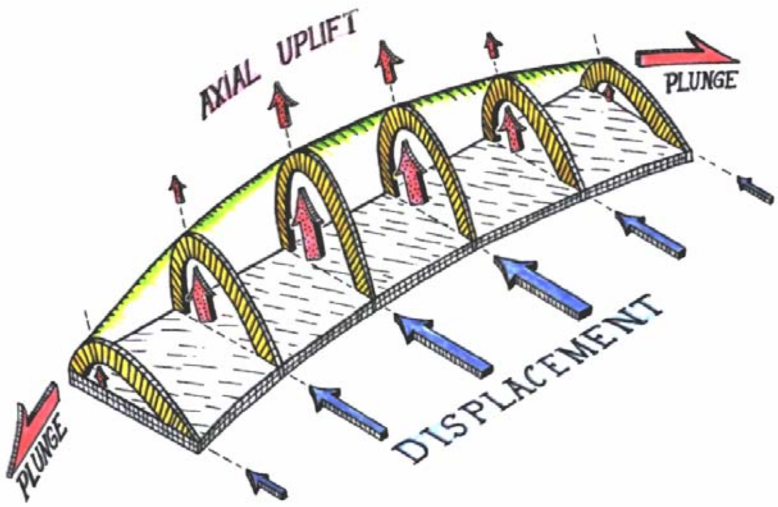


Figure 8. Model to explain fold mechanisms at Chickies Rock*. All slip is along the dip of cleavage parallel to Skolithus. In areas where overall displacement (blue) was greater, the axial uplift was greater. The result is a plunging fold wherein the internal Skolithus fabric does not reflect the plunge. The curving hinge line of the fold is a passive indicator of the amount of total uplift along the fold.*

Sub-Stop #3: Cleavage "refraction" (circled on Fig. 2 top) Small fold 50 m to S (Fig. 9)

1) Note bent cleavage containing *Skolithos* about 2-3 m above path. **NO HAMMERS**

2) There was a big arguments in past structural geology literature about how cleavage "refracts." Some argued it was result of changing angle of fracture *a la* Mohr diagram; others claim it was result of drag and flexural slip. Here the *Skolithos* prove originally planar cleavage was dragged by later flexural slip on weak phyllitic beds.

3) Folding at Chickies was result of cleavage piracy by younger deformation that made combined use of flexural slip on both bedding and cleavage to provide the overall ductility for the folds.

4) As you proceed southward along face, note small brittle fault displacements until reaching the large face at *end of outcrop. This is a large, brittle normal fault* with slicks evident at number of places up over the face. It dips about 70° at this elevation and drops younger Harpers Phyllite on south next to Chickies quartzite on the north. It is probably a

Mesozoic extension structure, reversing the motion and merging at depth in listric fashion with the master Chickies thrust. (see Fig. 2B)

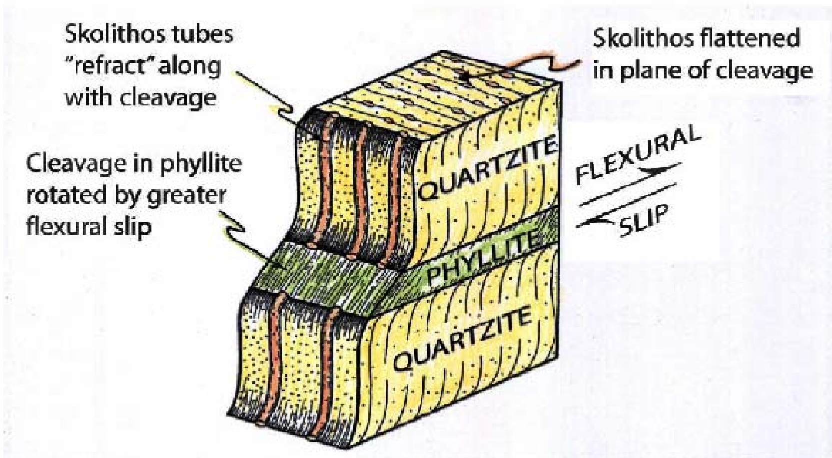


Figure 9. "Refraction" of cleavage. *These features, best seen at location 3 on Fig. 2, show the Skolithus "refract" along with the cleavage. The cleavage was originally planar with Skolithus contained in it. During continuing folding, flexural slip along phyllitic beds dragged the cleavage along with the Skolithus into the curved geometry. The basic mechanism of Chickies Rock folding was a combination of slip on two sets of planes, cleavage and bedding.*

Sub-Stop #4. Corkscrew syncline. (Circled 4 on Fig. 2 top) Minor fold in brush (Fig. 10)

1) Small fold is probably in transition beds of upper Chickies to Harpers phyllite, down-faulted with respect to main Chickies Rock face along listric normal larger fault (see above).
2) Detailed notes for the small fold
   A) Axial zone of fold. Note *Skolithos* tubes flattened in cleavage and lying in vertical plane normal to strike of fold axis despite the plunge of the fold.
   B) Limb of fold. *Stratigraphic thickness* of bed seems much less than on hinge. However, distance from top to bottom of bed as measured parallel to cleavage is the same. A*xial plane thickness* reflects original bed thickness in "deck-of – cards" folding. The "cards" all started as cleavage micro-lithons of the same length determined by layer-parallel shortening in the original bed. As folding proceeded with slip on cleavage, bedding suffered external rotation. Total bed length was stretched and as beds became thinner in the axis, the original thickness was preserved. Rather than the classic view of thickening of the fold at the hinge zone, here the limb that was thinned and elongated.
   C) Quartz veins are formed in openings where the quartzite beds have parted to create low-pressure voids. This is one of several ways of filling voids created by disharmonious folds.
   D) Quartz pods along phyllitic units. There was significant disharmonious flexural slip on phyllitic units to move a syncline partially over an anticline.
   E) Non-coaxial deformation. Around south side of outcrop, note corkscrew pattern of bedding / cleavage lineations (white lines on Fig. 10B). Alleghanian deformation along different axial trends has twisted the old Taconic cleavage

and its bedding/cleavage intersections and minor folds into patterns that now corkscrew around the axis of the new fold.

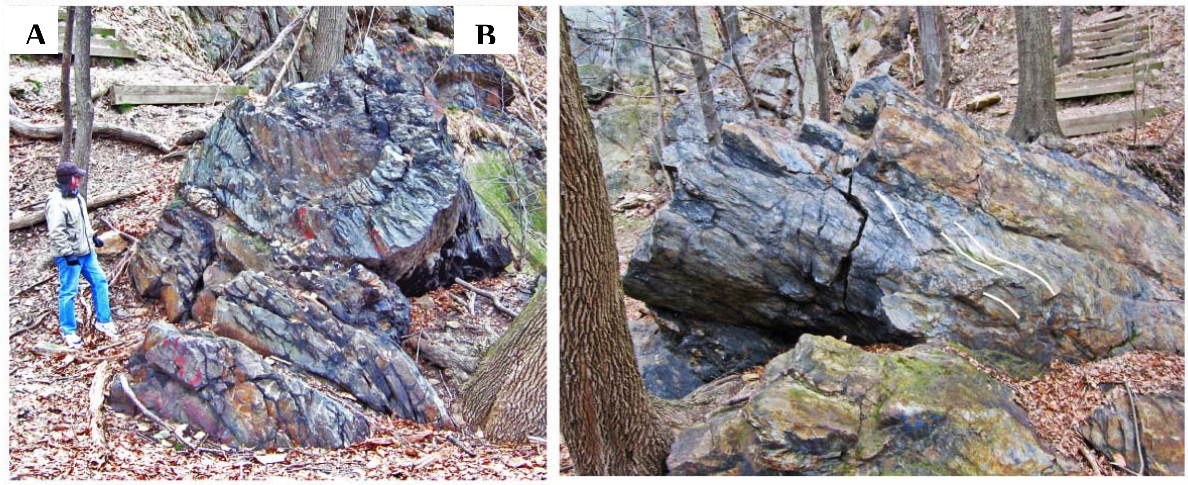


Fig. 10. Small fold at the south end of Chickies Rock *(location 4 on Fig. 2, Bob Ganis for scale). A) Cleavage fans the fold with Skolithus oriented strictly down-dip and not participating in the plunge. Bed thickness measured parallel to cleavage remains constant showing fold is by slip on the cleavage planes. Fold crest is not thickened, instead limbs have apparent thinning normal to bedding while apparent bed length is increased (Ignore red paint, remaining from 1960 field trip when such decorations were routine. How things have changed!)*

B) Side view of plunging fold has corkscrew lineations (enhanced by white lines on the photo, but not on outcrop!!). These are caused by the old Taconic cleavage being refolded about new Alleghanian axes. Hold a field book parallel to bedding with a pencil parallel to the lines. Rotate the "bed" back to horizontal and see if these lines approach the old N60E Taconic trends (But worry about <u>when</u> plunge was put into the geometry. Plunge development before, during, or after bedding was rotated and overturned makes a significant difference. This is a fine student homework exercise of using a net to calculate the paleo-strike with these differing scenarios to see which, if any, can produce an original N60E strike….. Then there is the problem of whether these old lines suffered internal or external rotation!!).

<u>References:</u>

Haldeman, S. S. 1840. Supplement to number one of a "monograph of the Limniades, or freshwater univalve shells of North America" containing descriptions of apparently new animals in different classes, and the names and characters of the subgenera in Paludina and Anculosa. Philadelphia, J. Dobson, 3 p.

Wise, D. U., and Kauffman, M. E., eds., 1960, Some tectonic and structural problems of the Appalachian Piedmont along the Susquehanna River, Guidebook of the 25th annual Field Conference of Pennsylvania Geologists, Lancaster, Pennsylvania, Chickies Rock, p. 68-75, Rheems Quarry, pp. 76-83.

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STOP #6: PROSPECT QUARRY-strange folds, boudinage, mylonites, and faults

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G. Robert Ganis, Independent Consultant, Harrisburg, PA

Location: Prospect Road, 1 km SW of the W end of town of Salunga. The name Salunga is part of the Indian word "Chickie-Salunga" or "place of the crawfish" but it is uncertain whether Chickies means "place" or "crawfish."

Chickies-Oregon Thrust: This quarry exposes a previously unrecognized large oblique-slip transpressional fault (Fig. 1) which is here interpreted as part of the Alleghanian Chickies-Oregon thrust system based on its style, orientation and location on the projection of a poorly constrained part of the Chickies-Oregon thrust (Fig. 2). The fault zone ranges from 10-20 m in thickness and contains complexly disrupted carbonate beds with lesser zones of carbonate mylonites and proto-mylonites. In the hanging wall, strongly boudinaged but barely cleaved beds are parallel to the fault but show Taconian N30W extension and deformational style (Figs. 7, 8).

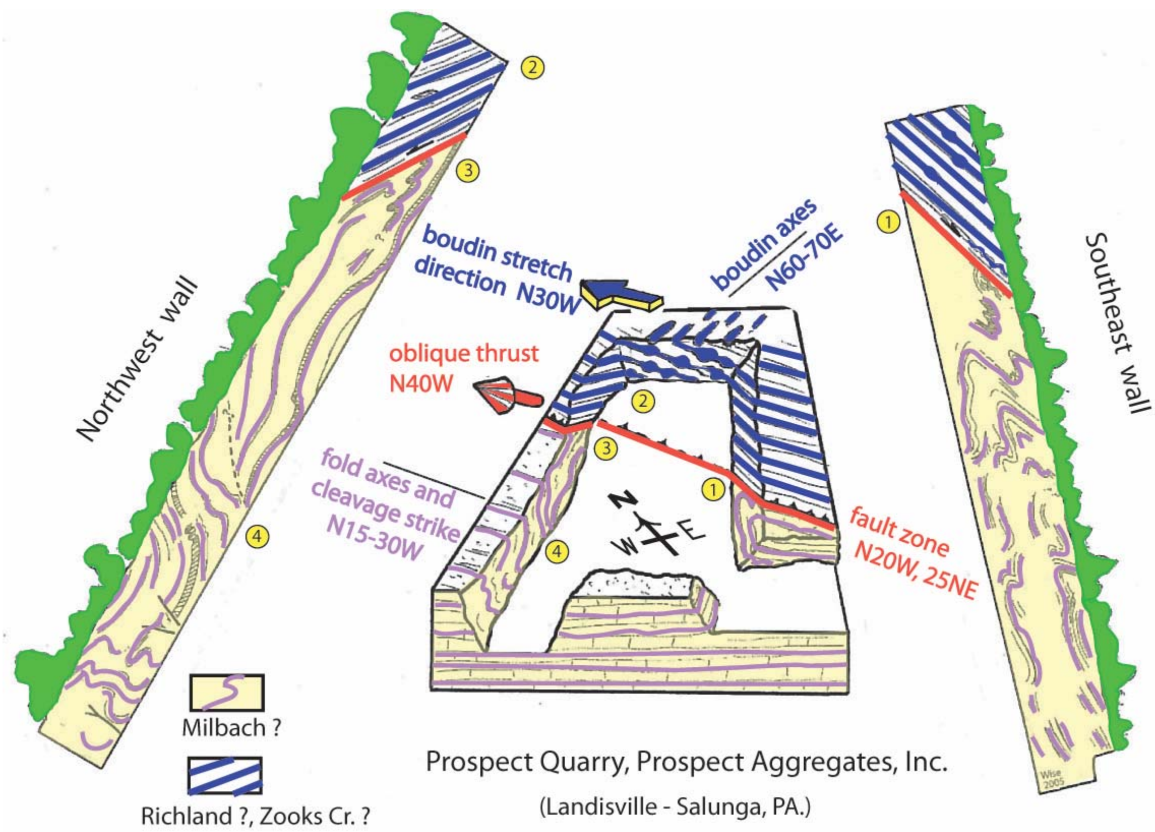

Figure 1. Block diagram of the Prospect Quarry. *The Chickies-Oregon Thrust, here a carbonate mylonite, separates two completely different structural styles of Taconic nappe structures. Circled numbers are locations described below in some detail.*

In complete contrast, the footwall is complexly folded near the fault with axes and local well-developed cleavage sub-parallel to it. Farther from the fault, the beds are more openly folded but again in the SW corner of the quarry they go into near-recumbent fold complexes. We suspect many of these differences in intensity and style of deformation result from some combination of changing ratios of limestone to dolomite during largely Taconian folding followed by more local disturbance with proximity to the Alleghanian age fault.

Wise, D.U. and G. R. Ganis (2010) Stop #6: Prospect Quarry - strange folds, boudinage, mylonites, and faults, *in* Wise, D.U and Gary M Fleeger, eds., Tectonics of the Pennsylvania Piedmont along the Susquehanna River, 75th Annual Field Conference of Pennsylvania Geologists, Lancaster, PA, p. 59 – 67

Stratigraphic units (?): This location was mapped by Meisler and Becher (1971) as part of lowermost units of the Cambrian Conococheague Group, lumped together as "Buffalo Springs dolomite/sandy Snitz Creek Formation." (Remember the Lebanon Valley Conococheague formations are from bottom to top: Buffalo Springs, Snitz Creek, Schaefferstown, Millbach, and Richland.) To our eyes, the footwall units include large percentages of light gray marble typical of the Millbach Formation. In the N corner of the quarry, the hanging wall shows an upward transition from some Millbach-like marble into interbedded, dominantly dolomites and lesser marbles but we are uncertain whether this is stratigraphic up or down. Opinions are welcomed.

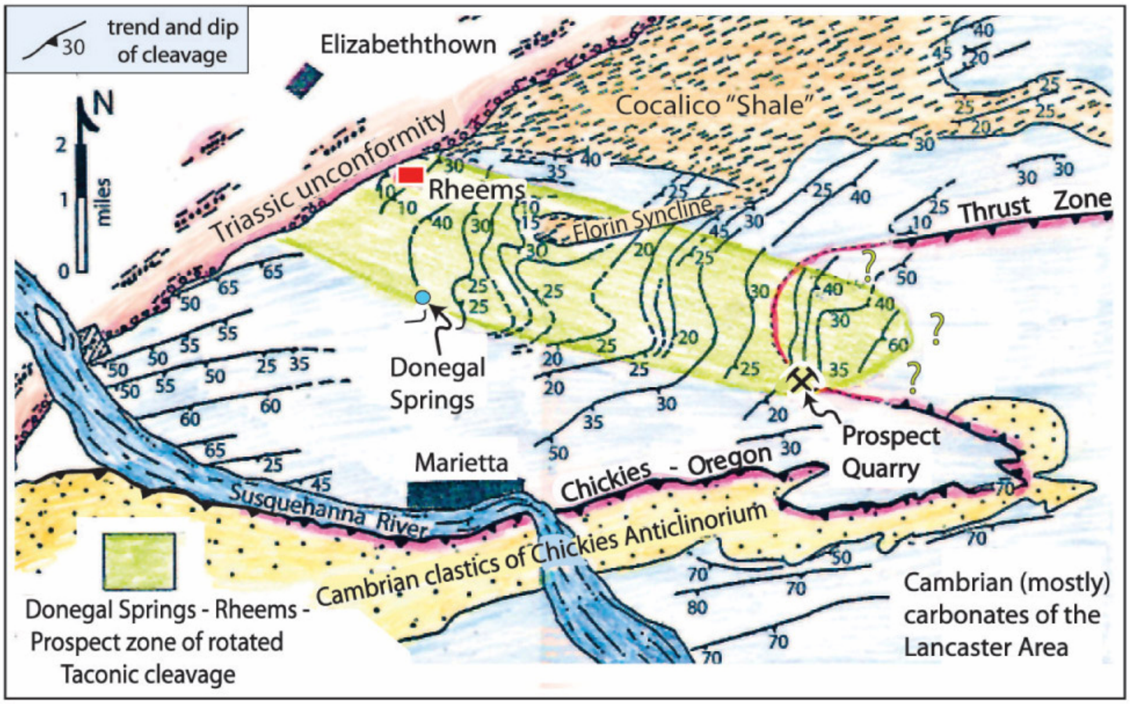

Figure 2. The Rheems-Donegal Springs-Prospect zone. *The zone of warped Taconic cleavage (green) marks the southwest edge of massive overturning of the Lebanon Valley nappe complex. The younger Alleghanian Chickies-Oregon fault loops into but does not follow this zone.*

Nappe edge structures: The quarry also lies at the SE end of the 3x12 km WNW-trending Rheems-Donegal Springs zone (Fig. 2). Rheems Quarry at its NW end has long been known for recumbent folding and deformation (Wise, 1958), a stop on the original FCOPG field trip (Wise, 1960) , DePaor, et al.'s boudinage study (1991), and a stop for a 2006 GSA trip (Wise and Ganis, 2006).

West and SW of the R-DS zone, the carbonates show pervasive N30W transport with folds and stratigraphy overturned to the N and cleavages dipping southward at 30 -60 º. North and east of the zone, dips of cleavage tend to be flatter, have massive overturning typical of the Lebanon Valley nappe complex but continue to show flow lineations of systematic N30W transport. Within the zone cleavage dips flatten and rotate in strike away from the regional pattern by 30-90°. Prospect quarry is located at the other or SE end of the zone and is quite unlike Rheems where fold axes trend E-W. At Prospect almost all other structures in both footwall and hanging wall, including fold axes but excluding boudin axes, are sub-parallel to the general WNW Taconic transport trends (Figure 8).

We interpret R-DS as a zone of more intense shearing near the edge and probable bottom of the final stages of emplacement of the Lebanon Valley nappe complex (Gray, et al., 1958). The zone might be visualized on the largest scale (Figure 3) as the viscous flow boundary of a thickened tectonic mass, largely gravity-driven into the gently WNW-tilted carbonate platform surface of the foreland basin. The final stages of this massive flow had to be late in the deformation because it warps and incorporates most of the adjacent regional cleavage and fold patterns. Late-stage flow had to be quite complicated combining lateral spreading, forward motion and probable incorporation of underlying and adjacent rocks and structures into a variety of local domains. The younger Alleghanian-age Chickies-Oregon thrust took advantage of the older anisotropic weaknesses by following it only locally rather than regionally (Fig. 2). However, it brought two formerly nearby edge domains with radically different strain histories into juxtaposition as the footwall and hanging walls exposed in the quarry.

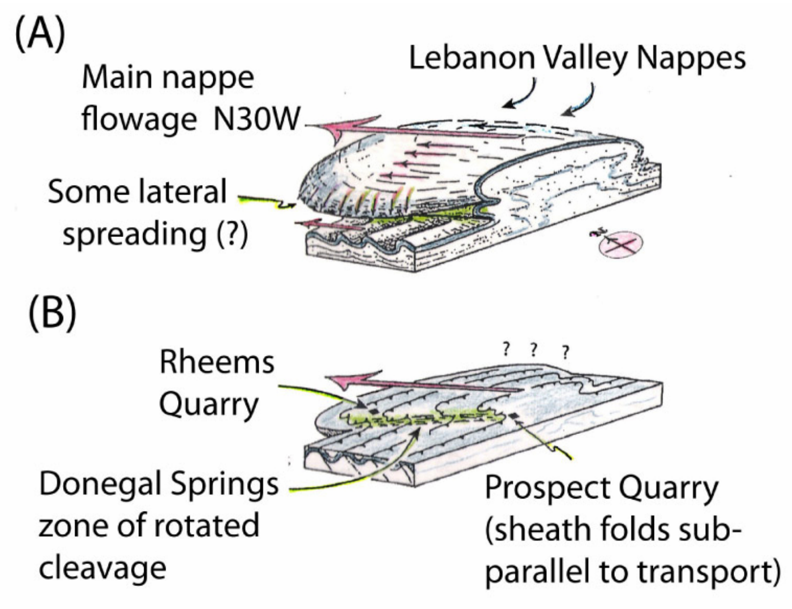

***Figure 3. Rheems-Donegal Springs-Prospect Zone** as the edge of major overturning of the Lebanon Valley recumbent nappes. The lesser folds at the Prospect Quarry are interpreted as sheath folds caught in the disturbed zone and elongated sub-parallel to tectonic transport along the edge of spreading and overriding nappe.*

<u>Structures requiring carbonate rocks:</u>

Carbonate-hosted structures of all types abound in the quarry: boudinage, proto-mylonites, pressure solution, local cleavages, veins, bedding plane faults, etc. Some later ones have strange orientations with respect to the regional pattern of pervasive N30W tectonic transport. Separation of early from late structures, overprinting and reactivation of these structures, clear distinction of whether the packages are upside-down or right-side-up, or even making a firm determination of proper formational names within the Conococheague Group remain for us as only partially settled questions. Four sub-stops within the quarry are indicated on the block diagram of Fig. 1. Any new insights or observations by field trip members are most welcome and should be conveyed to the group.

<u>Sub-Stop #1: Mylonites and fault zone on SE Wall</u>

1) Using the cross sections from the block diagram of Fig. 1 as a guide.

a) Walk along the face to the right (south) of the fault zone. Folds are overturned to the right, away from the fault while fold hinges are parallel to it.

2. Intensity of folding seems to decrease away from the fault.
3. Beware of simple cause and effect interpretation: there is no guarantee that fault motion and all the folding were contemporaneous as similar styles of folding occur in the SW corner of the quarry far away from this fault. (but perhaps near another concealed fault ?).
a) Walk to the left along the face until you are in uniformly dipping dolomites of the hanging wall. You have now crossed the fault. Beware: some of the mylonitic zones of the fault can look very much like bedding. (Examine the hanging wall units more closely at Sub-stop #2)
2) Examine fault zone, here 20-30 m thick. More athletic members of the group may want to go up over the rubble to see it more closely but be very careful. Much of the essence of the zone can be appreciated from rubble blocks near road level.
a) Zones of carbonate mylonite and proto-mylonite are interspersed with packages of more intact country rock.
3) *Mylonites:* Those unfamiliar with mylonitic lithologies in carbonates may have trouble identifying them at first. Many appear as "beds" of very fine-grained, nearly white marble with cm-spaced, irregular, paper-thin stringers of dark material (Figure 5).
a) Check the dark stringers with care. Small-scale isoclinal folding parallel to the zone is the rule while larger-scale, irregular isoclinal folds commonly are traceable *across* the "bed." These stringers are *not* depositional structures!
4) The protolith was probably one of the typical blue-grey marble beds that abound in this stratigraphy. With the catalytic effects of shearing and heating, the material was partly to completely recrystallized, the organic matter that provided the blue-gray color was segregated as graphite along some of the shear planes while the host material formed a very white, nearly pure, fine-grained calcite matrix. Continued shearing along the zone deformed the early graphitic planes into tight, small-scale isoclinal folds.
5) Anyone working in these Piedmont carbonates and finding a "bed" of this distinctive lithology while measuring a stratigraphic section would be well-advised to look immediately for repeats or omissions of real beds adjacent to it (Figure 4).

Figure 4. Bedding-parallel, mylonitized fault zone, *easily misinterpreted as a stratigraphic horizon instead of a potential stratigraphic repeat.*

6) Question: At what stage do small-scale depositional laminae cease to be called "bedding" and become "foliation"? How much shearing, stretching, pressure solution and/or recrystallization of a bed are necessary before one begins to call a proto-mylonite a mylonite ?

7) These specific questions can be considered for marble beds deformed in association with boudinage formation. You will get a chance to render an opinion at Sub-stop #2.

<u>Sub-Stop #2. Boudinage “heaven”</u> (Figures 1, 7, 8)

Location in the hanging wall units along NE wall. Depending on recent quarry operations, the quality of these exposures can vary greatly.

1) Lithology. This is part of the hanging wall of the thrust, visible just to the left of the corner. Going upward from the fault are about 20 m of Millbach-looking marble beds, 20 m of transitional lithologies, and finally continuous lithology of half meter to meter thick dolomite beds interbedded with marble.
   a) Formational name(s) are uncertain or even if unit is right-side-up or upside-down.
   b) This is an ideal lithology for boudinage formation. Marble will flow and stretch easily under extensional stress while the brittle dolomite will crack and leave lower pressure open spaces between the expanding “sausage” segments.

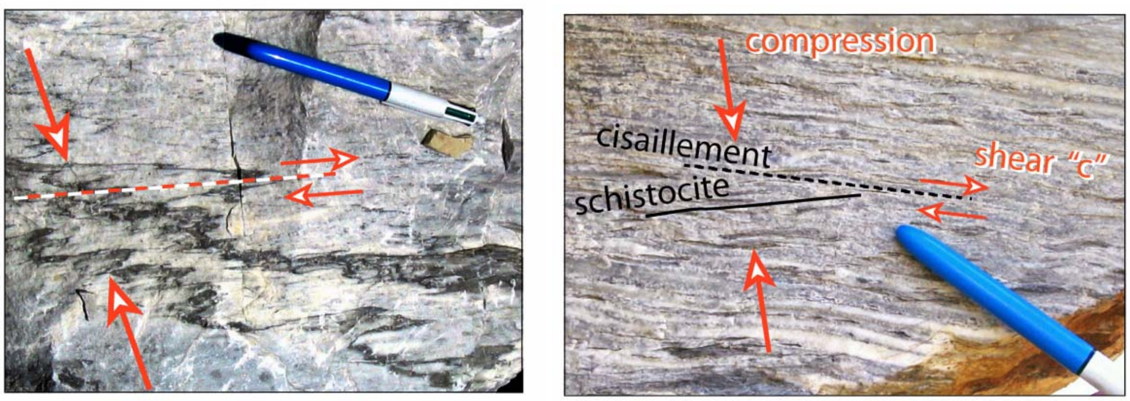

Figure 5. S/c carbonate proto-mylonite (left) and true s/c mylonite (right) *from Prospect Quarry. On the left, maximum compression is flattening dissolved solids of a remnant bed into incipient "schistocite" ("s" surfaces) with incipient shear planes ("cisaillement") developing. This process has gone to full-blown s/c mylonite development on the right with slightly oblique compression driving right-lateral shear along the "c" planes.*

   c) Equal area plots (Fig.8) show boudin necks striking N70E. Poles to calcite veins in neck area, presumably parallel to stretching direction, are N30W (+/- 15) or parallel with the regional nappe pattern.

2). Two classes of veins, mm and cm scale are present but both have about the same orientation.

3). Amount of stretching judged by total calcite vein population is 10-20%

4). De Paor et al., (1991) discuss role of pressure solution in boudin formation at nearby Rheems Quarry. Unfortunately, almost all of those excellent exposures have been quarried away but equally good examples may be exposed here depending on the position of the actively working face
   a) All the boudins involve layer-parallel extension of brittle dolomite beds, accommodated by ductile stretching of the adjacent marble beds. Depending on the

amount of flowage these may be partially or completely converted to mylonitic fabrics.

b) Open spaces between boudins are low pressure zones that will fill one way or another. As De Paor and others point out, pressure solution will dissolve some of the marble and redeposit it as veins in the interstices while bulk flowage of the adjacent marble beds will cause them to intrude as viscous plugs into the larger openings. A film of graphitic insoluble material commonly remains along the contact.

c) Some types of boudin structures are illustrated in Fig 6. Most common are simple calcite veins between dolomite tablets with adjacent marble units sucked toward the opening to produce an “hourglass” fold (Wise, 1958). Buckling of some of the tablets by the intruding marble plug may also occur as in the second panel from the top. With less ductility contrast between dolomite and marble beds, originally planar ends of the boudins can be curved into “fish-mouth” boudins while pressure solution may remove some of the sharp corners (De Paor, et al. 1971). In extreme examples, plugs sucked in from either side can nearly meet in the center to produce a “bow tie vein” (bottom panel)

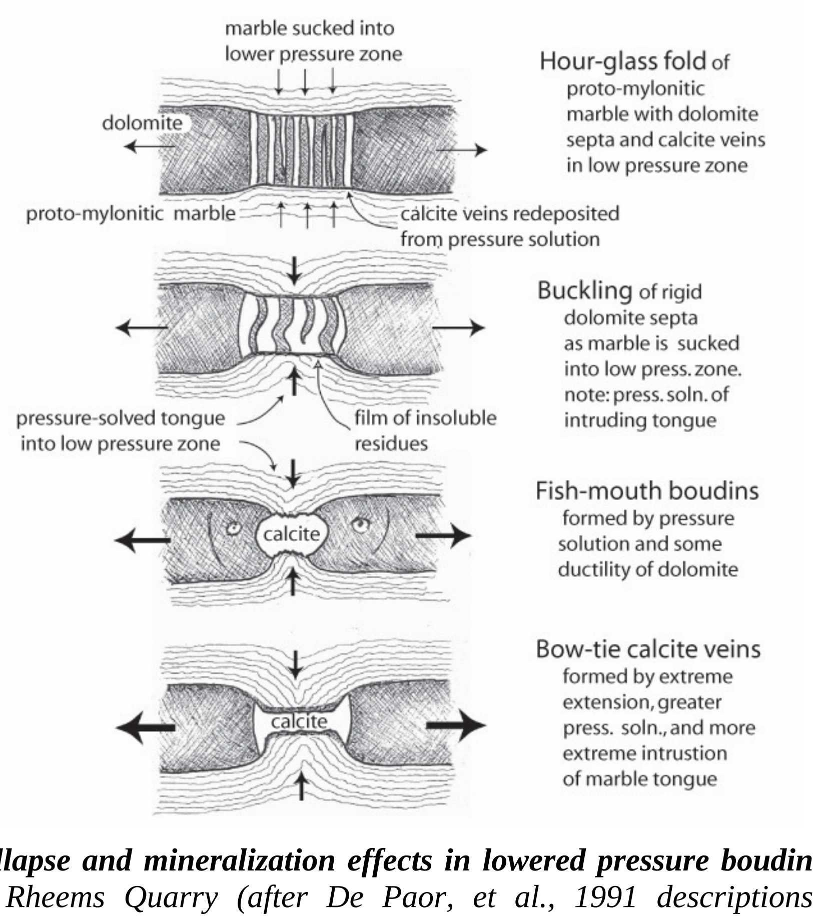

Figure 6. Collapse and mineralization effects in lowered pressure boudin neck zones *from nearby Rheems Quarry (after De Paor, et al., 1991 descriptions and DUW observations). Many of the same features are visible in Prospect Quarry boudins.*

3. One minor question remains. Because pressure solution occurs at points of high pressure, was solution of material taking place at the surface of the intruding plug? It seems more likely to have occurred as the marble passed over the sharp corners of dolomite tablets and slabs.

4. You can find a number of shiny, graphite-covered bedding surfaces as residues from pressure solution at points other than in immediate juxtaposition with the boudins. As De Paor and company point out, pressure solution is a pervasive phenomenon in this environment and needs to be taken into account in any retro-deformation exercise, be it stratigraphic thickness, bed lengths, or balanced cross sections.

4. The small-scale flow history of the marble must have been complex, first with layer-parallel stretching followed by possible reversal of sense and 90° change in direction of motion as it was sucked into the opening, complete with pressure solution along the intruding lobe contact. The result can be a most interesting set of minor folds and truncations of earlier stage graphitic stringers in the proto-mylonites. Look for them in the lobe zones.3.

Figure 7. Boudins visible in north wall of Prospect Quarry *(R.D. Hatcher photo, 2008).*

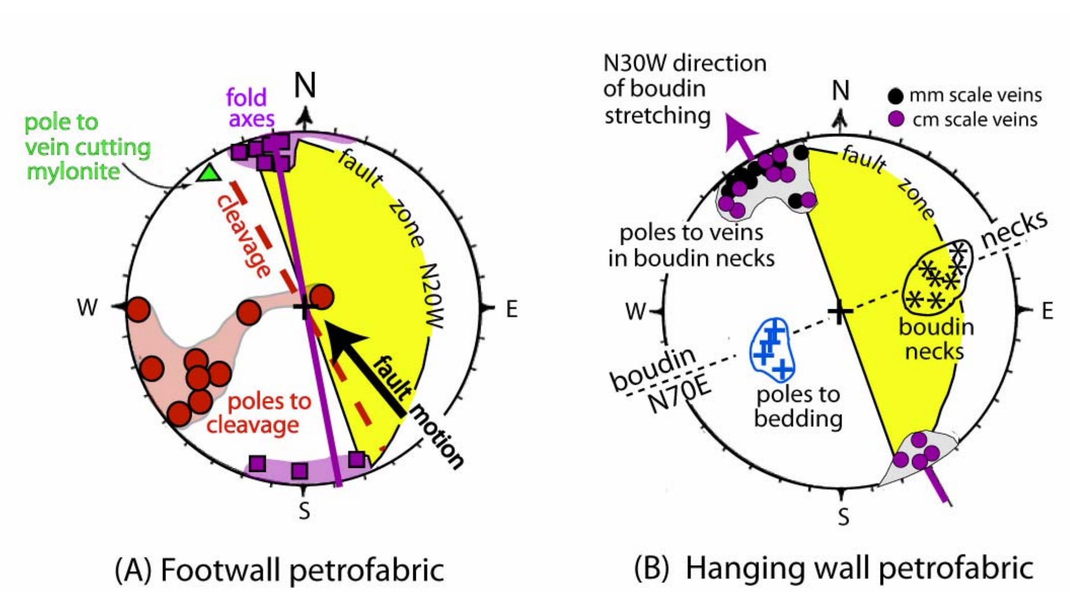

Figure 8. Contrasting petrofabrics between footwall and hanging *walls of Chickies-Oregon thrust in the Prospect Quarry. The hanging wall is typical of the Lebanon Valley nappe structures, dominated by N30W extension and boudins developed with roughly perpendicular orientation. The footwall folds are roughly parallel to the extension and transport direction (~ N15W). In this area, Henderson (1965) described small-scale folds that he later called sheath folds (Henderson 1993). This fabric may be part of a much larger zone sheath fold development as the Rheems-DS-P zone that forms the overturned SW edge of the Lebanon Valley nappe complex (Figure 3). The younger Alleghanian age, Chickies-Oregon thrust made partial use (Figure 2) of that older anisotropy with approximately parallel transport (N40W in contrast to N30W) shown by the mylonites.*

<u>Sub-Stop #3. Fault zone on NW wall</u>

1) The Chickies – Oregon disturbed fault zone here is only about 10 m thick but still contains some mylonites and proto-mylonitic zones.
2) Lineations in proto-mylonites near the base of the zone trend about N40W or slightly obliquely UP the zone which strikes about N20W, 20NE
   a) Hence the fault is a transpressional structure, a lateral ramp for the thrust that seems to increase regionally with greater displacements along its eastward projections toward the little town of Oregon.
   b) Dating of this fault is tenuous. The Chickies-Oregon Thrust is dated as Alleghanian because of its association with the Honeybrook Upland and its Mine Ridge partner that folds the Taconian schistosity across the Tucquan Antiform..
      1). The apparent N40W displacement seen here is closer to Taconian trends than to typical N-directed Chickies –Oregon displacements. This association in location and movement direction with many ductile Taconian fold structures is suspicious.
      2). A Taconian–oriented stretching phase was superposed on the proto-mylonitic foliation as shown by an undeformed thin calcite vein that cuts foliation at this sub-stop.
      3). Throw on the fault remains uncertain, awaiting better determination of units juxtaposed across it. In that both sides seem to be Conococheague Group, the throw is probably less than the 1-1.5 km value apparent at Chickies Rock, a reverse of the larger pattern. One explanation could be that this is only one splay of a larger fault zone.
      4). The linking of this fault with the mapped Chickies-Oregon thrust is purely geometric based on strike, dip, and a location that fits nicely on projection of a point where mapping loses the C-O thrust (Meisler and Becher (1971)..
      5). For all these reasons, our interpretation of this structure is tentative: a transpressional, lateral ramp of an Alleghanian age thrust that locally followed a zone of more intense deformation near the base of a pile of Taconian nappes.
   c) Note the thrust zone grades downward into a zone of dragged and "overturned" beds (rotated with respect to more distal, relatively flat lying beds to the left).
      1). Note the spaced cleavage is obvious only in a few of the thin beds. This cleavage was not generated by fault proximity; it can be traced in these beds across most of the entire length of the face to the left. Like the Chickies examples, this cleavage has been pirated as slip surfaces for creation of the folds adjacent to and overturned away from the fault.
      2). Away from the fault, the cleavage strikes N20W but rotates toward N35W in the folds closer to the fault.

3). If this is a Taconian cleavage it has a strange orientation with respect to the more regional ENE strikes. It may be a rotated fabric of the Rheems-Donegal Springs zone which seems to be change in dip as well as strike-slip shear.

Sub-Stop #4. South end of the SW wall

1) Use sketch of the wall on Fig. 1 to trace the beds through broad, open folds that include some bedding plane faulting.
2) The cleaved beds from the previous sub-stop also can be traced across most of the face, rotating from near vertical orientations to steeper and steeper E dips as one progresses to the left.
3) Toward the SW end of the face, the cleavage dips flatten to become axial surfaces of a few nearly recumbent small folds that in turn grow to SW into recumbent larger scale (5m + wavelength) folds that occupy the SW end of the quarry.
4) The timing, mechanics, and stress field orientation that produced this pre-thrust cleavage and its relationship to the recumbent folds continue to puzzle us. It is early but not typical of most Taconian cleavages in style nor orientation. It apparently is older than some typical Taconian-like recumbent folds that have a strange NNW hinge orientations. Next to the Alleghanian fault it was pirated for reactivation as slip planes to allow new drag folds to develop. Can this cleavage be an early product of bedding normal shortening something like the Chickies first cleavage but of a completely different strike?
5) Help !!

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DAY 2

Interval Mileage	Cumulative Mileage	Description
0.00	0.00	From the hotel driveway, turn right onto E. King Street
0.20	0.20	Turn left onto N. Lime Street (PA 272, US 222)
1.00	1.20	Turn left onto E. Liberty Street, following 222/272.
0.05	1.25	Turn right on Lititz Avenue, still following 222/272, toward PA 501.
0.60	1.85	Continue on Rte. 501 (Lititz Pike).
4.60	6.45	Immediately past the Lancaster Airport, turn right onto E. Millport Road.
1.20	7.65	At the traffic circle, take the second exit onto Kissel Hill Rd (if this was a straight intersection, you would turn left onto Kissel Hill Rd.).
0.40	8.05	Turn right onto Woods Road.
0.90	8.95	Turn left onto Owl Hill Road.
0.30	9.25	Turn left onto E. Millport Road (yes, this was shorter than staying on Millport Road).
0.40	9.65	Turn left onto Warwick Road.
0.20	9.85	**STOP 7.** Stop at wide grassy shoulder before reaching driveway. Busses will let off here. Walk up the driveway to the first part of stop.
0.20	10.05	Walk north on Warwick Road to Ballstown Road, viewing outcrops for STOP 7. Busses will meet you at Ballstown Road. Leave STOP 7 continuing north on Warwick Road.
0.90	10.95	Turn left on PA 772 (Rothsville Road). Follow 772 into downtown Lititz. Road name changes to E. Main Street.
2.20	13.15	Turn left on S. Broad Street to stay on PA 772
0.50	13.65	Turn right on W. 2nd Avenue.
0.10	13.75	Slight left onto Woodcrest Avenue.
1.70	15.45	Turn left on Erbs Quarry Road. The Rohrer's Quarry processing facility will be on your left.
0.20	15.65	Turn right on Lititz Road. Rohrer's Quarry is on your left. The quarry is in the Epler Formation. It supplies stone for a variety of applications: crushed stone, lime, concrete. Follow Lititz Road across PA 72 and past Root's Country Market Auction.
3.00	18.65	Turn left onto Graystone Road after Root's Auction.
0.30	18.95	Turn right on Landisville Road.
1.90	20.85	Turn right on Spooky Nook Road. The road immediately makes a bend to the left. Stay on Spooky Nook Road.
0.80	21.65	Turn right to merge onto PA 283 West.
7.40	29.05	Somewhere in here (Elizabethtown exit, at Kinsey's Outdoors store), we leave the Cambro-Ordovician platform rocks and cross into the Mesozoic Basin. Continue on PA 283 West.
3.70	32.75	The Pennsylvania Geological Survey office is on the hill to your right. Still in Triassic rocks. Continue on PA 283.
3.70	36.45	Continue to the traffic light at this T-intersection. Turn right onto S, Eisenhower Boulevard. In a few hundred feet, we cross out of the Triassic rocks into a narrow belt of Lebanon Valley carbonates (more platform rocks).

Interval Mileage	Cumulative Mileage	Description
0.20	36.65	Turn left onto Quarry Road.
0.20	36.85	Continue straight across South Harrisburg Street on Hempt Brothers Quarry entrance road. We will drive along the length of the quarry on the left.
1.00	37.85	**STOP 8. Hempt Brothers Quarry**. Busses will do some driving in the quarry during this stop. Retrace route back to the quarry entrance and leave STOP 8, driving back out the quarry entrance road.
1.00	38.85	Continue straight across South Harrisburg Street on Quarry Road.
0.20	39.05	Turn left on Eisenhower Boulevard. In a few hundred feet, we will cross the thrust contact from the carbonates into the Cocalico North phyllites. The Cocalico North underlies all the higher ground that extends to our east and west.
1.20	40.25	Take the 3rd right onto PA 441 South (Lindle Road)
0.10	40.35	Turn left on I-283 North. Right about here we make our first crossing of the Yellow Breeches thrust from Cocalico North in the hanging wall to Cumberland Valley carbonates in the footwall.
0.80	41.15	Take exit 3C to merge onto US 322 East toward Hershey. As we travel along 322, the carbonates will be in the valley to your left, and the Cocalico North holds up Chambers Hill on your right.
2.80	43.95	**STOP 9**. Pull over on the wide shoulder at Enterprise car sales.
	43.95	Leave STOP 9 continuing west on US 322, riding close to the Yellow Breeches thrust.
0.90	44.85	Turn left at the traffic light onto Grayson Road. We will descend into the carbonate valley.
0.10	44.95	Turn right onto Milroy Road. Note the outcrops of St. Paul Group limestone at the railroad overpass.
0.50	45.45	Intersection with Derry Street. Continue straight across intersection; road name changes to Nyes Road. Red shale in a thin sliver of the Dauphin Formation was exposed in the cut for construction of the Susquehanna Bank building on the northwest corner.
0.50	45.95	The first outcrops on Nyes Road, at this driveway south of Pine Hill Road, are Martinsburg Formation dark gray shale. We will now pass through the monotonous Martinsburg shale belt. Continue on Nyes Road.
2.10	48.05	Outcrops between Red Top Road and Hunters Run Road are limestone conglomerates of the basal Martinsburg. The number of limestone clasts increases northward (downsection) from rare at Red Top Road to abundant in the high bank south of Hunters Run Road.
0.90	48.95	Red shale under the guardrail on the right (across from N. Highlands Court) indicates that we have crossed into the Nyes Road Member of the Dauphin Formation - turbidites with deep water red shale and chert between cycles.
0.20	49.15	More turbidite and red shale exposed in the creek bank on the right (across from M Street).
0.40	49.55	Small outcrop of turbidite on the left.

Interval Mileage	Cumulative Mileage	Description
0.40	49.95	Turn left on Jonestown Road.
0.40	50.35	Turn right on Mountain Road.
1.70	52.05	Turn left on PA 39 (Linglestown Road).
2.30	54.35	Turn left into Sports City. **STOP 10** is the cut bank behind the building. Leave STOP 10. Turn right out of the parking lot onto PA 39 (Linglestown Road).
5.80	60.15	Turn left into Gables truck stop. Proceed to the back right (northeast) corner of the parking lot for **STOP 11**. Leave STOP 11. Turn left onto PA 39.
4.40	64.55	Somewhere around the intersection with Hanshue Road, we cross out of the Dauphin Formation into the Martinsburg Formation.
1.30	65.85	Turn left onto Canal Street.
1.00	66.85	**STOP 12**. Pull over onto the wide shoulder at the Pennsylvania American Water treatment ponds. Leave STOP 12. Continue north on Canal Street. Proceed through the village of Sand Beach.
0.50	67.35	Turn right on Sand Beach Road.
0.30	67.65	Turn right on Boat House Road. Once again, we are driving approximately along the Yellow Breeches thrust. Across Swatara Creek to your right is the Martinsburg Formation (you might see Stop 12 through the trees). The hill on your left is underlain by Cocalico North.
1.30	68.95	Turn left on PA 39. Before Hersheypark Drive, we cross out of the Cocalico North into the Lebanon Valley carbonates.
0.10	69.05	Turn right on Hersheypark Drive (still PA 39). You will see some limestone outcrops along the road.
1.30	70.35	Pass Pennsy Supply Road - quarry entrance (Ontelaunee and Epler Formations).
0.70	71.05	Merge onto US 322 via the ramp to Harrisburg/I-83.
0.60	71.65	Take the exit toward Middletown/Hummelstown.
0.30	71.95	Turn left at Quarry Road/Waltonville Road
344 feet	72.00	Cross US 322 and immediately turn right toward Middletown Road.
0.50	72.50	Turn left on Middletown Road. We are still driving on carbonate. The high ground you see to your left is underlain by Triassic rocks. We will cross the contact into the Triassic at about Swatara Creek Road.
2.30	74.80	Intersection with Schoolhouse Road. Pennsylvania Geological Survey office is just off of Schoolhouse Road to your right (can't see it from here).
0.30	75.10	Bear right onto the entrance ramp to PA 283 East toward Lancaster.
24.30	99.40	Exit at PS-72/Manheim Pike
0.20	99.60	Keep right at the fork, follow signs for Downtown/Lancaster and merge onto PA 72 S/Manheim Pike
2.00	101.60	Turn right at PA 72 S/Fruitville Pike/N. Prince St.
1.40	103.00	Turn left at W. Mifflin Street
0.10	103.10	Turn left at S. Queen Street. Lancaster Marriott at Penn Square is on your right.

STOP #7: COCALICO ALLOCHTHONS ON WARWICK ROAD

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Gale C. Blackmer, Pennsylvania Geological Survey

Location: Warwick Road is a side road through Kissell Hill, one mile south of Rothsville and two miles SE of Lititz. Abundant small outcrops of the Cocalico Formation occur as roadside cuts as the road follows the east valley wall of Lititz Run. The stop is at the south end of these road cuts where bedrock changes from flysch and allochthonous red deposits of the Cocalico Formation across a concealed zone into open farmlands underlain by the Beekmantown Group's Ontellaunee and Epler Formations.

Features. This stop is designed as an introduction to the structure and stratigraphy of the Taconic foreland nappes. These will dominate most of today's stops and discussions. There are several main points to be made at this outcrop.

Regional zones of nappe inversion versus areas of right-side up stratigraphy. This stop is located in the *E-W trending Kissell Hill belt of right-side-up basal Cocalico Formation and shallow water Cambro-Ordovician carbonates that lie immediately to the south* (White print on Figure 1).

1) Regionally the entire Taconic transport of slope deposits, shelf-edge carbonate pile and Lebanon Valley nappe system was consistently N30W (See figure from Stop #1)
2) Roadcuts at this stop expose the red to purple deep-water allochthonous sediments common near the base of the Cocalico Formation.
3) Northward the roadcut exposures do not include these easily identifiable allochthonous components, thus precluding a simple synclinal structure for the ridge..
4) Kissell Hill is largely a right-side-up Cocalico mass dipping to the north directly into the regionally inverted carbonates and Cocalico Formation that form the Lebanon Valley nappe system of Gray, MacLaughlan, Geyer, and others.
    a) The large carbonate valley just to the north of Kissell Hill is the overturned limb of the gigantic Lititz-Manheim nappe.

Kissel Hill Fault separates regional right-side-up zones on the south from inverted areas of Lititz and Lebanon Valley nappes to north

1). On the basis of the above Kissel Hill relationships, Meisler and Becher (1971) drew the Kissel Hill fault along the north flank of the ridge
    a) As M &B note, westward and south of Manheim the fault must change from a ridge-bounding structure to pass within the Cocalico map area and possibly emerge in the Florin syncline as a Cocalico septum (west of the edge of Figure 1).
2) Just to our east, the right-side-up basal Cocalico contact is almost flat.
    a) There (Figure 1), a "peninsula" of Cocalico extends for about a mile to the south, underlain by the uppermost Beekmantown Ontolaunee Formation.
    b) The geometry indicates that the basal Cocalico contact, though locally deformed, must have a relatively flat average dip in this area.
3) A possible reconstruction of the nappe and fault geometry is suggested in the cartoon cross-sections of Figure 2, pre-Alleghanian fold structure below and post-Alleghanian and with erosion above.. This displays one of several versions of how the younger Kissell Hill fault can juxtapose a regional boundary between right-side-up zones of Taconic folding on the south against regionally inverted Taconic Lebanon Valley nappe zones on the north.

Wise, D.U., G.R. Ganis, and G.C. Blackmer (2010) Stop #7 Cocalico Allochthons on Warwick Road, *in* Wise, D.U and Gary M Fleeger, eds., Tectonics of the Pennsylvania Piedmont along the Susquehanna River, 75th Annual Field Conference of Pennsylvania Geologists, Lancaster, PA, p. 71 – 79

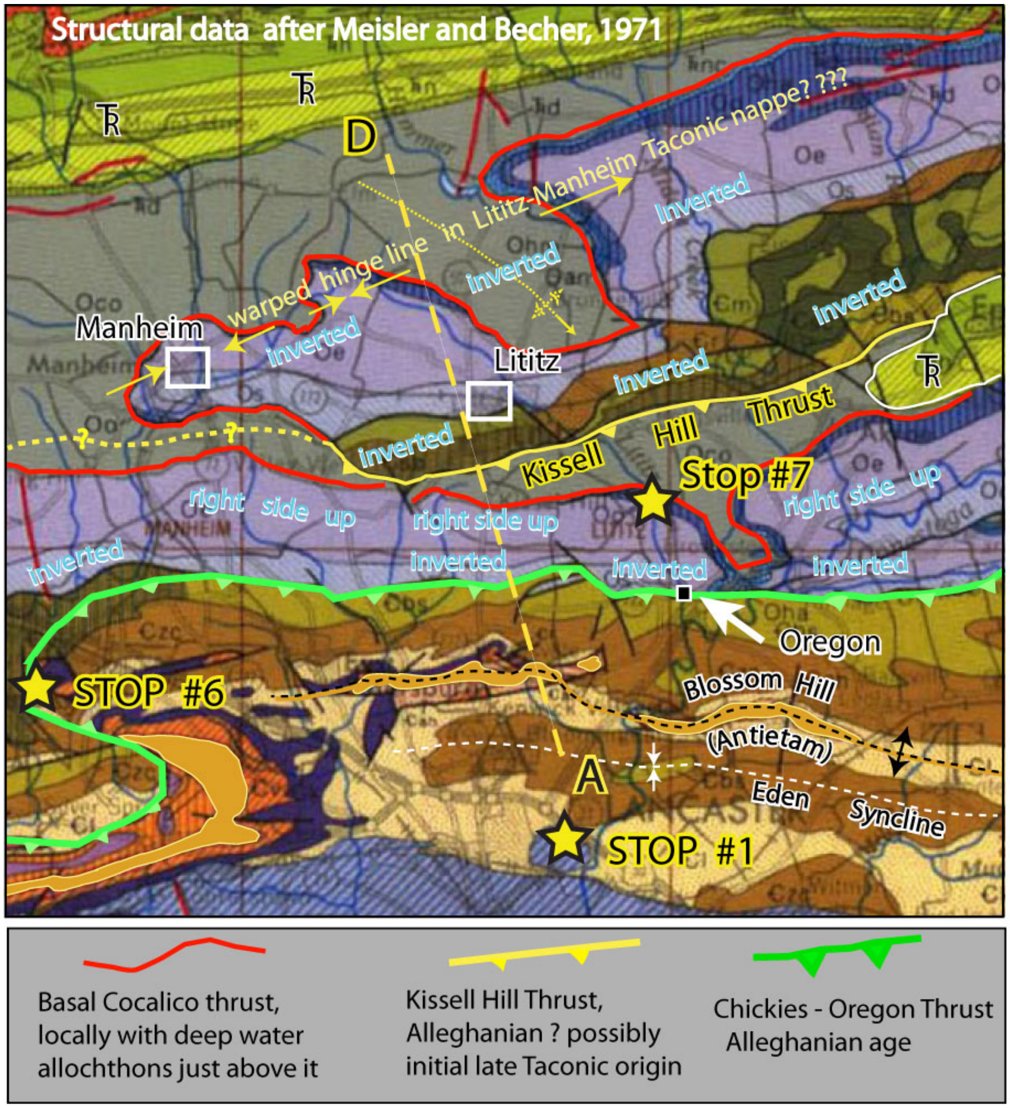

Figure 1. Tectonic annotations superposed over the state geological map *(Pennsylvania Geological Survey.) Basic structural data from Meisler and Becher, 1971. Line A - D is location of cartoon reconstruction of Figure 2.*

a) The cartoon of Figure 2 top panel includes the probable geometric origin of the large springs that emerge in Lititz. Overturned, karstic carbonates of the Lititz Valley are cupped above the relatively impermeable Cocalico shales and phyllites. Most rainwater escape must take place from springs in the valley as the source of Lititz run that forms this valley.

4) Age of Kissell Hill Fault (?). The fault cuts the Taconic nappe structures but is parallel to the older axial traces in the Kissell Hill section (Figure 1). The fault may well have started within or along the inverted and possibly faulted under-limb of a Taconian nappe to be reactivated as an Alleghanian thrust

The Chickies-Oregon Thrust is located about a mile to the south of this stop.

1) The fault trace runs through the middle of the valley separating this stop from Blossom Hill, obvious in the intermediate distance to the SSE.

a) Mapping by Meisler and Becher, (1971) shows the fault places the lowermost member of the Conococheague Group (Buffalo Springs Fm.) over the lowermost member of the Beekmantown Group (Stonehenge Fm.).

2). Just to our southeast near the *Oregon Hotel* and little crossroads by the same name, the thrust strongly deforms the south end of the Cocalico "peninsula" (Figure 1) to become the type locality for the eastern half of the "Chickies-Oregon thrust."

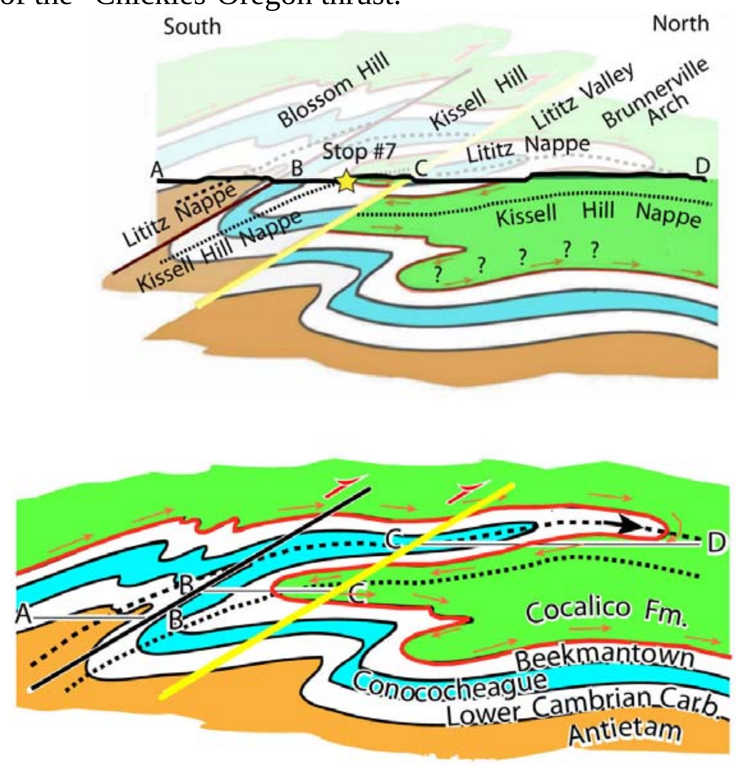

Figure 2. Cartoon showing possible pre-fault *Taconic nappe geometry. Present levels of erosion are shown by lines A - B, etc., in lower panel. (See Figure 1 for location.)*

a) The thrust can be traced eastward from Oregon for another 12 miles (Sorry, the local Pacific ocean has been closed for the day) , mostly through that distance as basal Conococheague Buffalo Springs Fm. thrust over basal Beekmantown Stonehenge Fm., a stratigraphic throw of about 3000 feet (1 km) until it disappears beneath the Triassic unconformity.

b) In the hanging wall, the Zooks Corner and Buffalo Springs Formations are complexly folded but generally dip northward into the thrust zone, apparently a continuation of roll-over structures associated with the thrust front and edge of the Honeybrook Upland basement rotations off to our east.

3) In the footwall, overturned beds of Conococheague units are part of a zone regional overturning along the thrust (Figure 1 after data from Meisler and Becher, 1971).

4) The model presented here suggests the buried edge of a broken but relatively strong Alleghanian age basement slab underlies the eastern half of the thrust zone. The exposed part of the slab comprises the Reading Prong - Honeybrook Upland -Mine Ridge. Its broad folds plunge westward to end in a zone from Reading to Lancaster. Tectonic styles on and off the sheet differ markedly and include added complexities in the transition zone. Additional arguments that it might form the SE end of New England are given in yesterday's notes for Stop #4

a) Wise and Faill (2002) proposed the Lancaster-Reading seismic zone results from modern N70E-S70W compressional strain concentrated along the NE-SW trending western edge of a basement slab lying a few km beneath the surface. Little South Mountain is a large block, possibly one of several, developed at the broken edge zone of the slab.

b) Seismic activity of the edge zone is in the upper 5 km whereas truly autochthonous North American basement must be 15+ km down.

c) The seismic zone trends NE across all the other structural gains. The authors could imagine no other shallow structure with such a trend..

d) In 1997 a magnitude 3.0 quake occurred 2 miles north of this stop.

e) In this model, the broadly open fold structure south of the thrust and results from the relative rigidity of the underlying west-plunging Honeybrook slab.
f) West of this slab edge the thrust curves through the Prospect Quarry to cut deeper into stratigraphic footwall levels of the Chickies Area.
g) South of Chickies Rock along the Susquehanna, a series of east-plunging folds in the Manor Hills have their noses aligned along a NE-trending zone located approximately along the same general zone
h). The same boundary may be the reason for the transition of the broad Newark Mesozoic Basin westward into the "narrow neck" of the basin (Figure 1). In addition a splay of the northern border zone of the basin curves to the south as it passes westward to drop the Ephrata Graben, the end of which appears on the eastern edge of Figure 1.
i) Stose (1924) noted a different type of Appalachian block faulting appears in passing westward and southward from the Ephrata graben into the Fruitville-Lancaster Area., the approximate trace of the proposed edge of the slab.

Gentle structures on the basement slab, hanging wall of the Chickies-Oregon thrust sheet.

1) On the hanging wall of the thrust sheet, above the proposed basement slab, a series of anticlinal ridges, including Blossom Hill, lies about 2 miles south of its trace with cores of Antietam Schist.
2) On Blossum Hill, the Vintage is omitted by faulting on the anticline's north limb whereas a few Vintage patches remain on its south limb.
3) Eastward the anticlinal zone is traceable for about 10 miles as a Ledger band with relatively intact Cambrian stratigraphy above doubly plunging Antietam ridges in its core. The zone ends by merger with west-plunging structures of the Honeybrook basement uplift.
4) Westward of Blossom Hill another Antietam fold crest appears as a right-stepping en echelon offset. Meisler and Becher's mapping shows the Lower Cambrian carbonates as complexly faulted and folded on both limbs of this fold. Farther west this increasingly complex line of anticlinal ridges appears to be truncated by the Chickies-Oregon fault as it curves southward into the Prospect Quarry area of Stop #6.
5) The Eden Syncline, about a mile north of yesterday's Stop #1, forms the south flank of the Blossom Hill line of anticlines (Figure 1). The syncline is a doubly plunging broadly open fold with dips on both limbs of about 30°. It forms a 1 to 2 mile wide band of Zooks Corner Formation that ends eastward by upwarping of its axis along the end of the Honeybrook upland.
6) A working hypothesis is that the Honeybrook massif plunges westward as the strong support beneath the hanging-wall structures. They end westward near the edge of the basement slab at about the same location where the east-plunging end of the Chickies Anticlinorium intersects the slab.

Broader tectonic controls by suture zones in the basement slab. The Mine Ridge basement geology is quite different from that of the Honeybrook Upland which in turn is different from that of the Reading Prong (Faill,1997). At least two major Precambrian sutures within the basement slab should separate the three areas. The Mine Ridge-Honeybrook boundary trends broadly N75W across the eastern end of Mine Ridge (See state geologic map in frontispiece). To the WNW the same approximate line forms the northern boundary of the Conestoga Formation in the Lancaster area while the Eden Syncline and the greater Blossom Hill Anticlinorium follow just to its north.

Cocalico Allochthons. Distinctive red to purple phyllitic beds and associated angular grained greenish quartzites occur commonly near the base of the Cocalico Fm. These can be examined in the roadcuts at this stop as described by Ganis in a following section.

1) Jonas and Stose (1930) recognized these distinctive deposits and mapped them locally as "volcanic ash."
2) The "sub-Cocalico unconformity"
    a) The Cocalico may rest on a variety of carbonate units, most commonly in this area on the upper Beekmantown - Epler Formation or the overlying Ontolaunee Formation
    b) In a few areas it rests on the pure limestones of the Annville Fm and even more rarely (south of the Mesozoic Basin) on the Myerstown Fm cement rock.
    c) Meisler and Becher interpret the missing units as the result of a removal by erosion on a pre-Cocalico unconformity. In this they follow Jonas and Stose (1930) in the Lancaster area and refer to Gray (1952), Prouty (1959), and Hobson's (1963) interpretation of a similar "unconformity" at the base of the equivalent Martinsburg Fm. in the Great Valley.
3) The "sub-Cocalico thrust"
    a) Ganis working on graptolites and Repetski on conodonts have found unmistakable evidence for a deep sea Cambrian and Ordovician origin in similar beds in the Great Valley.
    b) In the Great Valley Ganis and others (2002) have separated these beds as the Dauphin Formation beneath the more traditional flysch of a more restricted Martinsburg Fm.
    c) So long as these deposits were "volcanic" the unconformity model was plausible. With the deep sea evidence the sub-Cocalico unconformity model would require uplift and local erosion of parts of the carbonate shelf followed by unbelievable sinking rates to allow immediate burial by deep sea sediments. The presence of some Cambrian fossils in the overlying sediments marks the end of these interpretations.
    d) The alternative requires these to be far-travelled allochthons emplaced by a regional thrust at the base of the Martinsburg Fm.
    e) The only source for Cambro-Ordovician deep sea sediments must have been at least in the distal parts of the Octoraro Seaway or beyond that in front of some island arc beyond the Baltimoria cratonic microcontinent.
    f) The comparable Cocalico units have not yet yielded fossil dates but their similarity to the Dauphin examples is unmistakable.
    g) A sub-Cocalico tectonic contact is required. It it was a typical thrust this would a minimum displacement of at least 50 km and probably much more. An alternative is the caterpillar tread advance described at yesterday stop #2 and in Wise's Taconic paper for the symposium.

<u>The greater Martinsburg-Dauphin-Cocalico Taconic Foreland Basin.</u> The similarity of this outcrop to one that will be visited later today some 20 miles across strike to the north is unmistakable. (Pick up a piece here for later comparison.)

1) The Cocalico may be split into a north and south part by the Mesozoic Basin but both are parts of a single basin (Frontispiece tectonic map.).
2) The greater Cocalico area is separated from the Dauphin-Martinsburg Basin by the Yellow Breeches Alleghanian thrust.
3) The only real difference is that the Cocalico has suffered lower greenschist grade metamorphism whereas the Dauphin-Martinsburg has received little or no metamorphism.

4) All are part of a gigantic Taconic Foreland Basin that among its initial deposits on its carbonate floor had deep-sea allochthons from distances of 100 to 200 km or more to the SE. The mechanics capable of doing this represent provide some control on the general way the Taconic nappes could have been emplaced across the area. These must be part of the greater Taconic story of an orogeny that rolled across the Piedmont from roots south of the Martic Zone to distal parts of the foreland basin in 15 to 20 my (Ganis and Wise, 2008, Wise and Ganis, 2009)

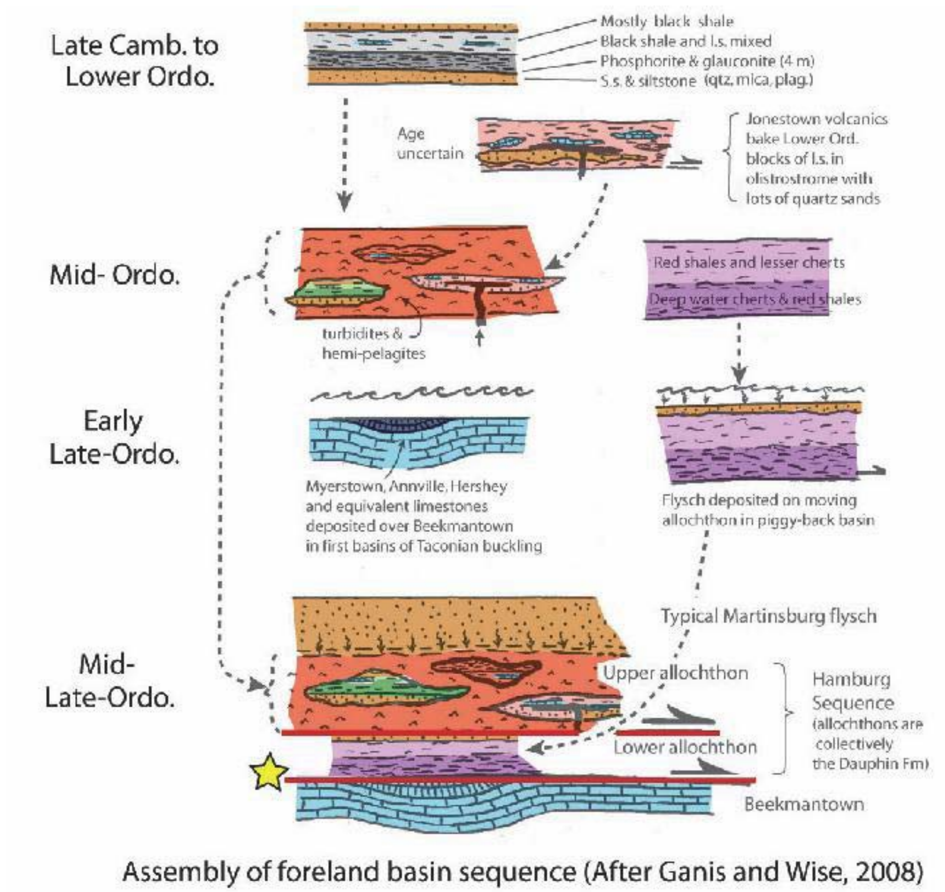

Figure 3. Assembly of units in the foreland basin.

<u>Description and examination of the allochthons at this stop.</u> The complicated Taconic nappe geometry and large scale Alleghanian detachment faulting has been described looking south across the Lancaster Valley. The exposures here along Warwick Road reveal the core of a recumbent fold that itself is riding on a low angle detachment. The exposure is a transect across Kissel Hill, which is the de facto type section of the "Cocalico shale" of Jonas and Stose (1926). Stose (1946) included the Cocalico as part of his Taconic series, a proposition we will be evaluating throughout the stops in Day Two.

The relationship of the Cocalico Formation to the carbonate platform is open to debate. Two options are: (A) the Cocalico is part of a Taconic allochthon thrust over the carbonates; or (B) it is a metamorphic equivalent of the Martinsburg Formation (foreland fill) in depositional contact with the carbonates. This debate has proven difficult to resolve. Because the Cocalico is really a phyllite at lower greenschist grade, it is difficult to correlate directly to the unmetamorphosed units found to the north in the Great Valley, like the Martinsburg or the allochthonous Dauphin Formation. There is very little datable material in the Cocalico in Lancaster County. Some questionable graptolites apparently found near our field trip stop in the early 20th century (see Ganis and Wise, 2008, for discussion) and some Ordovician conodonts reported by Repetski and Ganis (2001) represent the entire age data set. Despite the lack of precision dating, the general consensus is that the Cocalico is younger than the platform carbonates. Meisler and Becher (1971) described an angular unconformity at the base of the Cocalico (option B). As noted above, Stose (1946) included it in his allochthonous Taconic series (option A). We favor option (C), a "combination" model in which some of the Cocalico protolith was deposited as a proximal portion of the Martinsburg foreland fill, and some is structurally emplaced allochthonous elements. All was deformed and metamorphosed during the Taconic Orogeny. Later, the entire complex was transported over the carbonate shelf on an Alleghanian thrust.

Things to see at this stop (Figure 4):

1) **Stop 7A.** The outcrop on Warwick Road south of the driveway exposes a massive dirty quartzite. Examine it carefully as we would like to discuss it at Stop 9!

2) Stop 7B. North of the driveway, and extending along the road cut for some distance, are discontinuous exposures of purple-red phyllite. Stose (1946) included this lithology in the Taconic allochthon series, and even suggested that it was volcanic tuff. We certainly agree that this lithology has affinities to the allochthonous Taconic series but don't agree with the tuffaceous origin. This lithology would not appear to have any relationship, even as a metamorphic equivalent, to the Martinsburg Formation (which we will see at Stop 12). We would again ask you to store an image of this rock for discussion at Stop 9.

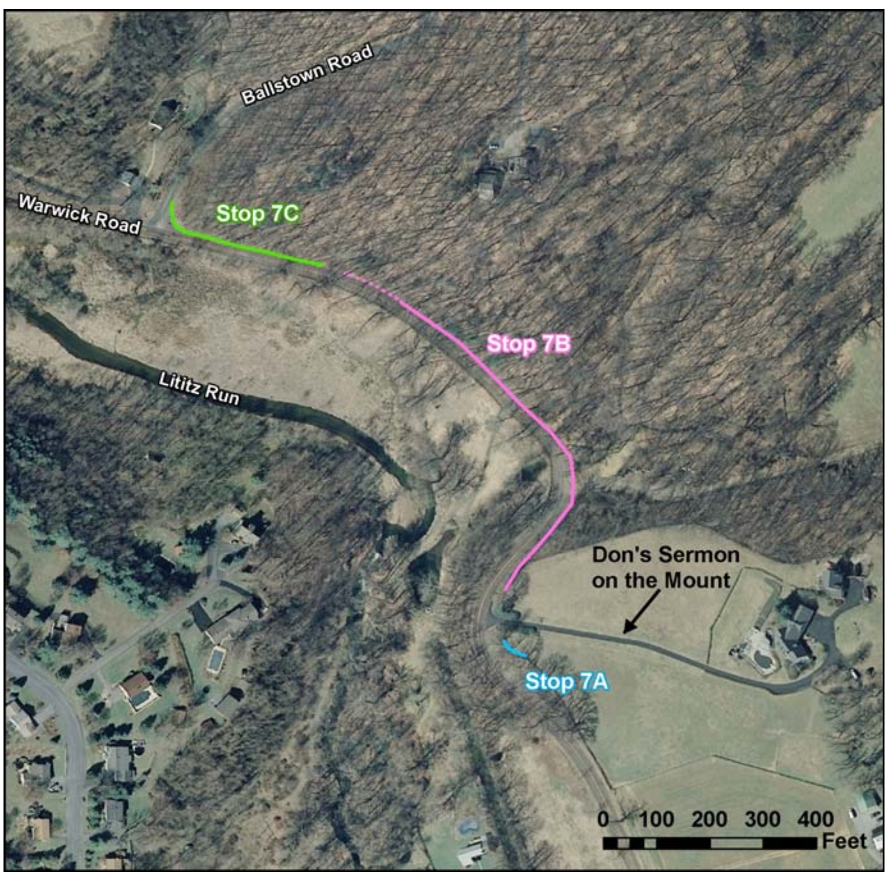

Figure 4 Layout of Stop 7 *(photo from PAMAP). Outcrops are along the east side of Warwick Road.*

Stop 7C. As you continue north along Warwick Road, the lithology changes to a uniform gray phyllite. All of the exposure is severely deformed. The gray phyllite appears to be above the purple-red phyllite. It is at least possible, but difficult to prove, that the gray phyllite is meta-Martinsburg. Perhaps judgment on this proposition should be reserved until we see the pristine Martinsburg at a later stop.

Conclusion. The theme for the stops today is a model for allochthonous Taconic rock emplaced into an early-formed foreland above the carbonate platform and then covered by the Martinsburg Formation. This stop is compatible with that model, but the proof is better examined in the non-metamorphic foreland of the Great Valley.

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STOP #8: HEMPT BROTHERS STEELTON QUARRY – TRANSITION TO FORELAND DEPOSITION

G. Robert Ganis, Consulting Geologist
Gale C. Blackmer, Pennsylvania Geological Survey

Location: From junction of S. Eisenhower Boulevard and Quarry Road, go west on Quarry Road for 1.1 miles (Figure 1).

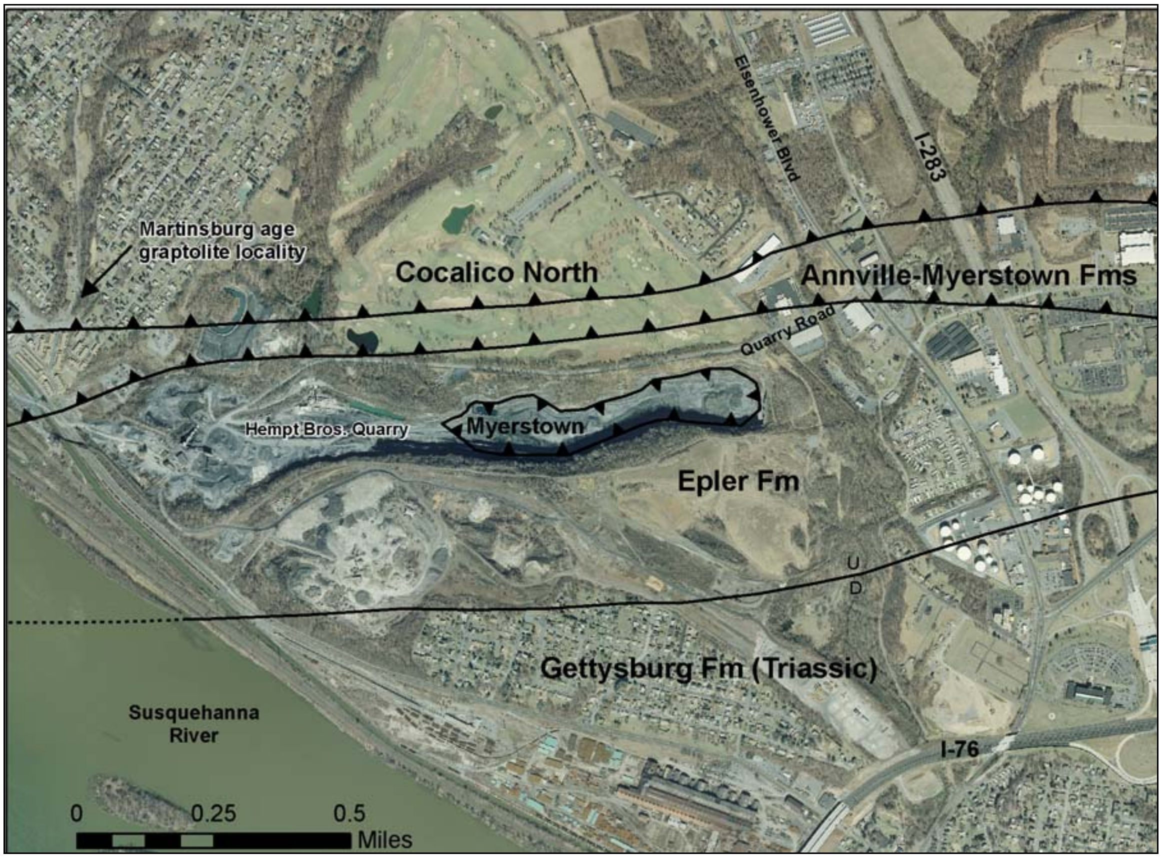

Figure 1. Geologic map of the Hempt Brothers Steelton Quarry area. *Here, the Annville Formation occurs as a thin fringe structurally above the Myerstown Formation. The contact is difficult to locate. Although the Myerstown was thrust over the Epler Formation, the whole sequence is overturned so that the Epler is now on top. Mapped contacts are approximated from MacLachlan (1967) and field work in the quarry by Ganis and D. U. Wise. Graptolite locality is referenced at Stop 9. Base is PAMAP imagery.*

The Hempt Brothers Steelton Quarry was originally owned by Bethlehem Steel; their foundry works, now Mittal Steel, are just to the west along the Susquehanna River. The steel company extracted high calcium limestone for steel making from the Annville and Epler Formations. The quarry has now expanded well below the elevation of the river. As quarrying progressed deeper and eastward, younger rocks were encountered below a thrust fault. Currently, the quarry extracts construction aggregate from the Myerstown Formation. The remaining reserves are in the Myerstown (Figures 1 and 2).

The oldest rocks exposed here are Beekmantown Group platform carbonates. They consist of limestone and dolomite in alternating layers 10's of feet thick, typical of the Epler Formation. However, the color banding that characterizes the Epler is not visible here. Still, MacLachlan (1967)

Ganis, G.R. and G.C. Blackmer (2010) Stop #8: Hempt Brothers Steelton Quarry – transition to foreland deposition, *in* Wise, D.U and Gary M Fleeger, eds., Tectonics of the Pennsylvania Piedmont along the Susquehanna River, 75th Annual Field Conference of Pennsylvania Geologists, Lancaster, PA, p. 81 – 83.

identified these rocks as Epler based on the chemistry. If that is correct, then the uppermost formation in the Beekmantown Group, the Ontelaunee Formation, is not present here. Presumably, it was cut out by the thrust fault above the Epler.

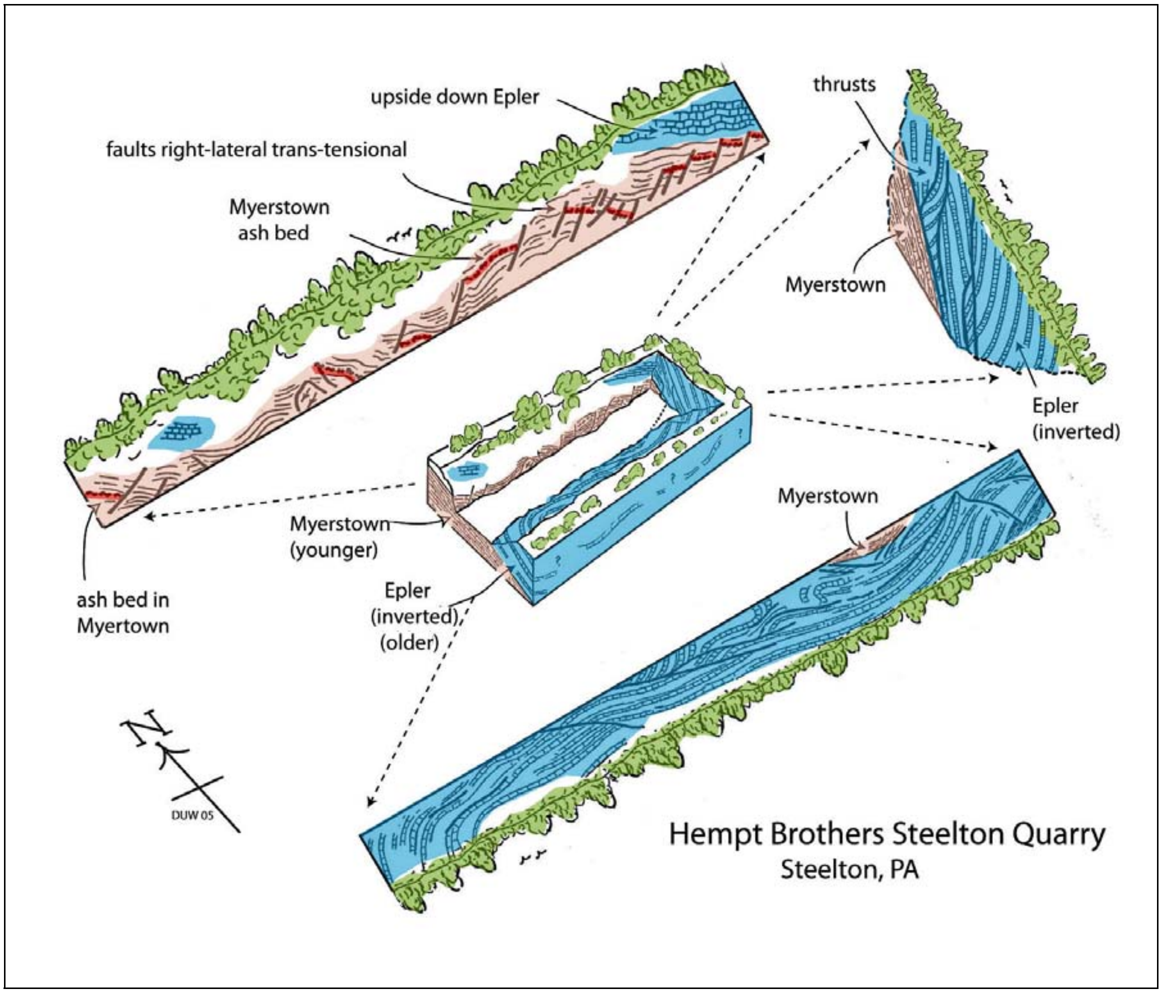

Figure 2. Sketch of geology exposed in the walls of the Hempt Brothers Steelton Quarry *(modified from Wise and Ganis, 2006).*

The next unit stratigraphically above the Beekmantown Group is the Annville Formation, a high-calcium limestone. In this area, the Annville is thin and lensy. Although some may still remain hidden the highly faulted quarry walls, the continuous body has been quarried out. The Annville marks the early stages of deepening water as the carbonate platform began to subside in response to the advancing allochthons (Dauphin Formation) during the Middle Ordovician.

The youngest unit in the quarry is the Myerstown Formation. The organic-rich, fossil-poor, dark gray limestone was apparently deposited in a restricted circulation euxinic basin. A few thin, inch-scale ash beds in the Myerstown appear as green slaty shale with abundant pyrite. The Myerstown represents the transition from platform carbonates to the Martinsburg foreland. The upper part is locally quite shaly, strongly resembling the Martinsburg.

Several stages of structural deformation are on exhibit here. First, the Annville-Myerstown sequence was thrust over the Beekmantown Group, probably during the early stages of true Taconic compression. That whole pile was then folded and transported during Taconic nappe formation. The big picture geology here is an overturned, south dipping nappe limb, with the Myerstown now structurally lowest in the hanging wall of a thrust fault which has been overturned by folding. Structurally above that is the Annville Formation in the western part of the quarry. The Annville was cut out, either stratigraphically or structurally, in the eastern portion of the quarry. In the eastern face of the quarry, the Epler can be seen in thrust contact with the Myerstown and is now highest in the quarry wall. North of the quarry, the stratigraphically higher, allochthonous Cocalico North dips beneath the Myerstown as part of the overturned nappe sequence (we will see the allochthonous Cocalico (again) at stop 9). The entire massive, Alpine scale nappe described above was transported on the Yellow Breeches Thrust during the Alleghenian orogeny (Figure 3). Note: This is one possible interpretation of the early structural details. The relative timing of overturning and thrusting/bedding plane movements is open to discussion.

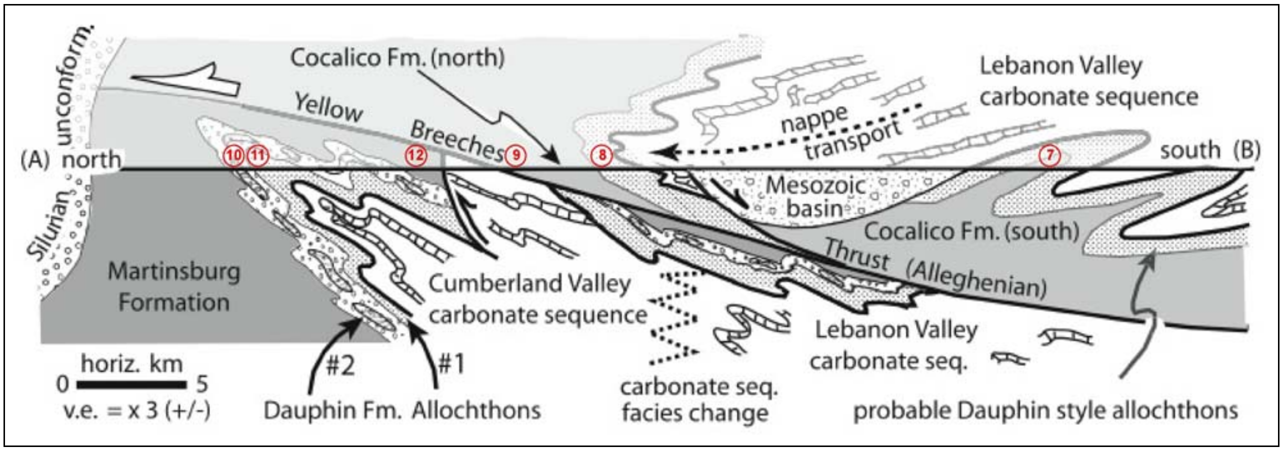

Figure 3. Schematic cross-section of the Martinsburg/Dauphin foreland. *Horizontal line represents present land surface. Numbers above the land surface represent Day Two field trip stops. The Alleghenian-age Yellow Breeches thrust juxtaposes two overturned to recumbent Taconic anticlinoria. On the north, an overturned anticlinorium of Martinsburg Formation plus two major allochthonous sheets of the Dauphin Formation is cored by the Cumberland Valley carbonate sequence, a western facies. On the south, the Mesozoic basin separates the recumbent lower limb of a greenschist-grade anticlinorium into Cocalico North and Cocalico South portions. The core rocks of this anticlinorium are part of the Lebanon Valley carbonate sequence, an eastern and southern facies. (modified from Ganis and Wise, 2008)*

A series of oblique right-lateral faults repeat a thin bentonite bed in a number of fault blocks in the north wall of the quarry (look for iron staining from the breakdown of associated sulfides to locate the bentonite). Age of this fault system is uncertain, but a good guess would be Mesozoic strain along the north edge of the Mesozoic basin which lies a few hundred meters to the south.

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STOP #9: CHAMBERS HILL OVERLOOK – COCALICO NORTH AND THE YELLOW BREECHES THRUST

G. Robert Ganis, Consulting Geologist
Gale C. Blackmer, Pennsylvania Geological Survey

Location: South side of US 322, 0.8 miles east of Mushroom Hill Rd. A private access road leads past Enterprise Car Sales up the hill to the Hill Top Body Shop (figure 1). Park on the wide shoulder in front of Enterprise car sales.

Figure 1. Geologic map of the Stop 9 area. *Route 322 lies approximately on the sole of the Yellow Breeches thrust, with Cocalico North in the hanging wall to the south. St. Paul Group carbonates occupy the valley north of Route 322, and are in turn thrust over the allochthons and foreland rocks. Base is PAMAP image over lidar-derived hillshade.*

The rocks underlying Chambers Hill are part of the massive overturned nappe that includes all of the stratigraphy from this point south to the Mesozoic Basin, including the carbonate rocks of the Lebanon Valley Sequence seen at Stop 8 at Hempt Brothers Quarry (Stop 8, figure 3). This nappe was transported on the Yellow Breeches thrust, an Alleghanian structure (MacLachlan, 1967). The Cocalico phyllites, which we will see here, are the only metamorphic rocks in the Great Valley.

As you exit the bus, you will step upon the nearly-horizontal sole of the Yellow Breeches thrust (figure 1). St. Paul Group carbonates (Ordovician platform) in the footwall of the thrust are exposed in the bank immediately below the north side of the Rt. 322 roadbed (we will not view these today).

Ganis, G.R. and G.C. Blackmer (2010) Stop #9: Chambers Hill Overlook – Cocalico North and the Yellow Breeches Thrust, *in* Wise, D.U and Gary M Fleeger, eds., Tectonics of the Pennsylvania Piedmont along the Susquehanna River, 75th Annual Field Conference of Pennsylvania Geologists, Lancaster, PA, p. 85 – 86

These carbonates underlie the narrow valley between Rt. 322 and the north side of Derry Street. They are in turn thrust north over a thin exposed sliver of Dauphin Formation and the Martinsburg Formation (foreland fill), which is exposed in the low hills north of Derry Street.

We infer red shales exposed during building construction on the north side of Derry Street to be part of the allochthonous Dauphin Formation (more at Stops 10 and 11). This unit is stratigraphically below the Martinsburg Formation. That it peeks out here suggests a fold (perhaps drag on the thrust fault, or the edge of a regional fold?).

As you walk uphill on the south side of Rt. 322 along an access road, into the hanging wall of the Yellow Breeches thrust, you should see rocks that look very much like those of Stop 7B today. Near the bend in the road are excellent exposures of the “same” purple phyllite we saw nearly 30 miles to the southeast in Lancaster County. A dirty quartzite similar to that seen at Stop 7A is also present here.

This is <u>not</u> the Martinsburg Formation, although it has been mapped as such until now. As we shall see at Stop 12, the Martinsburg Formation is dark gray, unmetamorphosed shale. Although they are now separated by the Mesozoic Basin, the amazing similarity of this stop to Stop 7 is striking evidence for a connection between the Cocalico in Lancaster County and the rocks exposed here on Chambers Hill. We agree with Stose (1946) that the purple phyllites of the Cocalico in Lancaster County are part of the Taconic allochthon, and we ascribe a similar origin to this outcrop. Ganis and Wise (2008) unified the Cocalico in Lancaster County with the Cocalico north of the Mesozoic Basin and called them Cocalico South and Cocalico North, respectively.

We said at Stop 7 that the gray phyllites in the Cocalico South are probably meta-Martinsburg. Similar gray phyllites in the Cocalico North (weathered tan in outcrop) are exposed north of Hempt Brothers Quarry (Stop 8). Ganis and Wise (2008) found graptolites at the locality shown on figure 2 of Stop 8, which are permissive of Lower Martinsburg age, lending support to the correlation.

The remainder of today’s stops will be below the transported metamorphic rocks of the Taconic foreland basin – the Dauphin Formation allochthons and the Martinsburg Formation above them. We will see what we believe to be the unmetamorphosed equivalent of the purple phyllite as red shale of the Manada Hill Member of the Dauphin Formation (Stop 11).

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STOP #10: SPORTS CITY, LINGLESTOWN – SHELLSVILLE MEMBER OLISTOSTROME

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Location: Behind Sports City, south side of Rt. 39 (Linglestown Road), 0.3 miles west of Colonial Road (Figure 1).

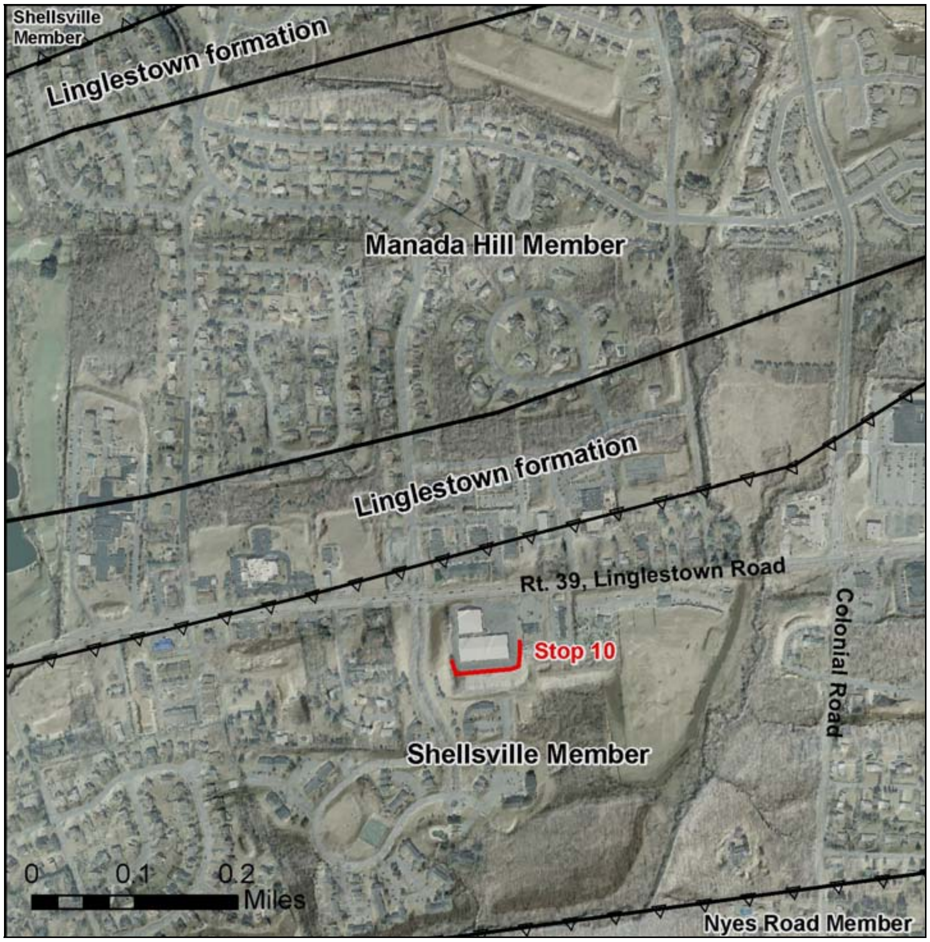

Figure 1. Geologic map of the Stop 10 area. *The stop is in the Shellsville Member of the Dauphin Formation. The outcrop belt of the Manada Hill Member of the Dauphin Formation to the north traces the axis of the regional Dauphin anticlinorium. Barbs on faults indicate the upper plate of gravity thrusts. Base is PAMAP image over lidar-derived hillshade.*

The exposure in the steep banks behind Sports City is an olistostrome – a chaotic mass of blocks and mud that accumulated by submarine gravity sliding or slumping. The olistoliths (blocks within the olistostrome), scattered within a dark banded hemi-pelagic shale matrix, are pebbles to boulder-sized chunks and slabs of platy-bedded limestone, massive limestone, greywacke, shale, and chert.

This outcrop is part of the widespread Shellsville Member of the Dauphin Formation, which consists of a mud matrix hosting olistoliths ranging in size from pebbles to kilometer-scale slices, deposited in a trench environment. Some of the larger olistoliths were emplaced as coherent, lithified sequences with their own internal stratigraphies; for example, one near the Dauphin-Lebanon County border contains graptolite zones spanning the entire Lower Ordovician.

Ganis, G.R. and G.C. Blackmer (2010) Stop #10: Sports City, Linglestown – Shellsville Member olistostrome, *in* Wise, D.U and Gary M Fleeger, eds., Tectonics of the Pennsylvania Piedmont along the Susquehanna River, 75th Annual Field Conference of Pennsylvania Geologists, Lancaster, PA, p. 87 – 89.

Many of the olistoliths have been dated using either graptolites or conodonts (see Ganis and others, 2001, for details). Collectively, the olistoliths cover a time span from Late Cambrian through lower Middle Ordovician (Figure 2). The lithologic sequence represented by the olistoliths consists of, from oldest to youngest: feldspathic, fining upward sandstone; black shale with phosphatic and baritic intervals; platy bedded and massive limestone; and hemipelagic shale/siltstone. The latter can be difficult to distinguish from the Shellsville Member matrix without benefit of graptolite ages.

Conodonts collected from limestone olistoliths are deep, cold water Baltoscandian types, not the North American Midcontinent types associated with Laurentia (Repetski and Ganis, 2001). In other cold water conodont suites known to be associated with Laurentia (e.g. Newfoundland), a small representation of splash-over shallow water types are commonly found. Since no Laurentian splash-over conodonts are found in the Dauphin Formation olistoliths, it can be inferred that a significant oceanic barrier separated their original site of deposition from the Laurentian margin.

The olistoliths are embedded in a middle Middle Ordovician matrix, consisting of hemi-pelagite shale/siltstone with rare turbidites. Using graptolites, the matrix has been consistently dated over a wide area as Darriwilian 3/4 (Ganis and others, 2001). The graptolite ages allow approximately 1 m.y. (462-463 Ma) for deposition of the Shellsville matrix and incorporation of the olistoliths. The time gap between the youngest olistoliths and the olistostrome matrix is about 4.5 million years (467-462.5 Ma). During this interval, as the Iapetus Ocean closed, the original sequence represented by the olistoliths was moved to a peri-Laurentian trench, fragmented, and incorporated into the olistostromes and turbidites of the Dauphin Formation. It was then tectonically ejected from the trench to be emplaced as an

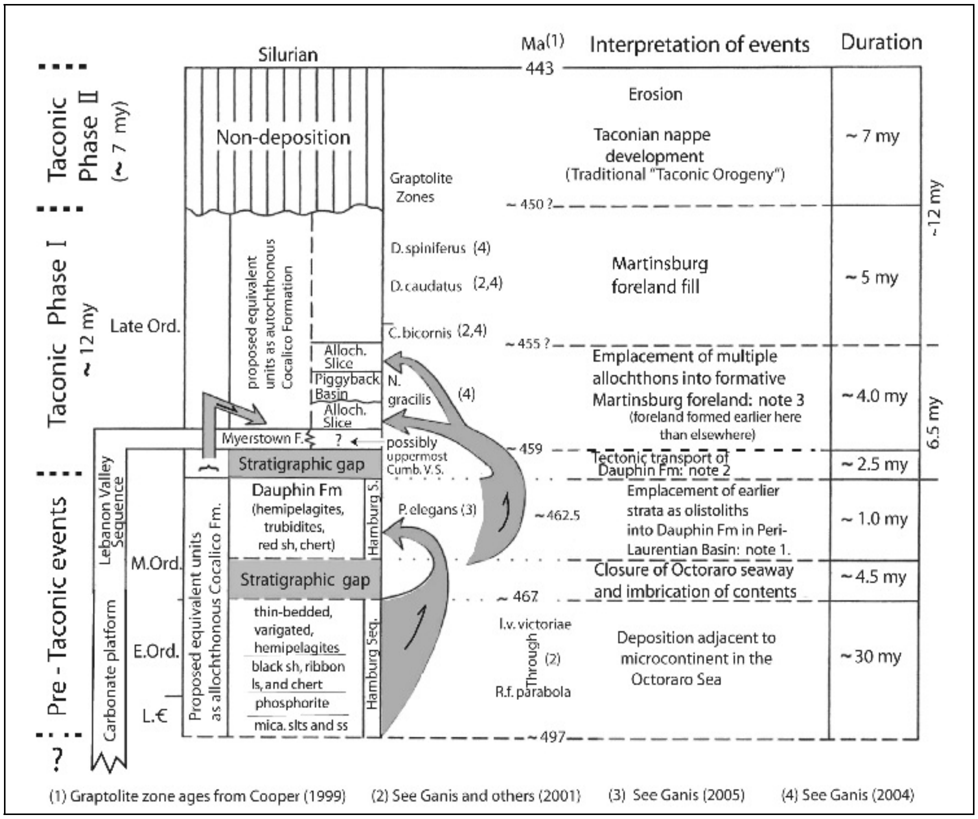

Figure 2. Fossil-dated relationships among phases of the Taconic orogeny in the Martinsburg/Dauphin foreland. *The arrows indicate packages that have been moved as allochthons to be embedded into younger units with fossil-dated matrices. Stratigraphic time gaps of few m.y. commonly separate the two events. References to fossil dates are at the bottom of the figure. Not 1 on figure, the Jonestown volcanics were emplaced into the olistostrome. Note 2 on figure, presumably, this occurred as the Westminster terrane obducted onto the Laurentian margin. Note 3 on figure, in this area the foreland basin formed about one graptolite zone or perhaps 1 to 1.5 m. y. earlier than area to the east. (from Ganis and Wise, 2008)*

allochthonous complex above the Myerstown Formation in the newly subsided foreland basin. Figures 2 and 3 are graphic representations of the assembly and emplacement of the allochthonous sequence described above.

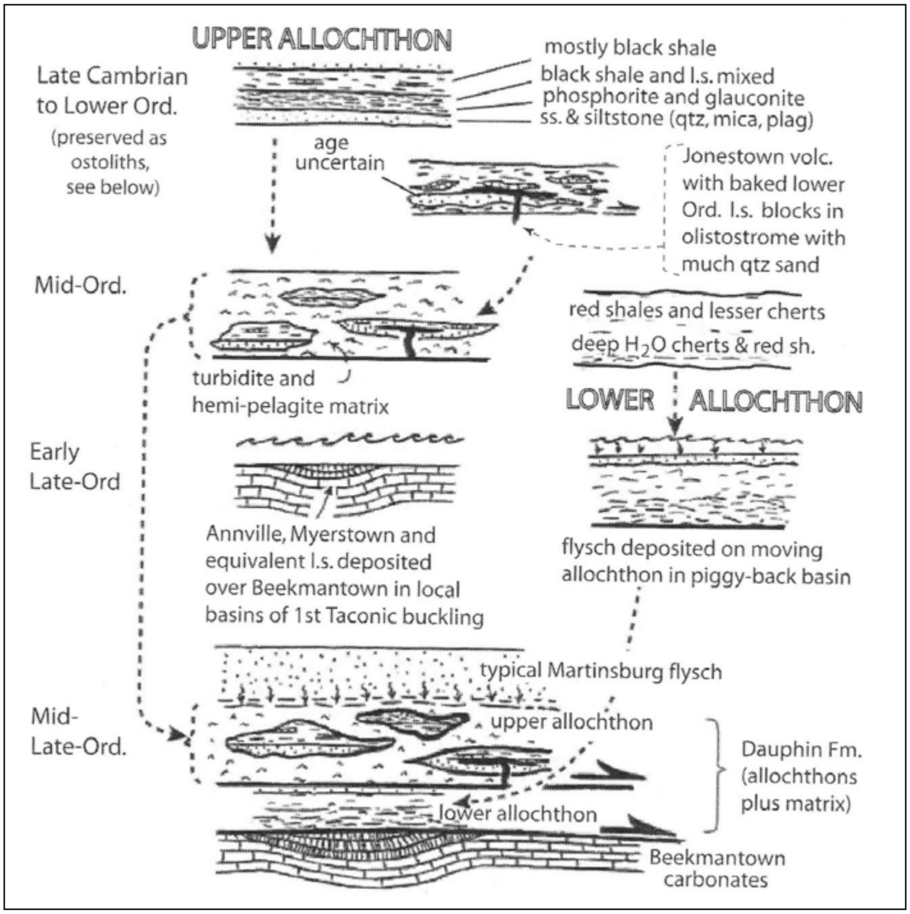

Figure 3. Assembly of allochthons within allochthons of the Martinsburg/Dauphin foreland. *Read top to bottom. Pre-Taconic Late Cambrian and Early Ordovician deep-water units became allochthons embedded in Middle Ordovician deep-water, offshore clastic matrices. These were moved onto and across the Early to Middle Ordovician platform, some picking up piggyback cover enroute, and were finally emplaced as the two contrasting, major allochthonous sheets comprising this area's Dauphin Formation. After final emplacement, the sheets were covered by thick Martinsburg flysch. (from Ganis and Wise, 2008)*

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STOP #11: GABLES TRUCK STOP – MANADA HILL MEMBER AND LINGLESTOWN FORMATION

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Gale C. Blackmer, Pennsylvania Geological Survey

Location: Gables truck stop is on the north side of Route 39 (Linglestown Road), second truck stop west of the Manada Hill interchange of Interstate 81. Proceed to the extreme back of the parking lot for Stop 11A. Stop 11B is toward the entrance, on the Route 39 side of the scales (Figure 1).

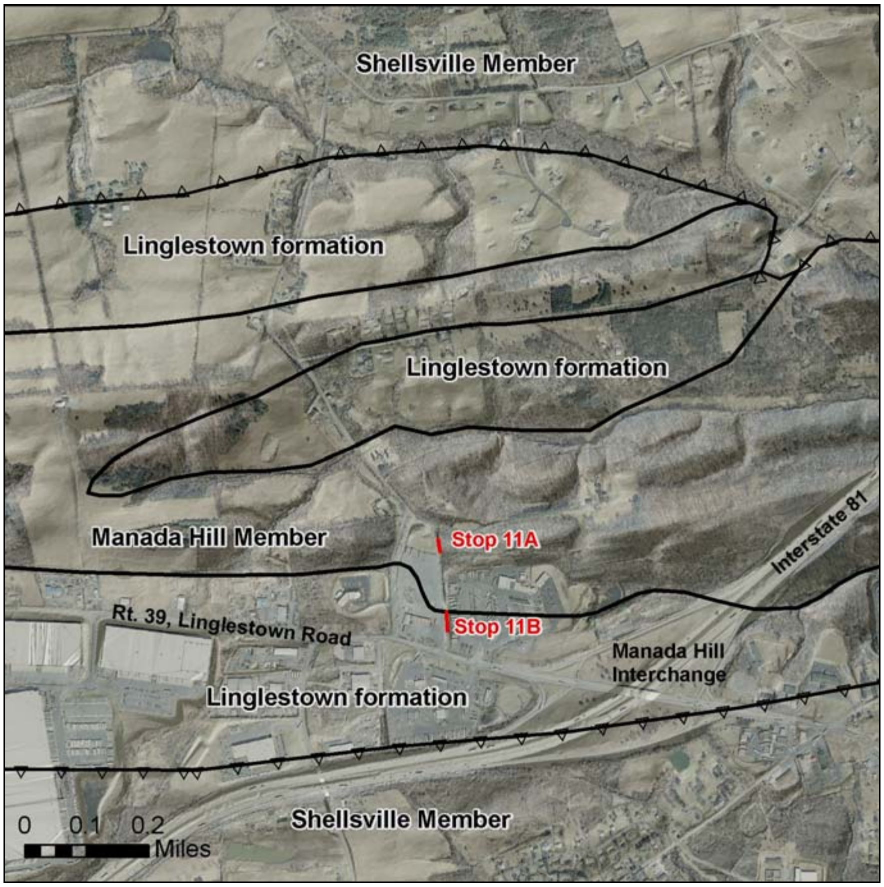


Figure 1. Geologic map of the Stop 11 area. *The Manada Hill Member (allochthon; Stop 11A) is in the core of the Dauphin anticlinorium, overlain in depositional contact by the Linglestown formation (piggyback basin; Stop 11B). The Linglestown formation also occurs in a parasitic infold in the axial zone of the anticlinorium. The Shellsville Member overlies the Linglestown-Manada Hill package on a gravity thrust. Base is PAMAP image over lidar-derived hillshade.*

Stop 11A. The cut at the back of the parking lot at the Gables truck stop exposes steeply dipping red/tan shales interbedded with radiolarian cherts of the Manada Hill Member of the Dauphin Formation. Conodonts found on the shale surfaces are the same age as the matrix of the Shellsville Member olistostrome viewed at the last stop (462-463 Ma). We can therefore infer that the olistostrome complex that formed in the trench had a more distal oceanic facies where these pelagic rocks were deposited. Like that from the Shellsville Member, the conodont fauna from the Manada Hill Member indicates a significant oceanic barrier between the depositional basin and Laurentia.

Ganis, G.R. and G.C. Blackmer (2010) Stop #11: Gables Truck Stop – Manada Hill Member and Linglestown formation, *in* Wise, D.U and Gary M Fleeger, eds., Tectonics of the Pennsylvania Piedmont along the Susquehanna River, 75th Annual Field Conference of Pennsylvania Geologists, Lancaster, PA, p. 91 – 92.

A question to ponder is whether these red shales are the unmetamorphosed equivalents of the Cocalico purple phyllites.

The geologic map in the guidebook indicates our location in the lowest exposed unit near the axis of a large-scale anticlinorium, overturned to the north (Figure 2). This unit can be traced across most of Dauphin and Lebanon counties at the same structural level. It would appear that the Manada Hill Member represents a very large-scale, fairly coherent allochthon. Structural indications are that it is the lowest and earliest-emplaced allochthon in the Dauphin Formation. The subsided carbonate bank is below at some undetermined depth.

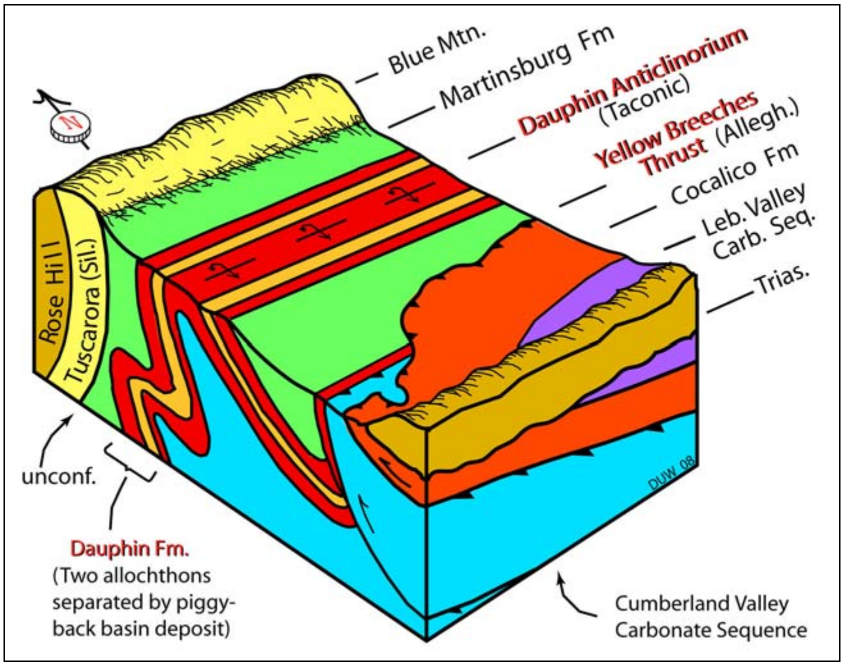


Figure 2. Cartoon block diagram of the Great Valley in Dauphin County. *Early in the Taconic orogeny, the allochthons of the Dauphin Formation were emplaced over platform carbonates on gravity thrusts, and covered by the Martinsburg Formation foreland fill. The whole stack was further folded and faulted during the later Taconic and Alleghanian orogenies. The Cocalico arrived during the Alleghenian orogeny on the Yellow Breeches thrust.*

Stop 11B. Closer to the entrance to the truck stop parking lot, near the truck scale (Figure 1), is a shallow cut which exposes the uppermost beds of the red/tan shale with a sharp break to overlying turbidites. The contact is interpreted as depositional, as there is no indication of structural discordance. The turbidites are two graptolite zones younger than the Manada Hill Member and are interpreted as syntectonic “piggyback” sediments that accumulated as the allochthon moved slowly from its original site to its new position in the foreland basin. We have informally named this unit the Linglestown formation. The piggyback basin dates the transport of the allochthon (459-460 Ma), which is the same age as the platform to foreland transition marked by the Myerstown Formation (458-461 Ma). Thus it appears that as the incoming allochthons impinged on the continental margin, the platform subsided to form the Myerstown basin. The allochthons then moved into the basin over the Myerstown Formation, leading to further subsidence.

The geologic map and the cross-section in Figure 2 show that the olistostrome and turbidite complex (Shellsville and Nyes Road Members) is a second allochthonous emplacement above the piggyback basin. The entire allochthonous sequence was covered by Martinsburg Formation foreland fill.

STOP #12: CANAL ROAD – MARTINSBURG FORMATION AND NYES ROAD MEMBER OF THE DAUPHIN FORMATION

G. Robert Ganis, Consulting Geologist
Gale C. Blackmer, Pennsylvania Geological Survey

Location: Canal Road south of bridge over Manada Creek, at the Pennsylvania American Water Co. treatment facility (Figure 1). Park on the wide shoulder north of the treatment ponds.

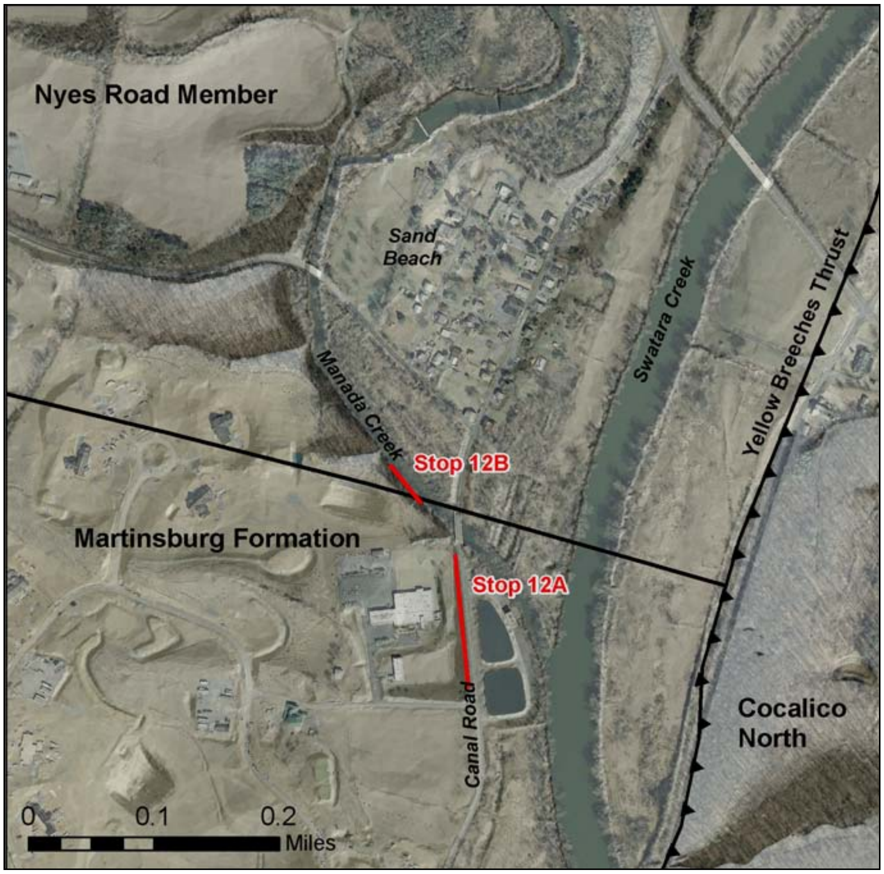


Figure 1. Geologic map of the Stop 12 area. *The Martinsburg Formation is in depositional contact above the Nyes Road Member of the Dauphin Formation. The Cocalico North overrides both units on the very low-angle (at this location, at least) Yellow Breeches thrust. Base is PAMAP image over lidar-derived hillshade.*

Stop 12A: The high bank along Canal Road is a typical Martinsburg shale exposure. You can see from the geologic map that we are on the upright limb of the anticlinorium that occupies the Great Valley, with a companion inverted limb forming an outcrop belt of Martinsburg on the north. In this limb, the Martinsburg is uniformly south-dipping. The Martinsburg forms a "blanket" cover over the Dauphin Formation, with a large continuous outcrop belt across southern Dauphin and Lebanon counties. Graptolite ages from the Martinsburg Formation are uniformly younger (450-455 Ma) than those in the Dauphin Formation.

The Martinsburg foreland fill, therefore, covers the allochthons of the Dauphin Formation. This model stands in stark contrast to the Hamburg klippe model proposed by Stose (1946) of a great allochthon covering the Martinsburg. Although it cannot be seen here, at some places near the base

Ganis, G.R. and G.C. Blackmer (2010) Stop #12: Canal Road – Martinsburg Formation and Nyes Road Member of the Dauphin Formation, *in* Wise, D.U and Gary M Fleeger, eds., Tectonics of the Pennsylvania Piedmont along the Susquehanna River, 75th Annual Field Conference of Pennsylvania Geologists, Lancaster, PA, p. 93 – 94.

of the Martinsburg, boulder-sized fragments of Lower Ordovician conodont-bearing limestone conglomerate, clastic conglomerate, and graywacke can be found in a wildflysch of graptolite-bearing Martinsburg shale. These are fragments of Dauphin Formation and up-scraped shelf carbonates.

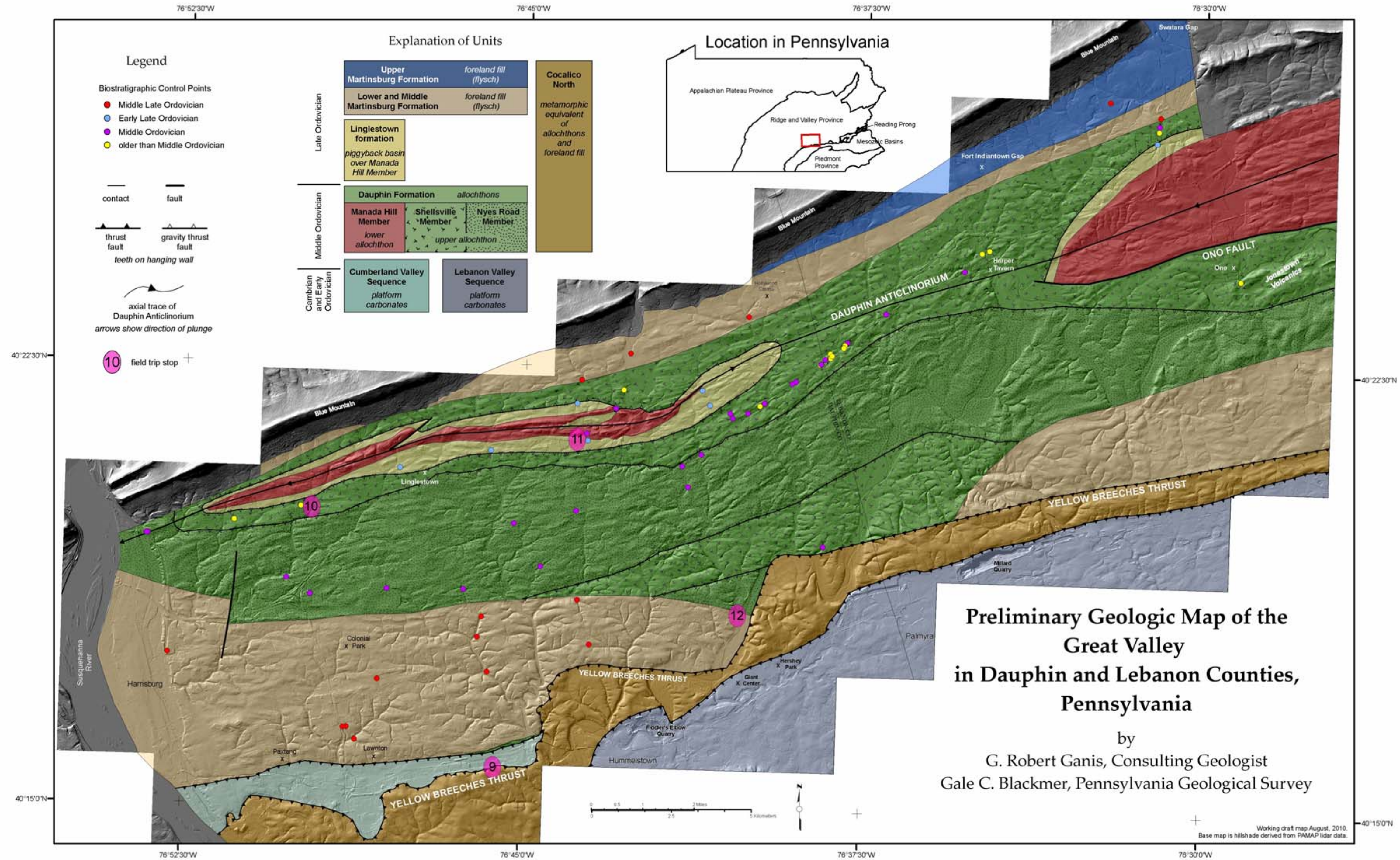
The places where Martinsburg age graptolite fossils, and some shelly fossils as well, have been recovered from these fold limbs are shown on the geologic map. A well-developed cleavage formed at a high angle to the bedding has ruined the chances of recovering graptolites from this outcrop.

Stop 12B: The contact of the Martinsburg cover over the Dauphin Formation allochthons can be seen to the north, along the high bank of Manada Creek. Walk across the bridge and scramble down to the creek on the east side of the road. Follow the faint path to a ruined building. The outcrops are visible across the creek (wadeable under most conditions with whatever you consider to be proper footwear).

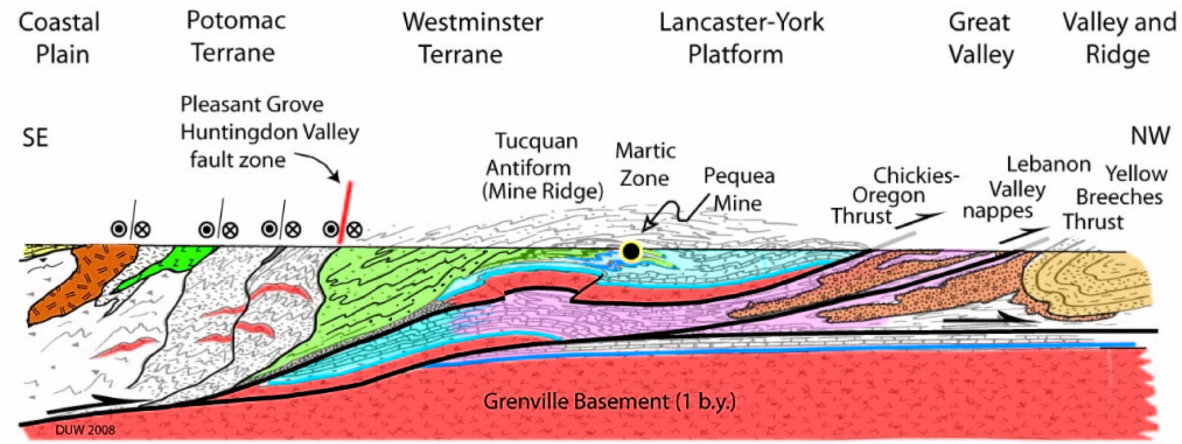
The formation change is subtle, from brown-gray, rather uniform Martinsburg shale to turbidites of the Nyes Road Member of the Dauphin Formation containing massive graywackes that stand out as resistant beds. This turbidite sequence is widespread and easily traced. It has been dated at numerous locations as the same age as the matrix of the Shellsville Member olistostrome seen at Stop 10. The sedimentological model for the allochthonous sequence involves a ramp into a trench where slumping hemipelagic mud accumulates, mixing with tectonically delivered olistolith fragments (Shellsville Member). The ramp is cut by submarine channels that exit into submarine fans, forming turbidite deposits (Nyes Road Member). The fans can flow well out into deeper water and sit. During the quiet periods between turbidite events, the tops of the fans accumulate red ooze, now seen as red shale and chert horizons a few feet to a few hundred feet thick within the turbidites. Even more distal into pelagic depths, a much thicker red ooze accumulates (Manada Hill Member).

Reference

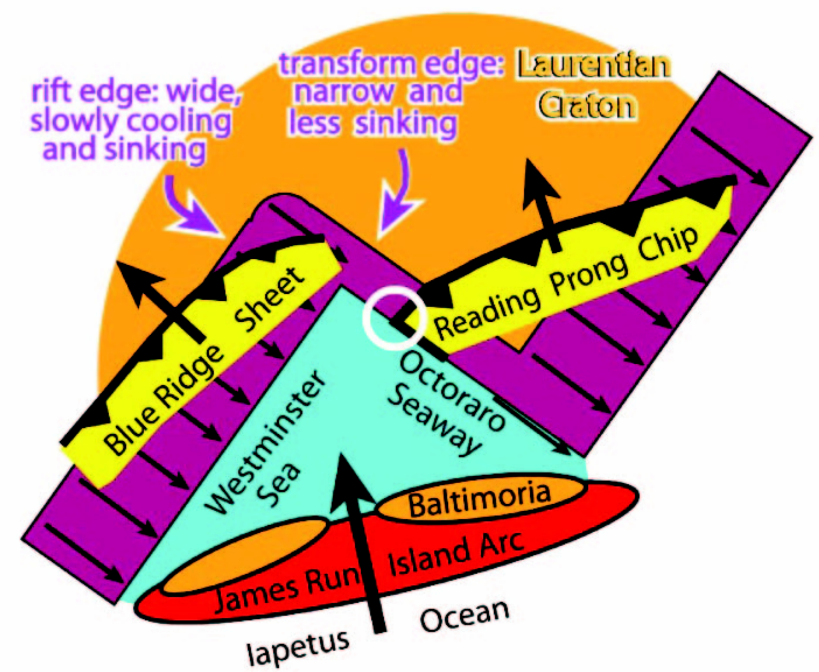
Stose, G. W., 1946, The Taconic sequence in Pennsylvania, American Journal of Science, v. 244, p. 665-696.



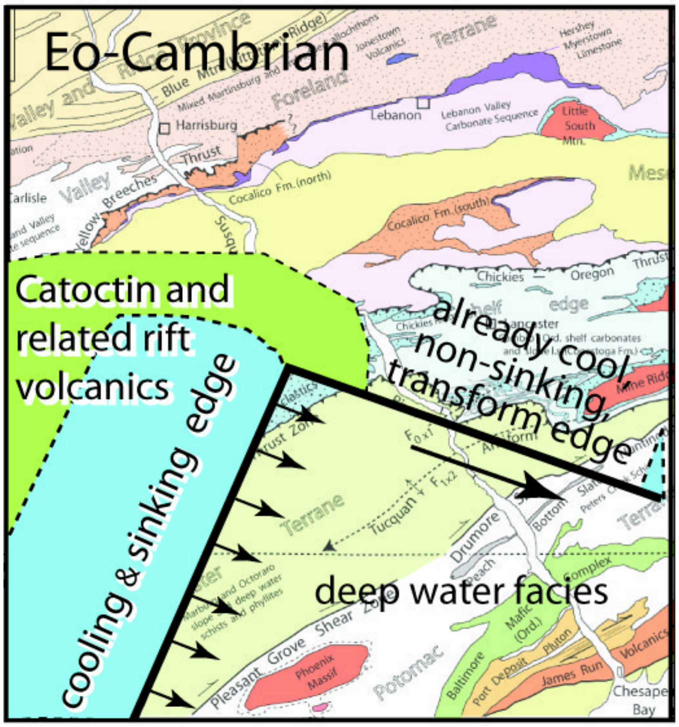
Preliminary Geologic Map of the Great Valley in Dauphin and Lebanon Counties, Pennsylvania
by
G. Robert Ganis, Consulting Geologist
Gale C. Blackmer, Pennsylvania Geological Survey
Legend
Biostratigraphic Control Points
Middle Late Ordovician
Early Late Ordovician
Middle Ordovician
older than Middle Ordovician
contact
fault
thrust fault
gravity thrust fault
teeth on hanging wall
axial trace of Dauphin Anticlinorium
arrows show direction of plunge
field trip stop
Explanation of Units
Late Ordovician
Upper Martinsburg Formation
foreland fill (flysch)
Lower and Middle Martinsburg Formation
foreland fill (flysch)
Linglestown formation
piggyback basin over Manada Hill Member
Cocalico North
metamorphic equivalent of allochthons and foreland fill
Middle Ordovician
Dauphin Formation
allochthons
Manada Hill Member
lower allochthon
Shellsville Member
Nyes Road Member
upper allochthon
Cambrian and Early Ordovician
Cumberland Valley Sequence
platform carbonates
Lebanon Valley Sequence
platform carbonates
Location in Pennsylvania
Appalachian Plateau Province
Ridge and Valley Province
Reading Prong
Mesozoic Basins
Piedmont Province
76°52'30"W
76°45'0"W
76°37'30"W
76°30'0"W
40°22'30"N
40°15'0"N
Blue Mountain
Swatara Gap
Fort Indiantown Gap
Harper Tavern
ONO FAULT
Ono
Jonestown Volcanics
DAUPHIN ANTICLINORIUM
Linglestown
YELLOW BREECHES THRUST
Millard Quarry
Palmyra
Hershey Park
Giant Center
Fiddler's Elbow Quarry
Hummelstown
Colonial Park
Harrisburg
Susquehanna River
Paxtang
Lawnton
10
11
12
9
Working draft map August, 2010.
Base map is hillshade derived from PAMAP lidar data.

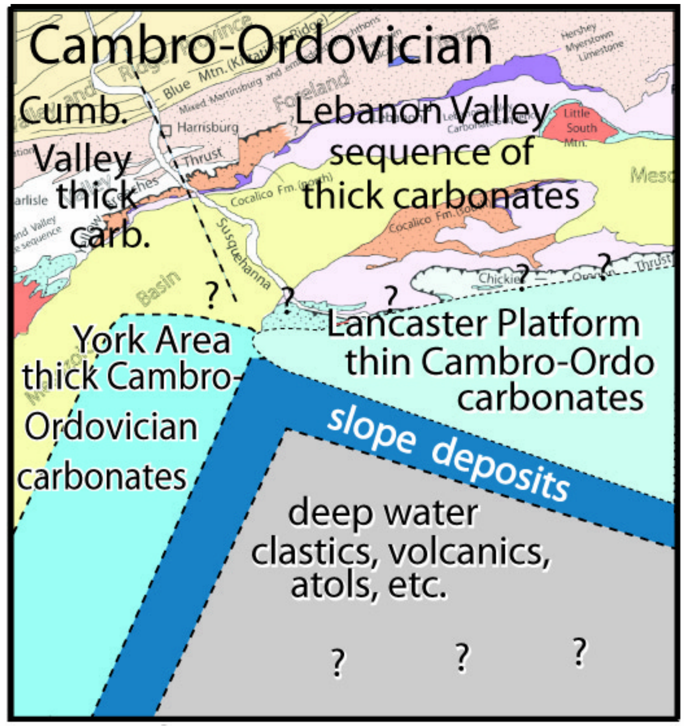


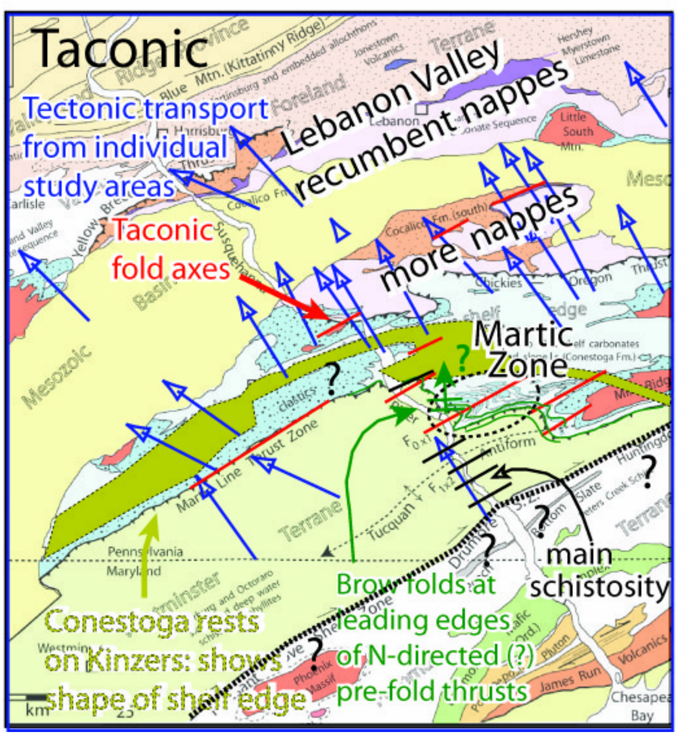
Schematic cross-section just east of the Susquehanna River (2008 version)

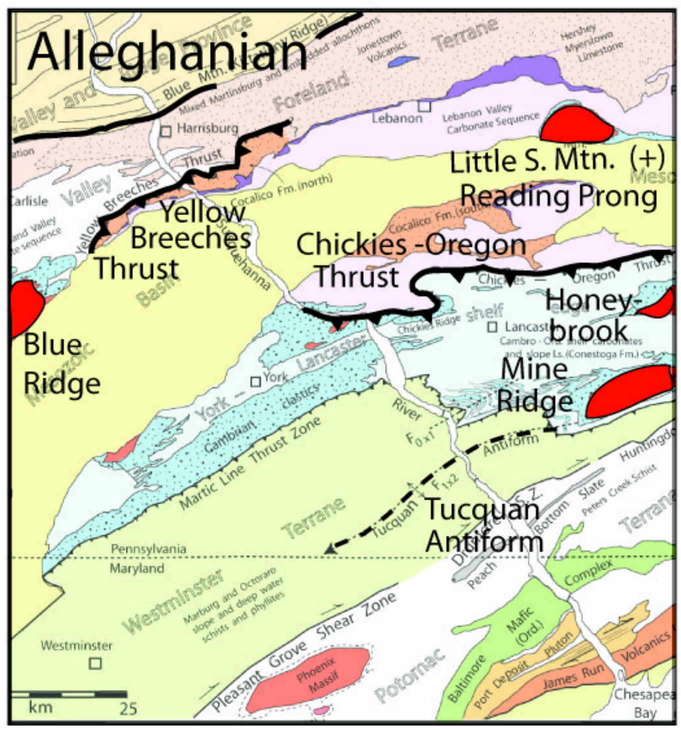


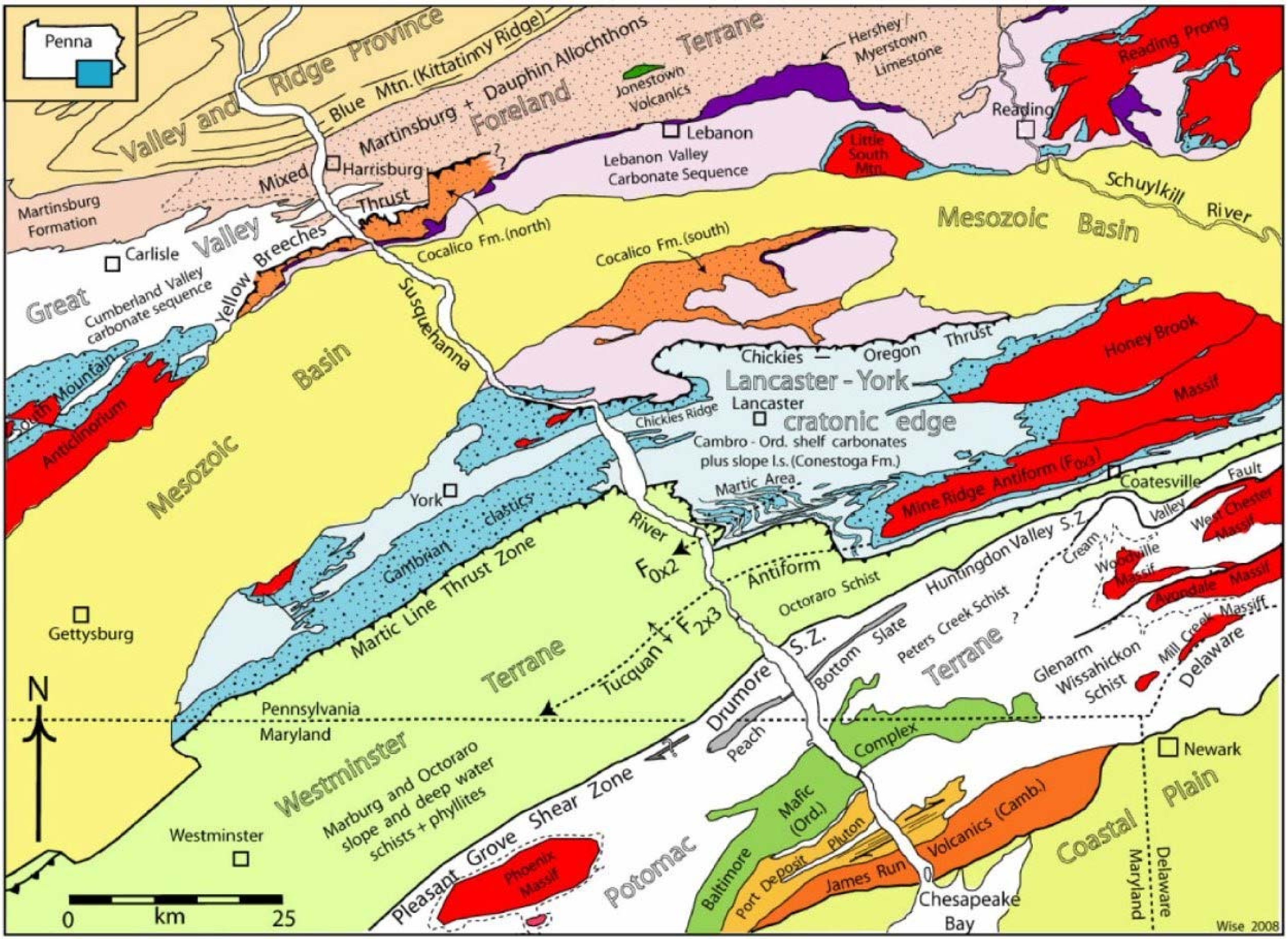
The York Transform Corner with several associated tectonic elements


Eo-Cambrian
Catoctin and related rift volcanics
cooling & sinking edge
already cool, non-sinking, transform edge
deep water facies


Cambro-Ordovician
Cumb. Valley thick carb.
Lebanon Valley sequence of thick carbonates
York Area thick Cambro-Ordovician carbonates
Lancaster Platform thin Cambro-Ordo carbonates
slope deposits
deep water clastics, volcanics, atols, etc.


Taconic
Tectonic transport from individual study areas
Lebanon Valley recumbent nappes
Taconic fold axes
more nappes
Martic Zone
main schistosity
Brow folds at leading edges of N-directed (?) pre-fold thrusts
Conestoga rests on Kinzers: shows shape of shelf edge


Alleghanian
Little S. Mtn. (+)
Reading Prong
Yellow Breeches Thrust
Chickies -Oregon Thrust
Honey-brook
Blue Ridge
Mine Ridge
Tucquan Antiform



Lithotectonic Map of the Susquehanna Piedmont