ROADLOG AND STOP DESCRIPTIONS - DAY 1

Mileage

Inc Cum DESCRIPTION
0.0 0.0 Leave parking lot of Holiday Inn. TURN LEFT onto Greenfield Road. In about 200 feet TURN LEFT to US Route 30 West.
0.2 0.2 Join US Route 30 West.
0.8 1.0 EXIT RIGHT to PA Route 23 West and Walnut Street.
0.4 1.4 Park on berm beyond the underpass but before the exit ramp.

STOP 1. ROAD CUT IN LEDGER DOLOMITE ON PA ROUTE 23 WEST AT ITS INTERCHANGE WITH US ROUTE 30.
Discussant: D. B. MacLachlan

The stop is located at the southwest end of a cut 1200+ feet long (Figure 59) which is probably the best, easily accessible exposure of the Ledger Dolomite in Lancaster County. The more northeasterly portions of the cut differ significantly in mesoscopic lithology from the rocks we will examine only by apparent absence of the primary structure we will observe and increasingly more massive bedding.

Figure 59. Geologic and location map for Stops 1 and 2. Collapse scar is defined by the mapped geology. Letters refer to specific features mentioned in the text. Geology is from Meisler and Becher (1971).

Oölites have previously been reported from the Ledger in York County in thin sections, but this station is the only place I know where they may be observed in outcrop. They are not conspicuous in this substantially recrystallized rock, but once your eye catches them you will recognize they occupy a considerable volume of the rock. The beds here are exceptionally thin for the Ledger in this area and a thin shale bed (very uncharacteristic of the Ledger in general) may be observed not far east of the beds to which your attention will first be
directed. It is reasonable to suppose that these relatively thinoolitic beds are on the foreslope of the prograding bank edge, but there appears to be little difference in dip between these beds and the more massive beds to the northeast. If a primary foreslope existed here, it was apparently very gentle.

The rocks here are also interesting because they lie barely more than 1000 feet east of a circular embayment projecting northward from the general trend of the Ledger/Conestoga contact in this area. The latter is approximately represented by the more-or-less east-west line near the southern margin of the map. This embayment is in part occupied by proximal Conestoga bank-edge collapse breccias whose clasts must derive at least in part from rocks similar to those exposed in this area. There is a difference however. The breccia clasts, though well recrystallized (regionally, biotite grade middle greenschist facies - inferentially from fairly remote radiometric determinations, the product of Taconic loading), are not dolomitized. This suggests that the Ledger dolomitization was not early in its diagenesis.

While a variety of conglomerates with presumably bank carbonate clasts are known in the proximal Conestoga, and some even extend down slope sufficiently to be associated with mid slope calcisiltites(?) with thin shale partings, the breccias are rare; and rudites generally comprise a small percentage even of the proximal rocks. The circular embayment is best interpreted as the scar left by a bank-edge slump. The thin belt of Ledger closing the southern side of the embayment shown by Meisler and Becher (1971) is inherited from Jonas and Stose (1930) - but they assign inferred contact lines only. This is consistent with the policy they adopted elsewhere in the map area of retaining features of the older map where they were not contradicted by data acquired during the remapping even if they could not be fully confirmed. The extent to which they have remapped the main contact both immediately east and west of this problematical area suggest that the original mapping is not very reliable in this vicinity. Meisler and Becher show an exposure in the middle of this interval (A on Figure 59), but the 75° dip seems anomalously steep, and it is possible the determination was made on a large collapse block. The question is unlikely to be resolved without drilling in the area.

If original interpretation, retained by Meisler and Becher, is correct, the overall geometry suggests that the youngest Ledger prograded over its own debris. Supposing this to be the case, the conglomerates at the Lancaster waterworks, supposed by Stose and Jonas (1923; the paper recognized by the U. S. Geological Survey as formal definition of the Conestoga), to be basal conglomerate of an unconformably overlapping Ordovician unit, and used by them as substantial evidence of the unconformity, would in fact lie beneath the youngest Ledger.

Additional information is given here about other places indicated on Figure 59. (B) Best exposed on the northwest side of the cut adjoining the barricade at the end of the pavement is a substantial anticlinal hinge in massive dolomite beds. All rocks previously observed in the cut appear to be in the south limb of this structure.

(C) Approximately half way (direct) from Stop 1 to the Conestoga River bridge in the immediate vicinity of a large drainage grate on northwest side of road. Some spoils of dark gray yellowish brown weathering dolomite which appear to come from the Zooks Corner Fm. and may well have been excavated from the drain. The distance from B to C is only slightly less than the distance from B to the Zooks Corner Formation near the north edge of the map, and this may in fact represent Zooks Corner in situ on the south limb of the anticline. In any case I believe some of the smaller dark clasts in the breccia may be derived from that formation.

(D) Beginning less than 100 feet southwest of the Conestoga River bridge and extending into the curve, a rock cut 3 to 5 feet high, now covered, was present on the northwest side of the highway during construction. A total thickness of about 100 feet of medium to thick bedded Conestoga Limestone without apparent allochthonous clasts was exposed. The road is essentially parallel and very close to the Ledger/Conestoga contact. The exposure unequivocally demonstrated that the breccia is not a basal phase of the Conestoga.

**LEAVE STOP 1. CONTINUE STRAIGHT AHEAD** on PA Route 23 West.

- **0.6 2.0** STOP LIGHT. TURN RIGHT onto Pleasure Road (unmarked). At this point the highway is located on a substantial fill which covers the original Lancaster waterworks which was located entirely on the west side of the river. Aerial photographs from 1969 show the filtration beds located on
the east side but structures, perhaps including the main pump house, were still present on the west side. The present pump house just upstream from the intake dam on the east side is obviously a quite recent structure. Several hundred yards down the river is the stone railway bridge built of shaly banded Conestoga obtained from a quarry west of Pleasure Road in the neighborhood of Stop 2. The "basal limestone conglomerate of the Conestoga Limestone at the Lancaster waterworks" (Stose and Jonas, 1923; Jonas and Stose, 1930) was formerly observed along the old road west of the river from approximately this point to E on Figure 59, but it has been entirely concealed by the new highway.

0.1 2.1 Park off berm before entrance to Deer Ford Drive.

STOP 2. CONESTOGA FORMATION BANK-BREAKDOWN BRECCIA AT SOUTH GATE, DEER FORD DEVELOPMENT.

Discussant: D. B. MacLachlan

Please leave all hammers on the bus. The managers of Deer Ford have created for your pleasure a display of the Conestoga breccia, for which they have been duly nominated for honorary membership in the Friends of Funny Rocks. I doubt, however, that they would appreciate that geovandalism was more justifiable than any other kind. A camera is, in any case, a more effective tool for collecting the kind of features that may be observed here. Those who doubt my assertion that the clasts are, at least almost, entirely calcareous although all visible probable sources are now dolomitic may use their acid bottles with impunity.

The parent ledge, from which at least some of the boulders displayed below derive, appears about 100 feet up the drive. Those interested in secondary phenomena should note the flowstone developed in an open fracture breached at the lower end of the cut. This cut is apparently fairly recent, but the occurrence of the breccia here was known to the operators of the Stoner quarry (behind the fence across Pleasure Road) in the early 1930's, then a 400-500 ton per day crushed stone operation (Miller, 1934). They expressed an intent to operate here (for ornamental stone?) and may have subsequently removed some stone from the steep bank behind the Deer Ford sign. Those with a limited tolerance for funny rocks who wish to see something more mundane may walk up the drive to the west and peer through the fence for a fairly good view of rather ordinary, but very thick bedded, Conestoga displaying some structure.

No other breccia has been observed in situ, but boulders are fairly common east of Pleasure Road to the north gate of the Deer Ford development with the westernmost occurrences in that area close to point F on Figure 59. I had assumed that the old quarry north of the Lancaster waterworks mentioned and photographed by Jonas and Stose in their description of the Conestoga Limestone was close to the waterworks and was now concealed. Subsequent examination of 1969 aerial photographs suggest that it is located on the north flank of the tongue of Ledger shown about 800 feet north of this stop. It is not apparent from the road and was not sought, but it is possible that some vestige of the original exposure may still be found there.

The Conestoga Traction Company quarry west of Pleasure Road was also recorded as a sporadically active crushed stone producer in the 1930's. If this pit is correctly located on the quarry map of Jonas and Stose, it is now entirely concealed under an obvious thick fill below the parking lot at the south corner of New Holland Avenue and Pleasure Road. This location may be inaccurate, however, as a smaller pit just over 100 yards north of the Stoner quarry and within the enclosure (not seen) is apparent on the aerial photograph, and it seems to fit the original description of the CTC quarry. The CTC pit was apparently first opened by the Pennsylvania Railroad to provide masonry stone for the bridge south of the waterworks, and some other railway structures and retaining walls in the Lancaster area.

LEAVE STOP 2. CONTINUE STRAIGHT AHEAD following Pleasure Road.

0.4 2.5 STOP LIGHT. TURN RIGHT onto New Holland Road.
0.2 2.7 STOP LIGHT. TURN RIGHT onto US Route 30 East.
3.2 5.9 The next three miles of US Route 30 is very commercially developed in response
to tourism interest in the Amish way of life. One does not see the real Amish countryside on this road. Secondary roads on either side of US Route 30 provide a realistic view of Amish farms. The geology between Stops 2 and 3 is by no means uninteresting, but except for a few gross topographic features, it is >99.44 percent invisible from the highway.

2.6 8.5 Stop light. PA Route 896 crosses US Route 30. CONTINUE STRAIGHT AHEAD.
1.5 10.0 Ronks is to the left.
1.8 11.8 Now in Paradise (PA).
3.0 14.8 Village of Vintage (PA).
0.6 15.4 Type locality of the Vintage Formation is in the railroad on the right.
0.4 15.8 Village of Kinzers.
0.8 16.6 Good view ahead and right of the north flank of Mine Ridge. Mine Ridge is underlain by Grenvillian gneiss overlain by Chilhowee sandstone.
1.5 18.1 Intersection of US Route 30 and PA Route 41. Gap is on the right. The Gap Nickel Mine is located 6.5 km SW of the town of Gap or about 400 m SW of the village of Nickel Mines. The deposit was known prior to 1720 and Benjamin Franklin tinkered with the copper-bearing water. Friedrich August Ludwig Karl Wilhelm Genth, Chief Chemist and Mineralogist of the Second Pennsylvania Geological Survey and a man of probable German descent, determined the important metallic component of the ore was nickel. Significant production was mainly in the latter half of the 19th century under the direction of Joseph Wharton.

Rose (1970) estimated production at 3,600 metric tons of nickel, about 60 tons of cobalt, and lesser amounts of copper. Present reserves are reported to be 240,000 metric tons of "ore" containing 1.1% Ni and 0.7% Cu. The deposit may be of the Sudbury, Ontario, immiscible sulfide type. It occurs in a 600 m long by 200 m wide body of mafic to ultramafic rock. The main ore minerals were primary pentlandite and chalcopyrite and secondary millerite.

Analyses of a fresh rock intended to be barren (GAPNIB) and one containing very lean disseminated mineralization (GAPNID) yielded:

0.7 18.8 Starting to climb up the north flank of Mine Ridge.
1.1 19.9 Now on top of Mine Ridge. Note the general lack of outcrop.
3.1 23.0 Stop light. PA Route 10 crosses US Route 30.
13.0 36.0 EXIT RIGHT to PA Route 113.
0.1 36.1 STOP SIGN. TURN RIGHT onto PA Route 113 South.
0.6 36.7 STOP LIGHT. TURN LEFT onto US Route 30 Business East.
1.3 38.0 STOP LIGHT. TURN RIGHT onto Quarry Road.
0.6 38.6 TURN RIGHT into quarry entrance. Quarry office is ahead on left where permission to visit the quarry must be obtained.

STOP 3. GENERAL CRUSHED STONE COMPANY, DOWNINGTOWN QUARRY; LEDGER, ZOOKS CORNER, AND HENDERSON MARBLE FORMATIONS.

Discusssant: D. B. MacLachlan

NOTE: Hard hats are required for anyone approaching the quarry wall.

This stop is located in the newer and smaller west pit of the General Crushed Stone Downingtown Quarry. Attention will be directed to some features in the south wall in the neighborhood of the debarkation point; but the primary focus will be the section exposed in the west wall. A somewhat longer composite section including more of the upper and lower units could (theoretically - the high wall above the "accessible" Ledger is a nearly sheer 300+ feet) be assembled in the east quarry, but this is the longest, best, and safest.
continuously accessible exposure on the property. Some additional variations in rocks here assigned to the Henderson Marble, including some lighter colored rocks which I consider more typical of this formation as a whole, can be observed on the south side of the east pit. A fairly complete comparable section may be established in this area, however, from the stripped area south of this pit and exposures along the railway spur and the Amtrack tracks (the latter are definitely not recommended for field trips).

By matching color bands across the quarry it becomes apparent that, unlike many quarries, the pit configuration is not determined by the bedrock structure. The average strike is about N65°E with little local variation with an average dip of about 70° SSE, while the north and west walls are aligned on the cardinal points and the east wall parallels the public road above with little more than the legal minimum spacing from the roadway. The constraining factor is obviously property lines, and it is a reflection of local real estate prices, and the value of the product in this area, for which this quarry is the principal supplier.

Property line configuration is more complex in the eastern quarry, but the same controlling parameter prevails, augmented by the construction of the new US Route 30 bypass which largely precludes expansion even by property acquisition. The south margin of both pits, especially as delimited by areas where extraction has been conducted on more than one level, is less regular. Geology will have its way, willy-nilly. The answer is most readily apparent in the large spoil pile that has been built south of the rail spur at the eastern end of the quarry property in recent years. There it may be observed that, although the rock exposed in the quarry is predominantly dolomite, the spoils are predominantly limestone, which I suppose does not meet some major customer specification - I surmise the PENDING class A aggregate standard. The spoils rock appears to be suitable for many ordinary limestone uses and I would certainly start here if I were in the market for cheap rip-rap in this area.

Northward expansion of these quarries is limited not only by the cultural features previously noted, but also by the Exton shear fault. This fault subtly affects the structure in this quarry, and it lies so close to the western end of the east quarry that the berm there is constructed mainly from Conestoga (which appears on the north side of the fault) excavated from shallow pits on the north side of the berm.

In a regional context, the section north of the quarry area, from the southern edge of the Honey Brook upland to the Exton fault differs little from a standard Lancaster County section (Ledger to Conestoga version) as described by Stose and Jonas (1922). The dip decreases from over 50° in the Chilhowee to about 20° near the fault, where there is a major discontinuity in structural attitude as well as the lithic sequences that appear on either side. The northern Ledger is (inevitably) poorly exposed and is either exceptionally thick or conceals an anticline of moderate proportions. The "Gap overthrust" of Bascom and Stose (1938) lies at the south edge of the northern Chilhowee belt exposed in this quadrangle. The Exton fault offsets the south edge of the upland near the western margin of the Downingtown quadrangle and may project into the fault at Gap (Bliss and Jonas, 1929). This "Gap" in interpretation is briefly addressed elsewhere in this guidebook. The section exposed at this stop is rather like that prevailing in the eastern Chester and White Marsh Valleys, though the Henderson Marble is more extensive there. In this area, the southern limit of the eastern sequence is defined by the Coatesville shear, which may be precisely located under the Amtrack bridge on Boot Road about 1200 feet south of the quarry south wall. The Coatesville fault passes just south of Stop 4, where the impress of its shearing on Henderson Marble more typical than you will observe here will be demonstrated. To the west this fault apparently merges into the Chilhowee contact northwest of Coatesville. The quarry area may thus be in the same late structural block as Mine Ridge, which D. U. Wise proclaimed three decades ago had "popped up like a railroad tie" late in the deformational sequence. The facies relations here require a somewhat more complex movement plan, but the relationships are not otherwise inconsistent. A thin belt of Conestoga appears in the Boot Road vicinity and is bounded on the south by the South Valley shear, which is believed to be the parent of both of the previously mentioned shears, and the Octoraro phyllite of the South Valley Hills. This belt widens westward until it embraces the full width of the Chester Valley west of Coatesville.

Viewed from across the quarry, the quarry appears to be a simple homocline with predominantly very thick beds distinguishable by color variation. Closer examination will show that the majority of these units have a thin to medium parting, are frequently laminated, and the laminae may show small, bed-parallel isoclines. Particularly competent dolomite beds
are not infrequently necked and are occasionally stretched to rupture. The orientation of the stretching is not easily determined in these vertical exposures. A more striking example that the deformation here is considerably more complex than one might first suppose is to be found in a steeply plunging tight fold located about 200 feet north of the point where the bench is blocked to vehicular access. Even when I know where to look I cannot spot this feature from across the quarry. This deformation is believed to result from transpressional shearing between the major bounding shears with a more or less vertical component of extension due to flattening. The deformation is believed to be related to the retrograde chlorite-grade metamorphism (or vice versa) of apparent Late Paleozoic age.

The chemical analyses (Table 12), except for the only full (major element) analysis I have for the Zooks Corner Formation in certifiable strike continuity with the Lancaster type section, are from the east quarry. The analyses were made in 1960 and 1961 apparently during a major development phase by a prior operator. The present quarry superintendent said he did not even know they existed, much less how these zones were distributed in the quarry. Apart from these facts all that is presently known about these analyses is the appended summary. If the presumption is made, however, that sampling zone width was controlled by the appearance of the interval sampled and not arbitrary equal width units, that information taken at face value provides a good correlation with the lithic units I have proposed in this area. If the 1700 feet of sampled interval (representing a stratigraphic section of just under 1600 feet) starts at the northern highwall at the west end of the east pit, then it extends just to the railway spur to the south. Northern zone is obvious Ledger with its characteristically near stochiometric dolomite. The insolubles are several times that of the stone most prized by the chemical and flux producers, but well within the range of hundreds of analyses of public

<table>
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<tr>
<th>CuCO₃</th>
<th>MgCO₃</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>R₂O₃</th>
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<td>2.1</td>
<td>47.9</td>
<td>33.6</td>
</tr>
</tbody>
</table>

Dowinton Quarry; sampling divided into 9 zones and covers a distance of about 1700 feet across the strike of the dolomites and limestones in the Chester Valley, results listed from north to south.

Zone 1

<table>
<thead>
<tr>
<th>Column 1</th>
<th>Column 2</th>
</tr>
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</table>
| Zone 1   | Analysis of limestone beds only from preceding zone.

J. C. Showalter, Inc.,
Blue Ball, Pa.

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record for this unit. The southern dolomite zone in fact crops along the railway spur south of interbedded carbonates exposed along the south side of the east quarry, but they project under cover south of the west pit. The ends of this section are apparently well anchored and we may attempt to relate the intervening compositions to the exposures in the west pit.

As you will be starting at the south end of the quarry it is appropriate to consider the table of analyses from the bottom upward. As previously noted, the last interval (9) projects under cover south of the rail spur here. Among the things concealed under that mess is an old quarry noted by Bascom and Stose (1938) which means they had some control here. It should be noted that the main quarry was opened after their mapping. If it had been open then they would have drawn a very different cross section across this area than the one they published, although I am uncertain what they would have made of the stratigraphy here. The southern contact of the Ledger as they mapped it in this area appears in this vicinity and may have been determined by some exposure of this interval. The interbedded zone (8) appears in part along the south wall (also for a bit along the east wall) of this pit and in the stripped area above it. The dark magnesian limestone occupying the south end of the west wall below obvious karst development, which is not apparent beneath the dolomites to the north, evidently represents zone (7). These three zones I assign to the Henderson Marble. The last, in particular, does not look much like rocks I consider typical of this unit (which are better represented at Stop 4), but my experience suggests that the lithic contrast between this rock and the dolomites to the north is the type of feature which is most consistently mappable with poor exposure; and their is no obvious named unit to which it may be assigned in this apparently conformable sequence. I estimate an additional 500 feet of Henderson, predominantly white calcic marble, south of zone (9).

For mapping purposes, zones (6) up to (2) are included in the Zooks Corner Formation. The somewhat calcic dolomites here are a bit purer than the reference analysis from the Showalter Blue Ball quarry, but there is insufficient data to say how representative any are of the formation as a whole.Generally the lime/magnesia and silica/other insoluble ratios are similar and distinct from the Ledger analyses. Zone (5) does appear to converge in character with the Ledger and may represent rock I surmised might represent an upper tongue of this formation, but this is nothing I would attempt to map in the (general) absence of exposure of the quality displayed here. The Ledger of zone (1) is obvious enough at the north end of the west wall.

LEAVE STOP 3. TURN LEFT onto Quarry Road.

0.6 39.2 STOP LIGHT. TURN LEFT onto US Route 30 Business West.
1.2 40.4 STOP LIGHT. CONTINUE STRAIGHT AHEAD.
0.3 40.7 STOP LIGHT. CONTINUE STRAIGHT AHEAD.
0.2 40.9 STOP LIGHT. CONTINUE STRAIGHT AHEAD.
0.2 41.1 STOP LIGHT. CONTINUE STRAIGHT AHEAD.
0.2 41.3 STOP LIGHT. TURN LEFT onto Viaduct Avenue. Proceed through the underpass and follow road as it bears right.

0.3 41.6 CONTINUE STRAIGHT AHEAD toward gate in chain link fence on unmarked street.
0.1 41.7 Park in railroad yard.

STOP 4. HENDERSON MARBLE NEAR COATESVILLE SHEAR, ABANDONED QUARRY IN AMTRACK DOWNINGTON SERVICE YARD.

Discussant: D. B. MacLachlan

On examination, it will be recognized that much of the yard area lies on an old quarry floor cutting into the hill to the south and east. Miller (1934) mentions this in passing as "an old quarry in micaceous limestone". I know nothing of its history or use (possibly railway ballast?), but it is apparent that a considerable volume of stone was removed. By a traverse over the hill from the south, I estimate that the Coatesville shear lies < 100 feet and perhaps about 30 feet south of the south wall. Comparing the rock exposed in the east highwall with that to the south suggests, however, that this is only coincidental in the quarry development. It is clear that the target rock was limestone and the work stopped at the more dolomitic zone to the south. The Conestoga south of the shear has a strong subhorizontal lineation imposed on it, which can be most easily observed along the north edge.
of a parking lot near the swimming pool on the south side of the ridge.
We will proceed directly to the east wall to examine the evidence of shearing in these rocks, which I consider to be more representative of the Henderson Marble than those seen previously.

**LEAVE STOP 4. RETURN VIA THE SAME ROUTE** through the underpass to the stop light.
0.4 42.1 **STOP LIGHT. TURN RIGHT** onto US Route 30 Business East.
0.2 42.3 **STOP LIGHT. CONTINUE STRAIGHT AHEAD.**
0.2 42.5 **STOP LIGHT. CONTINUE STRAIGHT AHEAD.**
0.3 42.8 **STOP LIGHT. TURN LEFT** onto PA Route 113 North.
4.1 46.9 **Lionville. STOP LIGHT. TURN LEFT** onto PA Route 100 North.
0.3 47.2 **Sheree Boulevard.**
0.5 47.7 **Entrance to PA Turnpike.**
1.5 49.2 **TURN LEFT** onto Little Conestoga Road at the Eagle Tavern (on left).
0.2 49.4 **FLASHING YELLOW LIGHT. TURN LEFT** onto Park Road.
2.2 51.6 **Park in parking lot for picnic area in Marsh Creek State Park.**

**STOP 5. MARSH CREEK, BRANDYWINE CREEK, AND LUNCH.**
Discussant: William D. Sevon.

**INTRODUCTION**

Brandywine Creek drains 314 mi$^2$ of land in southeastern Pennsylvania and has a length of about 45 miles. The land surface is underlain by a diverse suite of sedimentary and metamorphic rocks. Marsh Creek is a major tributary to East Branch Brandywine Creek. The area of Marsh Creek not covered by the lake is typical of the floodplain areas of the drainage basin.

Brandywine Creek was the site of a significant study done by M. G. Wolman (1955). The abstract from the Professional Paper is repeated here in total. For those interested in the theoretical and practical aspects of equilibrium in natural streams, Wolman's discussion on "Equilibrium and the longitudinal profile" (p. 45-49) is worthwhile reading. An additional study of interest is that of Olmsted and Hely (1962) on the relation between groundwater and surface water within the drainage basin.

**ABSTRACT**

This study of the channel of Brandywine Creek, Pennsylvania, consists of three parts. The first is an analysis of the changes which take place in the width, depth, velocity, slope of the water surface, suspended load, and roughness factor with changing discharge below the bankfull stage at each of several widely separated cross sections of the channel. Expressed as functions of the discharge, it is found that the variables behave systematically. In every section studied, as the discharge increases, the velocity increases to about the 0.6 power, depth to the 0.4, and load to the 2.0 power of the discharge. The roughness decreases to the 0.2 power of the discharge. The relative magnitudes and the direction of these variations are similar to those which have been observed in other rivers in the United States, primarily in the West. Some modifications of the hypotheses applicable to the western rivers are probably required because on Brandywine Creek the difference between the materials on the bed and in the banks is considerably greater than it is on most of the western rivers studied.

In the second part of the paper the progressive changes of the same variable in the downstream direction with increasing discharge at a given frequency are described. Despite the disorderly appearance of the stream, it is found that the variables display a progressive, orderly change in the downstream direction when traced from the headwater tributaries through the trunk stream of Brandywine Creek. At a given frequency of flow, width increases with discharge to about the 0.5 power. Depth increases downstream somewhat less rapidly, while the slope and roughness both decrease in the downstream direction. Despite a decrease in the size of the material on the bed, both the mean velocity and the mean bed velocity increase downstream. The rates of change of these variable are in close accord with the changes observed on rivers flowing in alluvium and in stable irrigation canals. These relationships
hold for all flows up to the bankful stage. Analysis of the streamflow records indicates that
the annual maximum discharge equals or exceeds the bankfull stage roughly once every 2 years.

The regularity in the behavior of the variable with changing discharges both at-a-station
and in the downstream direction and the similar rates of change of the variables on Brandywine
Creek and in stable irrigation canals suggest the existence of a quasi-equilibrium in the
channel of the creek.

Part three of this study is concerned with this concept of equilibrium in streams. By
analogy with canals and with several rivers in diverse regions of the United States it may be
concluded that is quasi-equilibrium is closely related to the discharge, and to the
concentration of the suspended load. The shape and longitudinal profile of the channel are
determined by these two independent factors which operate within the limits set by the local
geology. The latter determines the initial size, shape, and resistance of the material
provided to the channel.

The existence of a quasi-equilibrium among the variables studied suggests that most
reaches on Brandywine Creek are at grade. This is true if the term "grade," when applied to
natural rivers, is synonymous with quasi-equilibrium. The adjustability of the variables in
the channel rather than the stability of any particular shape of longitudinal profile of the
channel is emphasized when the word "equilibrium" is applied to Brandywine Creek."

**DISCUSSION**

Of particular interest in Wolman's paper are his studies of the bed and bank materials.
Virtually everywhere within the basin, samples show that 50 percent of bed material is greater
than 1 inch in diameter. Limited thickness information indicates a range of at least 3 to 15
feet. In contrast, analyses indicate that 100 percent of bank material is less than 0.1 mm in
diameter. Wolman (p. 19) did not believe that he had sufficient information to adequately
discuss the origin of the floodplain. I would suggest that his statement reflects, to a large
extent, the state of knowledge at the time of his investigation, and, additionally, his focus
on stream process.

The coarse material comprising the bed seems to be relatively uniform wherever observed
during reconnaissance of the drainage basin. Not emphasized by Wolman, but very evident in
places where the valley is narrow and valley walls are close to the creek margins, are the
numerous boulders and blocks that occur in the stream bed and protrude above floodplain
sediments. There is no evidence that these large rocks are being moved at the present time.
In all probability they are artifacts of Pleistocene glacial intervals during which such
material was frequently dislodged by freeze-thaw from outcrops on the slopes and then moved by
gravity to lower slope positions. It is likely that most or all of the coarse material making
up the bed was eroded and deposited during the Pleistocene.

Subsequent to the last glacial interval, climate warmed, forest vegetation covered the
landscape, and relatively little material was eroded within the drainage basin and then
deposited on the floodplain. When the area was settled by Europeans, the land was cleared and
cultivated and the amount of erosion was severe (Trimble, 1974). Much, if not most, of the
eroded topsoil was deposited either in alluvial fans at the bases of gullied slopes or on
floodplains. All of this eroded material was fine grained. Within the last 50 years, land
use has gradually changed through a combination of better agricultural practices and return of
land to an uncultivated state through home development or just cessation of cultivation. The
result is that presently little material is being added to the floodplain and the stream
channel is incising.

The material occurring on the floodplains within the basin has very little development of a
soil profile. Most of the floodplain materials along Brandywine Creek are mapped as Chewacla,
Congaree, Lindside, and Wehadkee soils (Kunkle, 1963). All of these soils have an Ap horizon
(plow zone) and no B horizon. They vary primarily in texture which reflects the materials
from which they were derived. These soils are developed on young material that has not had
sufficient time for time for development of a good soil profile thus supporting the concept
that at least the upper part, and maybe all, of the bank material was deposited subsequent to
European settlement. Frequently, post-settlement floodplain sediment elsewhere in Pennsylvania
occurs above a buried A horizon. No buried A horizon has been observed in the floodplain
sediments of the Brandywine Basin, but the number of points of observation have been few.
LEAVE STOP 5. RETURN VIA SAME ROUTE to PA Route 100.

0.3 51.9 Park office on right.
1.9 53.8 FLASHING RED LIGHT. TURN RIGHT onto Little Conestoga Road.
0.2 54.0 STOP SIGN. TURN RIGHT onto PA 100 South.
2.0 56.0 STOP LIGHT. TURN RIGHT onto Sheree Boulevard.
0.2 56.2 STOP SIGN. TURN LEFT onto Eagleview Boulevard.
0.5 56.7 STOP LIGHT. TURN RIGHT onto PA Route 113 South.
2.4 59.1 Route travels down slope into the Chester Valley.
1.1 60.2 STOP LIGHT. TURN RIGHT onto US Route 30 Business West.
0.5 60.7 STOP LIGHT. TURN LEFT onto US Route 322 East. After the route passes through an underpass, it crosses over East Branch Brandywine Creek and then follows the creek valley to Stop 6.
2.1 62.8 Outcrops of Octoraro schist on the right.
1.2 64.0 US Route 322 curves to the left. GO STRAIGHT AHEAD. STOP SIGN.
CONTINUE STRAIGHT AHEAD on Waltz Road (gravel).
0.1 64.1 Park along berm before outcrop on right.

STOP 6. SYNOPSIS OF THE FEATURES OF THE CREAM VALLEY FAULT.
Discussant: Gil Wiswall

This outcrop lies about 300 m north of the Cream Valley fault trace. In this area, the fault trace is located at the northern contact of the Poorhouse massif. This lithology is mapped as Wissahickon schist, but it is different from the middle to upper amphibolite grade rocks south of the fault (herein referred to as the "Landenberg" schists). The mineral assemblage here falls within the garnet zone of the greenschist facies. The rock is composed of quartz, plagioclase, chlorite, and muscovite with millimeter-sized garnets.

Texturally, this rock is a button schist (Lister and Snake, 1984). The texture is produced by three foliations. S1 is the metamorphic foliation defined by phyllosilicates. It is largely overprinted by S2, the dominant foliation in this outcrop. Careful examination of the east face of the outcrop reveals a Type II S-C relationship where S1 is deflected by S2 indicating a top to the northwest sense of displacement. This records the Embreeville thrust phase of deformation. The latest foliation, S3, is best observed on the north face of the outcrop. S3 surfaces rake toward the southwest deflecting S1/S2 indicating oblique slip with both normal and dextral components. Note that S3 is nonpenetrative. It can be traced along strike to the southwest for approximately 6 km to the northeast side of the Wodville nappe where it disappears. This indicates that the magnitude of strike-slip displacement decreases to the southwest.

LEAVE STOP 6. CONTINUE STRAIGHT AHEAD.

0.9 65.0 T-INTERSECTION. TURN RIGHT onto Telegraph Road.

The route will now traverse along a northeast-southwest-trending valley that has no through drainage (Figure 60). This valley is the result of erosion along the contact between felsic gneiss on the north side and schist on the south side. The erosion has been enhanced by the presence of some small discontinuous bodies of Cockeysville Marble that developed on the schist. The schist-marble-gneiss contact is presumably a fault although not shown as such on the Geological Map of Pennsylvania (Berg and others, 1980) or Map 61 (Berg and others, 1983).

After traversing this valley for 2.1 miles, the route turns right onto Strasburg Road and crosses the floodplain of Broad Creek as the road passes through a narrow gap. Another northeast-southwest-trending valley with no through drainage is encountered (Figure 60). This valley is not as deeply eroded as the one to the south, but it is notable just the same. This valley has been eroded along the fault contact between schist of the Wissahickon Formation to the north and felsic gneiss to the south. There is no Cockeysville Marble in this valley which presumably is the reason that the valley is not as deeply eroded as the valley immediately to the
Figure 60. Part of the Unionville 7.5-minute quadrangle showing the two parallel valleys that have no through drainage but striking topographic development because of erosion along weak geologic boundaries.
south.

All of the drainage in this area is very well adjusted to structure. Where there is no fault or contact control, tributaries and larger streams either parallel the strike of foliation or are normal to foliation. Note on Figure 60 that just north of the route, Broad Run, which is flowing normal to strike throughout most of its length, makes a right-angle turn and follows the trend of foliation for more than a half mile before making another right-angle turn and returning to its across-structure trend.

It is interesting to note that this area of structurally controlled drainage is locally restricted to the northern half of the Unionville 7.5-minute quadrangle. Drainage south of the West Branch Brandywine Creek in this quadrangle lacks obvious adjustment to structure as does the area farther west. Why?

1.1 66.1 **STOP SIGN. TURN LEFT** following Telegraph Road and Sugarbridge Road. Within 300 feet **TURN RIGHT** following Telegraph Road (Sugarbridge Road turns left).

0.8 66.9 **STOP SIGN. CONTINUE STRAIGHT AHEAD** across Marshalltown-Thorndale Road.

0.2 67.1 **STOP SIGN. TURN RIGHT** onto Strasburg Road.

2.6 69.7 **TURN LEFT** onto Youngs Road.

0.6 70.3 **CONTINUE STRAIGHT AHEAD** as other road turns left.

0.9 71.2 **TURN RIGHT** onto Laurel Road.

0.2 71.4 Park on right berm after passing outcrop on right.

**STOP 7. ROAD AND RAILROAD OUTCROPS OF THE PETERS CREEK FORMATION AND THE BALD FRIAR METABASALT.**


David W. Valentino and Alexander E. Gates

This stop is located in the upper section of the Peters Creek Formation that contains the thin-graded metasandstone lithofacies interlayered with minor greenstone. Figure 7 (p. 39) shows a detailed lithologic column for a section of the railroad cut outcrop that faces south. The outcrops contain meter-scale interlayered feldspathic metasandstone and schist and minor greenstone. The dominant schistosity is the layer parallel S1se schistosity. Interlayered sandstone, siltstone, and shale are the inferred protoliths for this sequence, and a turbidite-fan is a likely depositional model drawing on more regional relationships. There are three important things to note at this outcrop: (1) the Peters Creek Formation is not a "schist" as referred to by the earlier workers, (2) except for the presence of greenstone, the variability and proportions of lithologies at this outcrop are typical for most of the upper portion of the formation; and (3) the compositions of the metasandstone layers, containing up to 30 percent detrital K-feldspar, and the presence of granitic fragments suggests a granitic or granitic basement source.

**Tectonic significance.** Basement-sourced feldspathic clastics interlayered with greenstone is a lithofacies combination consistent with continental rifting. Similar lithofacies of the Peters Creek Formation will be examined at Stops 14 and 15 at the Susquehanna River, and a more complete tectonic history will be portrayed.

Robert C. Smith, II

The geochemistry of the Bald Friar Metabasalt is briefly discussed by Smith and Barnes (this guidebook). The rock here consists of lower-amphibolite-facies hornblende-epidote-albite(?) metabasalt containing accessory biotite, rutile, and hematite. The fabric varies from laminated to weakly crenulated.

At this roadcut and the associated railroad cut (Figure 61) the following activities are encouraged:

1. Note the structural and sedimentologic complexity of the outcrops in which the metabasalt occurs.

2. Decide how you might be able to recognize and verify small ultramafic fragments if any are present.
Figure 61. Schematic cross section of Stop 7 showing relative locations of Bald Friar Metabasalt bodies noted to date along Laurel Road and the adjacent Octoraro Railroad cut. X represents locations from which samples were collected and analyzed.
3. Learn how to recognize this particular metabasalt by its heft, the color of a fresh surface, the presence of amphibole and epidote, and its laminated fabric. (A few roofing nails have been driven near some of the contacts to assist.) If possible, observe the similarity of slabs from this stop and some from the type locality, Bald Friar, Cecil County, Maryland.

4. Examine the fabric within the larger metabasalt blocks to see if you recognize pillow structures. (If there were not well-preserved pillows in the same metabasalt at Bald Friar, we would be only 40 percent convinced that they exist at this stop. As it is, we are 60 percent convinced.) If you think relict pillows are a possibility here, contemplate the effect of initially brittle glassy rim fragments on the difficulty of trying to establish precise contacts. Contemplate the susceptibility of volcanic glass that has been altered, possibly to smectite, to movement by sedimentary and/or tectonic processes. Could the sole of the Embreeville thrust locally be an ophiolitic mélange?

5. Sketch possible additional metabasalt bodies into the blank areas on Figure 61. Locate possible unrecognized ultramafic bodies (now likely to occur as sheared chloritetic "partings" between massive beds).

Gil Wiswall

This outcrop of Peters Creek schist lies approximately 1.8 km north of the Cream Valley fault. At the fault trace, the same fabrics observed at Stop 6 are present. At this location you will note the absence of S3. However, S1 and S2 are present. Here, centimeter-scale mica fish preserve S1 and indicate a top to the northwest sense of motion. Note that the dominant foliation orientation is S2 and parallels compositional layering.

A contrast in competence between the metabasalt and enclosing metasediments is clearly visible at this location. The streamlined shape of the metabasalt body suggests its present geometry may be the result of shear within the Embreeville thrust zone. Notice the folds developed in the Peters Creek around the upper contact of the metabasalt. These appear to be drag features developed by relative movement along the contact. The metabasalt also appears to be internally folded. However, the presence of pillows at other locations within the Bald Friar introduces the possibility that the fabric is actually the cross sections of pillows rather than folds.

Careful examination of the psammitic layers away from the contact of the metabasalt reveals a southeast-dipping schistosity oriented at about a 15° angle to layer boundaries within individual "beds". Microscopic examination reveals that this foliation is axial planar to tight, isoclinal folds in surfaces defined by compositional and grain size variation within the layer and, therefore, is S1. As S1 approaches the layer boundaries, it is deflected by shear surfaces (S2) oriented parallel to the layer boundary. Thus, the dominant foliation throughout this outcrop that parallels compositional layering is S2.

The parallelism between mesoscopic compositional layering and S2 has interesting implications. The internal deformation within layers and slip along layer boundaries raises the question of whether or not the layer boundaries represent original bedding surfaces. If the compositional differences and grain size variation visible within layers represent original bedding as seems likely, then bedding is, on average, parallel to S1 not the mesoscopic layer boundaries. The facts that layer boundaries are shear surfaces and S1 is well preserved in only the psammitic layers suggests that slip associated with Embreeville thrust movement was partitioned into zones of weakness and, presumably, pelitic layers; another illustration of competence contrast. Folding within layers results in an increase in layer thickness thereby casting doubt on the significance of measured stratigraphic sections.

Note the southeast-dipping fault. While the upper metabasalt layers are truncated, the lower layer appears to cross the fault. The continuation of the fault seen along Laurel Road is exposed in the northeast face of the railroad cut. The metabasalt in the hanging wall of the fault is clearly truncated. No other metabasalts have been identified in the footwall in this exposure. Thus, a slip line connecting the upper contact of the metabasalt in the hanging wall here with the upper contact of the lowest metabasalt in the footwall on Laurel Road establishes minimum displacement. The apparent continuation of the metabasalt contact across the fault on Laurel Road is fortuitous. Based on the normal displacement and brittle
nature, this fault is presumably Mesozoic in age.

**LEAVE STOP 7. CONTINUE STRAIGHT AHEAD.** West Branch Brandywine Creek.

1.9 73.3 **STOP SIGN. TURN LEFT** onto Strasburg Road at Mortonville. Cross bridge over West Branch Brandywine Creek. Route will traverse terrain characteristic of Piedmont uplands.

3.2 76.5 Stop sign at Buck Run Road. **CONTINUE STRAIGHT AHEAD.**

0.5 77.0 Stop sign at PA Route 82. **CONTINUE STRAIGHT AHEAD.**

2.6 79.6 **STOP SIGN. CONTINUE STRAIGHT AHEAD** onto PA Route 372 West. Route is now back in the Chester Valley.

1.4 81.0 **STOP LIGHT. CONTINUE STRAIGHT AHEAD** following PA Route 372 west through Parkesburg.

1.1 82.1 **STOP SIGN. TURN RIGHT** following PA Route 372 West.

2.3 84.4 **STOP LIGHT. CONTINUE STRAIGHT AHEAD** following PA Route 372 West.

0.2 84.6 **STOP SIGN. TURN LEFT** onto Main Street. PA Route 372 turns right.

0.3 84.9 **CROSS BRIDGE. TURN RIGHT** onto unmarked road.

0.8 85.7 **CROSS BRIDGE. STOP SIGN. TURN LEFT** onto Creek Road. Enter Scenic Octoraro Creek. The creek valley is on the left.

0.5 86.2 **TURN RIGHT.**

1.1 87.3 Park on berm on right after passing outcrops on right. Buses go 0.3 mile ahead to turn around on left.

**STOP 8. OCTORARO FORMATION ALONG THE EAST BRANCH OF OCTORARO CREEK.**

**Discussant: David W. Valentino**

This stop is in the Octoraro Formation along the East Branch of Octoraro Creek in the Parkesburg quadrangle. There are abundant exposures along the creek valley and along the road that parallels the creek, but the outcrops of interest reveal most of the different geologic elements of the local Octoraro Formation. At this locality it is possible to see the various deformation and metamorphic fabrics in the rock, lithologic variability, and the approximate contact between two members of the Octoraro Formation.

The rock at the bend in the road is a muscovite-quartz-plagioclase schist of the Bowery Run member. The contact between this lithology and plagioclase-bearing schist of the Stewart Run member occurs approximately 20 m south along the road. The lithologic contact is gradational over a few meters. The most obvious structural feature at this locality is the southeast moderately dipping S2nw schistosity that superficially dominates the rock. This outcrop is located on the southern limb of the Tucquan antiform, therefore accounting for the local dip of S2nw. The S1nw schistosity is defined primarily by parallel alignment of muscovite, chlorite and minor biotite, planar aggregates of metamorphic plagioclase, and deformed quartz veins. The S1nw schistosity can easily be observed with close examination of the outcrop. The S1nw schistosity dips moderately northward and is defined by millimeter-scale segregations of mica and plagioclase at a high angle to the S2nw schistosity. Faint lineations on the S2nw schistosity surfaces are the hinges of F3 crenulations.

**Tectonic significance.** Two schistosities occur in the Octoraro Formation as compared to only one early fabric in the Peters Creek Formation located to the south. In addition, the Octoraro Formation is compositionally very different from the Peters Creek Formation. These differences suggest that these units experienced independent deformation and metamorphic histories and were juxtaposed relatively late in the geologic history. The juxtaposition of the two formations is the subject of the next stop.

**LEAVE STOP 8. RETURN VIA THE SAME ROUTE.**

1.1 88.4 **STOP SIGN. TURN LEFT** onto Creek Road.

0.4 88.8 **STOP SIGN. TURN RIGHT.**

1.1 89.9 **STOP SIGN. TURN RIGHT** onto Newport Pike (Old Route 41).

As we travel on Newport Pike after the right turn, the route ascends from the Chester Valley carbonate lowland to the schist uplands of the South Valley Hills. The highest local elevation of these uplands, 700+ feet, occurs just to the east of the top of the initial grade (Figure 62).
Figure 62. Part of the Parkesburg 7.5-minute topographic map showing the uplands and dissection in the South Valley Hills area south of Christiana and Atglen.
The upland crests traversed by the route are 620 to 670 feet. The route affords an excellent opportunity to view the visually accordant uplands developed on the Octoraro Formation in this area. These uplands retain their visual accordance as they gradually decrease in elevation to the south and southeast. There is a visual impression of relative flatness on these uplands, but in reality they are not flat. The soils mapped on these uplands, Glenelg series (Kunkle, 1963), have 3 to 8 percent slopes and the uplands are what most geologists would call gently rounded.

Bascom and Stose (1932, p. 2, Figure 3A) drew a north-south-oriented topographic cross section just east of the route and specifically referred to this level as the Harrisburg peneplain. Farther south and at a lower elevation they identified a Bryn Mawr peneplain. Discussion of peneplains in southeastern Pennsylvania is provided by Bascom and Stose (1932; 1938), Knopf (1924), and Knopf and Jonas (1929). Knopf and Jonas is the most informative and thought provoking with regard to peneplains, but none of the reports is particularly enlightening.

Despite the fact that peneplains are generally discredited today by geologists working in the Appalachians, there remain questions which may or may not be readily answered. The fact is that there is not only visual but also elevational accordance of some relatively flat uplands in this and other parts of the Piedmont. The uplands in this general area occur on a variety of different rock types, but seem to consist in elevation in local areas and also consistent in gradual elevation decrease to the south and southeast. See, for example, Figure 60 in which the uplands on either side and within the topographically defined erosional feature are remarkably accordant. Structural attitude is not always determinable for rocks in the Piedmont, particularly for the uplands where outcrop is nonexistent, but in general it can assumed that the dominant foliation has a moderate to steep south dip, such as is the case in this area. Thus, the relatively flat upland surfaces are cut across structure. What is the process that can erode to produce a flat surface that cuts across primary structural attitude as well as different lithologies?

One answer is development of a peneplain. Hypothetically, local streams, such as East Branch Octoraro Creek immediately to the west, could have controlled erosion at a level approximately equivalent to the preserved upland level and could have eroded the landscape to a relatively flat surface. Lowering of base level could have rejuvenated erosion caused the master stream to incise to a new level and initiate a new cycle of erosion that is currently lowering the landscape about 300 feet. Such a scenario is similar to that discussed by Cleaves (1989; 1993; Cleaves and Costa, 1979).

A second answer is that the uplands could represent the remnants of the lower part or base of a double planation surface (Büdel, 1952) that could have developed during an extended period of chemical weathering that lasted from the Late Cretaceous to the Middle Miocene and developed a thick saprolite throughout the Piedmont elsewhere. The base of this saprolite would represent the base of the lower planation surface which was the base of weathering. Vigorous erosion of clastics initiated in the Middle Miocene (Poag and Sevon, 1989) has removed most of the saprolite. The uplands could be remnants of lower planation surface.

A third answer is that the uplands represent cryoplanation surfaces developed by periglacial activity during the Pleistocene (Clark, 1991; 1993). During Pleistocene glacial intervals, much of Pennsylvania, even these lower Piedmont elevations had continuous to discontinuous permafrost to an unknown depth. During the warmer summer months the permafrost would thaw to some depth. The thawed material was usually water saturated and was quite mobile on almost any slope. The thawed surface material moved as a gravity-driven mass from higher to lower elevations. The process
is called solifluction. This material accumulated on side slopes and
particularly in small valleys previously cut into the sideslopes and is the
material we now call colluvium. Pollack (1992) identified three phases of
colluviation in the Conestoga quadrangle in western Lancaster County.
There is an abundance of colluvium in the small valleys adjacent to these
flat uplands (Figure 62). It is possible that a landscape that had been
dissected by erosion which started in the middle Miocene could have been
cut to approximately the topographic form and base level that exists today
before the Pleistocene and that cryoplanation during the glacial intervals
could have flattened previously rounded uplands. The material removed by
solifluction would have ultimately been deposited on the sideslopes, in
the small tributary valleys, and on the floodplains of the larger streams, and
some would have been transported out of the drainage basin. Cleaves (1993)
argues that such processes are necessary to account for aspects of the
landscape in adjacent Maryland.

Which of these options is the correct one? My (Sevon) opinion is that
both of the latter two options have operated on the landscape of Pennsylva-
nia. The landscape dissection that started in middle Miocene carved the
basic form of the topography prior to the start of the Pleistocene or may
have continued into the early Pleistocene. During the glacial intervals
periglacial activity enhanced lowering and flattening of the uplands while
storing material at lower elevations.

1.6 91.5 TURN RIGHT onto Highland Road. Lots of good views ahead.
0.9 92.4 TURN LEFT.
0.1 92.5 TURN RIGHT onto Schoff Road. Golf course on left.
1.7 94.2 STOP SIGN. CONTINUE STRAIGHT AHEAD past nice barn made of schist.
0.2 94.4 Cross bridge over Octoraro Creek. TURN LEFT onto Schoolhouse Road.
0.5 94.9 Park on right berm before bridge.

STOP 9. DRUMORE TECTONITE ALONG THE EAST BRANCH OF OCTORARO CREEK.
Discussants: David W. Valentino and Alexander E. Gates

The Drumore tectonite is exposed at road level and on top of the knob on the east side of
the road. The lithology is black to gray phyllonite. S3 schistosity dominates the rock, is
defined by parallel alignment of fine-grained micas (Figure 63A), and the schistosity dips 60°
to 70° toward the southeast. Commonly there are microscopic kink bands that show dextral
shear associated with S3. Pyrite porphyroclasts with quartz pressure fringes are abundant in
both exposures. There are multiple phases of pressure fringe development on the pyrite
porphyroclasts (Figure 63C), however, most fringes reveal a dextral asymmetry (Figures 63D).
The metamorphic mineral assemblage of the Drumore tectonite is chlorite-muscovite reflecting
the late M3 lower greenschist facies metamorphism. Late deformation features include minor D4
kink bands. This outcrop is located in approximately the middle of the Drumore tectonite
whose zone is about 1.5 km wide locally. Lyttle and Epstein (1987) suggested that a black
slaty unit in the Octoraro Formation was a thrust sliver of the Peach Bottom slate. The local
slaty appearance of this unit is related to development of the S3 schistosity, and not due to
simple prograde metamorphism. Field trip attendees are encouraged to collect a piece of the
Drumore tectonite at this locality for comparison with the Drumore tectonite and Peach Bottom
slate at the Susquehanna River.

Tectonic significance. The Drumore tectonite defines a segment of the Pleasant
Grove-Huntingdon Valley shear zone in Lancaster and Chester Counties. This shear zone
experienced primarily dextral strike-slip offset and is responsible for the final juxtaposi-
tion of the Peters Creek and Octoraro Formations. This shear zone also separates rocks with
contasting deformation and metamorphic history, and different lithofacies. The Pleasant
Grove-Huntingdon Valley zone is interpreted as a major crustal shear zone with a minimum of
150 km of late Paleozoic dextral offset (Valentino and others, 1994).

LEAVE STOP 9. CONTINUE STRAIGHT AHEAD.
0.9 95.8 TURN RIGHT onto Windy Top Road. Look for bison on left following turn.
Figure 63. Photomicrographs of deformation fabrics in the Drumore tectonite. [A] Fine-grained micas define the penetrative S3 schistosity (horizontal field of view is 5 mm); [B] minute kink bands associated with S3 indicate dextral shear (horizontal field of view is 7 mm); [C] rare pyrite porphyroblast with complex quartz pressure fringes; and [D] pyrite porphyroclast with asymmetric quartz pressure fringes (horizontal field of view is 10 mm for C and D).

1.4 97.2 STOP SIGN. TURN RIGHT onto PA Route 896 North (Georgetown Road).
3.8 101.0 Outcrop of weird schist on right.
0.8 101.8 STOP SIGN. TURN LEFT following PA Route 896 North.
0.2 102.0 STOP SIGN. TURN RIGHT following PA Route 896 North.
3.1 105.1 Peach Lane on left ends descent off Mine Ridge.
3.2 108.3 STOP SIGN. CONTINUE STRAIGHT AHEAD following PA Route 896 North.
0.4 108.7 STOP LIGHT. TURN RIGHT following PA Route 896 North. Now approaching Amish tourism area again.
3.0 111.7 STOP LIGHT. TURN LEFT onto US Route 30 West.
2.5 114.2 BEAR RIGHT following US Route 30 West. PA Route 462 goes straight ahead.
1.6 115.8 EXIT RIGHT to Greenfield Road.
0.2 116.0 STOP SIGN. TURN RIGHT onto Greenfield Road and then TURN RIGHT into parking lot of the Holiday Inn.

END OF DAY 1 FIELD TRIP. SEE YOU TOMORROW FOR DAY 2.
ROADLOG AND STOP DESCRIPTIONS - DAY 2

MILEAGE

Inc   Cum   DESCRIPTION

0.0  0.0  Leave Holiday Inn Parking lot. TURN LEFT onto Greenfield Road.
0.3  0.3  STOP LIGHT. TURN LEFT onto US Route 30 East.
1.0  1.3  EXIT to PA Route 340 West.
0.1  1.4  STOP SIGN. TURN LEFT onto PA Route 340 West.
1.4  2.8  STOP LIGHT. BEAR RIGHT onto PA Route 462 West.
0.1  2.9  Stop light at Lampeter Street. CONTINUE STRAIGHT AHEAD.
0.1  3.0  Cross Conestoga Creek.
0.7  3.7  STOP LIGHT. TURN LEFT onto South Broad Street. Route follows this main road which soon makes a broad right bend and becomes Chesapeake Street.
1.0  4.7  Stop light for Duke Street. Outcrop of Conestoga Limestone on right.
0.6  5.3  STOP LIGHT. TURN RIGHT onto South Queen Street.
0.0  5.3  TURN LEFT onto Hager Street (about 200-300 feet after turning onto Queen St.).
0.1  5.4  STOP SIGN. TURN LEFT onto South Prince Street and US Route 222 South.
0.5  5.9  Cross Conestoga Creek. Between here and mileage 8.7 are outcrops of Conestoga Limestone.
2.8  8.7  STOP LIGHT. CONTINUE STRAIGHT AHEAD on PA Route 272 South.
3.6 12.3  Vegetation-covered outcrop on left of Antietam Formation. This outcrop and the next two are part of fault blocks that incorporate Conestoga and Antietam rocks.
0.8 13.1  Outcrop on left is of Octorora Formation.
0.4 13.5  Underpass beneath now abandoned Conrail railroad line.
2.4 15.9  Top of hill is north side of Tucquan antiform. Folding of the major plane of foliation produced the antiform. Foliation dips north on the north side of the antiform, south on the south side, and is relatively horizontal across the broad crest. The schist is a resistant rock except along the planes of foliation where weathering proceeds following the natural planes of weakness. Here where the foliation is horizontal, the schist resists weathering and erosion and the Tucquan antiform forms a ridge that rises 100 or more feet above adjacent landscape where the foliation is moderately to steeply dipping.
1.4 17.3  South side of Tucquan antiform. A steep grade ahead leads to a blinker light at the base of the grade in Buck. Slow down and be ready for a right turn.
0.3 17.6  BLINKER LIGHT. TURN RIGHT onto PA Route 372 West. The route will parallel the low ridge on the right that marks the south margin of the Tucquan antiform. To the left (south), foliation in the schist has a moderate to steep south dip and the rock is moderately to deeply weathered. Uplands mark divides between small tributaries to the Susquehanna River. Note that the depth of dissection increases as the distance to the Susquehanna River decreases.
5.8 23.4  TURN LEFT onto River Road. Sign on right for Susquehannock State Park. Road on right is Old Pinnacle Road.
0.6 24.0  Cross dam for Muddy Run Reservoir. Reservoir collects water used at Muddy Run pumped storage facility.
0.3 24.3  Good view on right of distant Susquehanna River and the amount of dissection.
0.6 24.9  Intake for power plant is on right.
0.4 25.3  TURN RIGHT to PECO Energy Muddy Run Pumped Storage Plant and Wissler Run Park. Outcrops ahead on right are of albite facies schist of the Octoraro Formation.
1.1 26.4  PARK IN PARKING LOT AT MUDDY RUN FACILITY.

STOP 10. STEWART RUN MEMBER OF THE OCTORARO FORMATION.
Discussant: David W. Valentino

The outcrop for this stop is located along the railroad above the parking lot for the Muddy Run pumped storage power plant and the general location with respect to the Holdwood Dam
is shown in Figure 64. The lithology is plagioclase-muscovite-chlorite schist of the Stewart Run member of the Octoraro Formation. The metasandstone-bearing Puseyville member is structurally above the Stewart Run member at the Susquehanna River and the contact can be seen at Midway along the railroad south of this stop. The pelitic schist of the Tucquan Creek member occurs structurally below the Stewart Run member and the lithologic contact can be seen just south of the Norman Wood Bridge along the railroad (Figure 64).

Figure 64. Oblique aerial photograph of the Susquehanna River gorge south of Holtwood Dam looking north. The location of this stop and the Muddy Run power station are shown, as well as the approximate lithologic contacts in this region. Abbreviations: otc - Tucquan Creek member; osr - Stewart Run member; osc - Sams Creek metabasalt; ubt - Upper Bear Island tectonite zone; TA - Tucquan antiformal axis.

Figure 65. Metamorphic plagioclase porphyroblasts from the Stewart Run member of the Octoraro Formation. [A] Microscopic S1nw defining F2nw folds within a plagioclase porphyroblast that grew after the onset of D2nw deformation; and [B] M2nw plagioclase porphyroblast with M1nw garnet preserved as an inclusion (after Valentino and others, 1994).
The S2nw schistosity is the dominant structural feature at this locality and dips moderately toward to the southeast. The S1nw schistosity can be observed in the hinges of F2nw isoclinal folds, and is defined by millimeter- to centimeter-scale mineral segregations, and defomed quartz veins. Microscopically the S1nw schistosity also occurs as inclusion patterns in metamorphic plagioclase (Figure 65A). F3 crenulations and very weak S3 cleavage are also at this locality.

Locally the Stewart Run member is within the M2nw biotite zone on the southern limb of the F3 Tucquan antiform. Although it can not be observed at the outcrop, the M1nw metamorphic mineral assemblage at this locality contains garnet (Figure 65B). It appears that the M1nw metamorphism locally was at a higher grade prior to M2nw.

**Tectonic significance.** The Stewart Run member was mapped continuously from the Susquehanna River as far east as the West Branch of Brandywine River, and at this stop the Stewart Run member is observed for the second time on this field trip. Mappable units of the Octoraro Formation are continuous over tens of kilometers suggesting that the lithologic variation represents original sedimentary compositional variation on the map-scale. Assuming that the present structural stacking of members represents original sedimentary stacking, some interesting regional relationships persist. The transition from pelitic schist of the Tucquan Creek member to plagioclase-bearing schist of the Stewart Run member represents an overall decrease in mica content and relative increase in plagioclase and quartz. This compositional change probably reflects variation in the sedimentary protoliths for these rocks with an aluminum-rich shale (protolith for Tucquan Creek member) giving way to more quartz-rich shale and siltstone in a regressive sequence. The transition from the plagioclase-bearing schist of the Stewart Run member to the Bowery Run member in the east and Puseyville member in the west that contain thin- to thick-layers of metasandstone also shows a relative decrease in mica content and dramatic increase in quartz content structurally higher in the section. This relationship is consistent with an overall regressive sequence. The trip attendees are encouraged to collect a piece of the Stewart Run schist for comparison with the Peters Creek Formation at the next stop.

**LEAVE STOP 10. RETURN VIA THE SAME ROUTE.**

1.1 27.5 STOP SIGN. TURN RIGHT onto River Road.
0.2 27.7 TURN RIGHT onto Furniss Road.
1.1 28.8 STOP SIGN. CONTINUE STRAIGHT AHEAD following Furniss Road.
0.4 29.2 T-INTERSECTION. BEAR RIGHT following Furniss Road.
0.2 29.4 T-INTERSECTION. TURN LEFT following Furniss Road.
1.8 31.2 Cross Fishing Creek.
0.1 31.3 TURN LEFT onto Fishing Creek Road (not marked).
0.2 31.5 PARK ON BERM ON LEFT SIDE OF ROAD. Follow margin of wooded area and pasture on left to outcrop adjacent to Fishing Creek.

**STOP 11. FISHING CREEK METABASALT: ROCK, STRUCTURE, AND GEOMORPHOLOGY.**

*Discussants: Robert C. Smith, II, Rodger T. Faill, William D. Sevon*

Robert C. Smith, II

**The Fishing Creek Metabasalt.**

The Fishing Creek Metabasalt consists of greenschist-facies epidote-chlorite-actinolite-albite metabasalt containing some calcite. It also commonly contains accessory titanite and 1-mm octahedral magnetite. At this stop (Figure 66), accessory biotite is also present. S1, the primary cleavage, here trends N70°E, 58°S and, based on regional trend and thin sections from the type locality (39°47.58’S, 76°15.16’W) 1.8 km to the SW of Stop 11, is parallel to S0, compositional bedding. The geochemistry of the Fishing Creek Metabasalt is briefly discussed by Smith and Barnes (this guidebook). It is probably a plume or enriched ocean-floor basalt (P=EOFB). As Smith and Barnes note, talc schist of ultramafic origin occurs along apparent strike to the SW in Peach Bottom Township, York County. Thus, the possibility exists that, despite its lateral continuity and gradual systematic change in
Figure 66. Location of Fishing Creek Metabasalt (Stop 11) within the Drumore tectonite zone (dt) (Valentino, 1993). See also Figure 67 showing apparent metabasalt thickness along strike and sample names. X = location of analyzed metabasalt samples. ▼ = location of other good outcrops.

thickess in Lancaster County (Figure 67), the Fishing Creek Metabasalt may be related to an unnamed, poorly defined mélange in York County.

Primary features such as probable flow surfaces that have been chilled, 5- to 50-cm epidote knots that might have been pillows or pahoehoe toes, and tiny amygdules are best preserved at the less-accessible type section. Rodger Faill describes the structure at both the type section and this stop below. At the presently known NE limit of the Fishing Creek Metabasalt (Figure 66), the texture, slope, and float distribution indicate that the footwall of the Fishing Creek Metabasalt is a coarse-grained (2 x 5 mm) extrusive rock that contains actinolite and the hanging wall is a fine-grained metabasalt containing about one percent 3-mm cubic pyrite crystals. Because of the presence of apparently intrusive feeder float (sample site FSHCKINT) at the NE end of the known strike belt, we suggest that the paleoslope might have been to the SW (present direction), as now, and that it is unlikely that the Fishing Creek Metabasalt will be found to the NE.

An alternate reason for the inability to trace this metabasalt to the NE of sample site FSHCKINT may be related to the presence of a zone of vein quartz float upslope to the NE of that site that follows the curving 400-foot contour (Figure 66). The presence of a belt of silver-blue phyllite parallel to, but typically uphill from, the vein quartz float could be indicative of a low-angle thrust fault that may have terminated the metabasalt. If so, the Fishing Creek Metabasalt should be sought only at lower elevations to the NE.

At this relatively accessible outcrop of the Fishing Creek Metabasalt, consider doing the
Figure 67. Apparent thickness variation of Fishing Creek Metabasalt (Stop 11) along the presently verified strike length. Mapping by Stose and Jonas (1939) in York County could add another 6.5 km of length if their "sp" is in part equivalent to the Fishing Creek Metabasalt. The "FSHCKxx" labels refer to samples in both text and tables.

following:

1. Observe the resistance of this natural outcrop of metabasalt to weathering at stream level. It suggests that many more good outcrops remain to be found in the Piedmont.
2. Note the potential usefulness of the metabasalt as a marker bed in quadrangle mapping (Figure 66).
3. Note the systematic variation in thickness along strike (Figure 67), suggesting that the flow encountered a topographic low.
4. Contemplate the regional significance of this belt, the farthest inland from Iapetus that we know of containing oceanic basalt and ultramafic fragments on the SE side of the Tucquan anticline. Could you be standing on the Taconian suture? Could the Fishing Creek Metabasalt, ultramafic rock to the SW, and muscovite-paragonite schist within the hanging wall to the metabasalt be a subduction trench assemblage? Rast and Horton (1989) reported that in the northern Appalachians the Taconian suture consists of three belts: a western ophiolite mélange (perhaps corresponding here to the Fishing Creek Metabasalt, talc in York County noted by Smith in 1989 (Smith, 1993), and possibly some units to the SW), a medial ophiolite (the Baltimore Mafic Complex), and an eastern olistostrome (the Conowingo Dam diamictite of Higgins and Connant (1986)).

Rodger T. Faill

Three foliations in a metabasalt.

The most prominent structure in this outcrop of the Fishing Creek metabasalt is a pervasive foliation that dips moderately to the southeast. This foliation is designated $S_1$ for this outcrop, and is presumed to parallel compositional layering, $S_0$ (bedding). Supporting evidence for this presumption has not been found in this exposure. However, the $S_1$ foliation has the same trend as the series of metabasalt outcrops between here and the Susquehanna River 3.25 km to the southwest. There is very little grain alignment in the
metabasalt, in part because phyllosilicate mineral (chlorite) constitute only 15 percent of the rock. The S₁ fabric reflects a very fine-scale alternation of plagioclase-chlorite and tremolite-epidote-sphe-39lorite laminae. The S₁ orientations seem to fall into two clusters, S₁A and S₁B (Figure 68), with no clear continuum of orientations between them. The reason for this double cluster is not understood—it may be a consequence of a later bending, or large-scale kinking, across the regional trend, a feature that has been observed elsewhere at different scales in this part of the Piedmont.

A second foliation, S₂, is not nearly as well developed. It also dips to the southeast, but its trend is more northerly than that of S₁ (Figure 68). It can best be seen in the small ledge at the foot of the outcrop, north side. Some of the S₂ surfaces are present on the south side of the outcrop, near the creek.

A third, even more subtle foliation, S₃, has a trend similar to that of S₁A, but the dip is steeper (Figure 68). This S₃ fabric is best exposed on the east end of the outcrop, by the creek. The S₃ foliation is also represented in a few small surfaces along the north side.

The other type of structure present in this exposure is lineation. The lineations are crenulations, formed by the development of a second foliation across a preexisting foliation. The crenulations are long, straight microfolds of the phyllosilicate minerals that were parallel to the earlier foliation. The trace of the crenulation lineation lies along the intersection of the two surfaces.

The most prominent lineation here, one that pervades the entire metabasalt outcrop, is the steeply south plunging lineation formed by the intersection of S₁ with S₂, termed L₅₁x₃₂ (letting S₁ represent both S₁A and S₁B) (Figure 68). Many additional, very fine crenulation lineations with a large variety of plunges are present on S₁ as well, but they do not extend far on any one S₁ surface, or are they nearly as common as L₅₁x₃₂. The wide range of lineation plunges (Figure 68) probably reflects the variation in attitude of the foliation surfaces—small angular changes in foliation orientations can result in large differences in lineation plunge. The relative paucity of subhorizontal lineations (L₅₁x₅₃) indicates that the development of S₃ was not a strong event here.

The relative ages of the three foliations is not known. It is presumed that S₁ is the oldest, for two reasons: (1) S₁ presumably parallels bedding and therefore was produced by burial metamorphism, and not by a subsequent tectono-metamorphic event; and (2) the crenulations (and non-crenulated phyllosilicates) lie on S₁, suggesting it was acted on by the tectonic events that produced the other two foliations.

It is worth noting that this outcrop is in the middle of the Drumore tectonite zone (Figure 68; see Stop 12; see also Valentino, this guidebook). The absence of a strong subvertical shear fabric in this outcrop, and in correlative metabasalt exposures to the southwest and northeast, suggests that the Fishing Creek metabasalt occupies a tectonite-free pod/lens or enclave within the Drumore tectonite zone.

William D. Sevon

**Fishing Creek and its valley.**

The metabasalt outcrop at this stop and Fishing Creek valley, between here and its juncture with the Susquehanna River, provides information for speculation about the geomorphic development within the Piedmont. The longitudinal profile of Fishing Creek valley is similar to longitudinal profiles in other tributaries in the area but is not as pronounced. The character of the stream valley is very similar to that of other tributaries. The lower part of the longitudinal profile is convex upward below a knickpoint that occurs about 1.5 miles upstream from the mouth. Above the knickpoint the longitudinal profile is concave upward until another knickpoint is encountered about 8 miles from the mouth. The upstream-migrating knickpoints result from slow adjustment of tributaries to a new base level established by rapid downcutting of the Susquehanna River (see Stop 13 for more discussion of this).

The valley below the lower knickpoint and for another 1.5 miles above the knickpoint is steep sided with an abundance of exposed rock. Starting about 3 miles above the mouth of Fishing Creek, its valley becomes wider and the valley slopes are less steep and exposed rock is less abundant although still present. These gentler slopes have more colluvium preserved.
Figure 68. Stereogram of the foliations and crenulation lineations measured in the Fishing Creek metabasalt outcrop at Stop 11, 100 meters north of Fishing Creek Road, 1/3 km east of Furniss Road. The dominant foliation, $S_1$, plungetes to the southeast ($S_{1A}$ mean pole = 076-56; $S_{1B}$ mean pole = 065-62). $S_2$ trends more northerly (mean pole = 034-74), and $S_3$ dips more steeply (mean pole = 071-78). The $S_1$ and $S_2$ great circles intersect approximately at the plunge of the dominant lineation, $L_{S1\times S2}$ (mean plunge = 192-55). $n_S$ (foliation) = 22; $n_L$ (lineation) = 35.

on them than those in the lower part of the stream valley and the small valleys tributary to Fishing Creek contain abundant surficial materials in contrast to the minimal amount in the valleys tributary to Fishing Creek below the lower knickpoint. These features are evidence of the different intensities of erosion above and below the active knickpoint.
The entrenched meander pattern of Fishing Creek downstream from Stop 11 is striking (Figure 66). Examination of some outcrops within this meander belt did not reveal any evidence of a well developed joint system that might control stream-segment orientation although most outcrops do show a weakly-developed and closely-spaced jointing normal to the plane of primary schistosity. The long, straight segments are approximately normal to the primary foliation of the schist and the presence of the joints normal to the plane of primary schistosity probably affords an easier path for erosion than the planes of schistosity themselves. Assuming that joints control the orientation of the long segments and foliation controls orientation of the short segments, then how did Fishing Creek become adjusted to structure? The simplest explanation is that Fishing Creek developed by headward erosion and followed the structurally controlled paths of weakness. A more complex possibility is that the original course of Fishing Creek, when it flowed at an elevation 200-300 feet above present level, meandered, but in a much less tortuous fashion. As the stream entrenched, the meanders migrated laterally creating long, narrow slip-off slopes between long straight stream reaches. It is probable that the actual erosional history is more complicated than either of the above simplistic scenarios. As evidence of this, note the abandoned meander core about 0.9 mile upstream from the mouth and the large flat area at elevation 240+ feet just northeast of the meander core (Figure 66).

The metabasalt outcrop at Stop 11 is of interest from several geomorphic aspects. During the process of downcutting, Fishing Creek eroded through the metabasalt in two places along the trace of the rock. Once part of the creek was south of the steeply dipping rock, the creek migrated down dip on the south side of the erosion-resistant metabasalt. Fishing Creek apparently flowed across the present outcrop at a time when the bed of the creek was about 3 m higher than today. Limited exposure of the top of the outcrop indicates that it was once planed more or less flat and that water flowed over the downstream edge of the metabasalt in some sort of a waterfalls. As the water flowed over the lip of the falls, it beveled the downstream side of the metabasalt and also cut a respectable pothole that is about 0.8 m long and about 1.2 m below the lip of the outcrop. The well defined pothole is at the near-stream end of a pothole-like zone that is about 3 m long. Some parts of the pothole, the pothole zone, the beveled downstream outcrop edge, and the outcrop upper surface have a water-worn appearance. Whether this appearance remains from the time Fishing Creek flowed over the outcrop or whether it is the result of atmospheric and rainwater weathering is a matter for speculation.

Subsequent to eroding the pothole, Fishing Creek cut down about 3 m, attained a state of equilibrium, and widened its valley by meandering. During the valley widening process, it eroded all trace of the metabasalt in the valley bottom upstream from the outcrop and subsequently deposited a thin layer of alluvium. Note that the metabasalt has formed a small local knickpoint. The knickpoint has migrated a few feet upstream from the position where the outcrop would have continued across the creek. Note also that bedrock is exposed in the streambed near the left bank for several meters upstream from the knickpoint. This elongation of active riverbed erosion upstream from the knickpoint is common in the Piedmont. Here it may be partly illusion because the alluvial cover is very thin and bedrock is exposed in the streambed farther upstream and flooding may shift alluvial cover dramatically from time to time.

Because the metabasalt is relatively homogeneous and resistant, it presents a formidable barrier to lateral erosion by the creek and has caused Fishing Creek to swing across the floodplain to the right bank where it has eroded sufficiently to oversteepen the slope where its base is impinged by the creek. This aspect of erosion resistance in exposed outcrop is in variance with the character of the rock where it crosses the ridges formed by stream meandering between here and the Susquehanna River. The ridges have pronounced topographic depression (Figure 66), particularly on the ridge crests, where the metabasalt has been deeply weathered and eroded. The outcrop here appears to be losing material primarily from the lower part of the downstream side of the outcrop.

Perhaps more interesting is speculation about the age of the pothole. It would appear that there has been relatively little modification of the pothole since it was formed. If an unloading rate of 10 m/my (Pazzaglia, 1993; and Gardner, this guidebook) is used, the pothole could have been eroded about 300,000 years ago. However, if the general riverbed of the Susquehanna River has been at or near its present position for nearly 800,000 years as can be
inferred from the work of Sevon (1993) and Gardner and Sadowski (in press), then the probable age of the pothole is much older. The freshness and erosion resistance of the outcrop contrasts sharply to the deep weathering of the metabasalt on the previously mentioned ridges. This would seem to be indicative that the higher parts of the landscape have been exposed to weathering for a much longer period of time than the lower parts. An additional factor may be that the metabasalt may be more resistant to erosion and weathering when exposed directly to the atmosphere than when covered with soil. The surface of the metabasalt would be an interesting candidate for cosmogenic dating.

LEAVE STOP 11. RETURN VIA THE SAME ROUTE (back to Furniss Road).

0.2 31.7 STOP SIGN. TURN LEFT onto Furniss Road. Route goes up a small valley that has several feet of alluvium-colluvium in the valley bottom.

0.8 32.5 STOP SIGN. TURN RIGHT onto Harmony Ridge Road.

0.3 32.8 Good views ahead on both sides of visually accordant Piedmont upland surfaces.

1.5 31.3 STOP SIGN after crossing Fishing Creek. TURN LEFT onto Fishing Creek Road. Ahead are abundant outcrops of Octoraro Formation that occur in the lower parts of the dissected landscape near the Susquehanna River.

0.9 35.2 Park in wide area adjacent to railroad tracks. Walk south along railroad to outcrops.

STOP 12. THE DRUMORE TECTONITE AND THE PETERS CREEK FORMATION.
Discussant: David W. Valentino

This stop is the type locality for the Drumore tectonite (Valentino and others, 1994). Discussions will center around the Drumore tectonite, kinematic analysis, the contact relationship with the Peters Creek Formation, the deformation history, compositional control on deformation style, discordant deformation and metamorphic histories between the Peters Creek and Octoraro Formation, and dynamic retrograde metamorphism and the development of phyllonite.

The first outcrop that will be discussed is located near the railroad gate a few hundred meters south of the substation along the railroad. This outcrop is the northernmost Peters Creek Formation along the Susquehanna River. Compositional layering of metasandstone and schist are highly contoured and folded. These are meso-scale F3 folds with steep northeast striking axial planes (Figures 69A and 69B). Until now the only F3 folds observed at the outcrop scale were the minute crenulations in the Octoraro Formation. The fabric that is folded is the S1se layer-parallel schistosity. Rare centimeter-scale intrafolial isoclinal folds can be observed in portions of the outcrop with thin compositional layering. Unlike the Octoraro Formation with two distinct deformation fabrics with S1nw defining isoclinal folds, the isoclinal folds in the Peters Creek Formation (F1se) are defined by the same layer parallel schistosity (S1se) that encompasses the folds. Although greatly deformed, the metasandstone layers contain abundant detrital grains of quartz and K-feldspar primarily observable in thin section [these metasandstone layers were not used in the QFL plot of Valentino and Gates (this guidebook) because there evidence for extreme alteration of the primary grains]. Close examination of fresh surfaces with a hand lens may reveal some of the round grains of quartz or feldspar.

Walk north along the tracks to a small outcrop of black phyllonite. This is the Drumore tectonite at track level. The contact with the Peters Creek Formation occurs between this outcrop and the last. For a better exposure of this black phyllonite return to the gravel parking lot. The dominant fabric in this outcrop is the northeast striking and steeply dipping S3 schistosity. Pre-existing schistosities are difficult to see at the outcrop-scale except in the hinge regions of large F3 folds. Although in the field kinematic indicators are not obvious, microscopic kinematic analysis revealed a consistent sense of dextral shear. Common microscopic kinematic indicators are pyrite porphyroclasts with pressure fringes of quartz (Figure 69C) and preferred grain shape orientation of dynamically recrystallized quartz in thin mylonitized veins (Figure 69D). These microstructures were observed from locations in the Drumore tectonite along the entire length of the zone. A gradational boundary occurs between the Drumore tectonite and the Octoraro Formation suggesting that the Drumore tectonite originated as a higher grade schist, prior to shearing. The dark color of this tectonite is
Figure 69. D3 deformation features near Drumore. Outcrop-scale [A] and microscopic [B] F3 folds defined by S1se in the Peters Creek Formation; [C] pyrite porphyroclasts of pyrite with asymmetric quartz pressure fringes in the Drumore tectonite; and [D] quartz preferred grain shape from a mylonitized quartz vein in the Drumore tectonite (field of view is 5 mm).

due to the very fine grained dynamically recrystallized muscovite and chlorite that make up more than 90 percent of this rock.

Tectonic significance. The Drumore tectonite occurs in a segment of the Pleasant Grove-Huntingdon Valley shear zone and locally separates rocks with different histories. The Octoraro Formation, northwest of the shear zone, experienced two deformation and metamorphic phases prior to dextral shearing, and the Peters Creek Formation, southwest of the shear zone, experienced only one deformation and metamorphic episode prior to dextral shearing. Metamorphic grade (M2nw) increases at progressively lower structural levels in the Tucquan antiform, but conversely the grade increases at higher structural levels in the Peters Creek Formation. Pelitic schist, plagioclase-bearing schist, and interlayered metasandstone and schist characterize the units of the Octoraro Formation. Interlayered feldspathic metasandstone and schist and massive metasandstone bodies are typical lithofacies in the Peters Creek Formation. Juxtaposition of crustal blocks containing rocks of different affinity suggests that the blocks have traveled a relatively long distance, however this does not constrain the type of transport. The boundary between the Tucquan and Peters Creek block is a shear zone that apparently experienced dextral offset. Valentino and others (1994) argued for more than 150 km of late Paleozoic dextral offset on this zone to account for the anomalous distribution of Cambrian strata in the central Appalachians (Rodger, 1970). With this interpretation the Pleasant Grove-Huntingdon Valley shear zone is an ancient transform plate boundary, and the black phyllonite at this locality is a portion of the tectonized rock within the zone of shearing.
LEAVE STOP 12. RETURN VIA THE SAME ROUTE.

0.6 35.8 CONTINUE STRAIGHT AHEAD AND BEAR LEFT UPHILL on Susquehannock Drive.

0.4 36.2 Ahead on the left is an excellent example of a house built with local schist bedrock used as the building stone. There are many of these in the Piedmont.

1.1 37.3 TURN LEFT onto Park Drive to Susquehannock State Park.

1.2 38.5 Park in parking lot.

STOP 13. SUSQUEHANNA RIVER GORGE AND LUNCH
Discussants: Glenn H. Thompson, Jr. and William D. Sevon

Although there is no formal discussion at this stop, Conferees are encouraged to enjoy the view and contemplate some of the geologic facts and fantasies presented here. A more complete discussion of the problems is given in Thompson, 1990.

The overlook at Susquehannock State Park affords a fine view up the Susquehanna River toward Holtwood Dam and downstream to the Peach Bottom Nuclear Plant. The narrow gorge to the north commenced at Turkey Hill, about 32 km upstream (Figure 70), and is cut into schists of the Octoraro Formation that, despite their considerable lithologic variation and their susceptibility to chemical erosion, are quite resistant to physical erosion. Below the overlook, the Susquehanna River emerges from a narrow gorge that widens from 0.4 mile to nearly 1.4 miles at Peach Bottom Nuclear Plant. The wider river channel is cut into rocks of the Peters Creek Formation, a unit with lithologies that apparently are less resistant to physical erosion than those of the Octoraro. Features of interest here are: the islands between here and Holtwood Dam, the Susquehanna River deeps, and the convex upward longitudinal profiles of tributaries.

Thompson (1985; 1990) points out that the tops of the many islands just south of Holtwood dam (Figure 70) have a downstream rise in elevation relative to bedrock riverbed and that they are separated by channels whose margins have abundant potholes. He also notes that all tributaries to the Susquehanna in the gorge area have a convex-upward longitudinal profile in their lower reaches and a concave-upward longitudinal profile in their middle and upper reaches. He suggests that the two facts are related to rapid downcutting of the riverbed of the Susquehanna River at a time when a major falls, comparable to the Great Falls of the Potomac, migrated through the area as a knickpoint. This riverbed erosion was accomplished by a combination of potholing and plucking of foliation- and joint-bounded blocks. Downcutting in the Susquehanna River was more rapid than in tributary valleys and migration of the knickpoint has moved only a short distance up these valleys.

Thompson (1990) also discusses the Susquehanna River deeps, narrow and elongate (spoon- or bathtub-shaped) troughs that occur in the Susquehanna River riverbed. These troughs have depths of 100 feet or more and rise at both ends to riverbed level which is 100-110 feet in this area. The southernmost of these troughs occurs immediately below the overlook at Susquehannock State Park and its bottom is at or just slightly below sea level (Figure 71). The deep that occurs below the tailrace of Holtwood Dam was described by Mathews (1917) when it was partly drained. Photographs taken by him show the sides to be almost totally potholed.

Although the deeps have been an enigma in the past, their origin may be relatively easy to explain. The islands and the tributaries indicate that a knickpoint on the Susquehanna River migrated fairly rapidly through the gorge and that potholing was a significant contributor to the erosion. All of the deeps (Figure 70) occur where the river valley is very narrow, either because of constriction of the valley as a whole or because of the presence of islands. In addition, Thompson (1990) has noted that the orientation of the river, approximately northwest-southeast, is such that the winter sun angle creates a microclimate that causes the right bank of the river to be frozen much of the time while the left bank is free flowing. If downcutting occurred during the Pleistocene as suggested by Thompson, then the combination of natural constriction plus extra ice could have forced the river to rapidly erode its riverbed locally in order to accommodate available discharge. Thus the cutting of the deeps becomes part and parcel of the rest of the erosional history. This scenario seems reasonable, but it has some as yet unanswered problems. How does such extreme downcutting fit with deposition of Pleistocene outwash known to exist and how does the whole story fit with the late Cenozoic
Figure 70. Map of the Holtwood Gorge from Turkey Hill to Susquehannock State Park. The Susquehanna deeps are shown by diagonal lines.

The history presented by Pazzaglia and Gardner elsewhere in this guidebook?

LEAVE STOP 13. RETURN VIA THE SAME ROUTE.

1.2 39.7 STOP SIGN. CONTINUE STRAIGHT AHEAD on Park Drive.
0.2 39.9 T-INTERSECTION. BEAR LEFT onto Fern Glen Drive.
0.5 40.4 BEAR LEFT following Fern Glen Drive.
0.3 40.7 YIELD SIGN. TURN RIGHT onto Furniss Road.
2.7 43.4 STOP SIGN. CONTINUE STRAIGHT AHEAD following Furniss (Furnace) Road.
0.5 43.9 STOP SIGN. TURN RIGHT onto Slate Hill Road.
0.8 44.7 CROSS ROADS. CONTINUE STRAIGHT AHEAD.
Figure 71. Contour map of the Susquehanna River riverbed adjacent to Susquehannock State Park. General elevation of the riverbed is 100 feet above sea level. The local deep is between Maple and Sicily Islands and the left bank of the river. Note that the bottom of the deep is at sea level. Contour map is from Pennsylvania Power and Light Company (map made in 1933).

1.3 46.0 Trailer and farm on left.
0.1 46.1 TURN RIGHT onto lane at south edge of field. On this trip buses will drive along the lane to the wooded area. People will off-load and walk down to the railroad track and then along the railroad track to bus parking area. This stop is also accessed by parking in the designated parking area and walking along the railroad track to the outcrops. See road log at end of stop description for route to parking area at Peach Bottom Station.

STOP 14. PEACH BOTTOM SECTION AT THE SUSQUEHANNA RIVER.
Discussants: David W. Valentino, Alexander E. Gates, Robert C. Smith, II, Samuel W. Berkheiser, Jr., and William D. Sevon

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Bald Friar Metabasalt and geochemistry of ultramafic fragments.

The geochemistry of the Bald Friar Metabasalt is briefly discussed by Smith and Barnes (this guidebook). It is a normal ocean-floor basalt (N-OFB), presumably from a back-arc spreading center. The rock here consists of greenstone-facies epidote-chlorite-albite(?). metabasalt containing moderate amounts of accessory calcite and magnetite (octahedral) or ilmenite-rutile (laths) and trace subhedral titanite.

It should be noted that the Bald Friar Metabasalt, here at Stop 14 in an ophiolitic mélangé also containing both metamorphosed ultramafic fragments and a possible boninitic metabasalt on the N side of the Peach Bottom Slate, is from the same magma that produced the type Bald Friar Metabasalt in Cecil County, Maryland [see discussion of other metabasalt having boninitic affinity in Smith and Barnes ("Conowingo Creek metabasalt", this guidebook)]. At the type locality, the Bald Friar Metabasalt also occurs in ophiolitic mélange, however, Higgins and Conant (1986) mapped it as part of the Sykesville Formation. The distance between metabasalt and ultramafic rocks at Bald Friar, Maryland, is a few tens of meters, but here at Stop 14 it is only a few centimeters. As you can observe, a steatitized ultramafic fragment also occurs at the SE contact of the Cardiff Conglomerate SE of the slate, but metabasalt has not yet been verified there. As suggested by Smith in 1989 (published as Smith, 1993), the Peach Bottom structure is likely bounded by this folded, thrust-faulted, ophiolitic mélangé, now known to be equivalent to part of the Sykesville Formation of Higgins and Conant (1986).

The "stratigraphic" section of the mélange exposed at this stop from Whittaker Station SE to the NW edge of the Peach Bottom Slate was measured with reference to the locations of catenary poles (Figure 72) and is summarized in Figure 73. Features worth noting are the metabasalt-sediment contacts; the replacement type "banded iron formation" (BIF) that partially replaces one of the metabasalts; the sheared rock which, geochemically, is boninitic; sheared metabasalt in contact with a small metasomatized ultramafic fragment; and the large metasomatized ultramafic fragment (carbonate and minor talc). (The latter has "2 m of talc-magnesite schist on its NW side at an elevation of "300 feet which will not be examined on this trip. However, we will visit a chemically identical zone, represented by sample SETALC, on the SE contact of the Cardiff Conglomerate on the SE side of the slate.)

Descriptions, interpretations, and partial analyses of the ultramafic rocks and their reaction zones are provided in Tables 13-A and 13-B. At track level on the NW side of the slate, two ultramafic fragments in the mélange have been extensively metasomatized by Ca and CO₂, but their Cr contents of 1,000 and 1,800 ppm leave little doubt as to the protolith. Auclair and others (1993) described altered ultramafics from an extremely similar tectonic setting in Québec, but the rocks they described are mineralized with Cu, Ni, Zn, Co, and Au.

Figure 72. Map of Stop 14 along Conrail's Port Road (formerly the Pennsylvania Railroad, Columbia & Port Deposit Branch), from Whitaker Station to Peters Creek. The catenary pole numbers descend from No. 444 at the first outcrop to No. 422 at the end of the outcrop just north of the creek. Stations A through E are the locations for the Stop discussions, A-E. Participants will disembark on the Alan Weickel farm on the bluff above the Susquehanna River, descend through the woods to track level, and proceed southward along the track. When discussions end, everyone will cross the railroad bridge over Peters Creek and reboard busses in Peters Creek hamlet (Peach Bottom Station). 1. Bonsall & Yard quarry. 2. Gorusch open pits. 3. Smaller Gorusch quarries. 4. McSparran quarries. 5. Shank quarry.

* The rocks north of the Peach Bottom slate have traditionally been mapped as Peters Creek Formation, largely because the Peach Bottom structure was interpreted to be a regional syncline (see Knopf and Jonas, 1923). However, ultramafites and metabasalts (see discussion for Station A) are not rocks characteristic of the Peters Creek Formation. This problem, in addition to the uncertainty as to the nature of the Peach Bottom structure, raises the question of whether the name "Peters Creek" should be applied to the rocks north of the slate belt.
Figure 73. "Stratigraphic" section through ophiolitic mélangé from Whittaker Station SE to the NW edge of Peach Bottom Slate, NE shore of the Susquehanna River, Lancaster County. Scale divisions at all are 2-m intervals. + indicates sample location for which analytical data are presented in Table 13.
Table 13-A. Descriptions and interpretations of rocks of ultramafic affinities and their reaction zones from STOP 14, the NW-to-SE traverse across the Peach Bottom structure, Lancaster County. Four samples (SETALC, 20CMAPC, 17CMPC, and 3CMBKWL) represent a series of adjacent alteration zones. Two less altered ultramafic rocks (SHRTALC and CH-6) are included for comparison. Refer to Figure 72 for catenary pole locations.

<table>
<thead>
<tr>
<th>Sample Name</th>
<th>Description</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>7CMCARB</td>
<td>Metasomatized ultramafic fragment in contact with metabasalt containing 1.53% TiO₂, 35.5± m SE of BIF-bearing metabasalt and 38.5 m NW of 9.5-m-thick carbonate. Location, 14 m SE of Pole 443, plotted in Figure 72.</td>
<td>Protolith was ultramafic, based on Cr/Ti ratio and Ni. Extensive CO₂ and Ca metasomatism. Increase in volume shown by Cr dilution (Sanford, 1982).</td>
</tr>
<tr>
<td>9.5MCARB</td>
<td>Metasomatized ultramafic fragment from 1.5 m NW of SE contact. Same zone at elevation of ~300 feet is 5±2 m from Peach Bottom Slate and is 10.5±2 m thick, including ~2 m of talc-magnesite schist containing ~1,500 ppm each of Cr and Ni and ~0.5% TiO₂, NW side of slate. Location of middle of sample, 10 m NW of Pole 442, plotted in Figure 72.</td>
<td>Protolith was ultramafic, based on Cr/Ti ratio and Ni. Extensive CO₂ and Ca metasomatism. Increase in volume shown by Cr dilution (Sanford, 1982).</td>
</tr>
<tr>
<td>SETALC</td>
<td>Channel sample 1.9 m long of talc-magnesite schist collected at Pole 429 from contact between Cardiff Conglomerate and &quot;Peters Creek Schist,&quot; SE side of slate. Other analyses of this sample and its counterpart on NE side of slate in Smith (1993).</td>
<td>Protolith was ultramafic, based on Cr/Ti ratio and Ni. SiO₂ introduced from &quot;Peters Creek&quot; (contact with Cardiff faulted).</td>
</tr>
<tr>
<td>20CMAPC</td>
<td>Channel sample 20 cm long of altered &quot;Peters Creek&quot; from 3 to 23 cm SE of sample SETALC at Pole 429. SE 3 cm is rich in magnetite octahedra.</td>
<td>Protolith was &quot;Peters Creek,&quot; based on Cr/Ti ratio. May have supplied SiO₂ to talc-magnesite schist.</td>
</tr>
<tr>
<td>17CMPC</td>
<td>Channel sample 17 cm long of less visibly altered &quot;Peters Creek&quot; from 23 to 40 cm SE of sample 20CMAPC</td>
<td>&quot;Peters Creek,&quot; may have supplied SiO₂ to talc-magnesite schist.</td>
</tr>
<tr>
<td>3CMBKWL</td>
<td>Three centimeters of blackwall (Sanford, 1982) of dark chert and accessory rutile from 0 to 3 cm SE of sample 17CMPC.</td>
<td>Zr and Hf compared to above sample suggest a volume reduction to ~50±10%, primarily by SiO₂ loss.</td>
</tr>
<tr>
<td>SHRTALC</td>
<td>Composite of 10 chunks of float, each ≥28 cm, from 39°44'15&quot;N, 76°39'01&quot;W, Shrewsbury Township, York County.</td>
<td>Ultramafic altered to talc-anthophyllite-chlorite. On NW limb of Tucquan Anticline A Cambrian ultramafic in a mélangé, thrust in the Taconic and folded in the Alleghanian?</td>
</tr>
<tr>
<td>CH-6</td>
<td>Composite representing large volume from a quarry at 39°43'39&quot;N, 76°08'15&quot;W, Fulton Township, Lancaster County.</td>
<td>Relatively unaltered serpentinite from the main part of the Baltimore Mafic Complex.</td>
</tr>
</tbody>
</table>

Because of its relative immobility, Cr is a good reference element by which to estimate the volume increase that accompanied metasomatism of ultramafic rock. As noted by Sanford (1982), such volume increases are the norm. It is herein proposed that it is the volume increase during metamorphism or metasomatism of ultramafic rocks, as well as the low shear strength of talc, chlorite, and serpentine, that "attracts" faulting. Perhaps an ultramafic-bearing mélangé can best be conceptualized as a row of feather wedges that expand and push blocks of rock apart during the quarrying of dimension stone.

Sample SETALC, from the Cardiff—"Peters Creek Schist" contact on the SE side of the slate, chemically matches a similar sample from the NW side of the slate at an elevation of ~300 feet. Table 1 of Smith (published in 1993 but written in 1989) shows the similarity of samples SETALC and NW TALC for Ba, Co, Fe, Mn, Mo, Sc, Ti, V, Y, and Zr, as contrasted to three other chemically different talc samples from Lancaster and York Counties.

The three samples following SETALC in Tables 13-A and 13-B constitute a series of metasomatic reaction zones between the "Peters Creek" and the SE side of sample SETALC. As noted by Sanford (1982), country rock typically undergoes volume reduction by SiO₂ loss. The NW contact of the sample SETALC shows minimal reaction with the Cardiff, suggesting that some rock may be missing there because of faulting. Because of incomplete exposure, the thickness of the mélangé on the SE side of the slate is not known, but on the NW side it is at least 110 m.

**Peach Bottom Slate geochemistry.**

Analyses of four samples of Peach Bottom Slate from along the traverse for Stop 14 are
Table 13-B. Partial analyses of rocks of ultramafic affinities and their reaction zones from STOP 14, the NW-to-SE traverse across the Peach Bottom structure, Lancaster County. Two less altered ultramafic rocks (SHRTALC and CH-6) are included for comparison. Localities are as in Table 13-A.

<table>
<thead>
<tr>
<th>Name</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>CaO</th>
<th>MgO</th>
<th>Na₂O</th>
<th>K₂O</th>
<th>Fe₂O₃</th>
<th>TiO₂</th>
<th>Co</th>
<th>Cr</th>
<th>Ni</th>
<th>Th</th>
<th>U</th>
<th>Zr</th>
</tr>
</thead>
<tbody>
<tr>
<td>7CM CARB</td>
<td>31</td>
<td>1.4</td>
<td>20</td>
<td>13</td>
<td>0.1</td>
<td>0.02</td>
<td>4.5</td>
<td>0.04</td>
<td>44</td>
<td>1,000</td>
<td>890</td>
<td>&lt;0.5</td>
<td>&lt;0.5</td>
<td>&lt;10</td>
</tr>
<tr>
<td>9.5M CARB</td>
<td>23</td>
<td>1.4</td>
<td>21</td>
<td>16</td>
<td>.1</td>
<td>.04</td>
<td>6.1</td>
<td>.02</td>
<td>73</td>
<td>1,800</td>
<td>1,200</td>
<td>&lt;5</td>
<td>&lt;5</td>
<td>&lt;10</td>
</tr>
<tr>
<td>SE TALC</td>
<td>52</td>
<td>4.8</td>
<td>0</td>
<td>21</td>
<td>.1</td>
<td>.04</td>
<td>13</td>
<td>.71</td>
<td>100</td>
<td>2,300</td>
<td>1,600</td>
<td>&lt;5</td>
<td>&lt;5</td>
<td>50</td>
</tr>
<tr>
<td>20CM APC</td>
<td>54</td>
<td>20</td>
<td>.3</td>
<td>3.5</td>
<td>3.9</td>
<td>1.0</td>
<td>9.4</td>
<td>1.09</td>
<td>28</td>
<td>&lt;100</td>
<td>99</td>
<td>15</td>
<td>2.2</td>
<td>240</td>
</tr>
<tr>
<td>17CM PC</td>
<td>59</td>
<td>19</td>
<td>.1</td>
<td>2.2</td>
<td>.4</td>
<td>5.1</td>
<td>8.3</td>
<td>.90</td>
<td>19</td>
<td>&lt;100</td>
<td>41</td>
<td>15</td>
<td>3.6</td>
<td>210</td>
</tr>
<tr>
<td>3CM BKWL</td>
<td>35</td>
<td>18</td>
<td>.2</td>
<td>18</td>
<td>.2</td>
<td>.02</td>
<td>16</td>
<td>1.42</td>
<td>56</td>
<td>~70</td>
<td>73</td>
<td>22</td>
<td>2.5</td>
<td>480</td>
</tr>
<tr>
<td>SHR TALC</td>
<td>45</td>
<td>5.7</td>
<td>.5</td>
<td>24</td>
<td>.2</td>
<td>&lt;.01</td>
<td>16</td>
<td>.71</td>
<td>110</td>
<td>2,700</td>
<td>770</td>
<td>&lt;5</td>
<td>&lt;5</td>
<td>50</td>
</tr>
<tr>
<td>CH-6</td>
<td>37</td>
<td>2</td>
<td>.2</td>
<td>39</td>
<td>.01</td>
<td>.06</td>
<td>2.8</td>
<td>.0</td>
<td>–</td>
<td>–</td>
<td>~2,300</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

listed in Table 13-C, as is the best estimate for post-Archean average shales (PAAS) of Taylor and McLennan (1985). As a scan of the table reveals, all four samples are moderately similar despite their representing four varieties. Comparison with the data for PAAS indicates that the protolith for the Peach Bottom Slate was a shale, as expected. Based on the slightly high Fe, U, V, and Zn, it was likely a black shale. The high Al₂O₃ of the four Peach Bottom Slate samples likely reflects, in part, the loss of SiO₂ into Taconic quartz veins. Indeed, sample 3.7MPBM, which contains vein quartz ground into "nodules" by faulting, contains a more typical SiO₂ content (quartz veins were excluded from the other three samples). Low CaO, MgO, and Na₂O and high Al₂O₃ in the four Peach Bottom samples could reflect intense weathering of the source or loss during metamorphism.

David W. Valentino and Alexander E. Gates

Stops along the tracks:

The traverse along the railroad at the Susquehanna River includes the best exposed section of the Peach Bottom structure and the related formations. During this traverse through the Peach Bottom structure some questions to think about are:

1) What evidence is available to support a fold model for the Peach Bottom structure?
2) What are the various lithofacies of the different formations?
3) How many deformation phases are represented, and what phases are dominant?

Stop A: Peters Creek Formation just north of the Peach Bottom slate.

Deformed interlayered metasandstone, schist, and greenstone is the lithofacies at the southern margin of the Peters Creek Formation adjacent to the Peach Bottom structure. A zone of talc-dolomite-quartz rock separate the Peters Creek Formation from the black slate of the Peach Bottom Formation at this locality, however along strike eastward the Peters Creek Formation is in direct contact with the Peach Bottom Formation. The S3 schistosity is the dominant planar fabric in the Peters Creek and Peach Bottom Formations and the talc-dolomite-quartz rock. In the Peters Creek Formation S3 strikes about 040°-045° and dips 65°-70° southeast, while in the adjacent units S3 strikes about 030°-040° and dips 88°-90° southeast.
Table 13—C. Partial analyses of varieties of Peach Bottom Slate compared to a typical shale, the estimated post-Archaen average shale (PAAS) of Taylor and McLennan (1985). The mylonite zone used as a reference point for the first three samples occurs at Behre’s (1933) contact between Peach Bottom Slate on the NW and Peach Bottom Schist on the SE. It was described by Smith (1993, p. 5).

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Percent</th>
<th>Parts per Million</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>SiO₂</td>
<td>Al₂O₃</td>
</tr>
<tr>
<td>PBPYSL</td>
<td>Composite of 10 slightly pyritic pieces from 35 to 45 m SE of railroad</td>
<td>55</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>milepost 18 and 65 to 75 m NW of the NW edge of mylonite zone, between</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Poles 434 and 435.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBSL</td>
<td>Composite of 10 pieces from 1 to 10 m NW of the NW edge of mylonite zone,</td>
<td>56</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>2 to 11 m NW of Pole 432.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.7MPBM</td>
<td>Channel sample through 3.7-m-wide mylonite zone(^1) that trends N30°E</td>
<td>59</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>between Peach Bottom Slate and schist at Pole 432.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20CMCTD</td>
<td>Channel sample through 20-cm-thick chloritoid</td>
<td>55</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>zone, 14 m NW of Peach Bottom Schist-Cardiff</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>contact, 10 m NW of Pole 430.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PAAS</td>
<td>Estimated composition of post-Archaean average</td>
<td>63</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>shale (Taylor and McLennan, 1985).</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) \(^{40}\)Ar/\(^{39}\)K whole-rock analysis by Kruger Enterprises, Inc., (August 16, 1994) yielded an age estimate of 276±5 Ma for a sample collected by R. T. Faill and B. C. Smith, II, from the middle of the mylonite zone at an elevation of 4.5 m above track level. A similarly collected and analyzed piece of commercial slate from a small quarry 146 m to the NW yielded 279±5 Ma. These dates are in contrast to a K–Ar whole-rock estimate of circa 320 Ma for regional unloading (Lapham and Basset, 1964).
Figure 74. Microscopic deformation features of the Peach Bottom structure. (A) Magnetite porphyroclasts with chlorite pressure fringes in the Peters Creek Formation (horizontal field of view is 5 mm); (B) chloritoid porphyroclasts with quartz-muscovite pressure fringes in the Peach Bottom Formation (horizontal field of view is 1.5 mm); (C) S-C mylonitic fabric and dynamically recrystallized quartz in the Cardiff Formation (horizontal field of view is 5 mm).

This zone of S3 schistosity is separated from the Drumore tectonite by a thick section of Peters Creek Formation containing relatively lower D3 strain. In mylonitized quartz schist of the Peters Creek Formation magnetite porphyroclasts with asymmetric chlorite pressure fringes are common (Figure 74A). Although microscopic, these pressure fringes define a subhorizontal to moderately east plunging mineral-elongation lineation, and the asymmetry of the fringes is consistent with dextral shear.

Stop B. Peach Bottom slate adjacent to the Peters Creek Formation.

The Peach Bottom Formation is approximately 430 m thick along the railroad at the Susquehanna River. Field trip attendees should bring along the piece of the Drumore tectonite collected earlier for comparison with the lithologies of the Peach Bottom Formation. The northernmost section in the Peach Bottom Formation contains black slate with very planar S3 cleavage that strikes 025°-030° and dips 70°-80° southeast. A weak cleavage (S4) that strikes 270°-280° and dips 35°-50° north cross cuts the steeply dipping S3. The S4 cleavage will be discussed in detail at Stop 15, but the cross-cutting relationship between the S3 and S4 should be noted. Throughout the Peach Bottom Formation there are subhorizontal mineral elongation lineations associated with S3 that are made up of chloritoid grains with pressure fringes of quartz and muscovite (Figure 74B). These pressure fringes are both symmetric and asymmetric, and where they are asymmetric the distribution of pressure fringes about the porphyroclast is consistent with dextral shear. This suggests that dextral shearing occurring throughout the Peach Bottom Formation.
Stop C. Southern section of the Peach Bottom Formation and F5.

This stop is near the railroad mile marker 18. The lithology is silver-gray to silver-black slate and phyllonite. The S3 cleavage strikes 020°-025° and dips 70°-75° southeast. At track level there are F5 reclined folds that are defined by folded S3 cleavage and a weak S5 cleavage (Valentino and others, 1994; Valentino, this guidebook) is axial planar to the folds. The cross cutting relationship between the S4 cleavage and the F5 folds is not apparent at this stop, but it will be observed at Stop 15. In this area where F5 reclined folds are present the overall orientation of the S3 cleavage in the slate strikes 015°-020° and dips 70°-75° southeast. This change in cleavage orientation is probably due to large scale warping associated with F5 folding.

Stop D. Cardiff and Peters Creek Formations south of the slate belt.

The Cardiff Formation outcrops immediately south of the Peach Bottom Formation. The contact between the two units is abrupt, and is parallel to the S3 cleavage. The Cardiff Formation is a sheared conglomeratic quartzite at this locality with defomed white quartz pebbles (see Figure 43, p. 111) surrounded by recrystallized quartz and minor mica. The pervasive foliation in the quartzite is S3 (030° strike; 70° SE dip, and subhorizontal mineral elongation lineations (L3) are defined by elongate quartz pebbles. The quartz pebbles are dynamically recrystallized, and commonly dextral S-C mylonitic textures are present (Figure 74C). The Cardiff Formation is approximately 27 m thick at this locality. Immediately adjacent to the Cardiff Formation to the north is silver-black phyllonite and slate of the Peach Bottom Formation, and to the south is a thin zone of talc schist (Smith, 1993).

Figure 75 shows the lithologic sequence in the Peters Creek Formation just south of the Cardiff Formation along the railroad tracks. The lithologic sequence is as follows: (1) talc schist; (2) dark green chlorite-muscovite schist; (3) tan muscovite-quartz phyllitic schist; 4) interlayered metasandstone and chlorite-muscovite schist; and (4) thick layers of metasandstone with minor schist. The planar fabric in this sequence of rocks is the S3 schistosity, but the S1se can also be observed in the interlayered metasandstone and schist. Weakly developed S4 cleavage dips shallowly northward in the dark green chlorite-muscovite schist and the trace of S3 cleavage across discrete S4 cleavages reveals top to the north or normal offset. As we walk southwest through the Peters Creek Formation, away from the Peach Bottom Formation, the penetrative nature of the S3 schistosity weakens and the earlier schistosity (S1se) dominates the rocks.

Figure 75. Schematic outcrop diagram showing the lithologic sequence immediately south of the Cardiff Formation at the Susquehanna River. The view is looking northeast at a subvertical outcrop surface.

Stop E. Massive metasandstone units in the Peters Creek Formation.

The southernmost exposures along the railroad tracks adjacent to Peters Creek contain bodies of massive metasandstone and interlayered metasandstone and schist of the Peters Creek.
Formation. These massive metasandstone bodies contain mostly quartz with accessory micas and primary K-feldspar, and these bodies are compositionally identical to the Cardiff quartzite. The S3 schistosity is present at this locality, but the next outcrops to the south contain no evidence for S3, therefore this is the southernmost limit of D3 deformation at the Susquehanna River. The contact between the chlorite-bearing massive metasandstone and the underlying interlayered metasandstone and schist is folded. The S3 schistosity is axial planar to this fold suggesting that it is a third generation fold.

**Tectonic significance.** The syncline interpretation for the Peach Bottom structure (Knopf and Jonas, 1929) was based on map patterns of the Peters Creek, Cardiff, and Peach Bottom Formations. Based on new observations derived from mapping, meso- and microscopic structural analysis, metamorphic petrology, and lithofacies analysis, the Peach Bottom structure is interpreted to be a splay in a strike-slip shear zone system that is continuous with the Pleasant Grove-Huntingdon Valley zone (Valentino, this guidebook). This is a radical new interpretation that has serious implications with respect to the regional stratigraphic nomenclature and deformation history.

Because the Cardiff Formation has the same composition and tabular geometry as massive metasandstone bodies in the Peters Creek Formation, and it resides adjacent the Peters Creek Formation, the Cardiff Formation is probably related to the Peters Creek rift-related deposits. The Peach Bottom Formation resides structurally as a steeply-dipping, tabular-shaped body within the Peters Creek Formation. Smith (1993) suggested that Peach Bottom and Cardiff Formations were thrust onto the Peters Creek Formation along a talc-coated thrust fault. The calc schist that Smith (1993) proposed to be the thrust surface is currently dominated by S3 schistosity. A more likely explanation for the calc schist is structural emplacement during D3 strike-slip shearing, not some hypothetical thrusting for which there is no evidence. Correlation of the Peach Bottom Formation with the Arvonite slate based solely on lithologic similarity is unfounded. The Peach Bottom Formation is not a simple prograde slate. The slaty cleavage is the third regional fabric (S3) and is the second local fabric to penetrate the Peach Bottom Formation. The intense S3 cleavage and lithologic similarities with the Drumore tectonite suggest that the Peach Bottom Formation may have originated as a phyllonite, possibly an "ultraphyllonite". If the Peach Bottom Formation is an original sedimentary unit, then it is probably related to the Peters Creek rift-related sequence.

During this stop we walked across a major deformation zone in the Peach Bottom structure, but more importantly we walked out of a crustal scale dextral shear system and across an ancient transform plate boundary. Large offset on this boundary (Valentino and others, 1994) can account for the differences in lithofacies, deformation history, and metamorphic patterns between the Octoraro and Peters Creek Formations.

Samuel W. Berkheiser, Jr.

**Economic geology.**

You are looking at one of the world's best roofing slates. The Peach Bottom District was the birthplace of slate mining in Pennsylvania and roofing slates might have been mined here as early as 1785. The exceptionally high crushing strength and toughness of the slate are characteristics that made this product highly prized as a quality roofing product. Unfortunately, these very same characteristics lead to the premature demise of mining in this district, circa 1920. Slates from other localities, for example the Lehigh-Northampton District, are much easier to mill and shape into a wide variety of products such as blackboards, tiles, walk-way flagging, flooring, mantels, billiard-table tops, panels, sinks, turkey calls, etc. Only roofing slate, roofing granules, rough-finished grave vaults, and steps and risers were ever produced from the Peach Bottom District in any significant quantity.

The Peach Bottom slate is characterized as an unfading mica slate having a very bright luster. Mineralogically, the slate is composed of major mica (probably muscovite), chlorite, and quartz, minor feldspar (such as albite) and kaolinite, and a trace of other feldspar, such as microcline. Andalusite, graphite, pyrite, magnetite, rutile, zircon, chloritoid, and kyanite also have been reported.
The strike length of the Peach Bottom slate along its northeast-southwest trend in Pennsylvania and Maryland is approximately 18 miles. The Peach Bottom slate and associated schist is generally estimated to be approximately 1000 feet thick. Most quarries in the Peach Bottom District do not exceed about 200 feet in apparent stratigraphic width. At this stop, based on strike projections of abandoned quarries and pace-and-compass calculations, the ore zone is estimated to be approximately 375 feet in apparent stratigraphic thickness.

Some things to contemplate and look for:
1. Can you find indications of bedding?
2. How many cleavages can you observe in the ore zones?
3. How many cleavages can you observe in the Peach Bottom schist?
4. How can you tell when you are in the ore zones?
5. Besides hardness, what other features can you observe that would limit the commercialization of this product?
6. How does the jointing affect mining?
7. If the primary cleavage is axial-planar, what are the structure setting options?
8. Where might recognizable fossils be found?
9. Instead of a major fold belt, what are some of the structural alternatives for the Peach Bottom slate and schist?
10. What interpretations can be made about the protolith from the geochemical analyses?
11. To what use might the waste fines from the production of slate roofing granules be put?

Wiliam D. Sevon

Terrace gravels.

Potato stone, potato stone
    How round and firm you are.
Potato stone, potato stone,
    I wonder who you are.

Are you from the Piedmont,
    Only come a little way,
Or from the Ridge and Valley,
    Travelled far to stop and stay.

Conferees will depart from the busses and walk across a field to the wooded area where a descent will be made past a small slate quarry, across some slate waste piles, and down the slope to the railroad track.

As you cross the field keep your eyes open for "potato stones." These are rounded quartz pebbles and cobbles up to several centimeters in diameter. They are remnants of upland terrace gravels that Pazzaglia considers to be upland terrace Tg2 (Figure 48, p. 122) which was probably deposited ~14-11 ma and correlates with phase 2 of Bryn Mawr Formation deposition in Maryland (see Pazzaglia and Gardner, this guidebook). This location is about 300 feet above the riverbed of the Susquehanna River, a distance that should give you some appreciation of the amount of lowering accomplished by the Susquehanna River during the interval since deposition of the gravel.

Most of the upland terrace gravels have been colluviated from their original position and that is certainly the case here. However, enough gravels occur in essentially undisturbed positions (e.g., at mileage 50.4 on the route between Stops 14 and 15) that Pazzaglia was able to reconstruct terrace profiles with confidence and put together the excellent correlations and model presented in this guidebook and elsewhere.

LEAVE ENTRANCE TO FIELD LANE. TURN RIGHT onto Slate Hill Road.

STOP SIGN. TURN RIGHT and cross over Peters Creek.

Park in wide areas at Peach Bottom.

LEAVE PARKING AREA FOR STOP 14. RETURN VIA THE SAME ROUTE.

Cross bridge over Peters Creek and TURN RIGHT onto Peach Bottom Road.

BEAR RIGHT onto Riverview Road.

BEAR RIGHT uphill following Riverview Road. Road to left goes up Puddle Duck Creek valley which is an excellent example of the interrelationship of landscape position and surficial deposits (Sevon, 1991). In the valley bottom just upstream from the road intersection, a knickpoint occurs in
the stream bed and Puddle Duck Creek flows across bedrock. Downstream from the knickpoint the valley is narrow, v-shaped, has steep valley sides covered with little or no surficial material, and outcrops of bedrock are abundant. Upstream from the knickpoint the valley has a broad floodplain, outcrops of bedrock occur infrequently in the lower part of the drainage basin but are absent in the upper part and slopes of valley sides are less steep than those downstream from the knickpoint and are covered with variable thicknesses of colluvium. The valley floor beneath the floodplain surface has several feet of alluvium which intermixes with colluvium at the valley-bottom margins. The steepness of slopes decreases gradually upstream and slopes in the headwater areas of the drainage basin are very low. The developmental sequence is probably as follows: the drainage basin was eroded from an earlier landscape starting in the middle Miocene and the general form was carved prior to about a million years ago. During the Pleistocene glacial intervals, material was eroded from higher landscape positions and deposited on lower positions, mainly the side slopes. Some material was carried out of the drainage basin by Puddle Duck Creek. Sea level lowering associated with Pleistocene glacial intervals caused one or more knickpoints to migrate up the Susquehanna River. This resulted in lowering of base level for Peters Creek. A knickpoint migrated up Peters Creek past its juncture with Puddle Duck Creek. That knickpoint is the one now migrating up Puddle Duck Creek.

2.2 50.4 Outcrops on both sides of the road in the ditches contain abundant upland gravels composed of quartz pebbles. This gravel deposit is about 1.6 miles from the Susquehanna River and is at an elevation of 490-500 feet. Just over the hill crest to the northeast is the Kirk farm. Pazzaglia and Gardner (Figure 48, p. 122) place this gravel in Tg1 which correlates with phase 1 of Bryn Mawr Formation deposition in Maryland, ~20-15 Ma.

0.4 50.8 STOP SIGN. TURN RIGHT onto Pilottown Road at Black Baron.
0.3 51.1 TURN RIGHT onto Cooks Landing Road.
0.6 51.7 STOP SIGN. CONTINUE STRAIGHT AHEAD following Cooks Landing Road.
1.3 53.0 Park in area adjacent to railroad tracks.

STOP 15. THE PETERS CREEK FORMATION.
Discussants: David W. Valentino and Alexander E. Gates

This is the fourth stop in the Peters Creek Formation, and the final stop of the field trip. The goal of this stop is to summarize the lithofacies variation in the Peters Creek Formation, show the various early deformation features away from the Pleasant Grove-Huntingdon Valley zone and the Peach Bottom structure, and discuss the youngest phase of cleavage producing deformation in the western Piedmont along the Susquehanna River.

Thin-bedded, graded metasandstone interlayered with chlorite-muscovite schist is the lithofacies for the Peters Creek Formation locally (Figure 76A). Detrital quartz and K-feldspar are abundant in the metasandstone layers, and the contacts with schist layers are often gradational. Where younging features are preserved, such as grain-size and compositional grading, the beds are right-side-up, however, this does not preclude local reversal in the younging direction where beds define the F1se intrafolial folds. Compositional grading is best preserved at the northernmost part of the outcrop. Based on the scale and frequency of metasandstone and schist interlayering this lithofacies is interpreted to represent turbidites.

The penetrative schistosity that is parallel to the compositional layering is the S1se schistosity (Figure 1A). F1se intrafolial isoclnal folds are not common but with careful hunting it is possible to find a few of these folds in parts of the outcrop with centimeter-scale layering (Figure 76B). This outcrop is located in the M1se biotite zone and the metamorphic mineral assemblage is biotite-chlorite-muscovite. Note the absence of the steeply dipping S3 schistosity that occurs in the Peters Creek Formation near the Peach Bottom structure.

Late Paleozoic Extension (D4). Late deformation in the western Piedmont resulted in the development of open symmetric folds (Figure 77A) with axial planar spaced cleavage (Figure
Lithology and deformation features in the Peters Creek Formation. [A] Outcrop of interlayered metasandstone and schist; and [B] F1se intrafolial isoclinal folds cross cut by S4 and refolded by F4.

77B), conjugate box-folds (Figure 77C), meso- and micro-scale conjugate cleavages (Figures 78A, 78B and 78C), and kink bands (Figure 78D). At this stop, D4 deformation appears as spaced open symmetric folds (Figure 77A) defined by folded S1se and compositional layering, and variably spaced cleavage depending on the lithology. This phase of deformation is classified as D4 because it clearly cross cuts D3 structures in the Drumore tectonite. At the Susquehanna River the S4 cleavage generally strikes between 250°-275°, dips between 15°-50° north, and is axial planar to open symmetric folds. Discrete microscopic shear zones, often with evidence of pressure solution (Figure 78E) and magnetite porphyroclasts with quartz pressure fringes (Figure 78F), reveal normal shear sense or top down to the north. There is a minor cleavage that occurs at an angle and appears to be conjugate to the dominant cleavage. The minor cleavage strikes between 250°-275°, dips between 0°-30° north, occurs in conjugate box folds (Figures 77C, 78C, and 78D) with the dominant cleavage, and, using similar kinematic indicators, has top to the south shear sense. This minor cleavage was never observed independent of the dominant S4 cleavage, and both cleavages are associated with a chlorite-muscovite metamorphic mineral assemblage. Identical geographic distribution and identical mineral assemblages of recrystallization suggest that the two cleavages formed during the same thermal episode, possibly coeval. The opposing sense of displacement, and relative angular relationships between the cleavages and kink bands suggests they developed as a conjugate pair. To distinguish the dominant cleavage from the minor, the dominant S4 cleavage is considered the antithetic cleavage in a conjugate pair, therefore, the nomenclature S4a was adopted (Valentino, 1992; Valentino, 1993; Valentino and others, 1994). Similarly, the minor S4 cleavage is considered the sympathetic cleavage and referred to as S4s. Both S4a and S4s are associated with recrystallization of muscovite and chlorite.

Assuming the cleavages are a conjugate pair, the resolved orientations of the maximum and minimum axes of bulk strain are as follows: (1) the axis of bulk shortening plunges 75°-90° south and trends about north-south, and (2) the axis of bulk extension trends north-south and plunges 0° to 15° northward. These orientations for the axes of bulk shortening and bulk extension are consistent with extensional deformation.

The zone of S4 cleavage is adjacent to the Tucquan antiform; a broad open upright arch that is 27 km wide at the Susquehanna River and tapers to about 7 km in width over a distance of 45 km eastward. Bedrock geologic mapping indicates that the Tucquan antiform had 6-7 km of structural relief at the broadest point prior to erosion, and about 2 km of relief where the structure ends in the east. Within the zone of D4 deformation, the part of the zone adjacent to the lowest relief portion of the Tucquan antiform, in the east, is dominated by kink bands,
while chlorite-grade metamorphic cleavage is pervasive in the part of the zone adjacent the highest structural relief portion of the antiform at the Susquehanna River. Similarly the zone of D4 deformation is widest (4 km) and most confined (0.5 km) adjacent to the broadest and most narrow parts of the antiform, respectively. There appears to be a direct relationship between the trend-parallel variability in the amplitude of the Tucquan antiform and the along strike structural and morphological variation in the zone of cleavage. The along strike variation in metamorphism associated with the cleavage zone may be the direct result of differential crustal thickening along the trend of the Tucquan antiform. Low-grade metamorphism associated with the cleavage pair is regionally continuous with metamorphism associated with local Alleghanian dextral transpressive structures, specifically the Tucquan antiform and Pleasant Grove-Huntingdon Valley shear zone. There is no record of a separate low-grade metamorphic assemblage in rocks of this part of the Piedmont suggesting the S4 cleavages and Tucquan antiform evolved during the same thermal episode. Therefore, it is concluded that a transition from transpression to extension occurred during the same thermal event. This dramatic change in deformation regime during the same thermal event may be the result of localized gravitational extension after transpressive crustal thickening, but it cannot be ruled out at this time that the cleavages developed as the result of localized transtension, or as the result of the onset of Mesozoic rifting.

**LEAVE STOP 15. RETURN VIA THE SAME ROUTE.**

1.2 54.2 STOP SIGN. CONTINUE STRAIGHT AHEAD following Cooks Landing Road.

0.6 54.8 STOP SIGN. TURN LEFT onto Pilottown Road.

2.7 57.5 STOP SIGN. CONTINUE STRAIGHT AHEAD onto US Route 222 North (Robert Fulton Highway).
1.0  58.5  BEAR LEFT onto PA Route 272 North (US Route 222 turns right). Route will proceed across higher and higher Piedmont uplands. These uplands occur along the drainage divide between tributaries to the Susquehanna River on the left and tributaries to Conowingo Creek on the right. There are no outcrops of bedrock and the depth to bedrock may locally be as much as 100 feet.

3.3  61.8  Good views ahead and on the right of Piedmont upland terrain.

3.3  65.1  This is the highest of the uplands in this area of south dipping foliation. The elevation at the highest is 740 feet. This area is underlain by saprolite (Figure 56, p. 138). Note ahead as the route goes down slope to the blinking light at Buck that the south margin of the Tuscan antiform makes a prominent ridge rising to over 900 feet in elevation.

0.8  65.9  BLINKING LIGHT. CONTINUE STRAIGHT AHEAD.

8.7  74.6  STOP LIGHT. CONTINUE STRAIGHT AHEAD onto US Route 222 North.

2.8  77.4  Cross Conestoga Creek.

0.4  77.8  STOP LIGHT. TURN RIGHT onto Chesapeake Street.

0.6  78.4  STOP LIGHT. CONTINUE STRAIGHT AHEAD.

1.0  79.4  STOP LIGHT. TURN RIGHT onto East King Street and PA Route 462 East.

0.9  80.3  STOP LIGHTS. TURN LEFT onto PA Route 340 East.

1.4  81.7  TURN LEFT onto US Route 30 West.

0.8  82.5  EXIT RIGHT to Greenfield Road.

0.3  82.8  STOP SIGN. TURN RIGHT onto Greenfield Road and almost immediately TURN RIGHT into Holiday Inn parking lot.

END OF FIELD CONFERENCE. HAVE A SAFE TRIP HOME!!
Figure 78. D4 deformation features in the Peters Creek Formation. [A] View looking northeast at the conjugate S4s and S4a cleavage in pelitic schist at the outcrop scale; [B] conjugate S4s and S4a in a handsample; [C] photomicrograph of conjugate S4s and S4a (the horizontal field of view is 5 mm); [D] view looking west at conjugate S4 kink bands in the Drumore tectonite showing S4 cross cutting S3; [E] photomicrograph of a discrete S4s shear zone with concentration of oxide minerals as the result of pressure solution (the horizontal field of view is 5 mm); and [F] porphyroclast of magnetite with asymmetric pressure fringes of quartz associated with S4s in a quartz schist (the horizontal field of view is 4 mm).
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