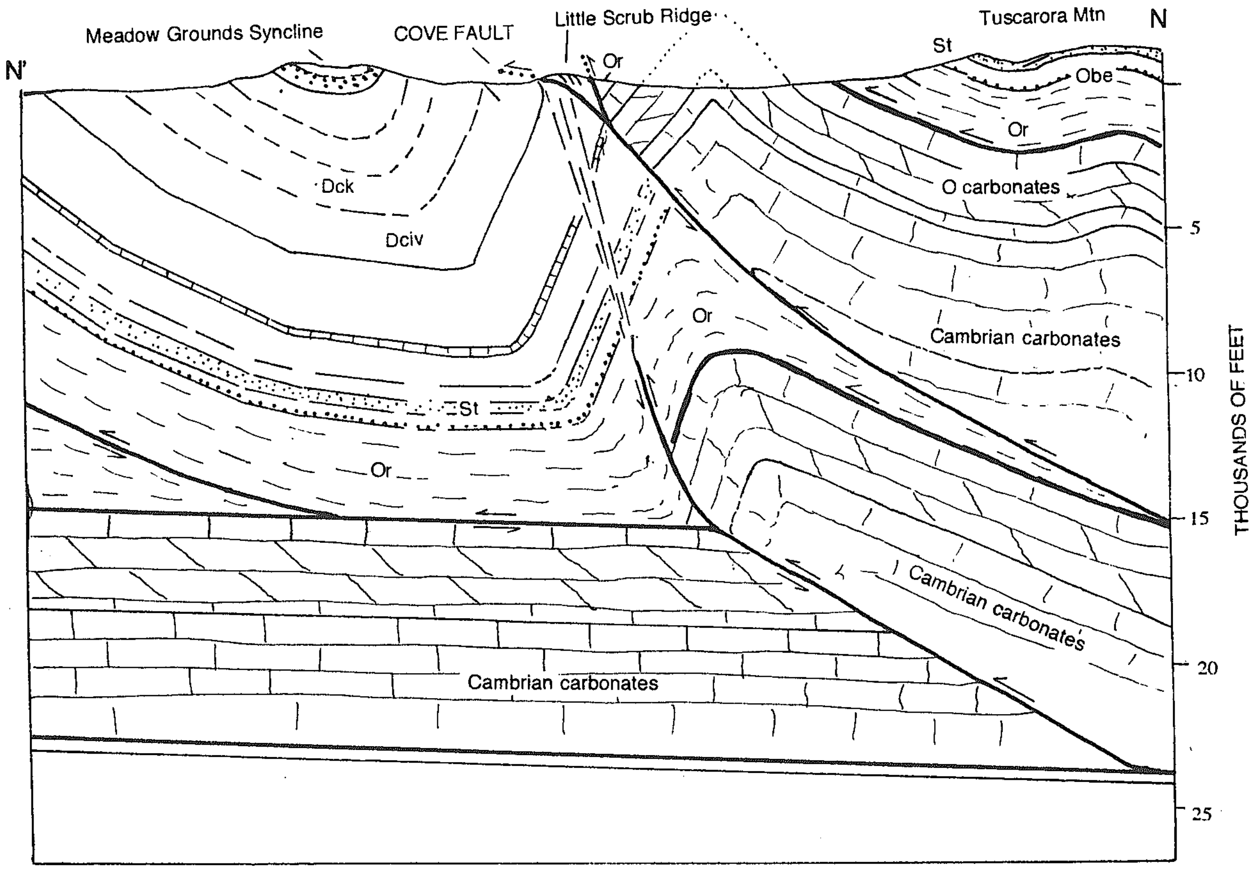
GUIDEBOOK

61ST ANNUAL FIELD CONFERENCE OF PENNSYLVANIA GEOLOGISTS

Alleghanian Sequential Deformation on the SW Limb of the Pennsylvania Salient in Fulton and Franklin Counties, South-Central Pennsylvania



Host: Bucknell University

October 3, 4, and 5, 1996
Chambersburg, PA

Guidebook for the

61st ANNUAL FIELD CONFERENCE OF PENNSYLVANIA GEOLOGISTS

ALLEGHANIAN SEQUENTIAL DEFORMATION ON THE SW LIMB OF THE PENNSYLVANIA SALIENT IN FULTON AND FRANKLIN COUNTIES, SOUTH-CENTRAL PENNSYLVANIA

Richard P. Nickelsen, Leader and Organizer

Additional contributors:
Donald P. Cederquist
Helen Delano
William Edmunds
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Kenneth A. Foland
W. D. Sevon
John A. Stamatakos
Rob Van der Voo

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Cover: Section through Little Scrub Ridge (Figure 32, p. 78, this guidebook).

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Frontispiece. 1995 Field Conference of Pennsylvania Geologists group photograph at Lockport Recreational Area, Lock Haven, PA.

TABLE OF CONTENTS

	Page
Alleghanian sequential deformation on the sw limb of the Pennsylvania salient in Fulton and Franklin Counties, south-central Pennsylvania - R. P Nickelsen.	1
Introduction	1
Structural studies in Fulton and Franklin Counties, south-central Pennsylvania	2
Introduction.	2
Pre-folding shortening directions.	2
The Tuscarora fault/Antes-Coburn detachment.	3
Two different fault populations on the northwest limbs of the McConnellsburg-Big Cove and the Path Valley anticlines	7
Early faults.	7
Late faults.	8
Summary	8
An attempt to date the Tuscarora fault/Antes-Coburn detachment - K. A. Foland	9
Introduction	9
Methods	10
Results.	11
Structural and tectonic framework of Alleghanian sequential deformation in the southwestern limb of the Pennsylvania salient from paleomagnetic and rock magnetic studies - J. A. Stamatakos, D. A. Ferrill, D. P. Cederquist, and R. Van der Voo	14
Introduction	14
Regional results	15
Age of remagnetization	15
Remagnetization and folding	16
Paleomagnetic rotations	16
Paleomagnetism of Ordovician carbonates from Franklin and Fulton Counties, Pennsylvania	18
Sampling and methods	18
Demagnetization results	18
Fold tests	21
Rotations	21
Age of folding.	24
Implications for Alleghanian deformation in Franklin and Fulton Counties	24
Anisotrophy of magnetic susceptibility	24
Surficial geology of the McConnellsburg quadrangle - W. D. Sevon	26
Introduction	26
Surficial materials	26
Residual regolith	26
Transported regolith	28
Alluvium	30
Geomorphology	31
Aspects of human history - R. P. Nickelsen	31
General comments - R. P. Nickelsen	34

Pre-folding shortening 35
The Tuscarora fault/Antes-Coburn detachment 36
Evolution of the SW limb of the Pennsylvania salient 36
Acknowledgements 37
Road log and stop descriptions - Day 1 43
Stop 1. Overview of McConnellsburg anticlinal valley and discussion of regional structural geology and geomorphology - R. P. Nickelsen and W. D. Sevon 43
Stop 2. Outcrop of basal Reedsville Formation containing an exposure of the Tuscarora fault/Antes-Coburn detachment - R. P. Nickelsen . 48
Stop 3. Tuscarora breccia in separated outcrops along the Cove Fault zone - R. P. Nickelsen 53
Stop 4. Cove Fault juxtaposes low-dipping Ordovician carbonates against vertical Ordovician-Devonian section at the south end of Lowery Knob - R. P. Nickelsen 59
Lunch stop. Mauch Chunk Formation in the Meadow Grounds valley - W. Edmunds 65
Stop 5. Structure of the Cove Fault zone on Little Scrub Ridge -R. P. Nickelsen 70
Stop 6. Evidence of pre-folding layer-parallel-shortening at the Burnt Cabins plunge-out of the McConnellsburg anticline - A. Gooch and R. P. Nickelsen 79
Road log and stop descriptions - Day 2 85
Stop 7. Tuscarora Formation with bedding plane exposures showing pre-folding strike-slip faults - R. P. Nickelsen 86
Stop 8. Pre-folding strike-slip faults in Ordovician carbonates of the Path Valley - R. P. Nickelsen 90
Stop 9. Ordovician carbonate-Reedsville section containing an exposure of the Tuscarora fault/Antes-Coburn detachment - R. P. Nickelsen. 92
Lunch stop. Cowans Gap debris slide-flow - H. Delano 95
Stop 10. Discussion of mapping that demonstrates overprinting of the later Path Valley fault upon pre-existing structures of Tuscarora Mountain and the Path Valley - R. P Nickelsen 98
Stop 11. Sink on trace of Path Valley fault where middle Ordovician Bellefonte dolomite is in contact with and strikes into upper Ordovician Reedsville shale - R. P Nickelsen 103
References cited 104

LIST OF FIGURES

Figure
1 Pre-folding shortening directions 4
2 Tuscarora fault/Antes-Coburn detachment localities 6
3 $^{40}Ar/^{39}Ar$ incremental heating age spectra for two rock samples . . 12
4 Paleomagnetic fold test and mean B- and C-component declinations . 17
5 Outcrop patterns of Cambro-Ordovician strata and sample localities . 19
6 Vector end point diagrams for thermal demagnetization 20

7 Site mean directions for thermal demagnetization 22
8 Map showing mean declinations for B-component magnetization . . 23
9 Anisotrophy of magnetic susceptibilty results show internal carbonate strain 25
10 Surficial geology of the McConnellsburg quadrangle, NE corner . . 27
11 Historical iron ore mines of Franklin county 33
12 Field trip route map 39
13 7.5-minute quadrangles of the 1996 Field Conference area . . . 40
14 Stratigraphic units of the Field Conference area. 41
Bonus figures from Pierce (1966). 42
15 View SW from Tuscarora Summit 45
16 View WNW from Tuscarora Summit. 45
17 Stereonet of rotated early strike-slip faults measured near Stop 1 . . 46
18 Map and section of the Tuscrora fault/Antes-Coburn detachment at Stop 2 . 50
19 Section of Tuscarora fault/Antes-Coburn detachment at a nearby farm . 52
20 Stereonet plot of structures in the Tuscarora fault/Antes-Coburn detachment 53
21 Geologic map of the NE part of the Big Cove Tannery quadrangle . . 54
22 Section S-S' through Lowery Knob 56
23 Section W-E through Lowery Knob 56
24 Outcrop map of the north end of Lowery Knob 57
25 Map of Big Cove Tannery quarry, SW plungeout of McConnellsburg anticline 60
26 Stereonet plot of strike-slip faults and wedges at Big Cove Tannery quarry . 61
27 Stereonet plot of slickenlines on wedges at Big Cove Tannery quarry . 61
28 Section through footwall of Cove fault along Esther Run 63
A Correlations of the Mauch Chunk Formation. 67
29 Outcrop map of Little Scrub Ridge near Stop 5 71
30 Detailed outcrop map of Stop 5 73
31 Geologic map of transverse faults along Scrub and Little Scrub Ridges . 76
32 Section N-N' through Little Scrub Ridge 78
33 Block diagram of fold-strike-slip fault relations at Stop 6 81
34 Poles to bedding of Keefer sandstone at Stop 6 82
35 Poles to bedding at Burnt Cabins plungeout of McConnellsburg anticline . 82
36 Poles to unrotated strike-slip faults at Stop 6 83
37 Traces of rotated strike-slip faults showing shortening direction at Stop 6 . 83
38 Geologic map of Tuscarora Mountain and the upper Path Valley . . 87
39 Poles to bedding and poles and traces of strike-slip faults, Stop 7 . . 88
40 Traces of rotated strike-slip faults, Stop 7 88
41 Fold axis defined by bedding poles in a carbonate anticline of the Path Valley 91
42 Traces of rotated strike-slip faults in limestones, Stop 8, Dry Run quarry . 91
43 Drawing of a section through the Tuscarora fault/Antes-Coburn detachment 93
B Location map of Cowans Gap State Park debris slide-flow 96
44 Geologic map of faults on Tuscarora Mountain 99
45 Outcrop map of the Tuscarora Formation in Carrick Valley Gap . . 101
46 Sections X-X' and Y-Y' through Tuscarora Mountain 102

LIST OF TABLES

Table		Page
1	Summary of $^{40}Ar/^{39}Ar$ age results	11

ALLEGHANIAN SEQUENTIAL DEFORMATION ON THE SW LIMB OF THE PENNSYLVANIA SALIENT IN FULTON AND FRANKLIN COUNTIES, SOUTH-CENTRAL PENNSYLVANIA

by
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INTRODUCTION

This field conference is about the evolution of the structures on the southwest limb of the Pennsylvania Salient during the Alleghanian Orogeny. Unlike the northeast limb of the salient where Alleghanian structural evolution involved clockwise overprinting of a sequence of tectonic structures, the southwest limb evolved through counter-clockwise overprinting. Evidence of widespread clockwise overprinting on the northeast limb was first recognized in a regional study of the Pocono Plateau and northern Anthracite Region by Geiser and Engelder (1983). Although not realizing their regional significance, local examples of this clockwise overprint had previously been described in the Lewisburg region (Faill, 1973, p. 119) and at the Bear Valley strip mine (Nickelsen, 1979). Gray and Mitra, (1993) have recently provided evidence that the clockwise overprint of Alleghanian structures in the Anthracite Region on the northeast limb of the Pennsylvania Salient is a continuous process involving five sequential, partially overlapping stages, and thus is not limited to only two distinct phases, Main and Lackawanna, as originally proposed by Geiser and Engelder (1983).

The counter-clockwise overprint of the Alleghanian sequential deformation on the southwest limb of the salient appears simpler, at least in the Fulton and Franklin County area, because the variety of stratigraphic units and structures available for study are limited, compared to the northeast limb, but it is possible to establish that the sequence here is multiphased, specifically including at least: (1) an early Alleghanian pre-folding period of layer-parallel-shortening documented largely by conjugate, strike-slip faults. This shortening seems to have occurred at about the same relative time and in the same orientation as the pre-folding, bed-parallel transport toward the foreland along the Tuscarora Fault of Pierce (1966), (2) a period of major folding which folded inferred shortening directions and the Tuscarora fault, and (3) several late, out-of-sequence, steep reverse faults, that overprint all older structures in the sequential assemblage and locally truncate earlier Alleghanian first-order folds.

The present work was begun after completing a study of the Kishacoquillas Valley (Nickelsen, 1988) where it first became apparent that the sequential overprinting of Alleghanian structures on the SW limb of the Pennsylvania Salient was counter-clockwise and that a final event in the deformation in that area was a steeply-dipping reverse fault (the Saddler Gap fault) that truncated previous structures. I was attracted to the Fulton/Franklin County area because here previous mapping had shown truncation of earlier structures by two major faults - the Cove fault and the Path Valley fault - and I wanted to see if they had similar fault fabrics to those in the Saddler Gap fault. Study of the Kishacoquillas Valley had also revealed the presence of a folded detachment or movement zone named the Antes-Coburn detachment that served both as the folded roof of an Ordovician carbonate duplex and as the floor of imbricate thrusts rising into the Silurian section. I wanted to compare this fault to the Tuscarora fault.

Two other geologists have participated in studies of the rocks of this region and have contributed to our knowledge of the structure and the age of deformation. John Stamatakos has been studying the Permian remagnetization of rocks in the Pennsylvania salient and has made major contributions to our knowledge of the origin of the salient. Ken Foland recently attempted to radiometrically date the Tuscarora fault/Antes-Coburn detachment, and has developed knowledge that will aid in a second attempt to establish a new age. They both have papers included in this guidebook.

Finally, Bill Sevon has reviewed the important surficial mapping in the McConnellsburg quadrangle by Ken Pierce (1966). This was the first modern surficial map of the Valley and Ridge Province in Pennsylvania and has served as a model for more recent surficial studies.

STRUCTURAL STUDIES IN FULTON AND FRANKLIN COUNTIES, SOUTH-CENTRAL PENNSYLVANIA

Introduction.

The study of sequential deformation on the SW limb of the Pennsylvania salient in the Fulton and Franklin Counties area has been directed by the availability of suitable outcrops. As work progressed, primary objectives remained the same but some parts were discarded because rock exposures were absent or inadequate. Structural studies have focused on: (1) regional measurement of pre-folding shortening directions on suitable rock types; (2) defining directions of folding, and describing their geometric relationship to pre-folding shortening directions, and to the Tuscarora fault/Antes-Coburn detachment; (3) discovery and study of all available outcrops of the Tuscarora fault/Antes-Coburn detachment; and (4) establishing the geometrical and sequential relationship of the two major faults in the region - the Cove and Path Valley faults - with the structures studied in (1), (2), and (3). These structural studies will be discussed generally in this introductory material under the following headings: [1] Pre-folding shortening directions; [2] the Tuscarora fault/Antes-Coburn detachment; and [3] Two different fault populations on the northwest limbs of the McConnellsburg-Big Cove anticline and the Path Valley anticline.

Pre-folding shortening directions.

In this field area, pre-folding shortening directions can only be defined as the acute bisectors of conjugate strike-slip faults or, in rare cases, the bearing of slickenlines on conjugate thrust-backthrust systems of faults. Strike-slip faults that are suitable must have slickenlines parallel or nearly parallel to their fault/bedding intersection, and occur in an array that includes at least some members that have acutely intersecting pairs that demonstrate conjugate right-lateral and left-lateral slip. A number of examples of the kind of faults and fault fabrics that are most useful will be demonstrated at Stops 1, 4, 5, and, particularly, 6 and 7. The data sets that have been dealt with are the minimum that could be used to achieve the results desired....there just aren't enough faults to be measured at most localities, except at Stop 6.

Interpretation of the measurements requires first a rotation with bedding until bedding is horizontal and the faults have attained their pre-folding attitude. Then the array of faults is plotted on a stereographic projection, paying special attention to any conjugate fault pairs that displayed different slip senses in the correct orientation to each other. The pre-folding shortening direction is inferred to be the mean strike of the array of strike-slip faults, which at many localities coincides quite well with the acute bisector of conjugate pairs of strike-slip faults from the same outcrops. As in other regions (Nickelsen, 1979; Gray and Mitra,1993), there is evidence here that deformation was continuous although it has been divided into a stage of layer-parallel-shortening, followed by a stage of folding. Thus, in many cases slickenlines on strike-slip faults are not rigorously parallel to the fault/bedding intersection because some folding preceded faulting, indicating that the transition from the layer-parallel-shortening stage to the folding stage did not always occur at the same relative time.

Figure 1 shows pre-folding shortening directions at 20 localities on the McConnellsburg-Big Cove anticline and the Path Valley anticline, some of which will be visited on this field trip. The shortening directions are not parallel thoughout the region but in most cases strike slightly north of the perpendicular to the strike of bedding. Only in the Stop 6 vicinity was it possible to clearly define the axis of the fold which overprinted the strike-slip faults that were measured. All of the localities have at least some strike-slip faults with slickenlines parallel to the fault/bedding intersection, and other faults where this is not the case are part of the same array. Because the transition from the stage of shortening to the stage of overprinted folding took place at different relative times and probably involved a counter-clockwise rotation of the stress field, considerable variation in the mean direction of the array of strike-slip faults is to be expected.

Data for this study was collected in the few stratigraphic units where a regional coverage was possible due to widespread exposure of the rock. The Tuscarora Formation was sampled at all suitable outcrops, but is not particularly well exposed on the SE dipping limbs of the two major anticlines. Better exposures are available on the NW limbs, but they are commonly so structurally complex, due to the disruption of the two major faults, that they cannot be used to establish the pre-folding shortening direction. At NW limb localities, conjugate early faults with slickenlines parallel to fault/bedding intersection can be found, but it is impossible to know what rotations have brought the enclosing rock to its present attitude. The Bald Eagle sandstone usually shows faults better than the Tuscarora, but is not well exposed on the SE limbs and is more structurally disrupted on the NW limb than the Tuscarora. Ideal units for structural studies of this type are the Silurian Keefer sandstone and hematitic Centre Sandstone Member of the Rose Hill Formation. They yield abundant data where they are exposed, commonly on the noses of plunging anticlines, such as Stop 6, but also locally along the fold limbs. Several good exposures of these units occur along the SE limb of the McConnellsburg anticline in the Little Cove synclinal valley, SE of Lowry Knob and Big Cove Tannery.

Regionally, there are other stratigraphic units that have provided good information on early shortening that has been over printed by later folding. A prime example is the study of deformation in the Siluro-Devonian carbonates, 30 miles to the west, by Markley and Wojtal (1996) whose results matched those of this study. No suitable exposures of these carbonates were found in the Fulton and Franklin County region.

The Tuscarora fault/Antes-Coburn detachment.

The Tuscarora fault of Pierce (1966) in the McConnellsburg-Big Cove-Path Valley region (McC-PV region) is the same structural feature that was named the Antes-Coburn detachment in the Kishacoquillas Valley, 75 km to the north (Nickelsen,1988; Faill and Nickelsen, in press). It consists of a bed-parallel fault zone of intense deformation and good cleavage development that is overlain and underlain by rocks showing little or no penetrative deformation. In the McC-PV region the fault zone is a thin cleavage duplex (Nickelsen,1986), manifested by a sigmoidal cleavage zone, 1 to 2 m thick, separated from enclosing rocks by slickensided and

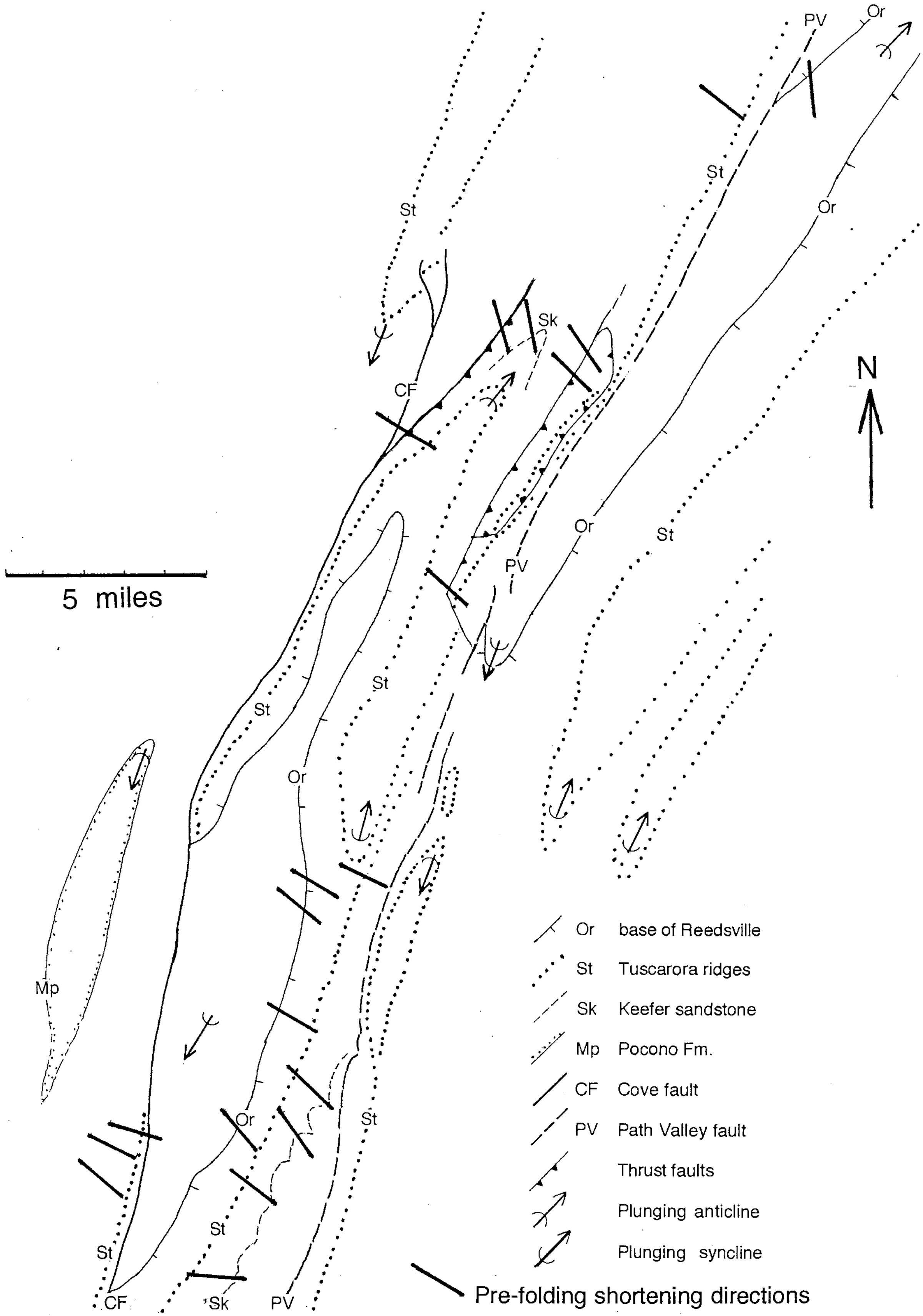

Figure 1. Pre-folding shortening directions at 20 localities.

slickenlined roof and floor thrusts (see descriptions of Stops 2 and 9 and Figure 2 showing 8 localities with their cleavage or slickenline orientations).

The fault zone is not a mylonite in the usual sense although Pierce and Armstrong (1966) used that term in their description. It does not show evidence of milling or grinding or extensive recrystallization, although this is probably a result of the "starter material" from which the fault zone was made. What is most obvious in the cleavage duplex is evidence of a pressure solution that has removed detrital quartz and left a residue of oriented phyllosilicates and carbon. Some recrystallization has occurred as suggested by the young ages found in the lower temperature heating steps during the attempt to radiometrically date the rock (See "An attempt to date the Tuscarora fault/Antes-Coburn detachment," p. 9), but evidence of recrystallization cannot be recognized in thin section.

In the Kishacoquillas Valley the Antes-Coburn detachment is thicker and less sharply defined, consisting of a zone of well developed spaced cleavage in the Antes shale, underlain by a zone of small, 4th-order folds in the underlying Coburn limestone (Nickelsen, 1988, p.105). The structures in both regions occur at the same stratigraphic interval and are manifested by more intense cleavage or small-scale folding than is found up or down section. There is additional evidence from scattered exposures and well records that this detachment is widespread, extending 25 km northwest toward the foreland, at least as far as the Jacks Mountain anticlinorium, and 90 km northeast, along strike, to the Shell Oil Company, Shade Mountain #1 well (Ryder, 1992). Differences between the Kishacoquillas Valley and the McC-PV region in the aspect of the fault are thought to be a function of greater depth of burial and temperature, displacement, and strain to the southeast in the McC-PV region. It is important to emphasize the lithologic character of the rock containing the Tuscarora fault/Antes-Coburn detachment because I think it played an important role in localizing the fault zone. At all localities save one it is a distinctive, carbon-rich, graptolite-bearing, condensed stratigraphic section at the boundary between the Cambro-Ordovician carbonate section and the overlying Upper Ordovician flysch of the Reedsville/ Martinsburg clastic wedge. This condensed graptolite-bearing section, the basal Antes shale member of the Reedsville Formation in central Pennsylvania, is the only horizon where a bed-parallel detachment horizon has been recognized.

In a larger sense, geologists have long realized the need for a bed-parallel detachment or decollement above the Cambro-Ordovician carbonates in the Reedsville-Martinsburg section, though they have not identified the precise horizon. In their view, this detachment or decollement has served as: (1) both the roof of the Cambro-Ordovician carbonate duplex and the floor of imbricate thrusts rising into the Siluro-Devonian section of this region (Gwinn, 1970; Perry, 1978; Mitra and Namson, 1989), and (2) the boundary zone between different styles and amounts of deformation in the Cambro-Ordovician carbonate duplex below, and in the Upper Ordovician - Pennsylvanian roof sequence above (Dunne, 1996, and many references he includes). Thus this horizon has been drawn as a place of considerable transport toward the northwest and as a boundary between different shortening above and below. It has been suggested within the Valley and Ridge, that the shortening by imbricate faulting in the stiff Cambro-Ordovician duplex is not equalled by the shortening of the Silurian-Pennsylvanian cover sequence, which has been interpreted to deform by macrofolding and faulting or penetrative deformation associated with rock cleavage formation. At Stops 2 and 9 on this field trip, you will have the opportunity to evaluate the Tuscarora fault/Antes-Coburn detachment in these possible geological roles.

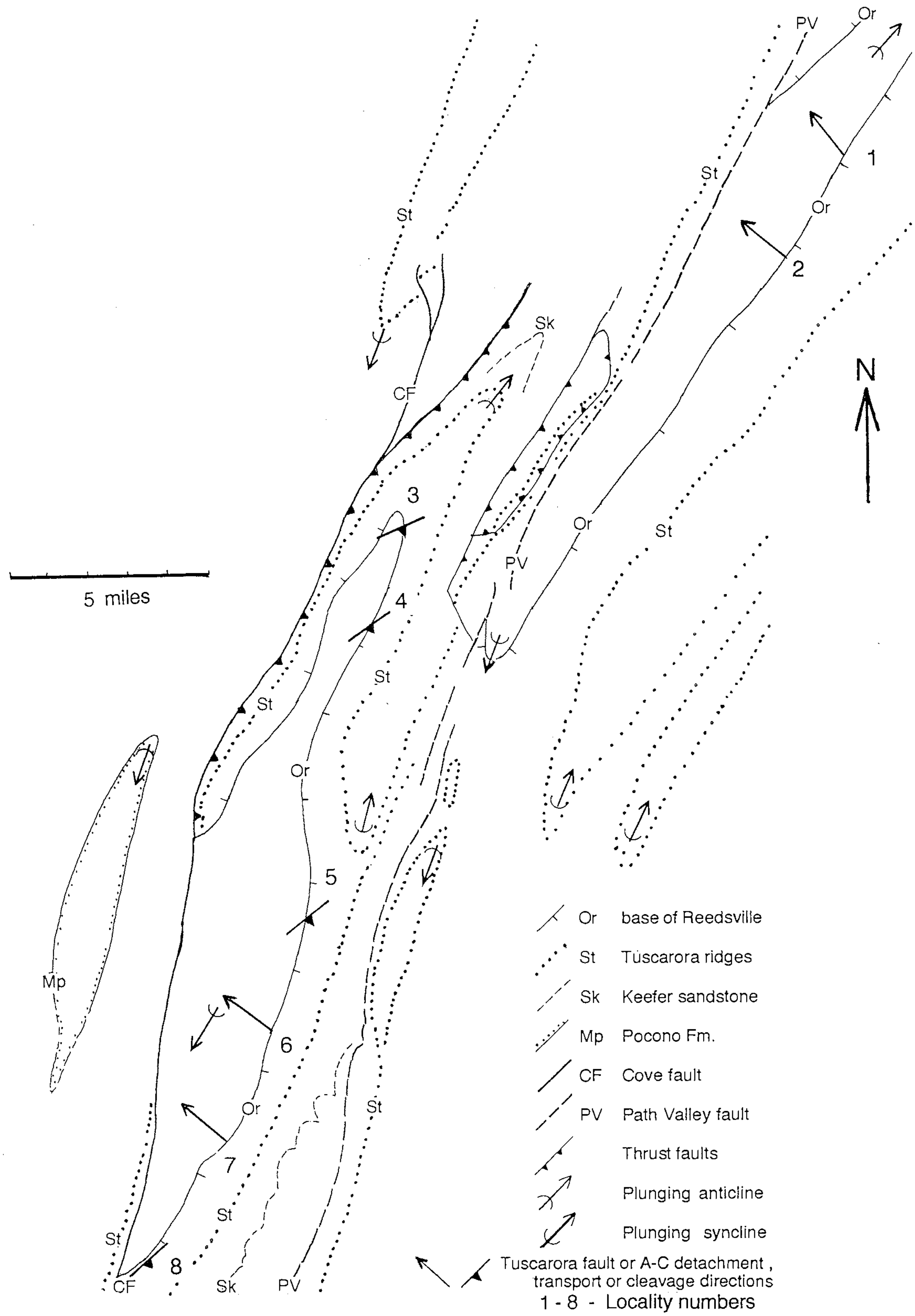

Figure 2. Tuscarora fault/Antes-Coburn detachment, 8 localities with either cleavage attitudes of the cleavage duplex or roof slickenline bearings plotted.

Pierce (1966) depicted the Tuscarora fault as being folded by Alleghanian structures, and this appears correct, because the fault is rigorously parallel to bedding in all exposures. However, I have not found the cleavage duplex manifestation of the fault at any of Pierce's northwest-dipping localities, or at other similarly dipping sites where it should be exposed. The Antes-Coburn detachment of the Kishacoquillas Valley was also folded during the Alleghanian (Nickelsen, 1988), but was interpreted to have formed initially during the Alleghanian, at an early stage of the sequential deformation that created Valley and Ridge structures (Nickelsen, 1979). With this background, the availability of more sophisticated Ar/Ar dating techniques, the new data on the changing direction of shortening during sequential deformation of the Alleghanian orogeny, and the paleomagnetic evidence indicating only Permian deformation, it seemed appropriate to reexamine the K/Ar date and seek new radiometric data on the Tuscarora fault.

The accompanying article in this guidebook by Ken Foland "An attempt to date the Tuscarora fault/Antes-Coburn detachment" (p. 9) is a description of the results of this first new attempt to reevaluate the age of the structure.

Two different fault populations on the northwest limbs of the McConnellsburg-Big Cove and the Path Valley anticlines.

Evidence of two different, juxtaposed, fault populations exists in rocks adjacent to the Cove fault and the Path Valley fault, major structures bounding the northwest side of the two 1st-order anticlines of the region. The four lines of evidence that suggest more than one fault population are: (1) differences in the fault fabrics of fault planes ascribed to the two different fault systems, (2) different structural relations and trends in the two systems, (3) differences in the ambient temperature and the composition of fluids in the two systems as indicated, in a preliminary way, by study of fluid inclusions in quartz crytals of the fault zones, and (4) presence or absence of iron oxides in the fault fabrics or the fine matrix of breccias and their relation to early iron prospects. Each of these lines of evidence is discussed below and reference will be made to observations at stops on the field trip where these differences can be seen. For ease of reference they will be referred to as Early faults or Late faults.

Early faults.

These faults commonly can be recognized as forming prior to folding, but they may undergo renewed slip during folding, as can be seen at Stops 6 and 7. They show excellent fault fabrics; slickensided surfaces of cataclasite with slickenlines demonstrating their slip direction and sense. Surfaces are usually small, measuring several square meters, although at Dry Run quarry (Stop 8) and the Big Cove Tannery quarry (Stop 4) there are early strike-slip surfaces of 100 m^2 in carbonate rocks. As small outcrop-scale faults they have been used to define the pre-folding shortening direction, but it is unknown if faults of this type may form major thrusts or strike slip faults. In addition to examples at Stops 6, 7, and 8, these faults may also be seen at Stops 4 and 10. Associated with these faults are gash veins that indicate slip sense and contain euhedral quartz fillings that are syntectonic. Other quartz crystals may be found that grew on fault steps or openings. Investigations of fluid inclusions in these quartz crystals have revealed that they are filled with saline solutions (15% wt.% NaCl) and commonly contain CH_4 and CO_2. The homogenization temperature of fluid inclusions ranges from 170° to 192° C in many specimens, but may be as low as 140° C. They are clearly faults that formed during creation and migration of hydrocarbons in the system. Presence of cataclasite, good fault fabrics, and abundant precipitated mineral matter, deposited syntectonically with the fault movements indicates that they formed before and during the main Alleghanian deformation. Iron oxide staining and deposits are not known to be associated with these faults.

Late faults.

It can be difficult to recognize these faults because their surfaces are never slickensided or slickenlined. Proof of their existence rests in finding truncation of previous structures and the unique brittle, fractured surfaces that can be seen at Stops 3 and 5. In places they are coated with thin layers of extremely angular breccia that does not show evidence of progressing toward a finer cataclasite. There are essentially no quartz crystal fillings in breccia openings or grooves in the fault plane and those that have been found are too small to study for fluid inclusions, and are of uncertain origin. They could be either fault related or more recent deposits from ground water. At Stop 3 a megabreccia of Tuscarora Formation shows major separated blocks, 300 to 500 feet long and 100 feet wide, that are apparently bounded by late faults. These late faults can be major faults on either the Cove fault or the Path Valley fault systems that juxtapose Ordovician carbonates against Reedsville shale, Bald Eagle sandstone, Tuscarora quartzite or various Devonian shales. Also, as pointed out at Stops 3 and 4 and also Stops 7 and 8, these faults are thought to truncate previous folds in the carbonates of the major anticlinal valleys. In addition, there is one place where the late Path Valley fault truncates a fault that has been interpreted to be associated with earlier thrusting and major folding. This is the Cowans Gap steep transverse fault mapped by Pierce (1966) in the McConnellsburg quadrangle and extended a short distance up the Allens Valley by Hoskins in his preliminary map of the Burnt Cabins quadrangle (Berg and Dodge, 1981). At its SE end, the Cowans Gap fault is truncated by the late Path Valley fault, suggesting that it is younger. One of the largest historic limonite mines (Mt. Pleasant Bank , see Figure 11) is located approximately at the juncture of the Cowans Gap fault and the Path Valley fault, and Robert Smith (personal communication, 1996) has collected a tectonic breccia containing hydrothermal pyrite at that site. Map relations are shown in Figure 44 and discussed at Stop 10.

At several places where Ordovician carbonates are in fault contact with Tuscarora quartzite, most notably along the Path Valley fault east of Carrick Valley Gap and Stop 10, float pieces of a spectacular, angular, quartzite breccia occur. In several cases the matrix of this breccia is a mass of botryoidal limonite with small, "floating," angular, quartz grains that are not very strained (i.e., no undulose extinction). Origin of the iron oxide matrix is uncertain. It could be a surficial development in the loose breccia of the fault zone, or it could be an alteration of primary sulphide minerals that are no longer preserved as relict grains.

Summary.

The most striking difference between these two classes of faults is the presence or absence of fault fabrics and fault-related minerals. Originally, it was thought that environmental parameters during faulting could be defined by a study of fluid inclusions in the two different fault types. This failed because late faults had no quartz crystals in associated openings or vugs. It is possible that the different fault fabrics and gross relationships are related. Thus, faults cutting sandstone or quartzite might produce better fault fabrics whereas faults juxtaposing shale or carbonate against sandstone or quartzite do not develop the milling, dissolution, and migration of fluids bearing dissolved mineral matter that would lead to better cataclasites, fault fabrics, and fault-related minerals.

I would prefer to think that Early and Late faults formed in fundamentally different temperature and pressure environments at very different times in the Alleghanian orogeny. If this is true, the cause of the different ambient conditions in the two classes of faults must be sought in major structural features that have not yet been elucidated. For discussion of this, see the Summary for Stop 5.

AN ATTEMPT TO DATE THE TUSCARORA FAULT/ANTES-COBURN DETACHMENT

by
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INTRODUCTION

The Tuscarora fault of Pierce (1966) in the McConnellsburg region is the same structural feature that was named the Antes-Coburn detachment in the Kishacoquillas Valley, 75 km to the north (Nickelsen, 1988; Faill and Nickelsen, in press). The feature is a bedding-parallel zone of intense deformation overlain and underlain by rocks showing no penetrative deformation. The deformed zone is a thin cleavage duplex (Nickelsen, 1986), manifested by a sigmoidal, penetrative cleavage in a zone, 1 to 2 m thick, separated from enclosing rocks by slickenlined and slickensided roof and floor thrusts.

Pierce and Armstrong (1966) attempted to date the Tuscarora fault by conventional K-Ar dating of whole-rock samples. Dick Armstrong analyzed samples described as "mylonite" and "overlying black shale" collected in McConnellsburg Cove. A K-Ar date of 430 Ma was obtained for the shale while dates of 360 and 320 Ma were obtained from two analyses of the mylonite sample. Pierce and Armstrong (1966) concluded that the mylonite lost Ar and that, if all Ar had been released at the time of movement and no subsequent loss occurred, the movement ended at about 340 Ma, raising the possibility that thrust movement on this zone occurred during the Acadian Orogeny. In both the McConnellsburg region (the Cove and the Path Valley anticlinoria) and the Kishacoquillas Valley anticlinorium, the Tuscarora fault/Antes Coburn detachment occurs in a distinctive, carbon-rich, graptolite-bearing condensed stratigraphic section at the boundary between the Cambro-Ordovician carbonate section and the overlying Upper Ordovician flysch of the Reedsville/Martinsburg clastic wedge. Pierce (1966) depicts the Tuscarora fault as being folded by Alleghanian structures and the Antes-Coburn detachment of the Kishacoquillas Valley is also folded by Alleghanian structures (Nickelsen, 1988). However, in the Kishacoquillas Valley the Antes-Coburn detachment was interpreted to be early Alleghanian, an early stage of the sequential deformation that created the Valley and Ridge structure (Nickelsen, 1979). Faill (1985, p. 28), in his careful analysis of the suggested Acadian radiometric dates of structures within the Appalachian basin, concluded that Acadian deformation within the Valley and Ridge Province is unlikely. Moreover, knowledge of Ar behavior in sheet silicate minerals accumulated over 30 years since publication of the report, makes it unlikely that all Ar would have been expelled from all phases and grains of the fault rock. A total resetting would require complete recrystallization of all K-bearing minerals or a temperature in excess of 300°C over geologic intervals, conditions that do not comport with the petrography of the rock. With this background, it seemed appropriate to seek a more reliable and modern isotopic age that might give the date of thrust movement.

METHODS

The foliation of the fault rock indicates growth of new sheet silicates at the time of its development. Thus, in the shale whole rock there are expected sheet silicates formed at the time of development of the foliation and older ones that are a mixture of detrital and, perhaps, authigenic material. Pierce and Armstrong (1966) concluded that the mylonite lost Ar and recognized that their whole-rock conventional K-Ar date would reflect the date of movement only if all Ar was lost and that this assumption remained unproven. In terms of obvious petrographic changes during faulting, it is unlikely that the temperature was sufficiently high for long enough to reset all the detrital grains. It is likely that much of the apparent loss of Ar is growth of new grains. Thus, there is likely to be a significant component of detrital grains that will not have been reset during faulting and therefore, the K-Ar result of 340 Ma would be a "mixed" date.

To address the issue, the $^{40}Ar/^{39}Ar$ incremental-heating variant of the K-Ar method was applied in an attempt to isolate young from detrital phases. The advantage of this approach is that the samples can be heated to release Ar incrementally providing a series of ages for the successive steps. It is likely that the release of Ar will be different for the different sheet silicates owing to grain size and compositional variations. In some previous studies, it has been observed for some very low-grade schists that the "metamorphic" sheet silicates release their Ar at lower temperatures than detrital counterparts. As a result, it has proven possible to determine the age of metamorphism even when some precursor grains that retained Ar are present. In the measurements on the Tuscarora fault rocks, it is anticipated that sheet silicates developed during formation of the foliation will release their Ar at lower temperatures than detrital grains in the step-heating procedure; it is hoped that the separation in temperature of Ar laboratory release and the amount of newly-formed minerals may be sufficient to determine the timing of this overprinting.

A total of five rocks from two localities (Mellot Farm and Lockings) were dated by the $^{40}Ar/^{39}Ar$ technique. For both localities, "country rock" and "fault rock" were analyzed. The country rock is the "starter" material, unaffected shale above the fault zone. The fault rock is foliated shale from the fault zone, cleavage duplex of the Tuscarora fault. From the Mellot Farm locality, "transition" material or "fault boundary rock" that is shale with space cleavage directly above the "roof thrust" was also analyzed.

The age measurements were performed in the Radiogenic Isotopes Laboratory at Ohio State University using the normal procedures that have been described previously (Foland and others, 1984; 1993). Aliquots of the whole-rock samples (60 to 80 mesh size fraction) were irradiated at the Ford Nuclear Reactor of the Phoenix Memorial Laboratory at the University of Michigan using a 446 Ma biotite (AL-1) as a monitor; an overall systematic age uncertainty of ±1% is assigned to reflect uncertainties in this monitor. Two aliquots of each of the five samples were analyzed, one in a single heating step where the sample was fused totally and another that was heated incrementally to release Ar in about 15 steps for temperatures increasing progressively over the range of generally 200° to 1,300°C.

Table 1. Summary $^{40}Ar/^{39}Ar$ age results.

Sample	%K	K/Ca	K/Cl	t_f	t_{tg}
Mellott Farm locality					
McC 94-1	**country rock**				
	1.34	38	140	560	
	1.25	11	134		555
Average	1.3	25	137		558
McC 94-2	**fault boundary rock**				
	1.30	8.3	141	511	
	1.30	8.3	127		505
Average	1.3	8.3	134		508
McC 94-3	**fault rock**				
	1.46	22	68.5	438	
	1.32	11	67.0		440
Average	1.4	16	68		439
Lockings locality					
McC 94-4	**country rock**				
	1.18	30	141	604	
			178		598
Average	1.18	30	160		601
McC94-5	**fault rock**				
	1.46	38	135	496	
	1.30	12	149		498
Average	1.4	25	142		499

t_f is the single-step, total fusion age, in Ma
t_{tg} is the total-gas age derived from the summation of all fractions of the incremental-heating analysis, in Ma.
% K is in wt %.
K/Cl and K/Ca ratios are weight ratios.

The results for ages and the abundances of K, Ca, and Cl are summarized in Table 1. Because considerable time elapsed between irradiation and Ar measurement during which most of the ^{39}Ar decayed, the K/Ca ratios are only approximate values, particularly for the incremental-heating analyses. Both the total-fusion age from the complete fusion measurement and the total-gas age, which is the weighted summation of all fractions of the incremental-heating measurement in Table 1, are equivalent to a conventional K-Ar age. The apparent ages of the incremental analyses and the heating temperature are illustrated in Figure 3. A full listing of results is available.

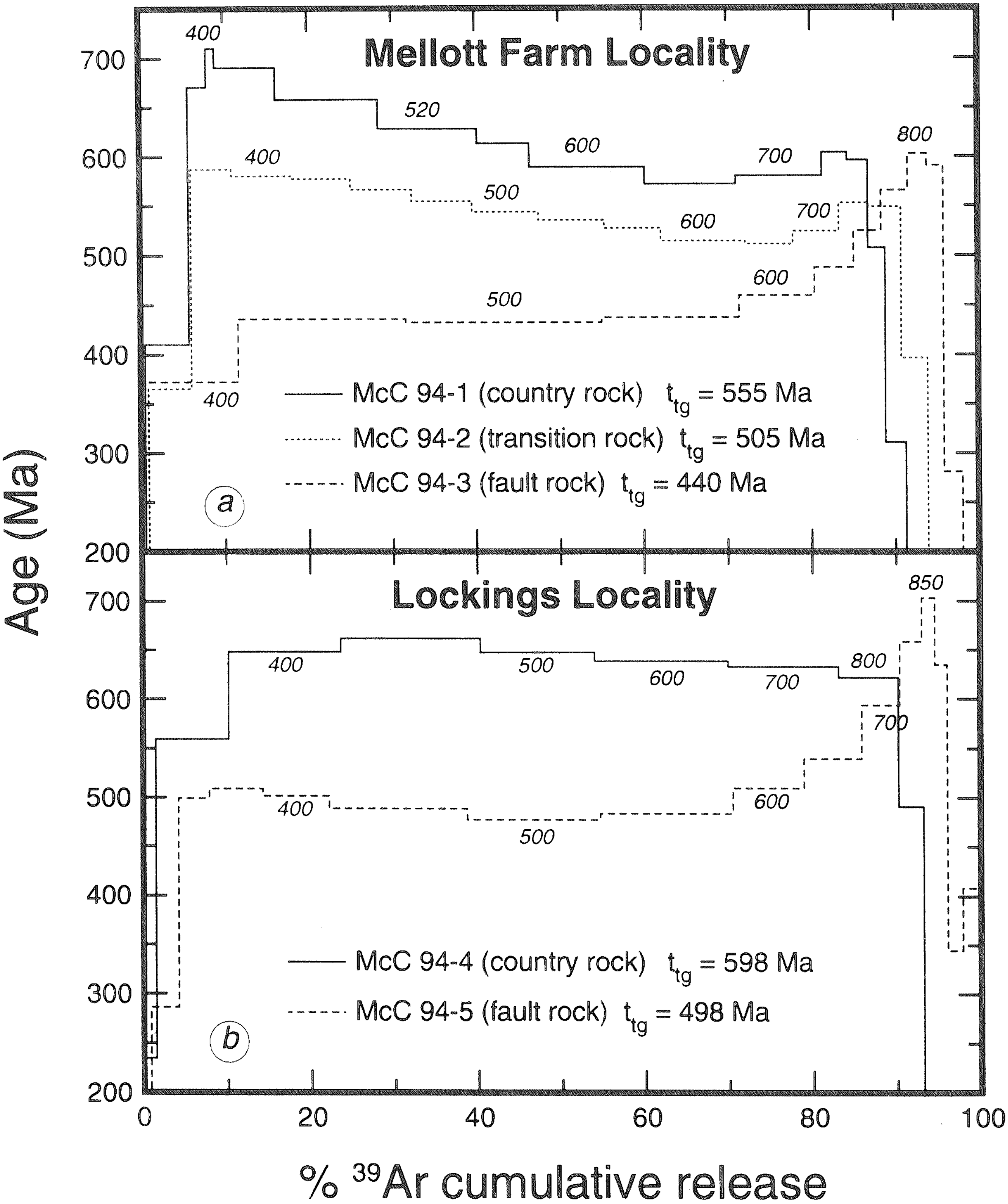

Figure 3. $^{40}Ar/^{39}Ar$ incremental-heating "age spectra" for rock samples associated with the An tes-Coburn detachment at the Mellot Farm locality (a) and the Locking locality (b). The temperatures of various heating steps (in degrees C) are given for selected frac tions with the unlabelled ones being intermediate.

RESULTS

The results of replicate analyses show good agreement in terms of comparison of the total-fusion analyses with sum of all fractions in step-heating runs for each of the samples. The replication is good not only in terms of the chemical compositions (K, Ca, and Cl concentrations) but also in apparent $^{40}Ar/^{39}Ar$ ages. In terms of the bulk concentrations and ratios of K, Ca, and Cl, all the samples are very similar. Thus, it is reasonable to assume that the starting compositions and likewise the K-Ar ages of the original shales were relatively uniform.

There are clear and significant differences in the bulk-rock ages, with total-gas $^{40}Ar/^{39}Ar$ ages ranging from about 555 Ma (McC 94-1) to 440 Ma (McC 94-3). For both localities the ages of the country rock (560 and 600 Ma) are distinctly older than those for the fault rock (440 and 500 Ma). At the Mellot Farm locality, the transition rock is intermediate (510 Ma). The differences are systematic and substantial, with the fault rock about 100 Ma younger than the immediate country rock. Thus, it is reasonable to regard this difference as reflecting the development of new sheet silicates and perhaps also the loss of some Ar from existing phases during the deveopment of the Tuscarora fault.

The incremental-heating "age spectra" are all discordant with significant variations in apparent age beyond analytical uncertainties. The variations seen in these spectra (as well as the total-gas ages) most likely reflect contributions from both detrital and younger phases formed or reset during deformation. Some of the variations, in particular the sharp decrease in apparent age at the higher heating temperatures, are thought to be analytical artifacts; they most likely reflect the release of ^{39}Ar that recoiled into quartz during the irradiation procedure and may be ignored here. Although the fault rocks each give a fairly "flat" region of apparent age over a large portion of the Ar release, these are not true age plateaus; indeed, the apparent ages of these regions differ by more than about 50 Ma and the indicated ages are clearly too old on geological grounds. The release patterns are systematic and similar for each locality. Both fault rocks step up to higher apparent ages, similar to those of the country rock at higher heating temperatures. The major differences in the patterns are the younger ages for the lower temperatures of the fault rocks.

The two samples with the lowest total-gas ages, McC 94-3 and McC 95-5, display some similar features. They both give younger bulk ages with significantly younger apparent ages for lower temperature heating increments, relative to their nearby counterparts. These relationships are consistent with larger proportions of younger sheet silicates in the deformed shales that give off their Ar at lower temperatures. The flat portions of the spectra for the fault rock (McC 94-5 and McC 94-3) at heating temperatures below about 600°C probably simply reflect Ar release simultaneously from older detrital and subsequently formed sheet silicates. Unfortunately, the Ar release characteristics of these two components and their relative amounts where the detrital component predominates, does not permit isolation of the younger-age component. Thus, the step-heating spectra provide only mixed ages and, as a result, do not define useful ages with any precision. The younger ages for the deformed shales do, however, indicate that these rocks contain a significant component of young sheet silicate that is consistent with their having developed a strong secondary foliation. Judging from the bulk rock ages, comparing the country rock versus fault rock ages, and assuming a Permian age means that about 20% of the fault rock K may reside in material formed or reset at that time.

The youngest bulk-rock date (440 Ma) found here is similar to the shale K-Ar date of Pierce and Armstrong (1966), but significantly older than their mylonite date. Their samples had significantly higher K levels (2 to 2.3%). In fact, the 430 Ma shale date is surprisingly young because the sediment is likely to be dominated by detrital phases, as noted by Pierce and Armstrong (1966). This coupled with a 10% difference in the ^{40}Ar concentrations measured call into question the accuracy of the previous K-Ar dates. Regardless, the incremental heating results indicate the presence of detrital phases and thus make it highly unlikely that the K-Ar date on the bulk sample indicates the time of folding.

STRUCTURAL AND TECTONIC FRAMEWORK OF ALLEGHANIAN SEQUENTIAL DEFORMATION IN THE SOUTHWESTERN LIMB OF THE PENNSYLVANIA SALIENT FROM PALEOMAGNETIC AND ROCK MAGNETIC STUDIES

by
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INTRODUCTION

Paleomagnetic and ancillary rock magnetic studies have played a critical role in unraveling the structural and tectonic evolution of the central Appalachians. In its most familiar application, paleomagnetism has been used as the basis for tectonic or paleogeographic reconstructions of the Appalachian margin. Reconstructions are based on the premise that most rocks preserve the ambient direction of the earth's magnetic field at the time the rocks were magnetized (either during original deposition or crystallization or during later geothermal or geochemical resetting events). Paleomagnetic techniques are designed to isolate and quantify these ancient magnetizations. If successful, the isolated magnetic components provide a record of the rock's earlier latitude and orientation relative to geographic north (or south). For stable regions of continents, that record is used to construct reference apparent polar wander (APW) paths that help retrace the motion of continents through geologic time. For more mobile parts of the earth's crust, APW paths provide a reference frame against which other crustal motions like the accretion history of suspect or exotic terranes can be determined.

Paleomagnetic studies (especially in the Appalachians) have also addressed more regional tectonic and structural questions by taking advantage of relative differences in paleomagnetic directions from folded or rotated rocks. Those most notable are sudies of the nature of fold and thrust belt curvture around salients and recesses (e.g., Kent, 1988; Stamatakos and Hirt, 1994) or estimates of the age and relative timing of fold and thrust belt deformation (Van der Voo, 1979; Miller and Kent, 1989; Stamatakos and others, 1996). At a finer scale of observation, paleomagnetic and rock magnetic studies have been used jointly in analyses of rock fabrics and internal strain of mildly to moderately deformed clastic and carbonate rocks (e.g., Housen and van der Pluijm, 1991; Stamatakos and Kodama, 1991a, b).

In this paper, we present an overview of our paleomagnetic results with either structural or tectonic implications to the central Appalchians. This should provide a framework for the more detailed discussions of Alleghanian structural deformation in Fulton and Franklin Counties, Pennsylvania. This overview is primarily derived from recent published compilations of paleomagnetic results; mainly from Upper Ordovician through Mississippian siliciclastic redbeds (Stamatakos and Hirt, 1994; Stamatakos and others, 1996). In addition, we present new paleomagnetic and rock magnetic results from Lower Ordovician carbonates at eleven sites collected on both limbs of the Path Valley, McConnellsburg, and Blacklog Creek anticlines. These new results are part of a larger study of remagnetization and folding throughout the Pennsylvania salient. They confirm earlier results that Alleghanian folding is Permian and that rocks around the salient experienced significant yet insufficient vertical axis rotations to explain the degree of curvature in the salient. The angle of rotation indicated by our paleomagnetic studies is between 20° and 30° that occurred prior to folding and thrusting of the foreland. It is not known if this represents clockwise rotation of the northeastern limb, counter-clockwise rotation of the southwestern limb, or a combination of both. An important implication of this result is that changes in the orientation of shortening in the region reflect modifications in paleostress directions (shortening directions) rather than physical reorientation of the folds through time.

REGIONAL RESULTS

Sedimentary rocks in the central Appalachians record up to three generations of paleomagnetic directions. Most rocks contain a low-unblocking temperature or low coercivity magnetization parallel to the earth's present field direction. This magnetization is carried by the unstable fraction of magnetic minerals (those in which the magnetic movments are constantly realigned parallel to the ambient magnetic field). Nearly all rocks in the region also contain a Late Paleozoic secondary magnetization acquired during the Alleghanian orogeny. In the carbonates, this magnetization is carried by authigenic magnetite. In the clastic rocks this magnetization is usually carried by fine-grained authigenic hematite, although in some of the ironstone formations, this component is also carried by magnetite. The source of the Late Paleozoic remagnetization appears to be precipitation of new magnetic phases as the rocks chemically interacted with orogenic brines expelled toward the foreland during the Alleghanian orogeny (Dorabek, 1989; McCabe and Elmore, 1989). However, the exact thermo-geochemical conditions that facilitated remagnetization remain uncertain. Finally, many of the siliciclastic redbeds retain a primary magnetization (penecontemporaneous with the deposition of the rocks) carried by coarse-grained hematite. For simplicity, paleomagnetists often refer to these three magnetization components as the A (present-day), B (Late Paleozoic secondary magnetization), and C (primary magnetization) components.

Age of remagnetization.

The age of the B-component magnetization is determined by converting the B-component directions to their corresponding paleomagnetic poles and comparing them to a reference North American APW path. For such analyses, the reference APW paths are constructed from either a moving average of individual reference poles (Irving and Irving, 1982) or a best-fit small circle (Gordon and others, 1984) or spline (Jupp and Kent, 1988) covering the interval of interest. Naturally, the reference poles used to construct the APW path must be independent from the poles we wish to date.

For the Late Paleozoic segment of the North American APW path, the various methods of constructing time-averaged APW paths yield very similar reference curves (Stamatakos and others, 1996). Comparison of the B-component magnetization to these curves indicates a Permian remagnetization age throughout the central Appalachians (the mean value is 265 Ma). There are no significant age trends either across or along the central Appalachian fold-thrust belt or much of the Appalachian Plateau in New York (Stamatakos and others, 1996). The sequence of progressive deformation in the cover rocks that includes folding was continuous (Gray and Mitra, 1993), and given the Permian age for remagnetization during folding of the central Valley and Ridge, Alleghanian tectonism of central Appalachians was therefore probably limited to the latest Pennsylvanian and Permian. These temporal constraints challenge Geiser and Engelder's (1983) hypothesis of a two-phased Alleghanian orogeny consisting of a Mississippian (Lackawanna) phase and a later Permian (Main) phase of deformation.

Remagnetization and folding.

The link between remagnetization and Alleghanian deformation was first noted by Van der Voo (1979), who concluded that the Alleghanian orogeny was most likely late Carboniferous in age based on the remagnetization of the Rose Hill and Juniata Formations in West Virginia, Virginia, and western Maryland. Using a more reliable APW path for north America, Miller and Kent (1988) argued that remagnetization progressed northward from the southern to central Appalachians. They noted Mississippian folding and remagnetization in the southern Appalachians and Early and Late Permian folding and remagnetization in the central Appalachians. More recently, Stamatakos and others (1996) have argued that the remagnetization of the central and southern Appalachians was discontinuous rather than progressive. The southern Appalachians were remagnetized during deformation in the Mississippian or Pennsylvanian. The central Appalacnians were remagnetized during folding in the Permian.

On a regional scale, the acquisition of the B-component magnetization coincides with folding (e.g., Kent and Opdyke, 1985). However, more detailed examination of individual folds across Pennsylvania based on individual paleomagnetic fold tests shows an interesting temporal and spatial trend (Stamatakos and others, 1996). Folding predates remagnetization near the hinterland margin of the Valley and Ridge, coincides with remagnetization in the central portion of the Valley and Ridge, and postdates remagnetization near the foreland margin of the Valley and Ridge (Figure 4A). The variation of local fold-test results suggests relatively rapid remagnetization across the region as thrusting and folding propagated more slowly toward the foreland.

Paleomagnetic rotations.

The paleomagnetic record of rotations within the Pennsylvania salient is not straightforward and has been the focus of considerable debate since the early 1960's (cf., Irving and Opdyke, 1965; Roy and others, 1967; and Kent, 1988 with Knowles and Opdyke, 1968; Schwartz and Van der Voo, 1983; and Eldredge and others, 1985). The debate has centered around whether the salient is an orocline (Carey, 1958). Much of this debate arose from an incomplete appreciation of the various ancient magnetic components, especially with regard to distinctions between primary and secondary magnetizations. In addition, there are differences regarding what actually constitutes an orocline. In some cases, the term has been used to describe any curved orogenic belt that exhibits paleomagnetically detectable rotations (e.g., Kent, 1988). A more strict interpretation (which we adhere to here) considers oroclines to develop from the bending of

(A)

(B)

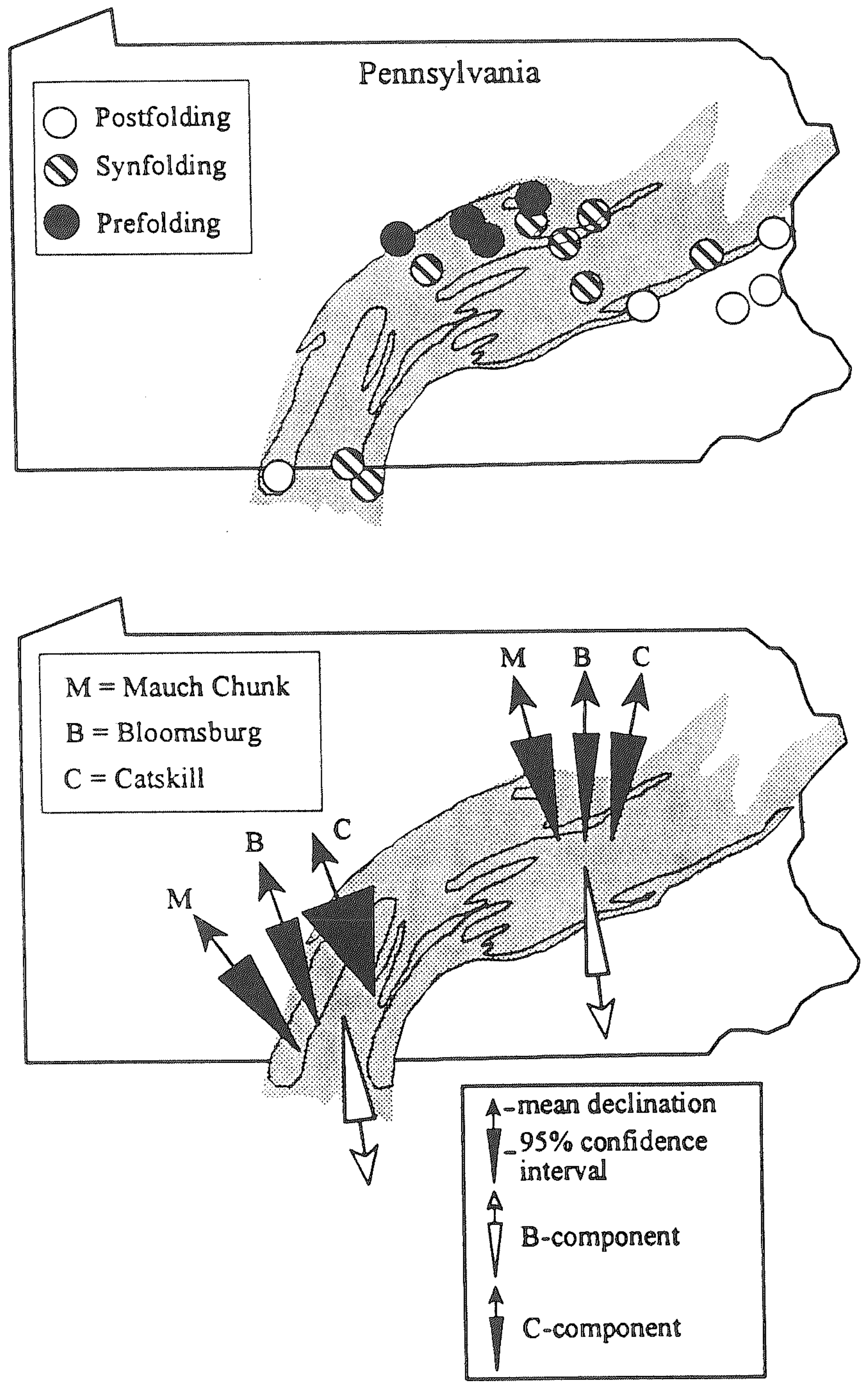

Figure 4. Map of Pennsylvania showing the Valley and Ridge (gray shading) and the outcrop pattern of Silurian rocks. (A) Paleomagnetic fold-test results across Pennsylvania (Stamatakos and others, 1996). The temporal pattern of folding relative to a rapid Late Paleozoic remagnetization indicates folding propagated toward the foreland. (B) Mean B-and C-component declinations for the two limbs of the Pennsylvania salient. Arrows are the mean declination values. Triangles show the 95% confidence regions about each mean declination. The C components are for the Bloomsburg Formation results summarized in Stamatakos and Hirt (1994) and the Mauch Chunk and Catskill Formation results from Kent (1988). B components are from Stamatakos and Hirt (1994).

a previously established and originally more linear fold and thrust abelt (e.g., Eldredge and others, 1985).

The subtle distinction between these definitions of an orocline is clearly manifested in the paleomagnetic record from the central Appalacahians. The primary, C-component magnetizations show a consistent 20^{0} to 30^{0} rotation (Figure 4B) that in a gross sense is consistent with overall curvature of the salient (clockwise in the northeastern limb and counterclockwise in the southwestern limb of the salient). Based on this observation alone, Kent (1988) concluded that the salient was an orocline that originated with about half its present curvature. Yet, in detail, the rotated C-component declinations do not show a direct correlation with strike of the structural trends around the salient as required by the orocline model (Eldredge and others, 1985). In addition, the B-component magnetization is unrotated (Figure 4B), even in cases where this magnetization was acquired before or during folding (Stamatakos and Hirt, 1996). Taken as a whole, these data indicate up to 30^{0} of vertical-axis rotation within the Valley and Ridge either before or during the earliest stages of Alleghanian deformation, but, prior to thrusting and folding. Structural features that could have accommodated these early rotations remains unknown. Because of the lack of vertical axis rotations since folding and thrusting (i.e., bending of a more linear fold and thrust belt), we do not consider the Pennsylvania salient an orocline in the strict sense.

PALEOMAGNETISM OF ORDOVICIAN CARBONATES FROM FRANKLIN AND FULTON COUNTIES, PENNSYLVANIA

Sampling and methods.

Rocks for paleomagnetic and rock magnetic analyses were collected in the field as oriented hand-samples a eleven sites (Figure 5). Three to five samples were collected at each site. Up to eight one-inch diameter paleomagnetic cores were drilled in the lab from each hand sample for paleomagnetic or rock-magnetic analysis.

Nearly all the Ordovician carbonates were thermally demagnetized because test experiments showed this technique most effective in isolating the magnetic component. Several test samples were also demagnetized in an alternating field but we only present the thermal results here. In thermal demagnetization, each sample was heated to progressively higher temperatures in an oven shielded from the earth's magnetic field. After each heating step, samples were cooled to room temperature in the same zero magnetic field and their remaining remanent vector measured using a cryogenic magnetometer. The effect of progressive heating is to randomize (and thus effectively remove) that fraction of remanent magnetization susceptible to the applied temperature (analogous to step heating in radiometric dating). Progressive heating is continued until the samples are completely demagnetized. The resulting vector after each heating step is plotted on a vector end-point diagram (Zijderveld, 1967) (Figure 6). Individual components are determined from the linear segments of the demagnetization trajectories on these diagrams. We used a least-squares technique (Kirschvink, 1980) to calculate the remanence components. Sample directions were averaged to obtain site means (8 to 12 sample directions were averaged per site). The 95% confidence interval about each site mean (referred to as the a_{95}) was computed using Fisher (1953) statistics.

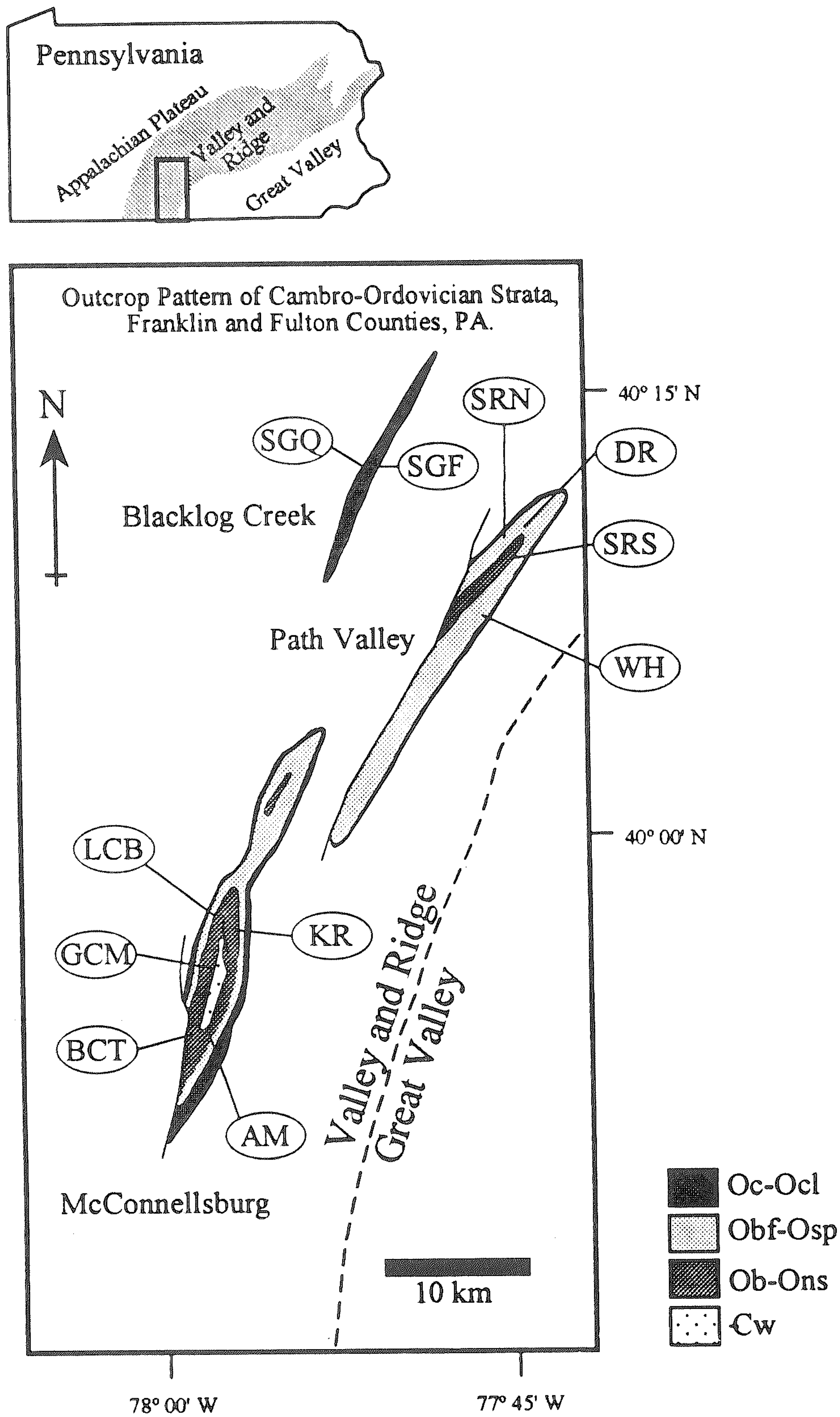

Figure 5. Map showing the outcrop pattern of Cambrian and Ordovician strata in the Valley and Ridge Province of Franklin and Fulton Counties, Pennsylvania. The eleven sampling sites for paleomagnetic and rock magnetic analyses are also shown.

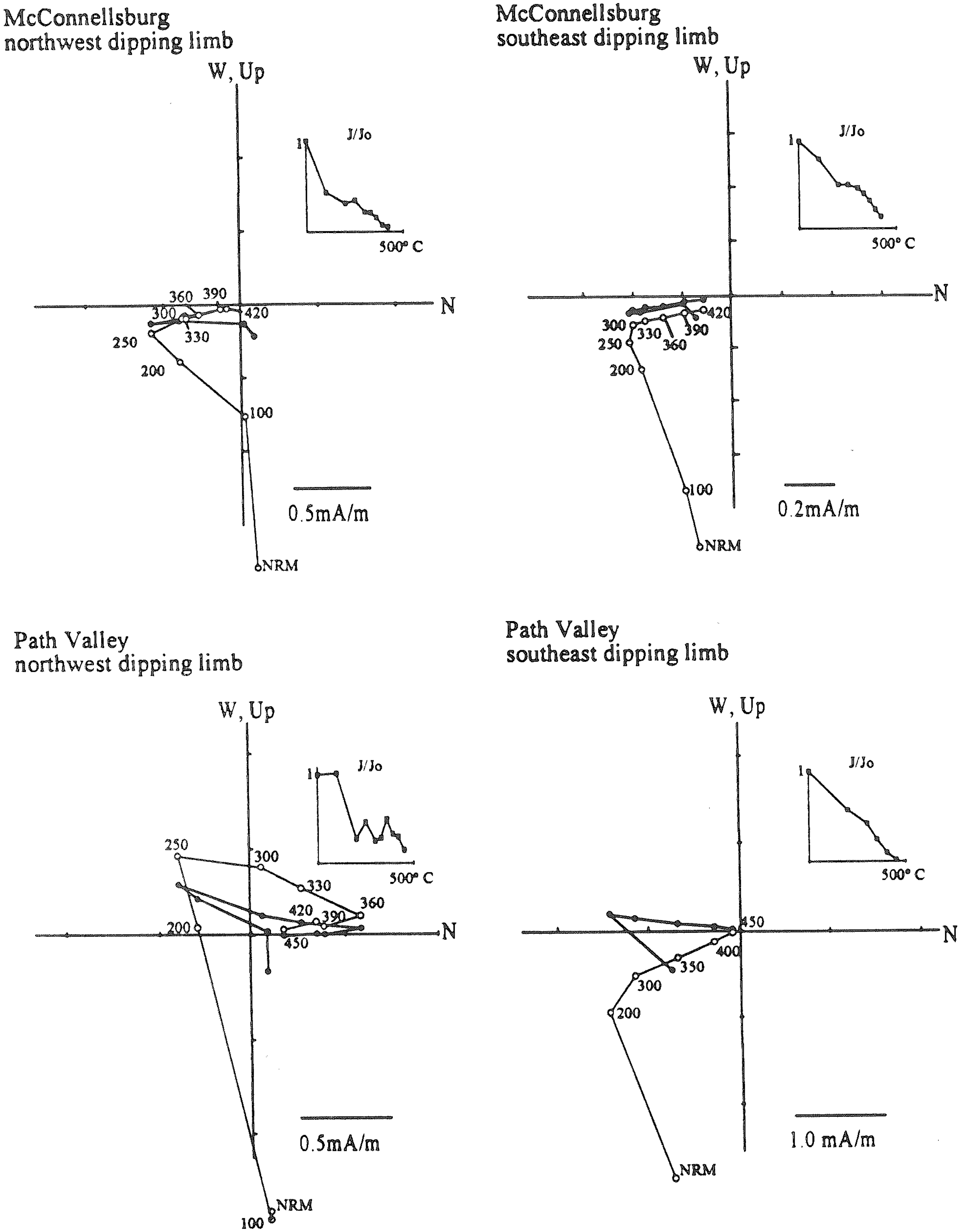

Figure 6. Vector end-point diagrams showing the thermal demagnetization of the Ordovician carbonates. Open (closed) symbols represent the projection of the remanence vector onto the horizontal (vertical) plane. Inserts show the relative decay of the remanence intensity (J) normalized to the initial intensity (Jo). Demagnetization steps are in °C.

Demagnetization results.

Thermal demagnetization revealed two remanence components in all samples. The first component removed is a low-temperature component (peak unblocking temperatures of 250°C to 300°C) with a north and steeply downward direction. This magnetization is typical of the A (present day field) component. We do not consider it useful tor tectonic and structural analyses. At higher unblocking temperatures (300°C to 450°C), the characteristic component is isolated with roughly southward and shallow downward or shallow upward directions (Figure 6) or an occasional antipodal north and horizontal direction (Figure 6 - Path Valley northwest dipping limb sample). This direction is typical of the ubiquitous Appalachian B-component magnetization. The carbonates show no evidence of a primary Ordovician remanence. That component (if indeed it ever existed at all) appears to have been completely replaced by the A- and B-component magnetizations.

Combining the sample directions to site means shows that a consistent B-component direction is isolated in all eleven sites (Figure 7). Sample directions are well clustered about their respective means. The 95% confidence circles about the means range between 5° and 10°.

Fold tests.

Sample directions from sites on opposing limbs of three folds provides the basis to determine the relative age of the B-component magnetization to folding. For this determination we used what is commonly referred to as the paleomagnetic fold test. The test was first introduced by Graham (1949) and is based on the premise that optimal clustering of the remanent directions represents relative position of the fold limbs at the time the rocks acquired the magnetization in question. If the magnetization directions are all similar without any restoration of the fold limbs, then the magnetization is considered postfolding. If the magnetization directions cluster after full restoration of the fold limbs to paleohorizontal, then the magnetization is deemed prefolding. If the directions cluster at a partial correction for folding, then the magnetization is considered synfolding, acquired as the rocks were defromed. Statistical parameters such as the Fisher (1953) precision-parameter kappa are used to judge statistical significance of the fold test.

The three folds analyzed in this study are roughly symmetrical with minimal plunges. Thus, unfolding the B-component directions was done by simply rotating the site mean directions about the line of strike in increments of bedding dips. All three folds yield synfolding magnetization suggesting acquisition of the B-component magnetization during folding. B-component directions cluster at 70% unfolding for the Blacklog Creek and McConnellsburg anticlines and 50% unfolding for the Path Valley anticline. Synfolding remagnetization in this portion of the fold and thrust belt is consistent with the overall foreland progression of folding and remagnetization noted in Stamatakos and others (1996).

Rotations.

Comparison of the mean declinations from the eleven sites indicates negligible verical axis rotation within the southern limb of the salient after acquisition of the B-component magnetization (Figure 8). Except for a possible anamalous south-southeast direction at the Blacklog Creek fold, all mean declinations show consistent southward declinations. In addition, corresponding paleomagnetic poles of the eleven site mean directions coincide with the Permian segment of the reference North American APW path (within the 95% error regions). Thus, the southern limb of the Pennsylvania salient has not rotated since acquisition of the B-component

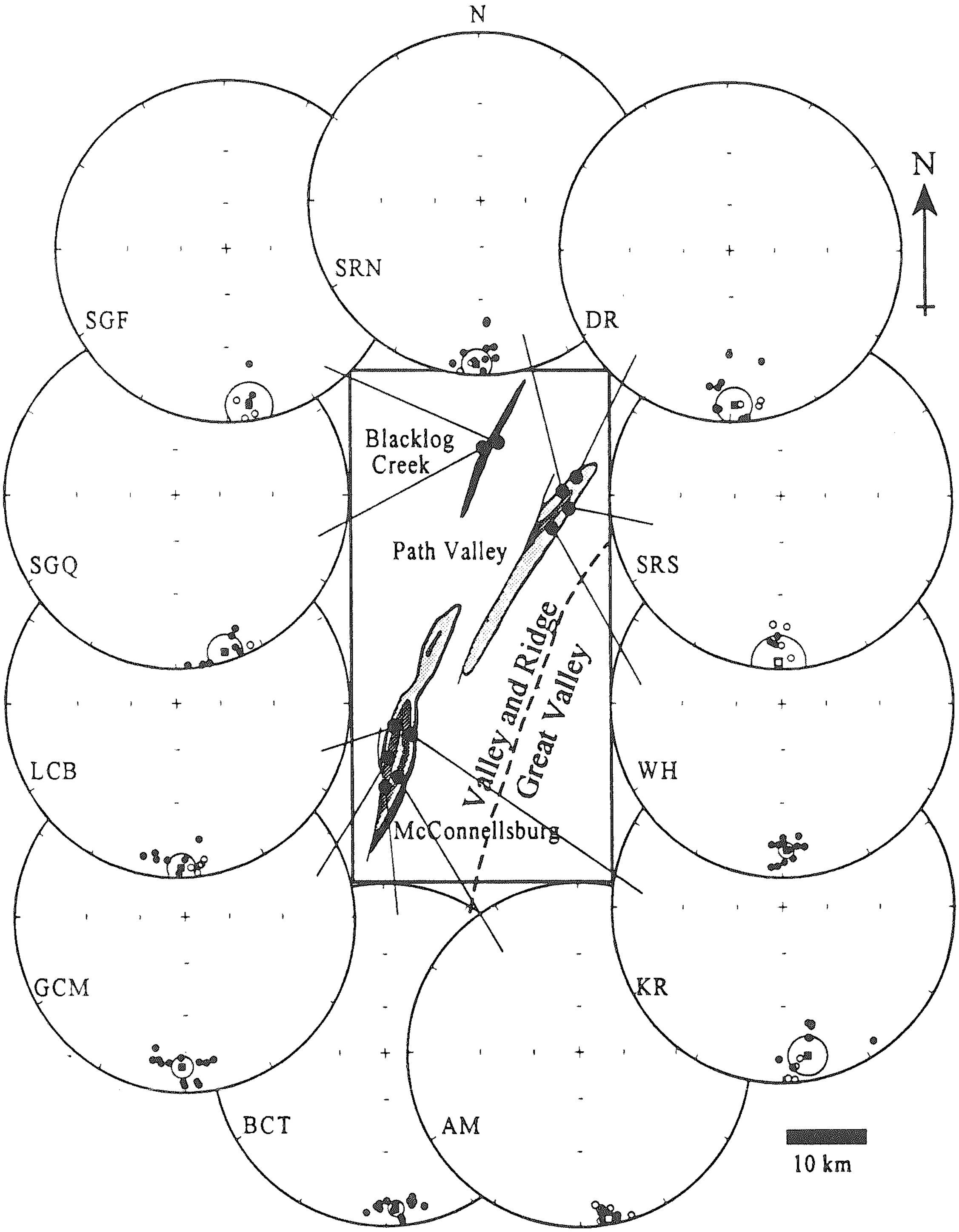

Figure 7. Equal angle stereonets showing the sample (small circles), site mean directions (large circles), and associated 95% confidence regions (largest circles) for the B-component magnetizations. Symbols represent projections onto the upper (lower) hemisphere. Directions are in the optimal tilt-correction for each fold based on the results of the paleomagnetic fold tests (50% for the Path Valley fold and 70% for the Blacklog Creek and McConnellsburg folds).

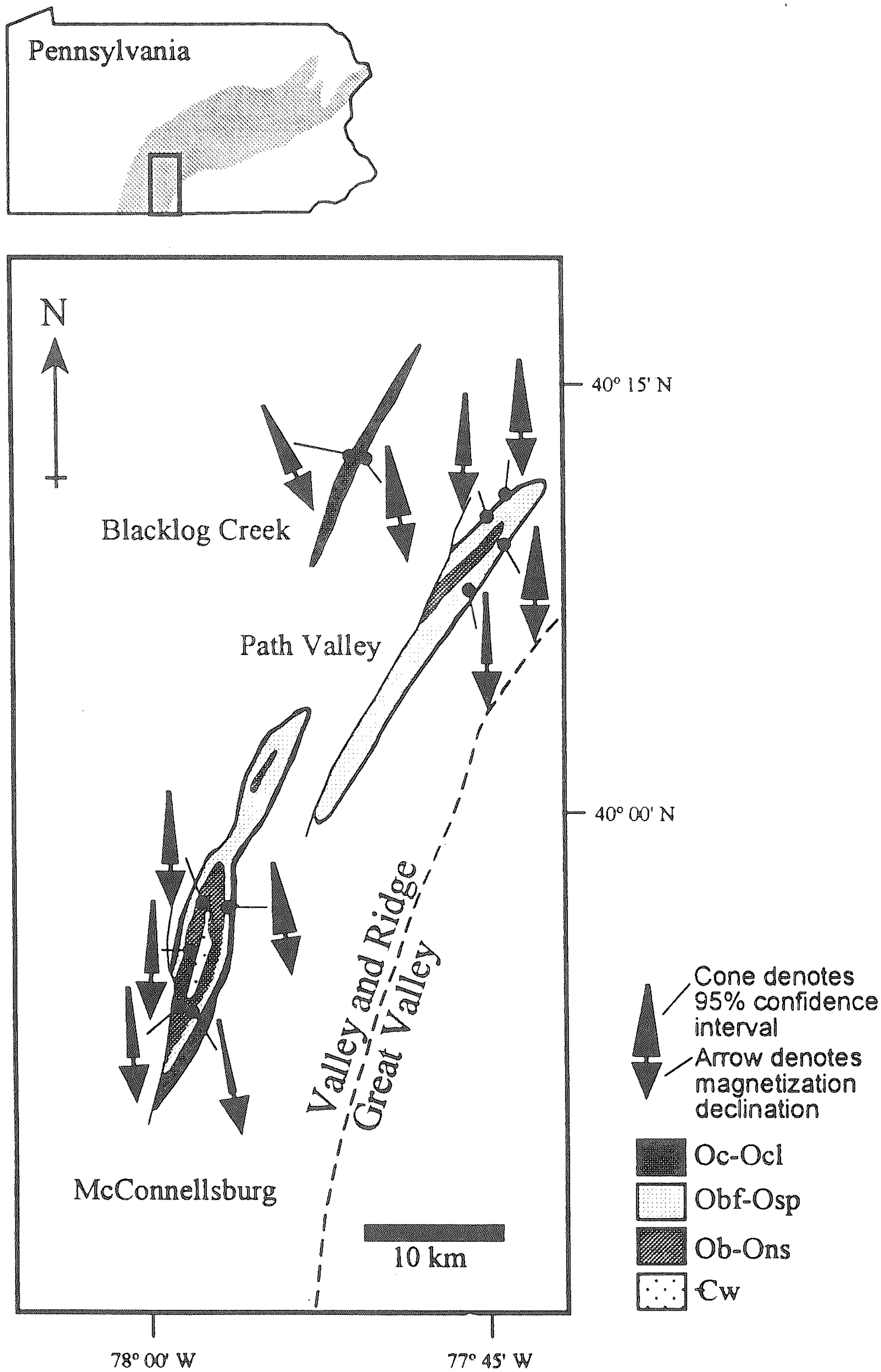

Figure 8. Map showing the mean declinations and associated 95% confidence regions for the B-component site mean directions. The consistent southerly declinations indicate negligible vertical axis rotation since acquisition of the B-component magnetizations.

magnetization. The current orientation of fold axes are the same as when the folds formed. Variations in fold axis orientation (northeast at Path Valley and north-northeast at Blacklog Creek and McConnellsburg) therefore reflect counterclockwise rotation of the shortening directions (changes in the paleo-stress directions), not physical reorientation of folds.

Age of folding.

To estimate when the rocks were remagnetized and folded, the eleven site mean paleomagnetic poles were compared to the reference North American APW path as described in Stamatakos and others (1996). We estimate remagnetization and folding at 271±25 Ma for Blacklog Creek, 247±18 Ma for Path Valley, and 252±17 Ma for McConnellsburg. The Path Valley and McConnellsburg folds yield remagnetization ages slightly younger than the overall B-component mean for the Appalachians (265±10 Ma). The Blacklog Creek remagnetization age is older but should be viewed with caution because it is based on only two mean directions which have divergent declinations. The overall mean age for all eleven sites is 255±19 Ma.

Implications for Alleghanian deformation in Franklin and Fulton Counties.

The paleomagnetic results from the Ordovician carbonates of Franklin and Fulton Counties support previously proposed temporal and spatial constraints on Alleghanian deformation (Stamatakos and Hirt, 1994; Stamatakos and others, 1996). Specifically, these results indicate that folding around the salient is Permian. We find no evidence for a multi-stage Alleghanian orogeny as proposed by Geiser and Engelder (1983). In addition, changes in the orientation of folds around the salient (which define the salient's curvature) resulted from changes in shortening direction (paleostress orientations) through time. The 20°-30° vertical axis rotation (physical reorientations of rocks) indicated by the C-component magnetization must have occurred prior to or very early (before fold growth) in the sequential Alleghanian deformation of the central Appalachians.

ANISOTROPHY OF MAGNETIC SUSCEPTIBILITY

Measurements of anisotrophy of magnetic susceptibility (AMS) utilize the induced component of magnetization to characterize rock fabrics. Magnetic susceptibility is the nonpermanent magnetization that arises from a sample's magnetization in an applied field. Although the same ferro-magnetic minerals that carry remanent magnetizations (hematite and magnetite) have very high intrinsic susceptibilities, the volumetrically more abundant paramagnetic minerals (especially clay minerals) often control the AMS of sedimentary rocks (e.g., Housen and van der Pluijm, 1991). Rock magnetic experiments indicate that the AMS of the Ordovician carbonates is dominated by a paramagnetic mineral, probably illite. Calcite and many other diamagnetic carbonate minerals have susceptibilities too weak to significantly affect the AMS of these samples.

AMS measurements were made on KLY-2 susceptibility bridge at the University of Michigan using a standard fifteen-position measurement procedure. The fifteen measurements were resolved into an AMS tensor from which the AMS ellipsoids were calculated. We measured AMS fabrics at seven sites (between 7 and 13 sample measurements per site).

AMS ellipsoids are oblate (e.g., SGQ or SRN) to slightly prolate (e.g., SRS) with minimum AMS axes normal to bedding and maximum axes roughly parallel to fold axes (Figure 9). We interpret this fabric as a composite bedding-tectonic fabric that probably arises from

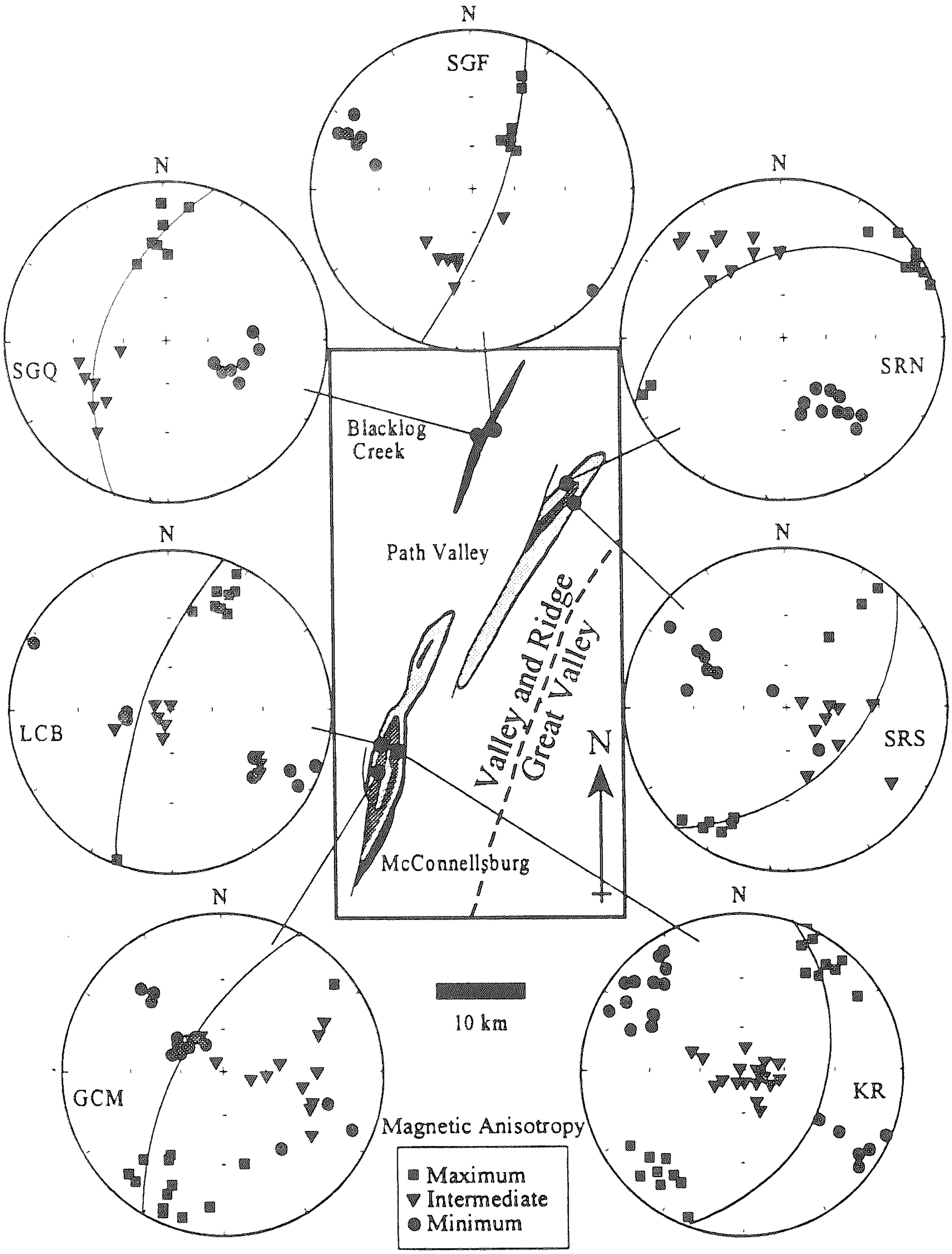

Figure 9. Equal angle stereonets showing the anisotropy of magnetic susceptibility results. Great circles indicate bedding at the site. The magnetic fabrics are carried by the paramagnetic clay fraction and represent a composite bedding-shortening fabric as indicated by oblate to slightly prolate fabrics with minimum susceptibility axes normal to bedding and maximum axes roughly parallel to the fold axes. These results suggest that the carbonates are internally deformed.

compaction of a small fraction of clay minerals in bedding during diagenesis and neocrystallization of a small fraction of clay minerals perpendicular to bedding during deformation. Recognition of this fabric is important because it demonstrates that the carbonates are internally deformed and as such this internal shortening must be accounted for in calculations of bulk Alleghanian shortening across the Valley and Ridge.

SURFICIAL GEOLOGY OF THE McCONNELLSBURG QUADRANGLE

A review and update of the work of Kenneth L. Pierce

by
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INTRODUCTION

"Bedrock and surficial geology of the McConnellsburg quadrangle, Pennsylvania" by Kenneth L. Pierce was published by the Pennsylvania Geological Survey in 1966. This publication was a milestone because it contained the first detailed mapping of surficial materials done in a non-glaciated part of Pennsylvania. Pierce studied the surficial materials in order to understand the erosional history of the area. In reality, it is difficult to avoid surficial material, not just in the McConnellsburg quadrangle but anywhere in the Ridge and Valley. Less than 2 percent of the McConnellsburg quadrangle consists of exposed bedrock (Pierce, 1966, p. 58; **Note:** Henceforth throughout this paper, only the page numbers will be given when Pierce, 1966 is referenced).

Pierce was astute in his recognition of the types of surficial materials present and in the selection of map units. As a pioneer in the area of Pennsylvania's non-glacial surficial materials, he pondered origin and age perhaps more than workers would today. His analysis of topography (p. 96-106) is a feature seldom seen in reports. Pierce did an excellent job mapping the surficial geology of the McConnellsburg quadrangle and his report is well worth reading.

SURFICIAL MATERIALS

Pierce divided surficial materials in the McConnellsburg area into two broad categories: residual regolith and transported regolith. Each of these categories was further subdivided in the report, but the map units combined several subdivisions of the transported regolith. Pierce is quite correct in his terminology, but many workers today would refer to some of the transported regolith as colluvium (e.g., Berg, 1975; Sevon, 1975a; Berg and others, 1977; Hoover and Ciolkosz, 1988; Ciolkosz and others, 1990). Figure 10 shows part of Pierce's surficial map (Plate 3). Mapping of this area today by me or some other mapper would probably differ mainly in the detail. There would be no real change in the basic units that Pierce mapped.

Residual regolith.

Pierce recognized three residual regoliths, those developed on carbonate, shale, and sandstone, the three rock types present in the McConnellsburg quadrangle.

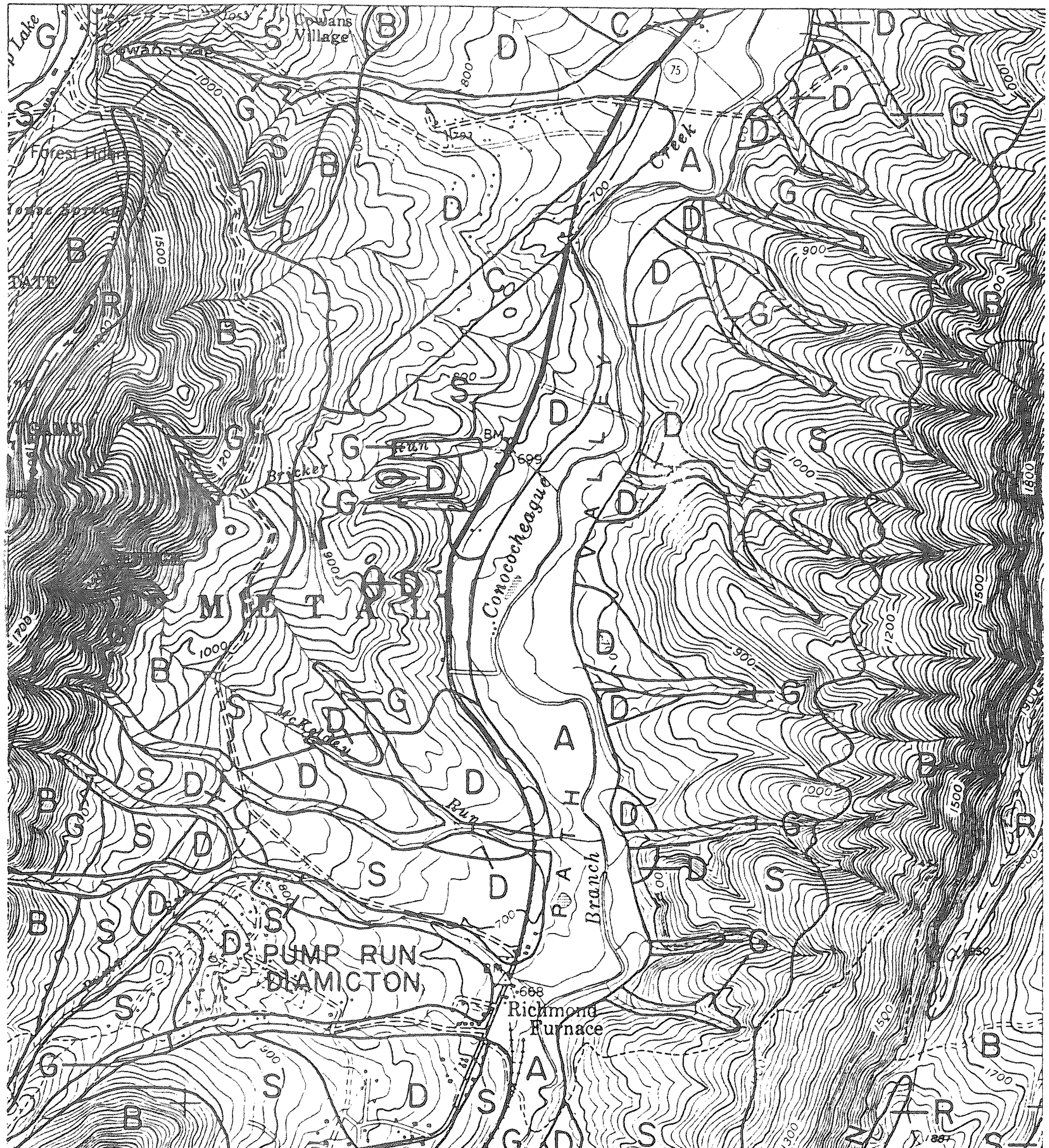


Figure 10. Northeastern corner of the geologic map for the surficial geology of the McConnellsburg quadrangle (Pierce, 1966, Plate 3). Map units are: **Residual regolith:** C - Carbonate residuum; S - Shale residuum; R - Sandstone residuum. **Transported regolith:** B - Sandstone rubble with plentiful matrix (boulder colluvium); D - Roundstone diamicton; G - Gravelly alluvium and sandstone rubble; A - Modern fine-grained alluvium.

Carbonate rock. Pierce noted the solution-weathering of carbonate rock and the production of thick residuum beneath roundstone diamicton deposits. He suggested as much as 30 feet of solutional lowering of the carbonate landscape beneath the diamicton. The carbonates underlie the lowest parts of the landscape.

Pierce made the interesting observation that carbonate outcrops apparently erode at a slower rate than carbonate that is residuum covered. The logic being that carbonate outcrops tend to persist and carbonate covered with residuum tends to remain that way. I have thought that might be true also, but believe that the factor of cow-induced erosion (Trimble and Mendel, 1995) must be considered. Observation suggests that cow hoofs and noses contribute to carbonate outcrop perpetuation and may actually be a significant factor in outcrop development.

Shale. Clayey residuum develops on shale with no isovolumetric change. It is generally not very thick either because it takes longer to form or because it is eroded more readily. Shales underlie topography that is intermediate in elevation between the carbonates and the sandstones.

Sandstone. The sandstones cap the ridges and weathering of the silica cement is sufficiently slow that very little sand residuum forms. However, the sandstones break up along bedding and fractures into large and small angular blocks that accumulate on the ridge slopes and form some of the previously described surficial deposits. Fragmentation of the sandstones was particularly enhanced by periglacial climate during the Pleistocene. Similar fragmentation presumably occurs today but at a much slower rate.

Transported regolith.

Transported regolith is subdivided into two categories: angular regolith and alluvium. Pierce also referred to the angular regolith as mountain regolith because most of the material was derived from sandstones of the Tuscarora Formation at or near the ridge crests. Shale-chip rubble is the exception. He further subdivided angular regolith into that occurring on the interfluves and that occurring on the valley bottoms.

Rubble on interfluves. Rubble on interfluves is subdivided on the basis of surface slope, presence or absence of matrix, and size of clasts.

Screes are the coarsest grained rubble deposits and occur on slopes steeper than 20°. Scree, also mapped elsewhere as talus (e.g., Berg, 1975), is widespread throughout the Ridge and Valley and is seen at Stop 1, Day 1 and mileage 38.2-38.7, Day 2 of this field trip. Pierce found evidence of some present-day movement of scree and hesitated to ascribe its origin exclusively to Pleistocene periglacial activity.

Rubble with a matrix and associated regolith on moderate slopes of 5° to 20°. This material covers nearly 70 percent of the mountinous area of the McConnellsburg quadrangle. We will see some rubble with matrix at Stop 5, Day 1 and between mileages 64.5 and 69.3 on Day 1. It is sufficiently abundant that it occurs many other places along the field trip route, but some care must be exercised not to confuse it with roundstone diamicton.

Pierce notes that the clasts in rubble with matrix are generally more weathered than those in scree and that the amount of matrix can be related inversely to the amount of runoff crossing the surface. His description is inadequate to determine if some of the rubble-with-matrix that he saw was an older colluvium such as described by Hoover and Ciolkosz (1988) and Ciolkosz and others (1990). These workers describe a complex colluvial stratigraphy that consists principally of two parts, but may have more as yet unrecognized parts.

The two-part stratigraphy consists of an upper brown colluvium overlying a buried red colluvium. The brown colluvium has a soil that developed in post Late Wisconsinan time (last 18,000 years). The red colluvium has much greater soil development and is presumably much older. The age of the soil has not been determined, but its position and weathering characteristics suggest that it is probably pre-Illinoian in age and possibly started to develop at least 780,000 years ago (Gardner and others, 1994). This two-part stratigraphy is almost ubiquitous in the Ridge and Valley and occurs also in the Appalachian Plateau (Waltman and others, 1990) and the Piedmont (Sevon, 1996).

My observations, which are similar to those of other workers, lead to the conclusion that large amounts of material were moved by periglacial activity during the glacial epochs of the Pleistocene. The colluvial stratigraphy is evidence of some of that movement. Pennsylvania has experienced at least four glacial episodes so that there should be at least four discrete colluvial units, two of which have not been identified. In addition, Gardner and others (1991) point out that each glacial epoch will have two periods of intense periglacial activity. This can create a complex stratigraphy with numerous colluvial units such as occurs in the Piedmont (Sevon, 1996)

Block fields. Block fields are open expanses of coarse-grained rubble with little or no matrix and slopes less than 10^{0}. These features are common in the Ridge and Valley wherever conditions were right for their formation. They have been mapped mainly in northeastern Pennsylvania and called boulder fields (e.g., Epstein and others, 1974; Sevon, 1975b).

Shale-chip rubble. Shale-chip rubble consists of accumulations of shale chips overlying shale bedrock. These well known and widely used deposits are common throughout the non-glaciated part of eastern and central Pennsylvania (Sevon and Berg, 1979). Pierce was not sure about their periglacial origin, but that has been clearly established by Gardner and others (1991).

Piles of rubble on valley bottoms.

Rubble ridges. Rubble ridges are low, elongate mounds of sharpstone occurring on the floors of some first-order-valley floors. The mounds (I prefer the name mounds to ridges, a term with a much different connotation in this area) are covered with matrix-free sharpstone that rests on sharpstone with matrix. The mounds have a distinct sloping front, sloping sides, and a relatively flat top that grades up gradient to join the valley floor. Pierce was uncertain about their origin although he favored periglacial. Similar mounds elsewhere in the Ridge and Valley are known, but have not been described. Carter and Ciolkosz (1986) describe somewhat similar mounds on a sandstone spur in central Pennsylvania and consider them to be solifluction lobes. They may also be debris-flow deposits that once covered the valley bottom but which have subsequently been incised by erosion along their margins (Osterkamp and others, 1995, Fig. 5, p. 8).

Debris slides and avalanches. Pierce describes lobate accumulations of rubble at the bases of very steep, first-order, valley heads. He ascribes their origin to debris slides and avalanches despite the lack of an upslope scar. This lack of a scar could be because they are old or because there never was a scar. Pierce mentions similar deposits in Virginia that were described by Hack and Goodlett (1960) and more recently by Osterkamp and others (1995). We will have the opportunity to look at a debris avalanche scar and associated deposits at lunch stop on Day 2 of the field trip (See description for that stop).

It is my observation that debris avalanches occur in Pennsylvania, but that they are not nearly as common or as large in Pennsylvania as they are farther south in Virginia (Hack and

Goodlet, 1960) or West Virginia (Kite and Linton, 1987). Debris avalanches occur when the shear strength of loose materials is reduced to the point of failure by water saturation during or following periods of excessive rainfall. Such rainfall is not uncommon in Pennsylvania. A possible explanation for the perceived regional difference in debris avalanche occurrence is that the materials needed for large and abundant debris avalanches may be lacking in much of Pennsylvania.

Debris avalanches orginate high on steep slopes and involve unconsolidated debris. In much of the Ridge and Valley of Pennsylvania, the higher parts of the slopes have relatively thin unconsolidated debris and that debris often consists of sharpstone with little or no matrix, an essential ingredient for debris avalanches. These materials are what remain after the extensive downslope transport of debris that occurred during Pleistocene periglacial conditions. Farther south, periglacial conditions were not as severe and less material was removed from the higher parts of the slope. Therefore, today there is more unconsolidated debris, both fine and coarse grained, available in positions suscepible to failure under the correct conditions. The reality of this explanation is unproven.

Rubble fans and rubble valley fill. Rubble occurs as fill up to 30 feet thick in small valleys and as fans where low-order, high-gradient streams join larger, lower-gradient streams. This rubble has the same appearance of much other rubble, but is differentiated because of topographic position and form. Pierce followed Hack and Goodlett (1960) and attributed these deposits to exceptionally large debris-flow events. He may be correct, but there is a lack of evidence that they are of recent origin. Rather, I suspect that they were formed as debis flows generated either partly or entirely during the Late Pleistocene.

Alluvium.

Modern alluvium. Pierce describes modern alluvium that occurs along several streams in the area. His descriptions seem typical of alluvial sequences--a lot of diversity, but nothing extra-ordinary except for an interpretation of a West Branch stratigraphic section (p. 71). He suggests that a sandy clay with abundant organic material may represent ponding of the stream and possible development of a lake. Ponding in this area is unlikely unless the site was once part of a cutoff channel, which is a definite possiblity. Additionally, in the same section he interprets a higher sediment as a paleosol.

Roundstone diamicton. Pierce spent considerable time (p. 74-95) discussing the roundstone diamicton that is widespread in the McConnellsburg area. This material is a nonlithified, essentially nonsorted, terrigenous deposit composed of sand and large clasts set in a muddy matrix. Pierce's discussion remains one of the most detailed and thoughtful on the subject. He points out that the material is widespread in the Cumberland Valley and elsewhere in the Appalachians, but has received very little attention. This still remains the case except for two recent field trip evaluations (Sevon, 1991; Whittecar, 1992) and a journal article (Whittecar and Ryter, 1992).

Pierce considered the diamicton to be mainly alluvial deposits that were sufficiently old to be deeply weathered. He used local stream names to identify some of the deposits (e.g., Pump Run diamicton on Figure 10). The pattern of diamicton distribution is related to underlying bedrock. Where bedrock is shale, the diamicton is present mainly in a fan-shaped pattern associated with a drainage and is mostly but not entirely missing from the higher interfluves (See Road Log, Day 1, Mileage 72.7). Where the bedrock is carbonate, the diamicton occurs as a continuous apron at the base of the steeper slopes (See Road Log, Day1, Mileage 23.4). Pierce discusses at some length the fact that the carbonates have been solution-weathered beneath the diamicton while the shale and diamicton have been locally eroded as much as 100 feet. He suggests that the amount of landscape lowering by solution (carbonates) and erosion (shale) are commensurate with the time since deposition of the diamicton.

Pierce proposed several alternatives for origin and age, but essentially concluded the diamicton to be alluvial deposits probably associated with the Pleistocene. He generally discounted mudflows as the transporting mechanism and attributed the muddy matrix to weathering of shale clasts. He suggested a similarity in degree of weathering to Illinoian glacial deposits (**Note: Probably** what Pierce referred to as Illinoian is now considered pre-Illinoian).

Serendipity is real. Reading, reviewing, and thinking about Pierce's work on the roundstone diamicton made me aware of some previously unrecognized (by me) relationships. On the 1991 Field Conference I showed and discussed at Mainsville the diamicton that mantles the carbonates on the north side of South Mountain (Sevon, 1991). A truncated soil profile at the top of a clastic dike cutting the diamicton at the Mainsville site was interpreted to be pre-Illinoian in age. Recent work by Gardner and others (1994) indicates that pre-Illinoian material in Pennsylvania is greater than 780,000 years old. Pierce had earlier noted (p. 78) the similarity between these diamictons and those in the McConnellsburg area.

In 1985 I wrote about isolated roundstones on shale residuum on the north side of the Great Valley near Possum Lake (Sevon, 1985). These roundstones occur on uplands as high as 100+ feet above the present drainage and with drainage reversal between them and their mountain sources, just as described by Pierce (p. 80). I assumed, as did Pierce, that the roundstones were transported across a nearly planar surface that existed sometime in the past. I calculated that it would take between 0.7 and 1.1 ma to erode that planar surface and produce the present landscape. These figures nicely bracket the 780,000 figure of Gardner and others (1994).

Pierce had a clear picture of the puzzle, he just lacked some of the pieces. It appears that the ridges were mantled by thick residual debris prior to a pre-Illinoian glacial epoch that occurred sometime more than 780,000 years ago. Transport of this debris, both by mudflow and fluvial activity, moved the debris to sites of deposition on a relatively low-relief surface at the base of the steep ridges. This transportation and deposition may have been caused by periglacial conditions accompanying the pre-Illinoian glacial epoch. Subsequent solution weathering of carbonates has lowered the carbonate land surface and created undrained depressions while preserving the diamicton mantle. In areas of shale bedrock, physical erosion locally has removed not only the diamicton but also 10's of feet of shale and in places only isolated roundstones remain on shale residuum. Some of the fan-shaped diamicton deposits at lower elevations are probably eroded and redeposited older diamicton.

GEOMORPHOLOGY

The McConnellsburg area is a good place to see the adjustment of topography to structure and bedrock. The ridges, capped by resistant sandstones, outline the structure nicely. Pierce noted the relationship between faults and various gaps. He saw no reason for the existence of any peneplain surfaces but adhered rather to the ideas of Hack (1960) that the topography is the result of continuous downwasting and adjustment to rock type. He particularly had no difficulty discarding the Kittatinny (Schooley) surface. He had more trouble with the Harrisburg surface because there seems to be more things related to that topographic level. He has many simple but valid observations in a report that remains well worth reading.

ASPECTS OF HUMAN HISTORY

by
Richard P. Nickelsen

There are a number of aspects of human history that were influenced by the physiography and geologic setting of the McConnellsburg-Fannettsburg-Mercersburg region. Conversely, human activities, particularly early iron mining, have contributed to our perception of the geology. But lets start at the beginning.

In the middle of the 18th century, one of the major pathways to the west, for both early settlers and British French and Indian war troops, passed through Fort Loudon, Cowans Gap, Burnt Cabins, and Fort Littleton, places we will visit on this field trip. They are all along the route of Forbes Road, started in 1755, to provide a pathway for westward transportation of men and materials to Fort Duquesne (Pittsburgh). Forbes Road was located here because Cowans Gap (elevation 1,200 feet) is the only low pass through Tuscarora Mountain for a NE-SW distance of 40 miles. After crossing Cowans Gap (our lunch stop on Day 2), the road followed Allens Valley to Burnt Cabins and Fort Littleton before continuing west to Forts Bedford and Ligonier. Even before Forbes Road was formally constructed, early settlers had moved into this region and built permanent structures on lands occupied by native Americans of the Eastern Woodland culture group - the Tuscaroras, Susquehannocks, and Delawares. Following protests by the indians about the permanent structures of the white settlers, provincial forces, in 1750, removed the settlers and burned their cabins, thus creating the name, Burnt Cabins. The grist mill near Stop 6 was built between 1750 and 1760 at the site of an earlier grist mill that had been burned.

Of particular geologic interest are the sites of historic iron mining and smelting that are located along the major faults that define the NW side of the two major anticlinal valleys that we will visit on this trip: the McConnellsburg-Big Cove valley and the Path valley. The sites in the McConnellsburg valley are associated with Hanover furnace, which operated from 1822 until 1847, utilizing ore from a mine on the east side of Lowrie's knob (Lowery of present usage), near Stops 3 and 4 on this trip. In the Path valley the sites were associated with Richmond Furnace and Carrick Furnace, which received their ore from 10 different historic mines aligned along the Path Valley fault for a distance of 7 miles (see Figure 11). These mines were apparently not operating at the time of Lesley's Annual Report of 1886 (d'Invilliers, 1886). It was Robert Smith (personal communication, 1995) who directed me to reports of these historic iron workings in Rogers (1858, p. 415, 479) and Stevenson (1882) for the McConnellsburg valley, and d'Invilliers (1886) for the Path valley. Ores were apparently limonite, var. botryoidal goethite, but all mining may have ceased by the middle of the 19th century, so no exposures of country rock or the old working faces are available for inspection. What is striking about these occurrences is their alignment along major faults which bring Ordovician carbonate rocks of the hanging wall in contact with upper Ordovician (Reedsville or Bald Eagle) or Silurian clastics (Tuscarora) of the footwall. My impression is that the largest workings were located where the fault places Ordovician carbonates of the hanging wall against Tuscarora quartzites of the footwall. I have found no primary sulfide mineralization at any of these sites, but some has been reported (Smith, personal communication, 1995, 1996). The possible significance of these historic mines to the structural interpretation of the region, is discussed elsewhere.

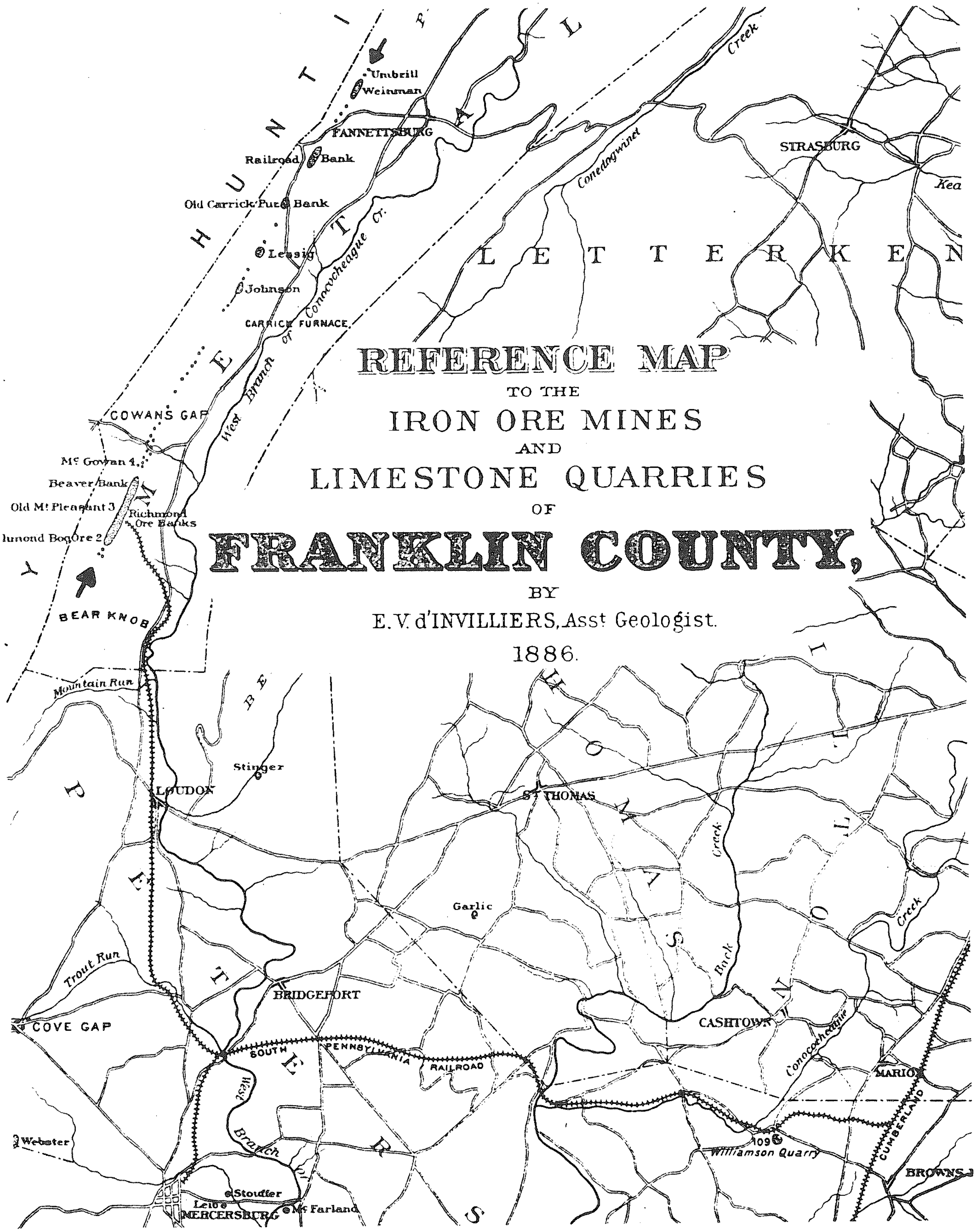


Figure 11. Historic iron ore mines of Franklin County aligned along the Path Valley fault.

During the years leading up to the Civil War, several sites in western Fulton County served as stations on the "underground railroad," a pathway north for slaves who escaped their owners to the south. During the Civil War, several groups of Confederate cavalry entered McConnellsburg after raids on Chambersburg and Mercersburg in June, 1863, just prior to the Battle of Gettysburg. The last Confederate bivouac in Pennsylvania was just south of McConnellsburg on July 31, 1864.

An interesting episode of economic conflict between railroad and steel magnates led to the beginning of construction of a railroad along parts of Forbes Road during 1883-85. The right of way of this never-completed South Penn Railroad was eventually acquired by the Pennsylvania Turnpike Commission for one million dollars. This purchase included six partially finished tunnels through Tuscarora ridges that were later enlarged between 1937 and 1940 for use by the new road. It all started when Andrew Carnegie, the Pittsburgh steel producer, joined William Vanderbilt, owner of the New York Central Railroad, in financing a new railroad to provide competition for the Pennsylvania Railroad, which Carnegie thought charged too much for transporting his steel across Pennsylvania. They raised $15 million and employed 6,500 men for a major construction that started in 1883. By 1885, the South Penn Railroad line was 60 percent finished when the banker, J. P. Morgan, arranged a settlement that caused construction to stop immediately. Partially completed railroad cuts are visible at a number of places along the present Pennsylvania Turnpike in the Burnt Cabins-Fort Littleton area, providing some of the better exposures of Devonian rocks west of Scrub Ridge. The story of the South Penn Railroad was introduced to me in 1994 by State Geologist Donald Hoskins during a visit to help me distinguish Devonian formations. Unfortunately, the railroad cuts are not accessible for visits by this Field Conference. Their condition suggests the immediacy of the STOP WORK order when the J. P. Morgan settlement was arranged. A number of older residents of Fulton county have pointed out that the county never had an operating railroad line, perhaps the only county in the state with this distinction. Oh, what might have been!

It has also been pointed out that commerce between McConnellsburg, in the center of the Big Cove Valley, and Chambersburg, to the east, took place over Tuscarora Summit (Stop 1) and that a special group of drovers were in the business of moving livestock eastward from the McConnellsburg area. This pathway was later developed into the local segment of **THE** major east-west route across Pennsylvania during the early days of the motor car in the 1920's and 30's -US Route 30. Until the completion of the Pennsylvania Turnpike in 1940, travel from Philadelphia to Pittsburgh followed Route 30 through Lancaster, York, Gettysburg, Chambersburg, McConnellsburg, Bedford, Ligonier, and Greensburg. Roadside establishments such as the Tuscarora Summit Inn record the better days of US Route 30 as a major east-west artery.

We will have lunch on the first day of the field trip at the dam of Meadow Grounds Lake on State Game Land # 53, a beautiful place with an interesting history. As long ago as the end of the 18th century, farmers in the Big Cove Valley (McConnellsburg valley) to the east used this enclosed, synclinal valley as a summer pasture for cattle. The cattle were daunted by the steep Pocono ridges bounding the valley, so the farmers apparently let them roam free and, in the fall, all participated in a "round-up" to collect their respective animals. The farmers managed the valley by controlled burning to increase the grass supply and enhance the blueberry picking. After the land was acquired by the Pennsylvania Game Commission, Carl Jarrett, a former Game Protector, became an advocate of the lake now present there. The dam was built in 1961 and has created a lake that is now an important stopover for migrating waterfowl and gulls as well as a favorite fishing place for local residents. Carl Jarrett will eat lunch with us and be glad to answer your questions or recall local history.

GENERAL COMMENTS

by
Richard. P. Nickelsen

My structural study of the McConnellsburg Big Cove anticline and the Path Valley anticline in Fulton and Franklin Counties, Pennsylvania should be integrated with the results of paleomagnetic work by John Stamatakos and his co-workers and the attempt to radiometrically date the Tuscarora fault/Antes-Coburn detachment by Ken Foland. These general summary comments are an attempt to point out relationships between these three areas of study and to suggest topics for future work.

PRE-FOLDING SHORTENING

The earliest structural features of the Alleghanian orogeny that I was able to measure in this region are the conjugate strike-slip and wedge faults in quartzites, sandstones, and carbonate rocks (Keefer, Tuscarora, Bald Eagle, Nittany, St. Paul Group) and the cleavage duplex of the Tuscarora fault/Antes-Coburn detachment, near the base of the Reedsville section. These early structural features, indicating either an early shortening direction, or the pre-folding vergence of a top-to-the-foreland deformation, have been folded by the major 1st- and 2nd-order folds of the region.

Early strike-slip faults have slickenlines that either parallel their fault/bedding intersection or show oblique-slip that can be understood as their participation in the early phases of the folding stage. The pre-folding shortening direction is derived by rotating early fault structures around the strike of associated bedding to find their orientation when bedding was horizontal. The pre-folding shortening direction is then established as: (1) the acute bisector of conjugate faults, (2) the mean of the strike of an array of strike-slip faults, or (3) the direction of slickenlines on wedge faults. At several localities (Stop 6 and 7) reactivation of the pre-folding strike-slip faults of certain orientations has resulted in an overprint of synfolding slickenlines upon earlier slickenlines that had been formed parallel to the fault/bedding intersection. It seems clear that a system of conjugate faults formed during layer-parallel-compression prior to major folding, and that they can be interpreted to indicate the local direction of shortening (Figure 1). What is less clear is what produces the variability in pre-folding directions throughout the region.

Pre-folding shortening directions are variable but are everywhere directed either perpendicular to, or, north of the perpendicular to, the strike of the Tuscarora ridges. In some places such as at Stop 6, there is striking evidence of the counter-clockwise overprint of folding upon the earlier shortening direction, but it is less obvious in other parts of the study area. Generally, in Fulton/Franklin Counties, folds overprint pre-folding shortening in a counter-clockwise direction. In a much larger region extending 30 miles WSW to Maryland (Markle and Wojtal, 1996) and 40 miles N to the Kishacoquillas Valley (Nickelsen, 1988) detailed studies have also documented shortening toward the NW that was later overprinted in a counter-clockwise direction by folding. In Maryland, Markley and Wojtal found pre-folding shortening of 10% recorded in the early, dissolution cleavage of Siluro-Devonian carbonate rocks, providing the only measure of the amount of early shortening in the larger region.

One of the interesting results of the Stamatakos and others magnetic studies described in this guidebook, was a measurement of the directions of the anisotropy of magnetic susceptibility (AMS) in the Ordovician carbonates from 7 localities in the McConnellsburg, Path Valley, and Blacklog Valley areas. Their origin is described in the accompanying paper as resulting from diagenesis and neocrystallization of a paramagnetic clay mineral (illite) parallel to incipient foliation in the carbonate rocks. The fabric observed is approximately parallel to incipient foliation in the carbonate rocks (Figure 9). It is also suggested that this fabric demonstrates internal deformation of the carbonates, a feature not noted in the Nittany dolomite at Stop 4, but recognized in the Chambersburg Formation part of the section observed at Stop 8. It is mentioned here because it is hoped that future work on AMS in these rocks will be able to address the question of whether this fabric is of pre-folding or an early folding age, by assessing the orientation of the structures producing the AMS.

THE TUSCARORA FAULT/ANTES-COBURN DETACHMENT

Transport or cleavage directions in this fault zone have been plotted on Figure 2, showing that the vergence toward the NW of the sigmoidal cleavage of the cleavage duplex or the slickenlines of the floor or roof is either perpendicular to the associated folds or trends to the north of the perpendicular to the folds. These orientations and departures from perpendicularity to folds are similar to the relationships shown in Figure 1 for the early shortening directions, leading to the belief that both the early shortening and the top-to-the-foreland shear of the cleavage duplex of the Tuscarora fault/Antes-Coburn detachment are formed at the same time under similar compression directions. Pierce (1966) depicted this as a pre-folding structure, but did not measure directions of transport. In this area, it appears that folding overprinted, counter-clockwise, the earlier movement along the Tuscarora fault/Antes-Coburn detachment.

The Tuscarora fault/Antes-Coburn detachment is the most likely "mid-level" bedding-parallel fault or detachment horizon in the Upper Ordovician Reedsville or Martinsburg section that has been incorporated in the structure sections of virtually all geologists of the middle Appalachian Valley and Ridge. Examples are Gwinn (1964, 1970), Mitra and Namson (1989), and many others referred to by Dunne (1996). Wilson and Shoemaker (1992, Figure 2) have provided a stratigraphic column in which they assess the relative mechanical strength and interval velocities of the Cambrian through Devonian section of the Broadtop thrust in West Virginia. The basal Martinsburg (equivalent to the Reedsville) is indentified as a weak unit with the lowest seismic velocity in the section, thus adding new dimensions to the physical attributes of the zone.

Although not finding enough young sheet silicate minerals in the fault zone to determine an $^{40}Ar/^{39}Ar$ age for movement along the zone, Ken Foland, in this guidebook, describes aspects of the fault zone that are available through modern analysis. Incremental heating (Figure 3) has revealed that all dates on this zone are "mixed ages" derived from relict, old detrital micas as well as new growth sheet silicate minerals. The 100 Ma difference (Table 1) in the bulk ages of the "fault rock" and the "country rock" is the result of growth of new sheet silicates that have released their Ar at lower temperatures than the release temperature for old detrital micas, during the incremental or "step" heating analysis. The previous K/Ar "Acadian" age of Pierce and Armstong (1966) was based upon the assumption that the temperature in the fault zone was sufficiently high to recrystallize all detrital grains and reset the "K/Ar clock". This is unlikely because it would require temperatures of above 300°C, whereas temperatures of filling for fluid inclusions in the quartz crystals along faults in the Bald Eagle sandstone and the Tuscarora Formation of the region don't exceed 200°C. We are seeking exposures of the Tuscarora fault/Antes-Coburn detachment in a region where sufficient growth of new mica has occurred to permit a radiometric age to be determined. It would be useful to have this age to compare with the ages derived from the Permian remagnetization event, which may be slightly younger.

EVOLUTION OF THE SW LIMB OF THE PENNSYLVANIA SALIENT

Structural evidence of the three-fold counter-clockwise overprinting of structures on the SW limb of the salient, supports the definitive paleomagnetic evidence presented in the accompanying paper by Stamatakos and others. Structural evolution involved NW to NNW layer-parallel-shortening and vergence of the cleavage duplex, followed by major folding that verged toward the NW or WNW, followed by steep reverse faulting that, in places, involved a counter-clockwise truncation of pre-existing folds.

Paleomagnetic evidence of the evolution of structures includes, first of all, a 20° to 30° rotation around a verical axis of the C (primary magnetization) components in Silurian, Devonian, and Mississippian redbeds (Figure 4B). This rotation, which could have taken place in either one or both limbs of the salient, apparently occurred prior to Alleghanian thrusting and folding, but cannot be identified kinematically in known structural features. It is possible that the early layer-parallel-shortening and Tuscarora fault/Antes-Coburn detachment movement occurred prior to this vertical axis rotation, or were involved with the rotation, but there is nothing in the structural evidence that advocates this view.

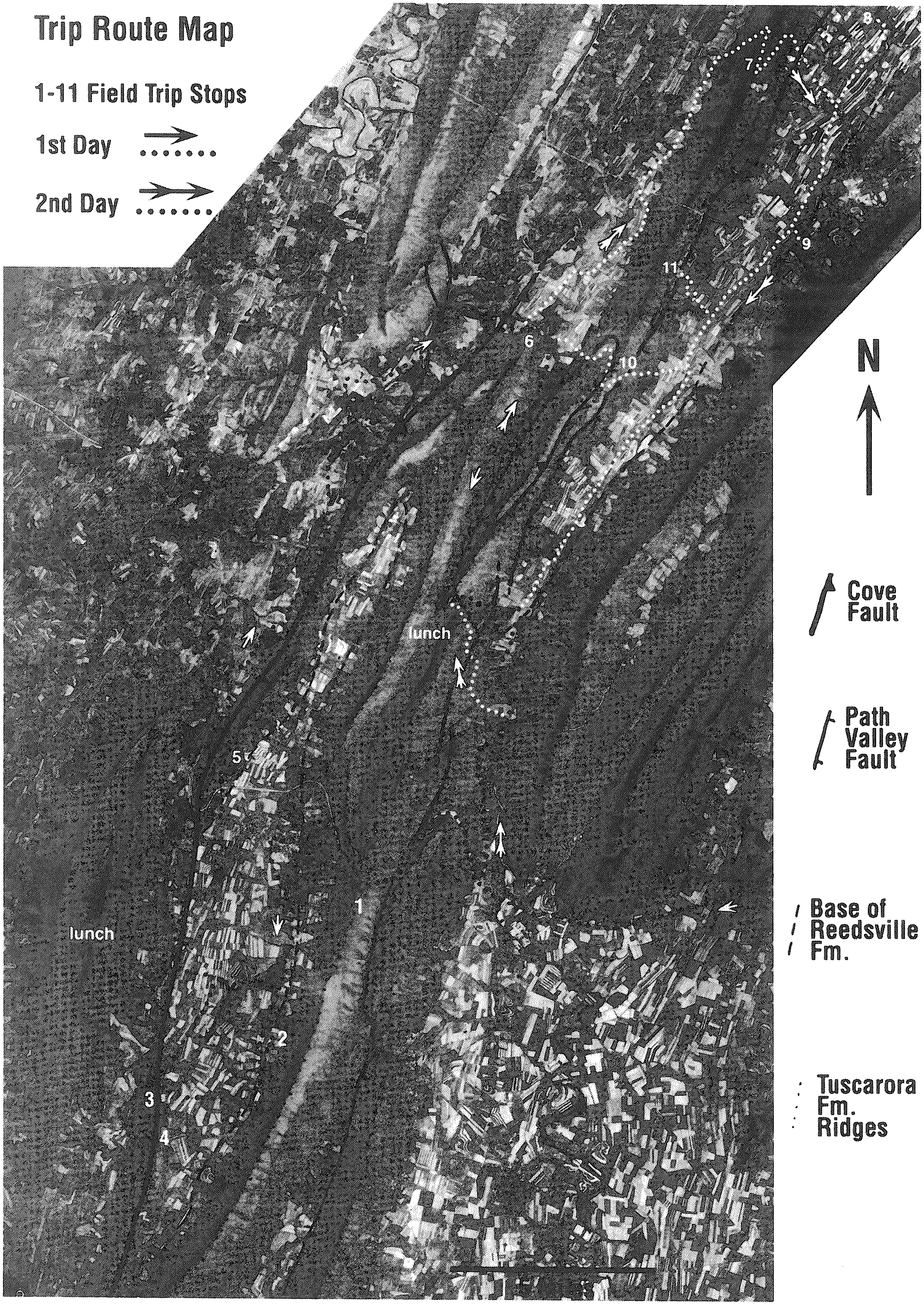
The important, Late Paleozoic, B-component remagnetization has mean directions throughout the region that allow it to be placed in the Permian (mean age 265 Ma) segment of the reference North American apparent polar wandering path (Figures 7 and 8). Depending upon the relative hinterland-foreland position of the folds, B-component remagnetization may have been later than folding (in the hinterland), synfolding or pre-folding (in the foreland) (see Figure 4A). There has been no rotation of these B-component, Permian, remagnetization poles around a vertical axis, so the current orientation of fold axes is the same as when the folds formed. Consequently, an oroclinal counter-clockwise rotation of originally straight fold axes into the SW limab of the Pennsylvania salient is not supported by the paleomagnetic data. Rather, the folds were overprinted upon earlier structures. This observation is compatible with the observation from structural geology that folds of mid-Permian age have been overprinted, counter-clockwise upon earlier shortening directions, although it is still not completely clear when the earlier shortenig occurred.

Finally, the truncation of these folds of mid-Permian age and the formation of segments of folds parallel to the late, reverse faults of the Cove and Path Valley systems, continues the process of counter-clockwise rotation during the sequential deformation of the Alleghany orogeny into a class of structures not previously isolated as distinct elements. These late faults with distinctive characteristics described in "Two different fault populations...." (p. 7) are the youngest structures of the region. They were formed under different environmental conditions from those that prevailed during pre-folding shortening and major folding.

ACKNOWLEDGEMENTS

Many individuals and groups have contributed to this guidebook and the successful access to and description of the geology that you will see in Fulton and Franklin Counties. They include: Brad Jordan, Bucknell Geology staff, for computer help and illustration finesse; Helen Mathias, Bucknell Geology staff, for typing and formating several papers; Mary Beth Gray, Bucknell Geology, for critical reading and geological advice; Bucknell students Adam Gooch, Rob Jacobs, Ted Ressler, and Liz Spiker for their efforts on traffic control and for giving up two days of summer vacation to learn more about the geology they will help demonstrate. Special thanks to Adam for his careful work at Stop 6; Bob Smith, Pennsylvania Geologic Survey, for his insight and encouragement; Don Wise, Franklin and Marshall College, for his critical review and suggestions; Rick Allmendinger, Cornell University, for use of his stereonet program; Jennifer Duncan, for her careful mapping help and measurements of structures; Paul Zell, The Pennsylvania State University, for his help with the carbonate stratigraphy of Stop 4; and The Pennsylvania Geologic Survey for its field support. The following landowners and people of Fulton and Franklin County have contributed greatly: Benny and Jerry Barnhart of the Tuscarora Summit Bar who provided bus parking space; Harold "Bud" Reed, who provided access to his borrow pit at Stop 2; Gerald and Barry Bivens of Twin Brook Farm who made an outcrop for us at Stop 2; Ralph Glenn, owner of the north part of Lowery Knob for access to Stop 3; Mellott Estate, Inc. Warfordsburg, PA for access to their quarry for Stop 4; Carl Jarrett, retired PA game protector who helped establish Meadow Ground Lake and will eat lunch with us on Friday to tell you of local history; John Funk, who granted permission to visit outcrops off the road at Stop 5; Carl Brown, for access to Stop 6; Jack and Sonja Blattenburger, for bus parking space at the Burnt Cabins Grist Mill; Jim Campbell, manager, and the New Enterprise Stone and Lime Co. for access to Dry Run quarry, Stop 8; Bill Elliott of Elliotts Tree Farm and Nursery for access to Stop 11.

Figure 12.


Trip Route Map
1-11 Field Trip Stops
1st Day
2nd Day
N
Cove Fault
Path Valley Fault
Base of Reedsville Fm.
Tuscarora Fm. Ridges
lunch
lunch
1
2
3
4
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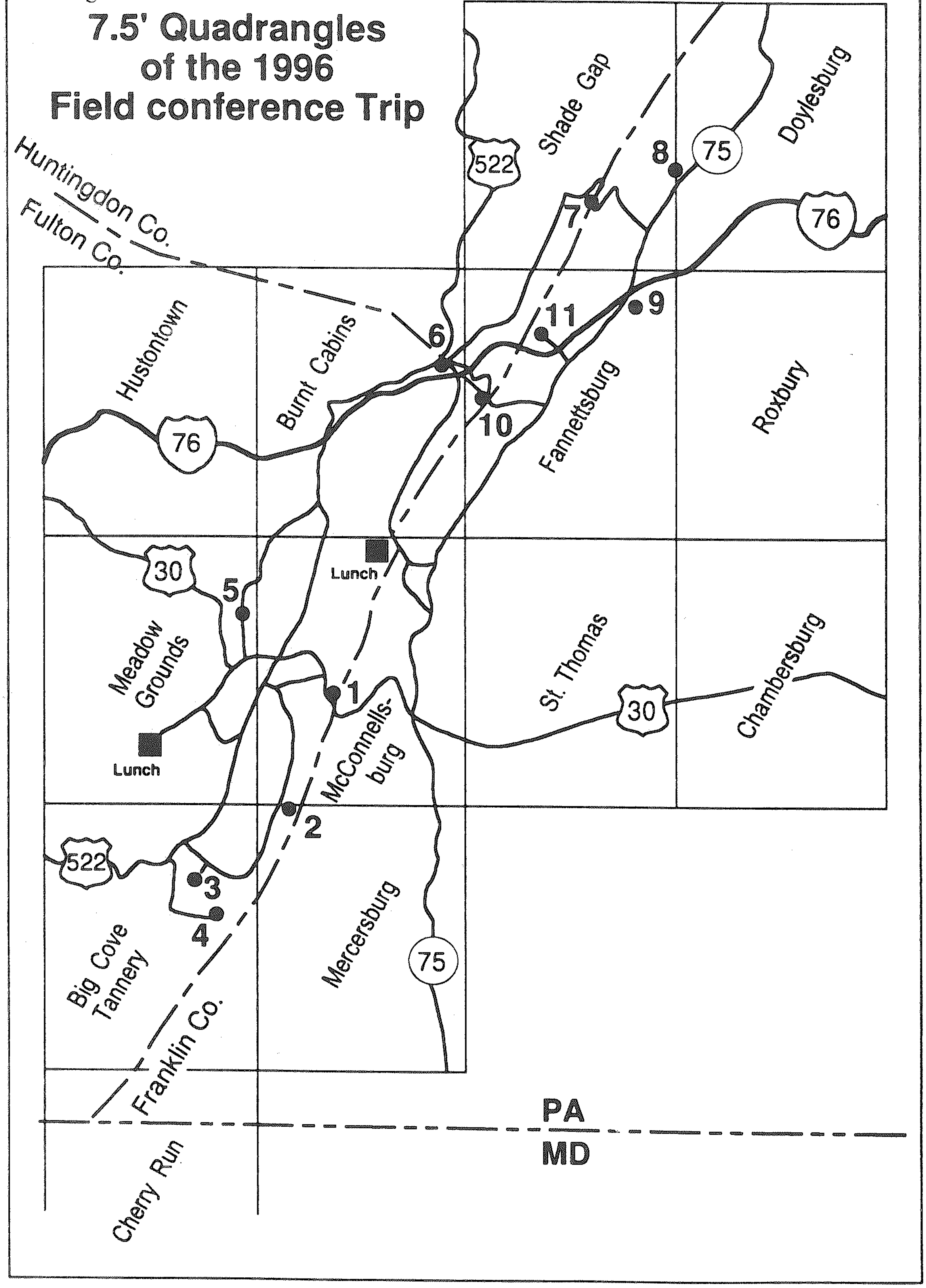
11

Figure 13.


7.5' Quadrangles
of the 1996
Field conference Trip
Huntingdon Co.
Fulton Co.
Franklin Co.
Shade Gap
Doylesburg
Hustontown
Burnt Cabins
Fannettsburg
Roxbury
Meadow Grounds
St. Thomas
Chambersburg
McConnellsburg
Big Cove Tannery
Mercersburg
Cherry Run
PA
MD
Lunch
Lunch
522
75
76
76
30
30
522
75
1
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3
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6
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11

STRATIGRAPHIC UNITS

Period	Epoch	Meadow Grounds	McConnellsburg	Path Valley	Stop Numbers
MISS		Mauch Chunk Fm. Pocono Fm.(ss) Rockwell Fm.			Lunch
DEVONIAN	U	Catskill Fm. Irish Valley Mbr. Brallier & Harrell Fms.	Catskill Fm. Irish Valley Mbr. Brallier & Harrell Fms.		↑
DEVONIAN	M	Hamilton Fm. Mahantango Marcellus	Hamilton Fm. Mahantango Marcellus sh. Onondaga-Old Port		STOP NUMBERS
DEVONIAN	L		Keyser ls.		
SILURIAN	U		Tonoloway ls. Wills Creek sh. Bloomsburg sh.&ss.		↓
SILURIAN	L		Mifflintown Fm. Keefer ss. mbr. Rose Hill Fm. w/ Centre Fe ss.mbr. Tuscarora Fm.	Tuscarora Fm.	6 1,3,4,5,7,10
ORDOVICIAN	U		Juniata Fm. Bald Eagle ss. Reedsville Sh. Coburn-Loysburg ls.	Juniata Fm. Bald Eagle ss. 4,5 Reedsville Sh. 2,9 Chambersburg ls.	
ORDOVICIAN	M		Bellefonte dol.	St.Paul Group ls. Bellefonte dol.	
ORDOVICIAN	L		Axeman ls. Nittany dol. 4 Stonehenge ls	Rockdale Run ls.	
CAMBRIAN				Conococheague ls.grp.	

Figure 14. Stratigraphic units of the Meadow Grounds, McConnellsburg, and Path Valley area.

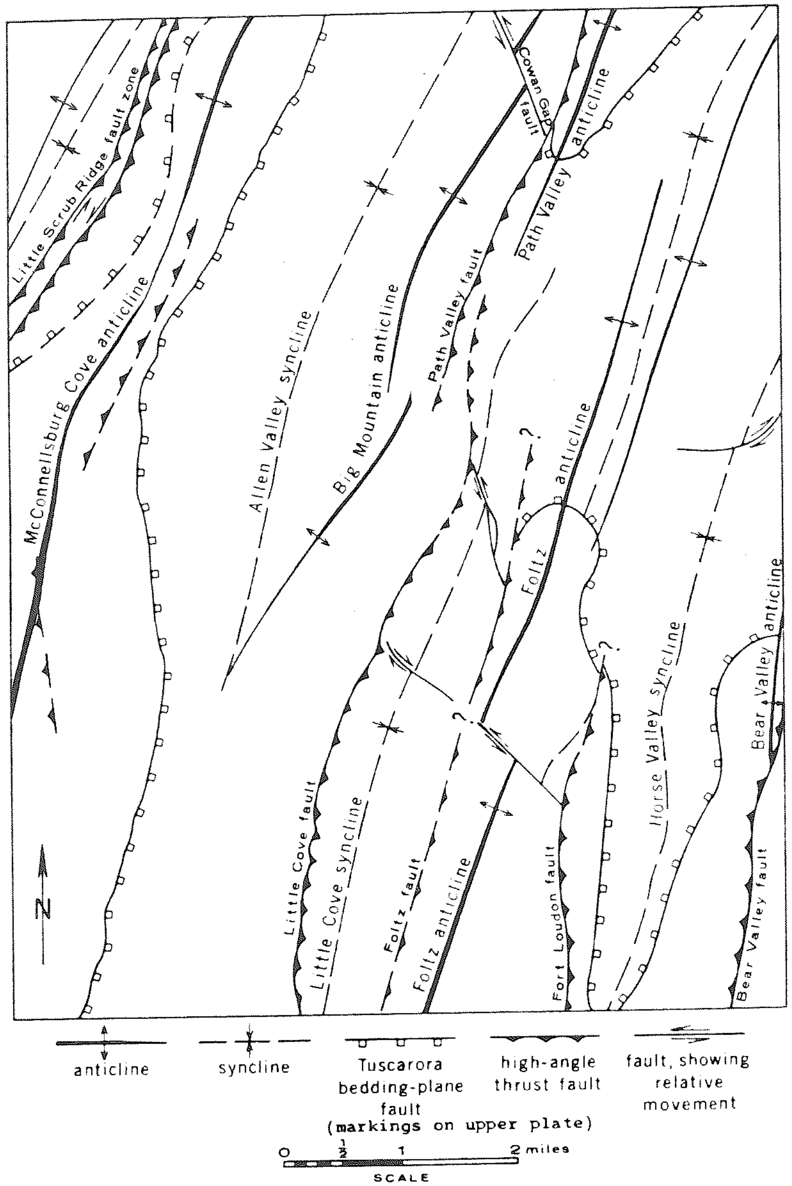


FIGURE 2. Major structures of the McConnellsburg quadrangle.

Bonus figures from Pierce, 1966.

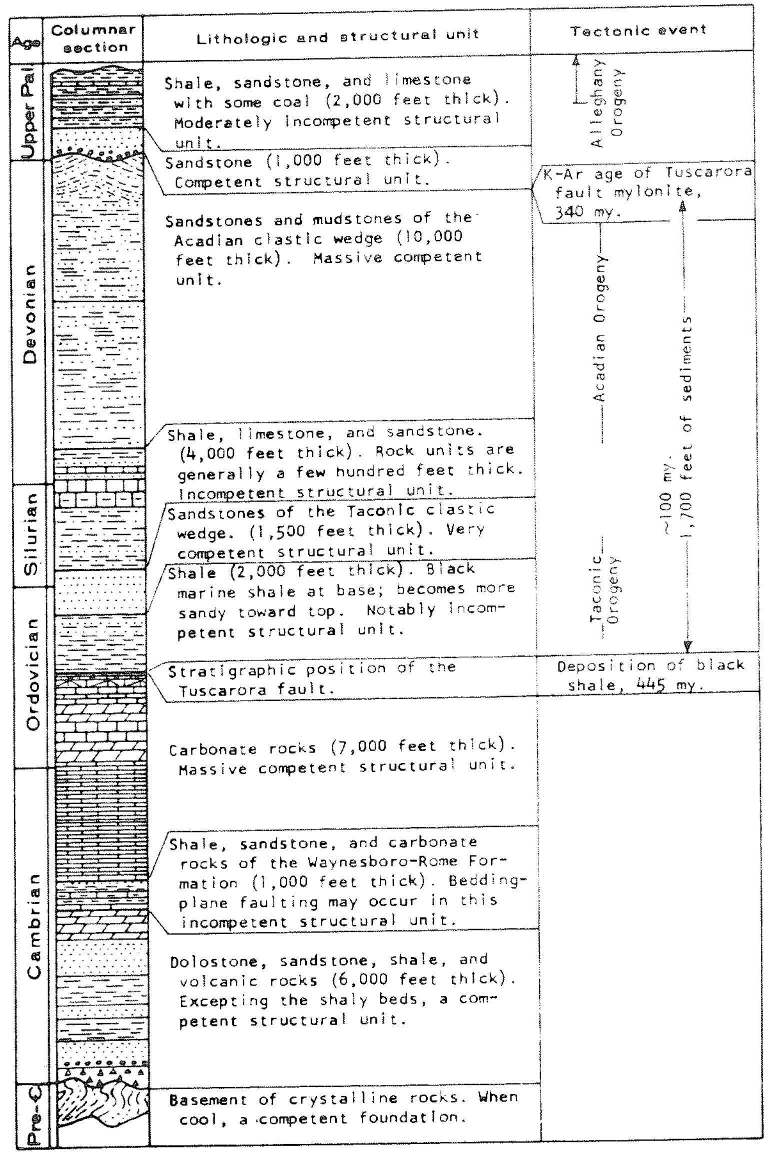


FIGURE 6. Geologic section of the Valley and Ridge province of the central Appalachians.

ROAD LOG AND STOP DESCRIPTIONS - DAY 1

Mileage		
Inc	**Cum**	**Description**
0.0	0.0	Leave parking lot of Holiday Inn. **TURN RIGHT** onto PA Rte. 316 heading NW toward Chambersburg.
1.3	1.3	Intersection with US Route 11, **MERGE RIGHT** (north) on US Rte. 11.
0.7	2.0	Intersection with US Rte. 30, **TURN LEFT** onto US Rte. 30 W.
0.1	2.1	Central Square of Chambersburg, **CONTINUE** west on US Rte. 30.
1.9	4.0	PA Rte. 995 on left (south). **CONTINUE** west on US Rte. 30.
1.8	5.8	Begin seeing a few roadcuts exposing Martinsburg Fm.
3.7	9.5	St. Thomas town center.
0.3	9.8	Martinsburg Fm. outcrop.
0.3	10.1	Begin seeing exposures of Cambro-Ordovician carbonate rocks.
0.7	10.8	PA Rte. 416 to the left (south). **CONTINUE** west on US Rte. 30.
2.2	13.0	Views to the left of erosional surface developed on carbonate rocks. In terms of the peneplain hypothesis this would be the Somerville partial peneplain. Pierce (1966) attributes the surface to non-cyclic downwasting.
0.2	13.2	View right toward Parnell Knob,the synclinal nose of Front/Broad Mtns. plunging NE. Tuscarora Formation is the ridge-maker, bedrock at road level is the Martinsburg Fm.
1.8	15.0	Ahead on both sides of the road will be occasional view of roundstone diamicton showing in small road cuts and erosional scars.
0.8	15.8	Intersection with PA Rte. 75, town of Ft. Loudon on the right. **CONTINUE** west on US Rte. 30.
0.8	16.6	Intersection with Main Street, Ft. Loudon on the right. **CONTINUE** ahead.
0.9	17.5	SW plunging syncline in the Tuscarora Formation on the left. Locality is called "Cape Horn".
0.4	17.9	Begin seeing exposures of Juniata and Bald Eagle Formations on the left.
0.5	18.4	Entrance to runaway truck ramp on the left.
0.9	19.5	Buchanan Summit. Path Valley fault up slope to left, and Tuscarora Formation in road cuts to the right, dipping SE. **CONTINUE** west on US Rte. 30.
0.7	20.2	**TUSCARORA SUMMIT, TURN LEFT** (with caution) **ACROSS EAST-BOUND LANE** and park at side of Tuscarora Summit Inn. Walk 200 yards SW along road to high Tuscarora Formation outcrop across field to right at hang-glider launch site.

STOP 1. OVERVIEW OF McCONNELLSBURG ANTICLINAL VALLEY AND DISCUSSION OF REGIONAL STRUCTURAL GEOLOGY AND GEOMORPHOLOGY

Discussants: Dick Nickelsen and Bill Sevon.

THE VIEW

This is one of the best, readily accessible viewing points in the Pennsylvania Valley and Ridge Province, providing both a look toward the southeast across the Great Valley to the Blue

Ridge (South Mountain) of Pennsylvania/Maryland and, more pertinent to this trip, views to the west across the McConnellsburg "Big Cove" anticlinal valley. You can see the location of several of the stops that we will visit later in the day.

Behind the ridges making up the northwest limb of this anticline there are other, synclinal ridges such as the Meadow Grounds syncline, where we will eat lunch on the today, and the Sideling Hill syncline, a southern extension of the Broad Top region. From this overview, it should be apparent that this 61st Field Conference of Pennsylvania Geologists is concerned with the structural evolution of the first-order anticlines that comprise the southeastern part of the Valley and Ridge Province of southern Pennsylvania.

The most unique features of the northwest limbs of these anticlines are the major high-angle reverse faults--the Cove and Path Valley faults--that overprint and truncate pre-existing structures of their northwest limbs. We will visit the Path Valley fault tomorrow, but one of the major purposes of Stop 1 is to illustrate the disruption of the northwest limb of the McConnellsburg anticline by the Cove fault, as shown in Figures 15 and 16.

Starting at the southwest, as illustrated on Figure 15, the Cove fault is in front of Dickey Mountain and Lowery Knob where we will observe its relationship to the Tuscarora outcrops of the footwall at Stops 3 and 4. Farther to the right (north) at Websters Mills the Cove fault has cut obliquely through the Tuscarora Formation and only two small greatly tectonized exposures of Tuscarora occur. The approximate location of the two small exposures of Tuscarora is shown on Figure 15 by the dot-patterned areas in front of Meadow Grounds Syncline. Note that the Tuscarora ridge is absent north of here. Farther north in the gap between the drawings of Figures 15 and 16, the Tuscarora ridge is totally absent and the Cove fault is placed at a contact between Devonian shales and Ordovician carbonates, which is decorated by a few remnant, mega-breccia fragments of highly-tectonized Tuscarora quartzite. This portion of the Cove fault has experienced great vertical and horizontal (strike) extension and section thinning. We will drive along this contact on our way from Stop 4 to the lunch stop. Still farther north as shown on Figure 16, the main Cove fault passes behind the southwest end of Little Scrub Ridge. This ridge contains a number of tectonized and rotated blocks of the hanging wall of the Cove fault that give the ridge its characteristic knobby appearance. At Stop 5 on Little Scrub Ridge you will be able to see the structures causing this physiography. A geologic outcrop map of this Stop 5 area is shown in Figure 29.

BEDROCK FEATURES

You are standing on the best outcrop of the Tuscarora Formation along the 20 mile stretch of Tuscarora Mountain which makes up the southeast limb of the McConnellsburg "Big Cove" anticline. Bedding dips 25° and there are a few, poorly-developed, early, strike-slip faults such as have been used throughout the region to establish the pre-folding shortening direction. Such faults are inferred to be pre-folding when their slickenlines parallel the fault/bedding intersection. Much better exposures of the early strike-slip faults occur nearby in the vicinity at Tuscarora, Juniata, and Bald Eagle outcrops along US Rte. 30, and Figure 17 is an illustration of the array of such faults. Before plotting the great circle traces of these faults in Figure 17, they were rotated the same number of degrees in the same direction as would be required to return bedding to horizontal. The array includes right-lateral faults which usually strike toward the WNW and left-lateral faults that usually strike more toward the NW, and also a number of strike-slip faults where slip sense could not be determined. In outcrops where pairs of conjugate right-lateral and

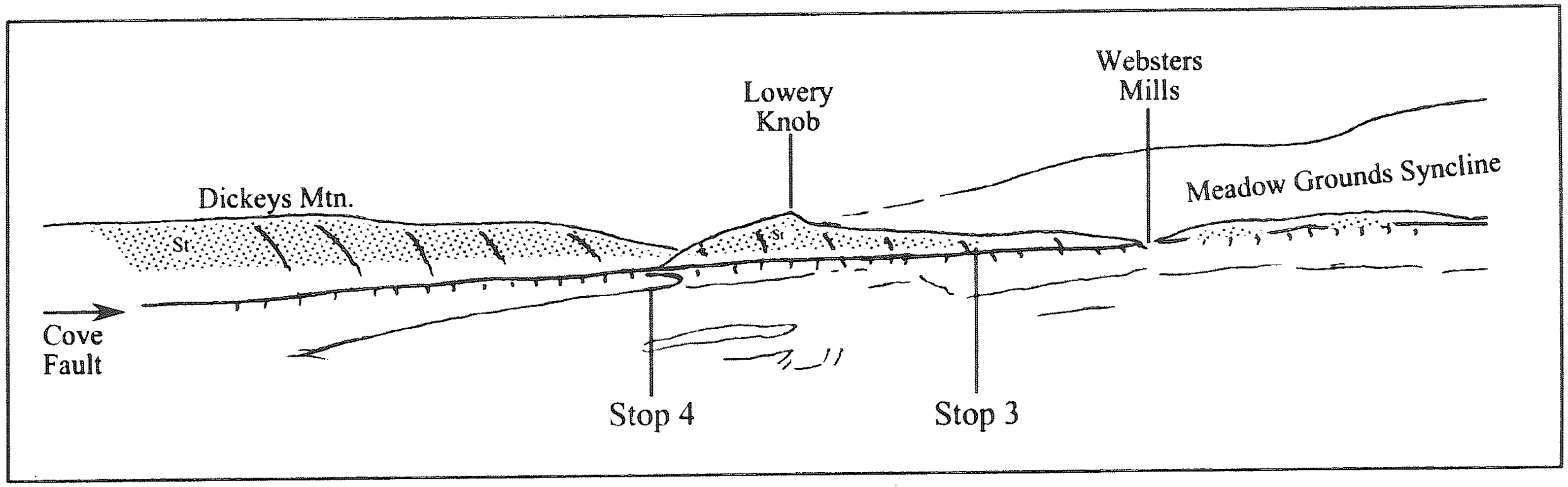


Figure 15. View SW from Tuscarora Summit toward the north termination of the Tuscarora ridge by the Cove Fault.

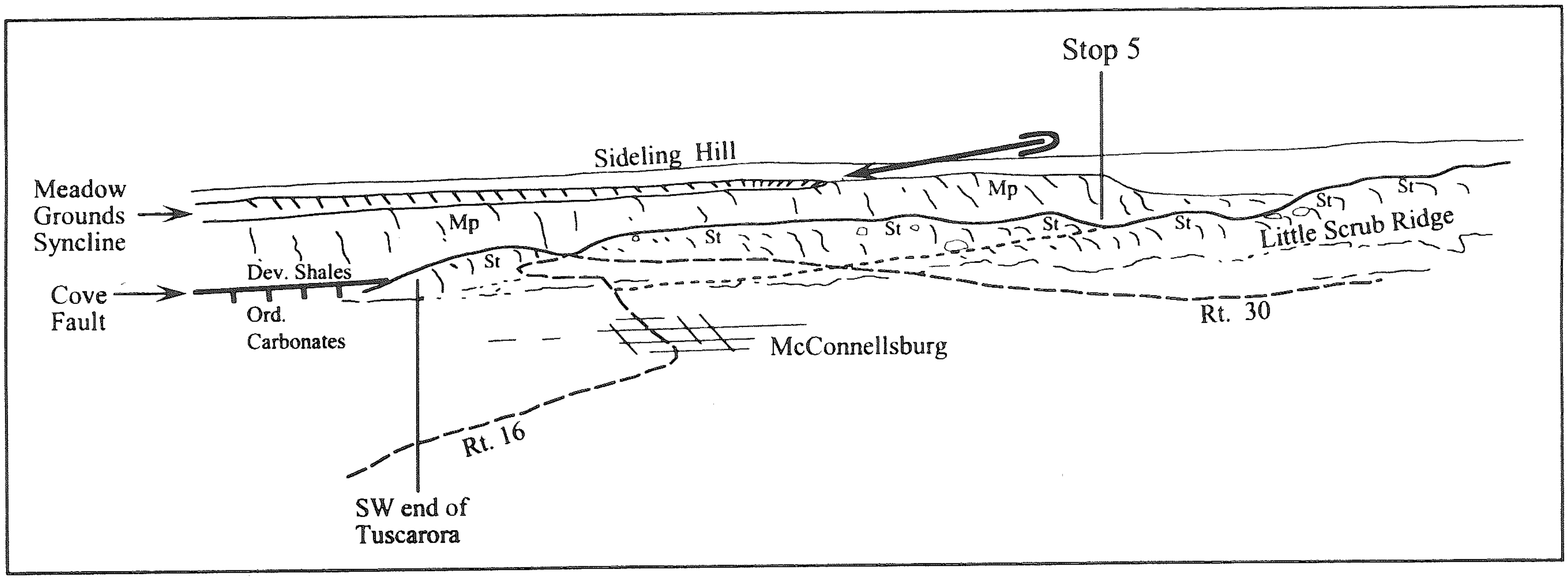


Figure 16. View WNW from Tuscarora Summit toward the south termination of the Tuscarora (Little Scrub) Ridge by the Cove Fault.

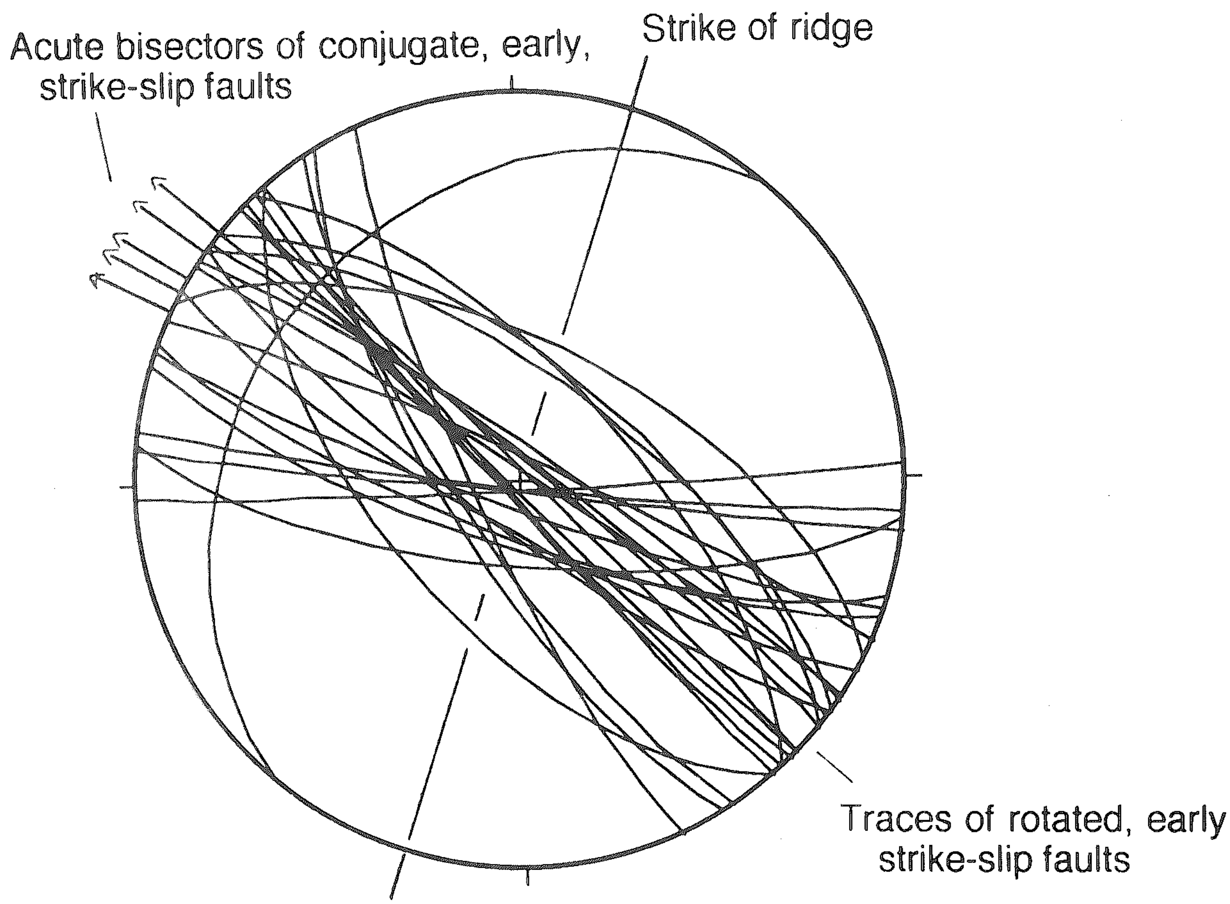


Figure 17. Equal area stereographic projection of the traces of rotated, early strike-slip faults measured near Stop 1.

left-lateral faults could be identified, the acute bisector has been determined and plotted on the NW edge of the stereographic projection of Figure 17. These acute bisectors of individual outcrops and the mean orientation of the total array are inferred to have been the direction of pre-folding shortening. Finally, the mean strike of the Tuscarora ridge in this vicinity has been plotted for comparison with the inferred shortening direction. It can be seen that the mean shortening direction and the cluster of acute bisectors at individual outcrops deviates from the perpendicular to the mean strike of bedding by 10° or 15° in a clockwise direction. Or, stated another way, the pre-folding shortening direction has been overprinted in a counter-clockwise direction by later folding.

We will see a much better example of these structural relationships at Stop 6 where the angle between the perpendicular-to-bedding strike and the inferred shortening direction is larger, but this is the only place, along the southeast limb of the McConnellsburg anticline, where I could demonstrate, to a large group of geologists, the subtle difference between the direction of pre-folding shortening and the direction of later folding, always a counter-clockwise relationship. In the tectonized, commonly overturned and rotated rocks of the northwest limb of the McConnellsburg anticline, conjugate early strike-slip faults of the pre-folding type have been recognized, but it has rarely been possible to trace the kinematic history that was involved in attaining their present attitude. The outcrops of early faults here are poorly accessible so very little time has been allotted for their inspection. It would take all day to demonstrate them to everybody.

ROCK AND WEATHERING

The ridge crest is formed by quartzites of the Tuscarora Formation and they crop out here. This is the most erosion-resistant rock unit in Pennsylvania, which is why it occurs at the ridge crest. However, it is not immune to the relentless forces of nature. The bedding and joint partings, which are numerous, are avenues for moisture penetration and subsequent rock fragmentation when the water freezes and expands in volume. The gradual fragmentation of a rock mass is well shown by the outcrop on the north side of the launch pad. Look at the slope below the ridge crest and observe the scree (talus) produced by fragmentation and downslope movement. One can speculate about how much of that scree is the result of fragmentation during Pleistocene periglacial climate and how much has been produced during the Holocene.

Chemical weathering also takes a toll on the tough, highly siliceous quartzite. Note the outcrop adjacent to the south side of the launch pad. The surface has been smoothed and rounded by solution weathering. The weathering has etched deeper into the rock along lines of partings and has given the surface considerable character. Note also the sugary texture of the surface of the rock. This results from removal of individual quartz grains, one at a time. Evidence of such removal is the fine quartz sand that occurs in the soil in the crest area. Compare this sugary texture with the very smooth surface of some of the unweathered parting surfaces in the outcrop on the north side of the launch pad.

Pierce noted that where the rocks forming the ridge crest are steeply dipping, as they are at Tuscarora Summit, the ridge crest is narrow and has scree developed on the side opposite the dip slope, the scarp slope. He points out, as did H. D. Rogers (1858), that the more gentle the dip of a resistant rock, the higher the crest elevation. This is well illustrated here where the elevation of Tuscarora Summit is 2,176 feet. To the north the ridge crest rises as the structure changes from a simple dip slope to the crest of anticline with horizontal strata. The crest elevation beneath the communication towers is about 2,340 feet and nearly two miles farther north at the crest of Big Mountain the elevation is 2,453 feet. North of Big Mountain the ridge becomes a dip slope again and the elevations drop to 2,000 feet or less. The wider area of rock at the ridge crest provides more resistance to erosion of the crest and thus a higher elevation. To the west at Meadow Grounds Mountain and Scrub Mountain, the eastern and western ridges, respectively, of a doubly plunging syncline, the ridges are even lower with elevations generally between 1,700 and 1,900 feet. These ridge crests are formed from sandstones of the Pocono Formation, rocks that are not as erosion resistant as the Tuscarora.

GEOMORPHOLOGY

Classical geomorphology, a la William Morris Davis, would argue that Tuscarora Summit is on the remnant of the Schooley (Kittatinny?) peneplain and that the ridges visible from this view point are also remnants of that peneplain. The lower Harrisburg surface is not well developed here because the lower shale slopes upon which it is generally defined are well dissected and have moderate slopes with few relatively flat surfaces. The valley bottom is developed on carbonate rocks and would be the Somerville partial peneplain. Pierce followed Hack and argued that peneplains are not necessary to explain the topography. There is no new evidence to argue for peneplains since Pierce did his work. The topography is the result of continuous weathering and erosion that has produced a landscape well adjusted to rock erosion-resistance and structure. Presumably, such weathering and erosion has been active in this area since some time in the Mesozoic, but with considerable variation in character and rate because of climate variation. The landscape we see today has been produced mainly by what has occurred in the last 16 million years, particularly the last two million.

		Leave Stop 1, **CONTINUE** West on US Rte. 30.
0.2	20.4	Begin seeing Juniata and Bald Eagle Fm. outcrops on right side of road.
0.1	20.5	Strike-slip faults in Juniata Fm.
1.3	21.8	**TURN LEFT OFF US RTE. 30 and proceed west, down hill toward McConnellsburg.**
0.5	23.3	**STOP SIGN. MERGE** with PA Rte. 16 and **CONTINUE** west on PA Rte. 16.
0.1	23.4	**TURN LEFT** (south) onto 7th Street, just beyond Johnnies Motel (on left) and across from McDonalds. Between here and Stop 2, note the irregular surface developed on carbonate rocks. Best views will be on the left. This whole interval has a cover of roundstone diamicton according to Pierce (Plate 3). There are some exposures in road cuts and stream banks that show matrix-enclosed Tuscarora roundstones. Tuscarora roundstones frequently are visible on field surfaces if vegetation is not too high.
0.7	24.1	JLG Factory on left and view up to Tuscarora outcrop at Tuscarora Summit.
1.9	26.0	Gas pipeline crosses road.
0.1	26.1	Great Cove Golf Club entrance, to right.
1.4	27.5	Cito Village. **STOP SIGN.** Road to right. **PROCEED STRAIGHT AHEAD.**
0.1	27.6	**TURN LEFT** into farm lane and continue to the barn.
0.3	27.9	Park buses at the barn. Ask permission to enter property from owner Harold Reed or his wife, and then walk 160 yards SE along road to the shale borrow pit.

STOP 2. OUTCROP OF BASAL REEDSVILLE FORMATION CONTAINING AN EXPOSURE OF THE TUSCARORA FAULT/ANTES-COBURN DETACHMENT

Discussant: Dick Nickelsen.

INTRODUCTION

This stop is one of 8 localities (shown in Figure 2) in the McConnellsburg-Big Cove-Path Valley region where the Tuscarora fault of Pierce (1966) can be seen and measured. It appears that this bedding parallel structure is present everywhere in the region at this stratigraphic position, because it is seen at every exposure of the correct part of the section, and because small pieces of distinctive float can be found at appropriate locations elsewhere. Pierce describes the Tuscarora fault from several localities on the northwest dipping limbs of anticlines, but I have not found the fault at these or other localities on northwest limbs, although I believe it should be present for reasons that I have stated in my introductory article about the Tuscarora fault/Antes-Coburn detachment. On the southeast limb of the McConnellsburg Big Cove anticline, the Tuscarora fault was recognized by farmers and apparently prospected as a possible coaly horizon for burning. I have not encountered anyone who has successfully burned the distinctive black, carbonized, reflective, cleaved rock of the Tuscarora fault and have not been able to ignite it in my stove or fireplace, but, nevertheless, there is evidence that many farms along the southeast limb of the anticline had a small adit into this horizon. Successful mapping of the horizon consisted of showing a piece of it to old farmers who were still working the land. Their look at the specimen would usually elicit detailed instructions about how to find the appropriate locality, or, perhaps, the unfortunate information that it had been all covered up. One would think that the "old farmer" network would have uncovered some outcrops of the fault on the northwest limbs of the McConnellsburg and Path Valley anticlines, but in many places the contact between the Reedsville and the underlying carbonates is faulted out, and everywhere the bedding dips very steeply, which would have meant a vertical shaft or a deep open pit to retrieve a small amount of 0-BTU shale. The 8 localities of Figure 2 are places where fault structures could be measured: e.g., cleavage attitudes, slickenline orientations on the floor or roof of the cleavage duplex, or minor fold axes that could be measured within the cleaved rocks.

DESCRIPTION OF THE TUSCARORA FAULT/ANTES-COBURN DETACHMENT

Figure 18 is a map and section of a small area in Reed's borrow pit where the fault zone, 1 to 2 m thick, can be seen in its typical stratigraphic position, within the grayish black, non-calcareous, graptolite-bearing clay shale of the Antes Shale member of the basal Reedsville Formation. The following paragraphs include descriptions of stratigraphy and structure that are visible here, as well as features that can be seen at a nearby, inaccessible outcrop.

Stratigraphy. The fault zone here is overlain by 5 m of grayish black shale, but little of the section below the fault is exposed. Nearby exposures indicate that 6 m is the maximum thickness of the typical condensed stratigraphic section in which the fault zone is usually embedded. Above the grayish black shale is dark gray calcareous siltstone which grades up to medium gray silty shale containing thin laminae of fine sandstone. Above this are interbeds of sandy distal turbidite more typical of the higher parts of the Reedsville Formation. The main feature to observe is the association of the fault zone with the non-calcareous, carbon-rich, clay shale, which serves as a detachment or decollement horizon in a stratigraphic section that apparently doesn't contain any other potentially ductile zone to serve either as a slip horizon or as a boundary to accommodate the different structural styles of the underlying Cambro-Ordovician carbonates and the overlying Upper Ordovician, clastic rocks. You might also like to collect a few graptolites to observe how relatively undeformed they are outside the fault zone. The big scandent graptolites are *Climacograptus*, a middle Ordovician, upper Trenton genera, but there are also other, smaller graptolite fragments as well as a few nautiloids. Here, outside the fault zone, some graptolite-bearing specimens show slight fossil distortion that is associated with a spaced, primary, crenulation cleavage that intersects bedding at an angle of approximately 20^{o}.

Structure. The interior of the fault zone is marked by a penetrative cleavage that, in thin section, shows phyllosilicates oriented parallel to planes of foliation, which are marked by dark carbon partings. No new mica growth can be recognized so their orientation is a consequence of much pressure solution and passive rotation of detrital micas into foliation planes that were also enriched in the reflective carbon which attracted the early farmers. Dissolution of quartz and residual concentration of carbon and clay minerals have provided the black, reflective, cleaved, and folded rock that is so distinctive. In thin section, several generations of thin, folded veinlets of very fine quartz can be seen, but no calcite is present. Both the floor and roof of the cleaved zone are abrupt fault contacts with undeformed shale and these slickensided fault surfaces have slickenlines that indicate transport toward 305^{o}, slightly north of the perpendicular to the strike

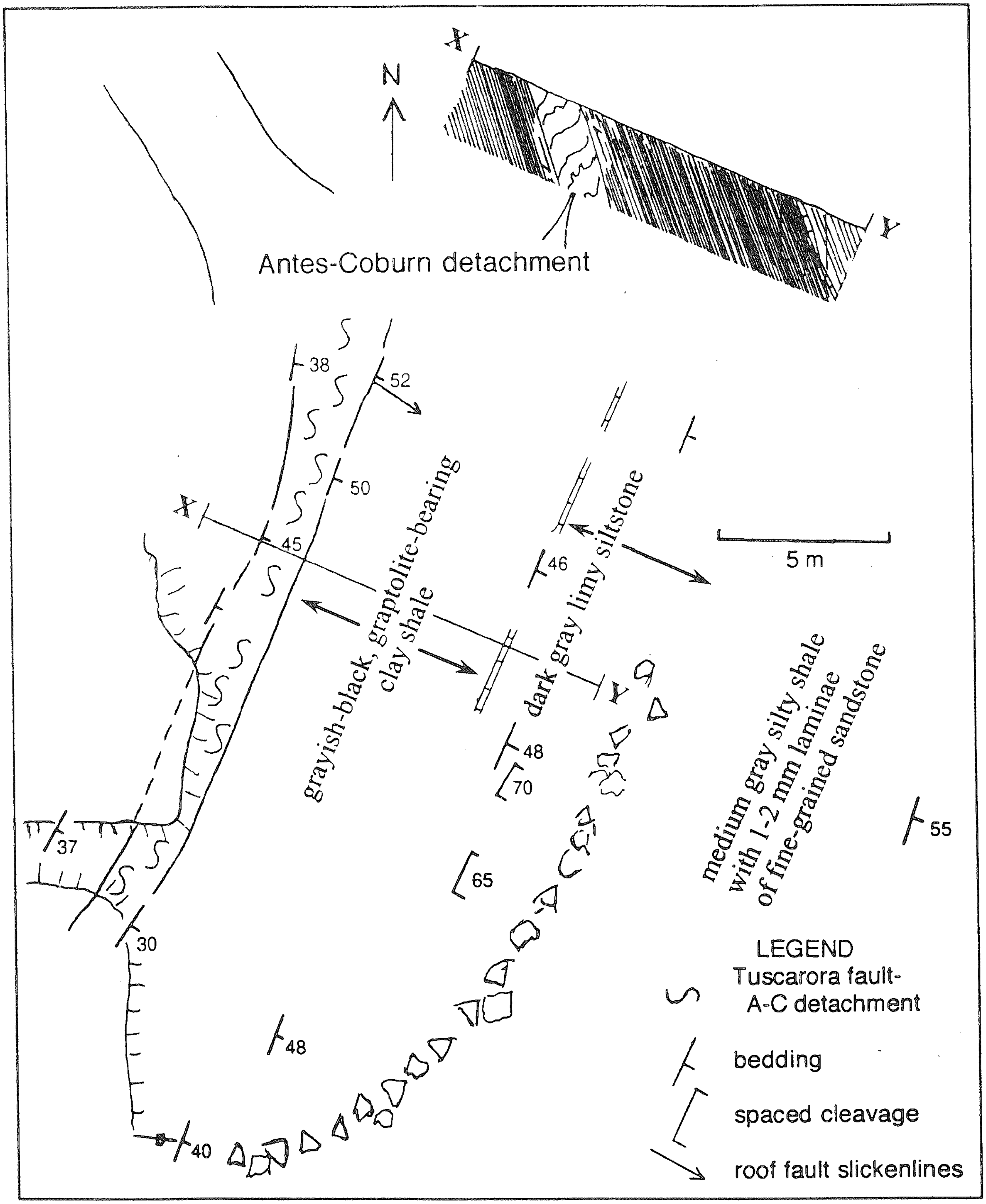


Figure 18. Map and section of the Tuscarora fault/Antes-Coburn detachment in the basal.Reedsville Formation at Stop 2.

of bedding. From this observation it can be inferred that pre-folding transport on the Tuscarora fault was slightly to the north of the direction of vergence of the later folds--a counter-clockwise trend sequence. Please don't expect to see and measure the slickenlines. They must be found after quarry work has exposed new surfaces. The attitude of rock cleavage within the fault zone cannot be measured at this outcrop but it is possible to discern asymmetric folds in the cleavage. You should observe the different aspects of the fault rock and of the graptolite-rich shale from which the fault rock was produced. Graptolites and bedding have apparently both been obliterated during cleavage formation in the fault rock. If you must collect a specimen of the fault zone rock, please do it here rather than at Stop 9, tomorrow.

Features at a nearby outcrop. Figures 19 and 20 illustrate a nearby outcrop that I had hoped to visit during this field trip. Figure 19 is a WNW-ESE profile through the section of limy and graptolite-bearing shales above the Coburn limestone that contains the cleavage duplex which is the Tuscarora fault/Antes-Coburn detachment at this locality. The enlarged inset of the 1 m thick duplex at the top of the figure is a drawing from a photograph of the complete fault zone, bounded by floor and roof thrusts. Cleavage within the fault zone is sigmoidal because the cleavage attitude, which started nearly perpendicular to the fault zone, has been dragged against the roof and floor thrusts as "top to the foreland shear" occurred prior to large-scale folding. The proposed kinematic development of cleavage duplexes has been described (Nickelsen, 1986) and a more complete evidence of major, top to the foreland shear in the Anthracite region has been documented by Gray and Mitra (1993). Figure 20, a stereographic projection of cleavage attitudes and roof and floor thrust slickenlines at this exposure, demonstrates the relationships between cleavage and slickenlines that suggest pre-folding "duplexing", thrusting, and top to the foreland shear toward 312^{o}. Given the perpendicular relationship that can be demonstrated here between the strike of cleavage in the duplex and the plunge direction of roof or floor thrust slickenlines, I have assumed, at other, poorer exposures that either slickenlines or the perpendicular to the mean strike of cleavage can be used to determine the transport direction on the Tuscarora fault/Antes-Coburn detachment. These are the measurements that I have plotted on the regional map, Figure 2. Again, it should be emphasized that the faulting or detachment is found only in part of a unique, 6 m, carbon-rich clay shale which apparently had lithologic or fluid pressure attibutes that attracted the movements.

		RETURN west along farm lane to road.
0.3	28.2	**TURN LEFT** (south) and **CONTINUE** along road trending S and SW and finally bending toward the west. Some fields ahead on the right have undrained depressions and diamicton mantle indicated by the Tuscarora roundstones. There is an abundance of roundstone exposed adjacent to the road in the area where the road makes two sharp right turns before heading west across the valley. This abundance is the result of close proximity to two small drainages that head high on the mountain slope.
1.8	30.0	Road intersection on left. **PROCEED AHEAD** toward the west on SR 1001.
0.2	30.2	Passing large dairy farm. Route is crossing the McConnellsburg Big Cove anticlinal valley, floored by Ordovician carbonate rocks that produce residuum and rock fragments. Note the absence of Tuscarora roundstones in the valley center.

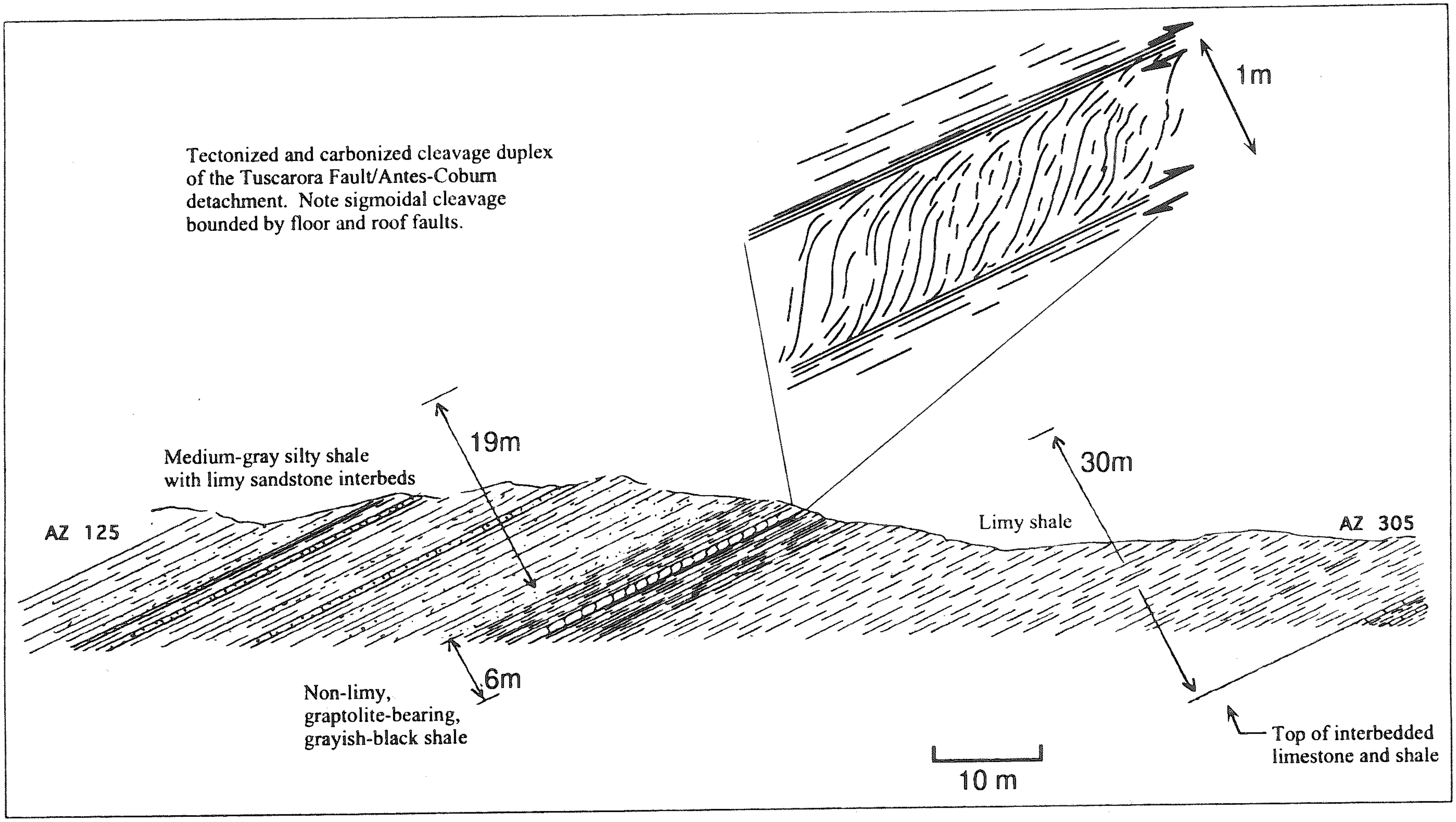


Figure 19. Section of the Tuscarora fault/Antes-Coburn detachment at a nearby farm.

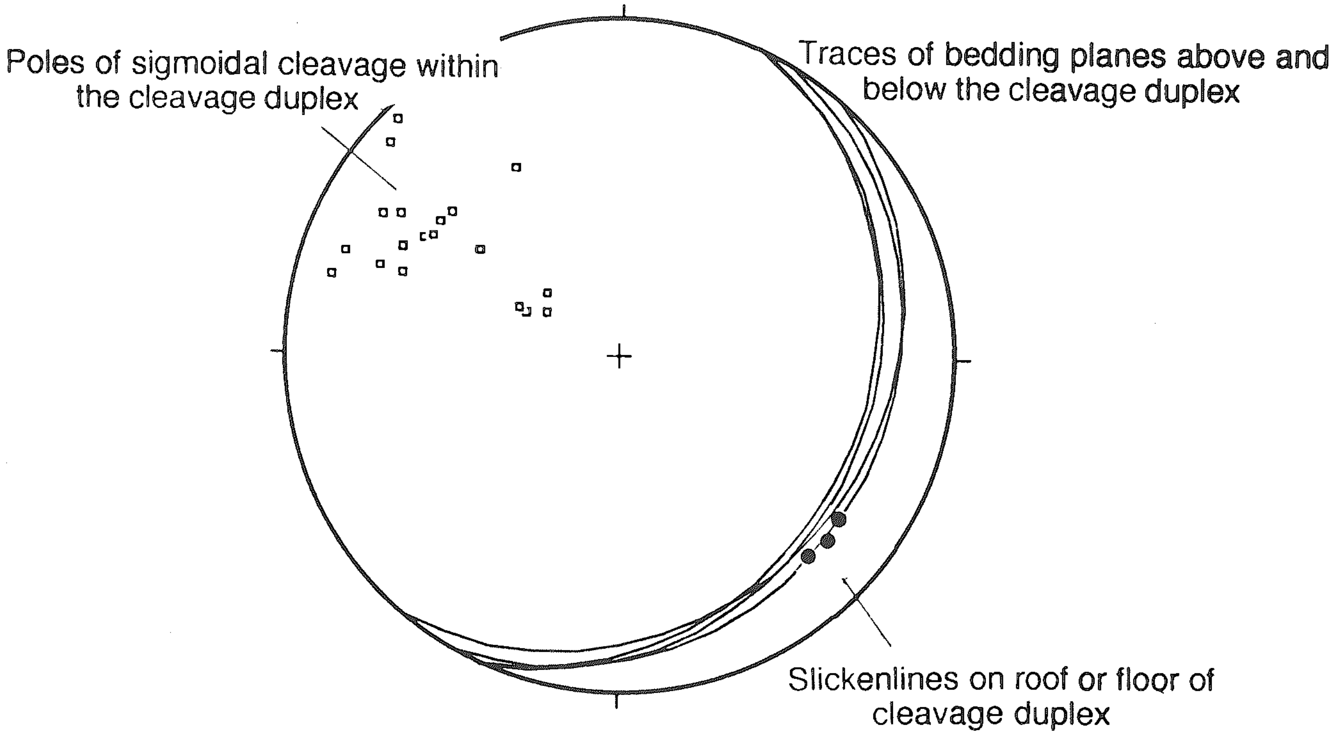


Figure 20. Stereonet plot of structures measured in the Tuscarora fault/Antes-Coburn detachment illustrated in Figure 19.

1.0 31.2 Road bends to the right (north) and **A LANE ENTERS THE ROAD ON THE LEFT. PARK IN THE LANE AND WALK 0.5 MILE SOUTH TO STOP 3** on the north end of Lowery Knob. See land owner Ralph Glenn for permission to enter.

STOP 3. TUSCARORA BRECCIA IN SEPARATED OUTCROPS ALONG THE COVE FAULT ZONE

Discussant: Dick Nickelsen.

INTRODUCTION

Stops 3 and 4 along the south part of the Cove fault near the plunge out of the McConnellsburg Big Cove anticline are included in this field trip to demonstrate the steep, extended and thinned section of rocks in the footwall of the Cove fault (seen at both Stops 3 and 4), as well as the gently-dipping carbonates close to the fault in the hanging wall (Stop 4). At both stops it is possible to traverse outcrops that are distributed through 500 feet of the steep vertical section of the footwall, but we will limit our walk for Stop 3 to a climb of about 180 feet at the north end of Lowery Knob. Although two stops are necessary to demonstrate the geology, it is difficult to

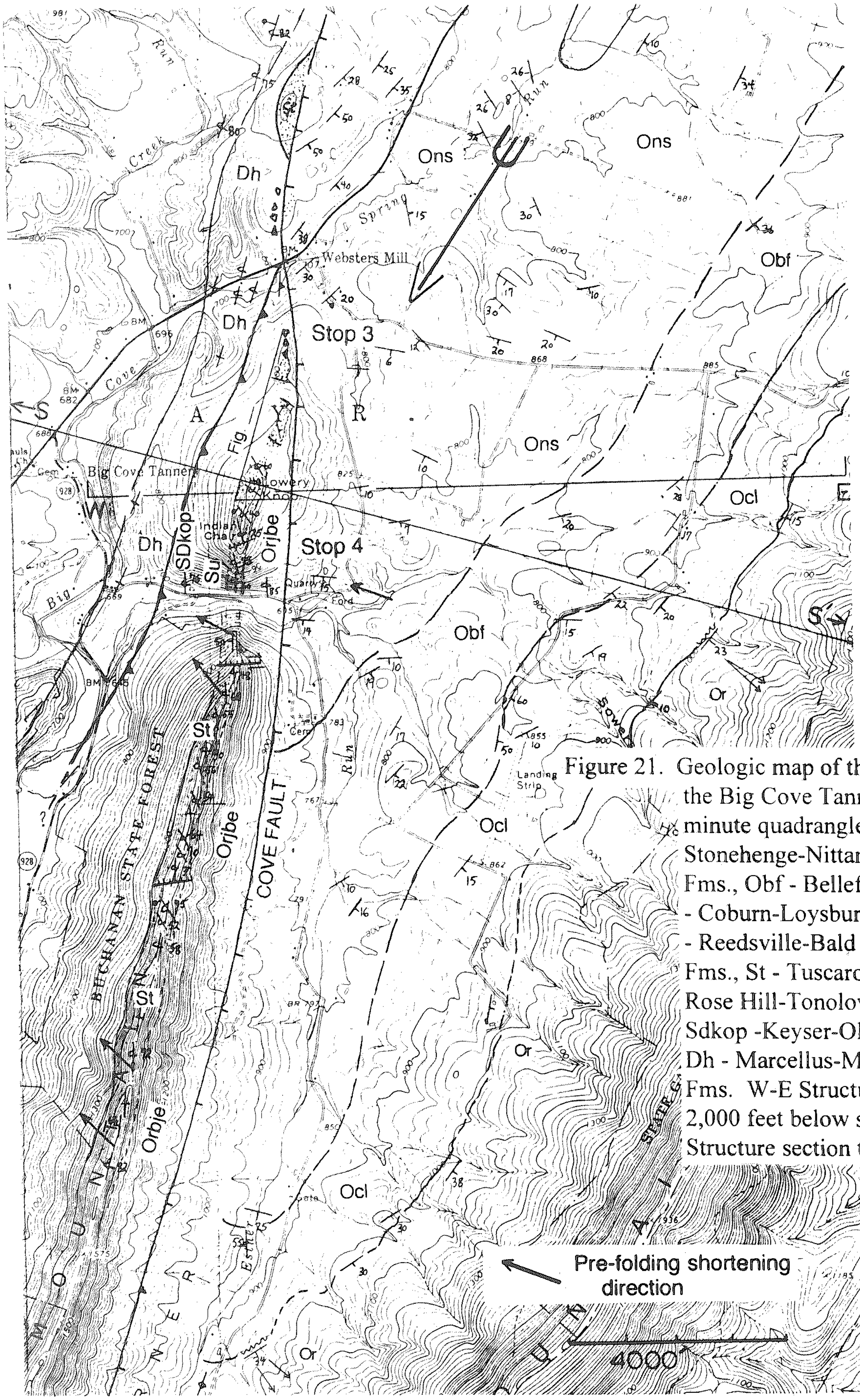


Figure 21. Geologic map of the NE 1/4 of the Big Cove Tannery 7.5-minute quadrangle. Ons - Stonehenge-Nittany-Axeman Fms., Obf - Bellefonte Fm., Ocl - Coburn-Loysburg Fms., Orjbe - Reedsville-Bald Eagle-Juniata Fms., St - Tuscarora Fm., Su - Rose Hill-Tonoloway Fms., Sdkop -Keyser-Old Port Fms., Dh - Marcellus-Mahantango Fms. W-E Structure section to 2,000 feet below surface. S-S' Structure section to basement.

subdivide the descriptive material into two separate packages. Consequently, the general geologic description may include features that you won't see until Stop 4.

GENERAL GEOLOGIC DESCRIPTION

Figure 21, a map of the southern plunge out of the McConnellsburg-Big Cove anticline, demonstrates two things:

1. The Cove fault, trending N5°W (Az 355°) to N15°E (Az 15°) in its various segments, truncates the S 30° to 35° W (Az 210° to 215°) plunging axis of the anticline at angles of 20° to 30°. This brings the axis of the anticline rather than the NW limb against the Cove fault. Farther north the NW limb of the anticline is against the Cove fault (see Figure 22 and 32, structure sections of the McConnellsburg Big Cove anticline, S-S', and N-N'). Proceeding south from Lowery Knob along the Cove fault, successively younger rocks on the southeast limb of the anticline are either truncated against the fault or fold sharply to the vertical northwest limb.

2. The Cove fault cuts obliquely through the Tuscarora and other Silurian formations just north of Lowery Knob, placing Ordovician carbonates against middle Devonian shales. As might be expected, the Tuscarora Formation shows increasing dismemberment and tectonization as it approaches the fault zone at the north end of Lowery Knob. No other stratigraphic units in the Silurian-Lower Devonian section are exposed for study of this progressive increase in deformation as the fault is approached. Figure 23 is a small structure section along line W-E, drawn only to 2,000 feet below the surface, to show the structural setting of Stops 3 and 4. Stiff units such as the Tuscarora and Bald Eagle sandstones in the steeply dipping footwall are depicted as separated into the extensional blocks that we will see on our traverse.

DEFORMATION FEATURES OF THE TUSCARORA FORMATION ON LOWERY KNOB

Figure 24 is an outcrop map and suggested traverse map for a walk up the northern end of Lowery Knob to observe the following five features of the Tuscarora Formation:

1. Outcrops are not continuous, but rather occur in isolated blocks 50 to 100 feet wide and hundreds of feet long that are separated by low areas with a few Juniata exposures.

2. Bedding within the blocks is folded and terminated at their borders in a way that suggests a lack of structural relationship between their internal structure and the faults that bound the blocks.

3. A traverse from Lowery Knob summit at the south end of Figure 24 to the north through the three separated blocks shows the gradual increase in deformation as the Cove fault is approached. Bedding is very visible at Lowery Knob summit, less apparent at the north end of the first block that will be visited on the suggested traverse, and still harder to find at the north block that you will pass near the end of the traverse. As bedding is destroyed, the Tuscarora becomes an incipient breccia, in which every plane of breaking on a sample of the rock is a pre-existing fracture, commonly coated with iron oxides, but the fragments have not yet pulled apart to produce a breccia.

4. Faults bounding the blocks are typical of the late faults that have been found along the Cove and Path Valley faults. The best example in this traverse is at the north end of the north block, marked by the arrow, where the following fault fabric features can be seen:

   a. The fault surface has no slickensides or slickenlines.

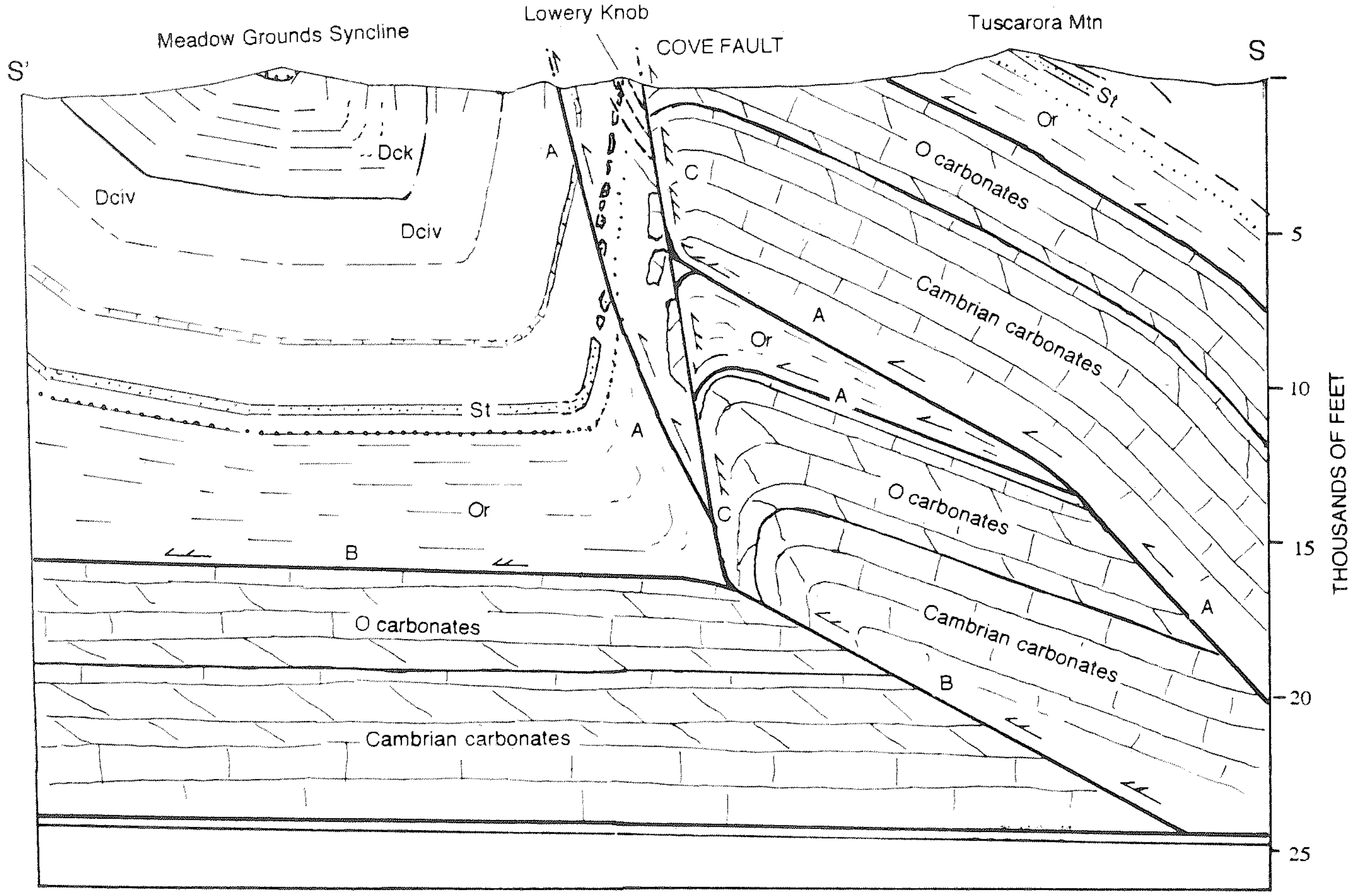


Figure 22. Section S - S' through Lowery Knob showing faults A, B, and C; Or - Reedsville Fm., Dciv - Irish Valley Member of the Catskill Group, Dck - Catskill Formation.

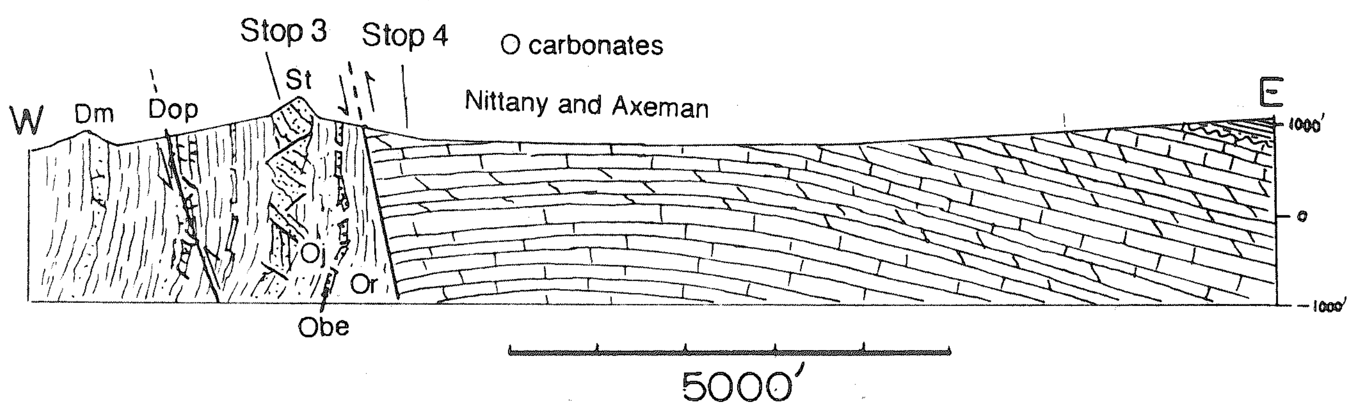


Figure 23. Section W-E through Lowery Knob to a depth of 2,000 feet.

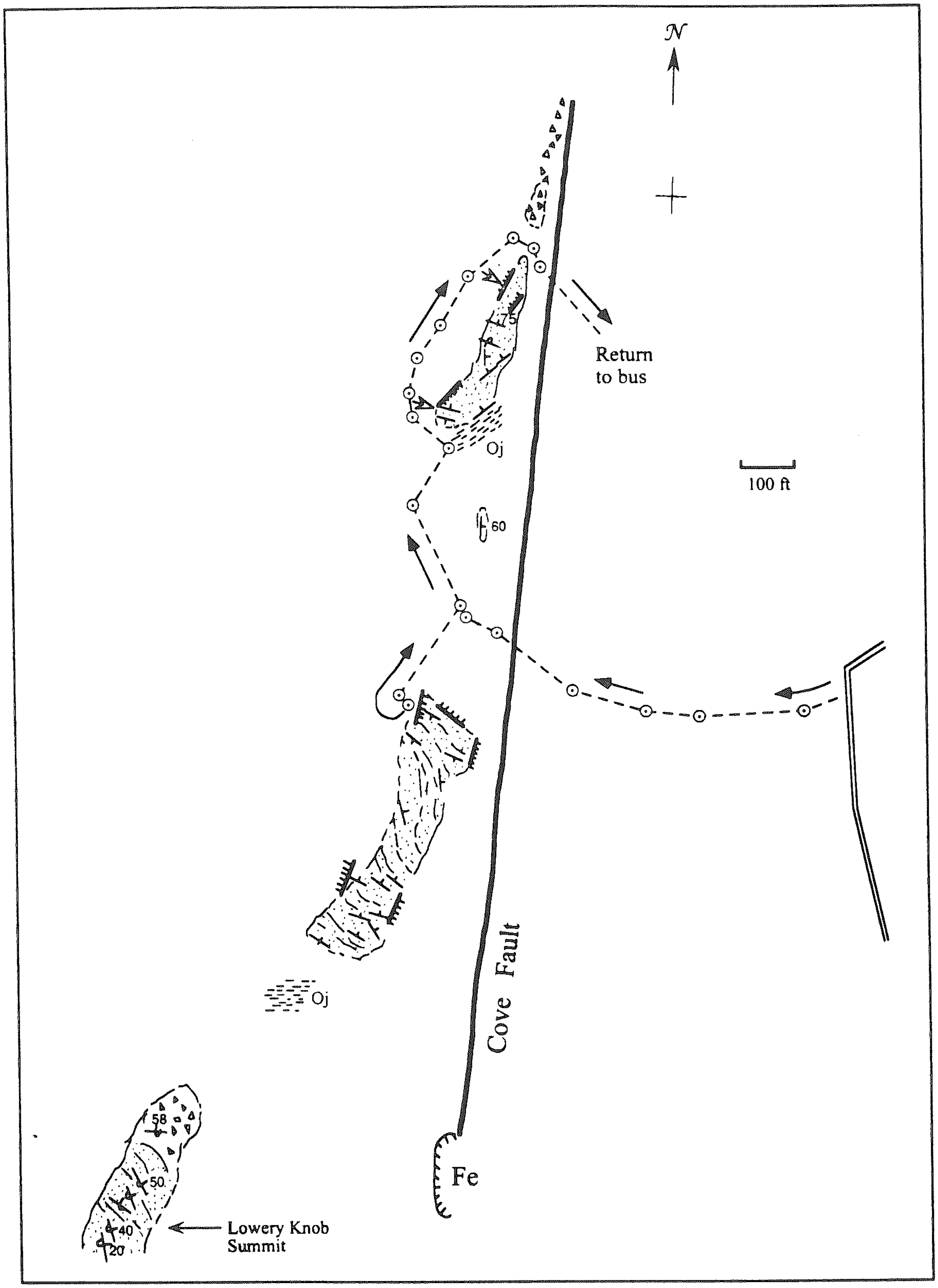


Figure 24. Geologic map of Tuscarora Formation outcrops at the north end of Lowery Knob, showing the suggested traverse at Stop 3. St - Tuscarora Formation; Oj - Juniata Formation; Fe - abandoned Hanover Ore Bank, limonite mine.

b. There are no fault-related quartz crystals in vugs, steps, or openings in breccias formed along this fault.

c. The dense, brittle fault surface is marked by several sets of joints that are perpendicular to the fault.

d. Small areas of very angular coarse breccia can be seen, in places containing an iron oxide matrix, but never showing any progressive decrease in the size of breccia fragments toward a finer cataclasite.

5. The dominant attitude of bedding is transverse to the ridge trend, having a northwest strike and northeast dip, with overturning toward the southwest proven by many cross-bedding observations in the less-tectonized rocks on the summit of Lowery Knob. This bedding attitude involves overturning around a horizontal axis of some orientation and counter-clockwise rotation of approximately 45^{0} around a vertical axis, both rotations apparently related to the Cove fault. Where the Cove fault is distant from the Tuscarora, one to two miles south of Lowery Knob on Dickey Mountain, bedding dips steeply and strikes parallel to the ridge trend. The bedding attitudes and separated outcrops of Lowery Knob are attained as the Tuscarora Formation approaches the Cove fault.

In summary, the separated blocks of Tuscarora on Lowery Knob show extension in both vertical and horizontal (NE-SW) directions of a rock that had undergone previous folding. The blocks are bounded by late faults with distinctive characteristics that show no evidence of having grown out of the folding strain manifested in the internal structure of the blocks. The separated blocks appear to "float" in a groundmass of more ductile shales of the Juniata and perhaps the Rose Hill Formations, and are more tectonized toward the northeast as they approach the Cove fault.

Finally, Figure 24 shows the location of an abandoned limonite mine (marked Fe) that is described in Rogers (1858, p. 479) as "situated on the S.E. flank of Lowrey's Knob, where the Matinal slate [Reedsville shale] emerges from the fault". Apparently the ore was in the Reedsville, not in the carbonate rocks. This was Hanover Ore Bank which supplied Hanover Furnace in Fulton County, but the exposures that existed then have disappeared, and it has no proven significance to the structural history of the region. It is one of the many abandoned mines that have been found along the two late faults of the region, the Cove fault and Path Valley fault. A geochemical study of ores from these abandoned mines along the faults would be required to discover if there is a genetic connection between the faults and the primary source of the ore.

		LEAVE Stop 3, **PROCEED NORTH** on SR 1001.
0.4	31.6	**STOP SIGN. TURN LEFT** onto US Route 522, (SW) at Fords Country Store.
0.1	31.7	You just crossed the Cove Fault.
0.1	31.8	Mahantango Formation outcrop, dipping vertically, on the right .
0.1	31.9	Passing Ravensburg Road, on right.
0.6	32.5	**TURN LEFT** (S) onto Route 928, toward village of Big Cove Tannery.
0.2	32.7	Village of Big Cove Tannery.
0.4	33.1	Bridge crossing Big Cove Creek (Potomac drainage). **TURN LEFT** onto Corner Road just beyond the bridge.
0.1	33.2	Mahantango Formation outcrop, dipping vertically, on left.
0.2	33.4	Ridgely-Keyser outcrop on left at the bend in the road.
0.1	33.5	Large outcrop of steeply-dipping, overturned, Tuscarora Formation on left.

0.3 33.8 Gateway to H. B. Mellott Big Cove Quarry. **Buses enter the quarry for turning and discharge of passengers, then proceed back to Tuscarora outcrop.**

STOP 4. COVE FAULT JUXTAPOSES LOW-DIPPING ORDOVICIAN CARBONATES AGAINST VERTICAL ORDOVICIAN-DEVONIAN SECTION AT THE SOUTH END OF LOWERY KNOB

Discussant: Dick Nickelsen.

INTRODUCTION

Stop 4 includes the Mellott Big Cove Tannery Quarry and a transect across the south end of Lowery Knob through the vertical footwall section of the Cove fault that you saw at Stop 3, although here you will be viewing the footwall rocks in a vertical section, rather than on a geologic map. Rocks on opposite sides of the Cove Fault have very different bedding attitudes, orientations of secondary structures, and intensities of strain that will be demonstrated at this Stop. We will debark from buses in the Mellott quarry to see features of the little deformed hanging wall, then walk west along the Esther Run section through the vertical footwall rocks as far up section as the Tuscarora Formation, where we will board buses for departure. The geological discussion will be divided into three parts: (l) the geology of the hanging wall of the Cove fault in the Mellott quarry, (2) the geology of the vertical footwall of the Cove fault along Esther Run, and (3) summary and conclusions about features observed at Stops 3 and 4.

GEOLOGY OF THE HANGING WALL OF THE COVE FAULT IN THE MELLOTT QUARRY

The south-dipping beds of Axeman limestone and Nittany dolomite in the quarry (Figure 25) owe their attitude to their position on the south-plunging nose of the McConnellsburg anticline, as shown in Figure 21. As pointed out by Geiser (1989), these rocks show no cleavage and have not been penetratively deformed. What can be seen are conjugate early strike-slip faults and wedges that are the product of layer-parallel-compression, resulting in shortening parallel to Az 290°-110°, about perpendicular to the SW plunging axis of the McConnellsburg anticline. The map of the quarry in Figure 25 shows the location of strike-slip faults and small thrusts and backthrusts (wedges) that are the only manifestation of layer-parallel-shortening in these stiff carbonates. Stereographic projections of the traces of conjugate strike-slip faults and wedges (Figure 26) and the bearing and plunge of slickenlines on wedges (Figure 27) demonstrate the Az 290°-110° shortening direction. Shortening is assumed to parallel the mean orientation of the bearing of slickenlines on wedges or the array of strike-slip faults. Here, on the crest of the McConnellsburg anticline it is impossible to discern whether these conjugate faults formed prior to folding, as would be possible with greater limb dips where inspection of slickenlines on the strike-slip faults could reveal whether the slickenlines paralleled the fault/bedding contact or not. Based on observations of hundreds of outcrops throughout the region, it is probable that these conjugate faults formed during layer-parallel-shortening, prior to folding. This topic will be thoroughly discussed at Stop 6, later in the field trip.

What is interesting is the attitude of the inferred shortening direction at this quarry and at other outcrops along the crest of Dickeys Mountain, farther south, where beds dip steeply and were rotated to horizontal before the shortening direction was determined and plotted on Figure 21. These shortening directions in both Ordovician carbonates and the Silurian Tuscarora

Formation on both sides of the Cove fault are more nearly perpendicular to the McConnellsburg anticlinal axis, not the Cove fault. I believe they were formed early in the Alleghany orogeny, prior to, or during, folding and then later overprinted by the Cove fault.

GEOLOGY OF THE FOOTWALL OF THE COVE FAULT ALONG ESTHER RUN

After walking west a short distance from the quarry the Cove fault is crossed and the vertical to steeply overturned beds of a fragmentary section extending from the Upper Ordovician Reedsville shale to the Middle Devonian Mahantango Formation is encountered. In Figure 28 the section as far as the Lower Devonian Old Port is shown in an attempt to illustrate the amount of stratigraphic thinning that must have occurred in these footwall rocks. Based upon comparison with measured or assumed stratigraphic thicknesses plotted at the bottom of Figure 28, this section has been thinned at least 50%, with both brittle and ductile units participating. Most striking is the 150 foot section of the Tuscarora Formation, which has been thinned from at least 400 feet (but I have measured sections of 500 feet). Stratigraphic markers that can be found at road level or in the slopes to the north include: Reedsville shale, Bald Eagle sandstone, Juniata interbedded red shale and sandstone, the Tuscarora, a covered interval, presumably underlain by Rose Hill shale containing float blocks of the hematitic Centre sandstone member, the Keefer sandstone, small outcrops of Bloomsburg and Tonoloway, and, finally, a continuous section of carbonate rocks - Keyser, cherty Old Port, and sandy limestone of the Ridgely Formation. The section continues west to the Mahantango Formation but we will not walk beyond the Tuscarora outcrop.

Mechanisms for this thinning are not obvious in the exposures, but, from observations in other parts of the region, are thought to include penetrative strain and flowage in shale units, and extensional wedging which caused separation of stiff units such as the Tuscrarora in both horizontal and vertical directions. The fault-bounded, isolated blocks of tectonized Tuscarora seen at Stop 3 are a product of extension parallel to strike, and evidence exists above you on the south slope of Lowery Knob for extension parallel to dip.

SUMMARY AND CONCLUSIONS ABOUT FEATURES AT STOPS 3 AND 4

Important features to be remembered for this discussion are:

1. In this part of the region the Cove fault trend is counter-clockwise from the trend of the axis of the McConnellsburg-Big Cove anticline with the result that it truncates the anticlinal axis and cuts obliquely through the Tuscarora and other Silurian units of its vertical footwall.

2. Prior to the Cove fault, the rocks on both sides of the fault were shortened in a WNW direction and folded, perhaps in that sequence or perhaps simultaneously. This shortening developed the conjugate strike-slip faults and thrust/backthrust wedges seen in the hanging wall at the Mellott quarry and the folds in the separated blocks of the Tuscarora Formation seen in the footwall exposures on Lowery Knob.

3. The rocks of the footwall of the Cove fault were extended both vertically and horizontally, and the vertical rocks of the stratigraphic section were thinned by more than 50% as stiff units such as the Tuscarora were broken into separated blocks.

4. The blocks are bounded by late faults with unique fault fabrics that do not grow out of fold structures within the blocks, but rather, unsystematically truncate the pre-existing structures.

Figure 22 is a structure section along the line S-S' drawn through Lowery Knob across the McConnellsburg anticline and extending to the basement at approximately 25,000 feet. It is

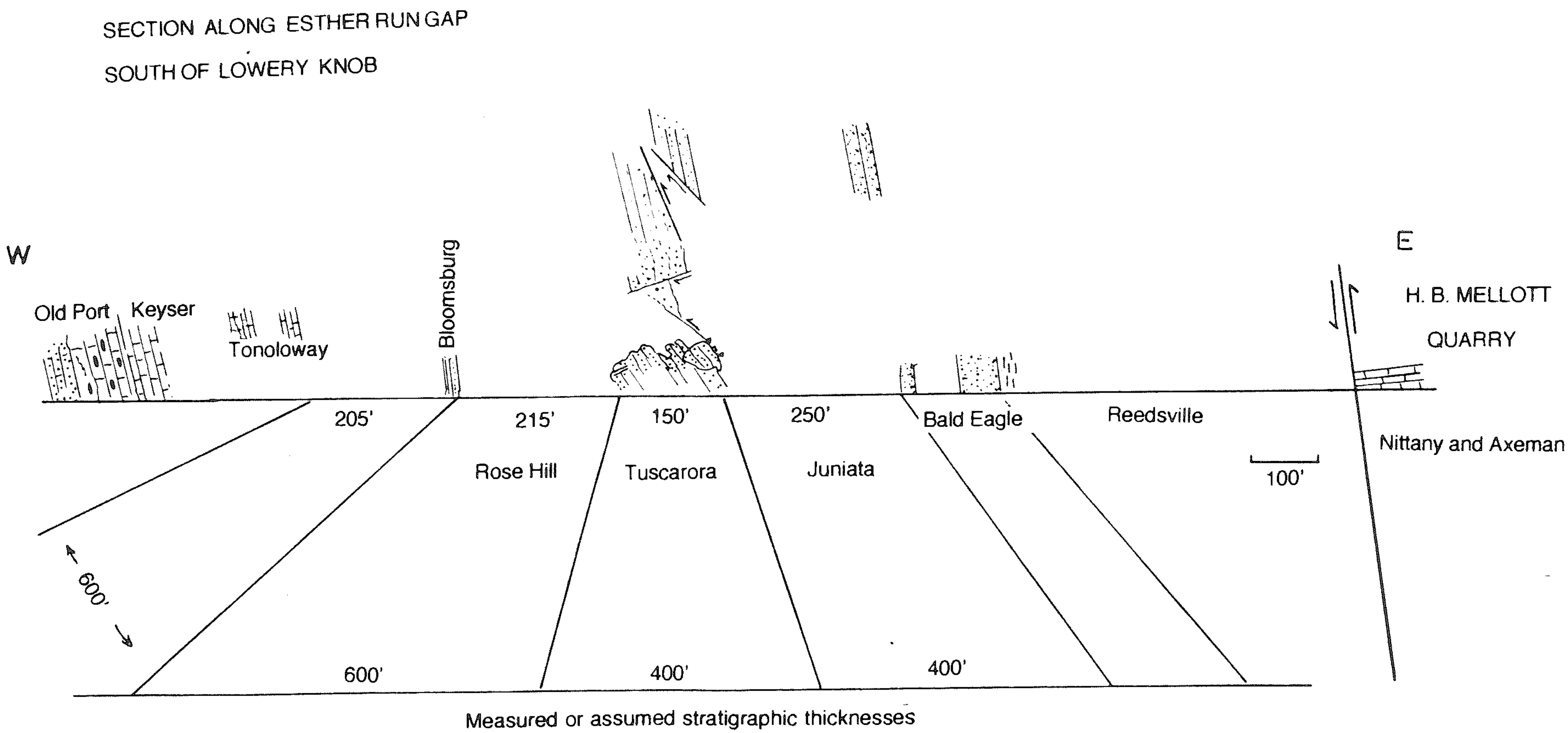


Figure 28. Profile of the Esther Run section across the south end of Lowery Knob, the footwall of the Cove fault, to show tectonic thinning in vertical beds. Comparison with the regional thickness estimates for the section, that are shown at the bottom of the diagram, suggests the amount of thinning.

an attempt to incorporate some of the features of the sequential deformation that are present on Lowery Knob and need an explanation founded in a structure section extending across the McConnellsburg anticline and the Meadow Grounds syncline. The classic balanced section drawn by Gwinn (1970) through this region, and recently redrawn by Mitra and Namson (1989), served as a model and starting point, but I accept all responsibility for drawing the Cove fault as a steep upthrust cutting through both the McConnellsburg anticline and the fault that created it (fault A on Figure 22). The McConnellsburg anticline originated as a ramp anticline on fault A (single-barbed arrows) which moved both along the Tuscarora fault/Antes-Coburn detachment and along a splay cutting up through the Reedsville section. At some time, as a frontal fold developed, a thrust rose from this fault into the Devonian section on the southeast limb of the Meadow Grounds syncline, as indicated by the single-barbed arrows. Later, fault B (double-barbed arrows) formed as the next ramp toward the foreland, flattening into the Tuscarora fault/Antes-Coburn detachment, and continuing west beneath the Meadow Grounds syncline. The steep fault C, which reaches the surface as the Cove fault, is drawn as an out-of-sequence steep reverse fault, rising from the ramp of fault B. This fault C cuts fault A and moves it upward above its splays (see three-barbed arrows), that are now incorporated in the deformed and thinned rocks of the footwall on Lowery Knob. The section, as drawn, allows less than 5,000 feet of reverse slip on this fault as it rises from ramp B, but the possibility also exists of reactivation of fault A as shown by three-barbed arrows. Extension of the footwall induced by the late steep reverse fault (fault C) explains the separated blocks of Tuscarora Formation that contain pre-existing folds which seem unrelated to the late faults. These pre-existing folds were generated when fault A passed through the present footwall. Fault C can either rise off the ramp as shown, or gain offset by reactivated slip on fault A.

		Leave quarry and walk west along road to board buses at the Tuscarora outcrop. **RETRACE ROUTE** back to US Rte. 522.
1.3	35.1	**STOP SIGN**. **TURN RIGHT** (NE) onto US Rte. 522.
1.1	36.2	Passing SR 1001 and Fords Country Store on right. **CONTINUE** onUS Rte. 522 to the NE.
1.7	37.9	Road to Cito on the right, church on the left. **CONTINUE** NE on US Rt. 522. The route is going N on Ordovician carbonates along the west limb of the McConnellsburg Big Cove anticline.
0.6	38.5	**TURN LEFT** (W) onto Rock Hill Road. At 0.5 mile along Az 72^{0} from this intersection, Consolidated Gas Supply Co. drilled their T. E. Nesbit #1 well to a depth of 8,650 feet, beginning in the Cambrian Conococheague Formation at the crest of the anticline and ending in the Ordovician Reedsville Formation.
0.3	38.8	Crossing Big Cove Creek (Potomac drainage).
0.4	39.2	T 379 enters from the left. **FOLLOW CURVE** to right. Strawberry Ridge, to the left along T 379, contains an exposure of a large, detached, block of Tuscarora breccia, as seen along the Cove Fault at Stop 3.
0.1	39.3	Longview Road on left.
0.1	39.4	Large detached blocks of Tuscarora megabreccia along the Cove Fault are visible in the field to the right.
0.2	39.6	Rock Hill Mennonite Church on the left. An isolated block of Tuscarora megabreccia is in the woods to the right, not visible from the road.

0.1	39.7	Crossing gas pipeline.
0.4	40.1	Several farmsteads surrounded by open fields. Note the absence of Tuscarora blocks, though we are on the trace of the Cove Fault, placing Ordovician carbonates against Devonian shales.
0.5	40.6	**T-INTERSECTION. TURN LEFT** (W) onto SR 1003.
0.4	41.0	Road bends right, toward the NE. **CONTINUE** on SR 1003
0.3	41.3	Begin seeing outcrops of Devonian Catskill, Irish Valley Member, on right.
0.5	41.8	**INTERSECTION. TURN LEFT** onto Meadow Grounds Road, T 389.
0.1	41.9	Outcrops of Devonian Catskill redbeds begin on the left.
0.3	42.2	Road bends left and begins steep ascent of Meadow Grounds Mountain, a ridge of Mississippian Pocono Formation. At the bend there is a small quarry of Catskill redbeds.
0.9	43.1	Outcrops of Pocono Formation on the right.
0.3	43.4	Crest of Meadow Grounds Mtn. Road bends right toward parking areas of State Game Land #33.
0.2	43.6	**TURN LEFT** down ridge toward Meadow Grounds Lake.
0.3	43.9	Parking area on lake shore. **CONTINUE** S, on road paralleling lake.
0.6	44.5	**STOP AND PARK** at dam on S end of Meadow Grounds Lake.
		LUNCH STOP AND MISSISSIPPIAN ROCKS. Visit rocks after lunch.

MAUCH CHUNK FORMATION IN THE MEADOW GROUNDS VALLEY

Discussant: William Edmunds.

INTRODUCTION

Meadow Grounds valley and the encompassing ridges are the topographic expression of the doubly-plunging Meadow Grounds syncline. Scrub Ridge to the west and Meadow Grounds Mountain to the east are sustained by the resistant sandstones of the Devonian-Mississippian Pocono Formation. For the most part the valley flanks are nearly dip slopes on the upper surface of the Pocono. The center of the valley is floored by a thin veneer of Mississippian Mauch Chunk Formation. Projection of structure contours seems to indicate that less than 50 feet of basal Mauch Chunk remains.

Exposures of the Mauch Chunk are typically poor, but an incomplete section of uppermost Pocono and lowermost Mauch Chunk is exposed at the spillway on the west side of the Meadow Grounds Lake dam (see described section below). This exposure includes a calcareous siltstone that is tentatively interpreted as a facies of part of the Loyalhanna Member of the Mauch Chunk.

Sandstone forming the top of the Pocono Formation crops out in the new channel of Roaring Run just south of the spillway. The variegated interbedded sandstone and siltstone, that occurs near the base of the Mauch Chunk Formation, forms the flat floor at the foot of the concrete weir and is submerged except during times of low flow. The "Loyalhanna" calcareous siltstone and overlying clayey silt shale crop out adjacent to the retaining wall on the west side of the spillway.

Although the exposed section is limited, its location at the extreme eastern edge of Mauch Chunk outcrop renders it potentially important in two respects. The first relates to the eastward or southeastward facies change of the Loyalhanna Member as it interfaces with prograding alluvial-deltaic red clastics from the eastern source area. The second is concerned with location of the eastern edge of an early Meramecian arch (or peripheral bulge) that disrupted deposition of the Mauch Chunk delta and formed a widespread unconformity throughout the central Appalachians. The two questions are largely interrelated.

The description of the exposed rocks is as follows:

Mauch Chunk Formation

6. Clayey siltstone, grayish-red (5R4/2-10R4/2), hackly, non-calcareous, **4.0+ feet**.
5. Calcareous siltstone, grayish-red to pale red (5R4/2 to 5R6/2), hard, dense (iron oxides or carbonates?); very fine grained, calcareous siltstone and ferrigenous clayey siltstone laminae; very angular grains, calcite crystal faces. Equivalent to part of Loyalhanna Member. **4.5+ feet**. The following description is from Robert C. Smith, II, Pennsylvania Geological Survey:

   A 1.6-m-thick exposed red, calcareous siltstone was sampled from the bank of Meadow Grounds Lake, Fulton County, approximately 30 m N25°E of the center of the spillway (latitude 39°54'22"N, longitude 78°03'36"W). This is presumably from near the base of the Mauch Chunk Formation and is likely related to the Loyalhanna Limestone, but lacks characteristic trough cross beds and visible quartz sand. The quartz observable in thin section is extremely angular to shard-like. X-ray diffraction suggests that the rock contains major amounts of quartz and calcite; minor chlorite, muscovite, and hematite; and trace albite. Possible traces of microcline and siderite cannot be ruled out. Leaching with 1.5 N Hcl for 72 hours suggests that 24.9% soluble $CaCO_3$ was present. Leaching with 6 N Hcl for the same length of time removed an additional 3% and changed the color of the insoluble residue from red (10R5/4) to off white (N9 to 5YR8/1), suggesting that the rock contains on the order of 3% hematite.
4. Cover. Spillway abutment retaining wall. **6.0± feet.**
3. Interbedded siltstone and silty sandstone (very weathered), silt to medium-grained, 1/8-1/2-inch laminae, grayish-red (5R4/2), pale red (5R6/2), pale brown (5YR5/2), grayish-brown (5YR3/2), and grayish-orange (10YR7/4), clayey matrix, sideritic (?), minor calcareous cement, micaceous, iron minerals (weathered to limonite or pin-head pits), semi-metallic dark gray to dark bluish gray (N3-5B3/1) mineralization on joint and cleavage surfaces (iron and/or manganese oxides?), 1/4 -3-inch beds. Exposed only during low flow in spill way. **1.0+ feet.**
2. Cover. Includes presumed unconformity. **6.0± feet**.

Pocono Formation

1. Sandstone, medium-grained, light gray to very light gray (N7-N8), weathers grayish-yellow to pale yellowish-orange (5Y7/4 to 10YR8/6), sub-angular grains, silica cement, micaceous flaggy 1-2-foot beds. Exposed in creek below spillway. **3.0+ feet.**

LOYALHANNA FACIES

The principal question is whether the Mauch Chunk red bed sequence in Meadow Grounds is equivalent to the late Meramecian-age Loyalhanna and rests unconformably upon the early to middle Osagean-age Pocono, as is the case throughout most of southwestern Pennsylvania including the Broad Top synclinorium, or whether these red beds are middle Osagean-age basal Mauch Chunk conformably succeeding the Pocono, as is the case throughout most of

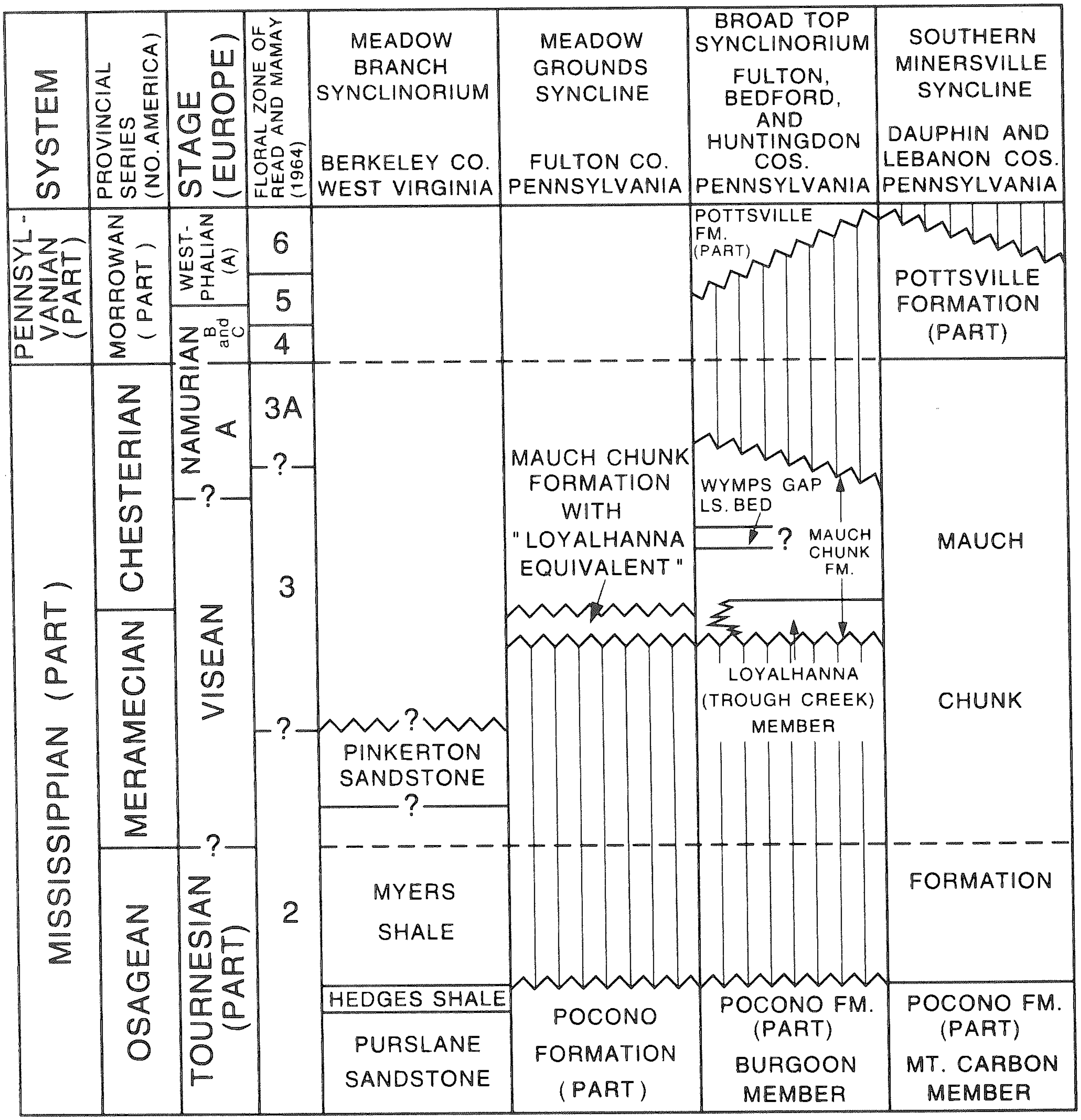


Figure A. Correlations of the Mauch Chunk Formation in south-central Pennsylvania and eastern West Virginia. Modified from Edmunds (1993a).

eastern Pennsylvania and the Meadow Branch synclinorium of Berkeley County West Virginia (see Figure A). Although the evidence is largely circumstantial and less conclusive than might be desired, the former alternative seems more likely.

While the exposed calcareous siltstone bears little resemblance to the highly cross-bedded arenaceous limestones or calcareous sandstones of the typical Loyalhanna Member of the Mauch

Chunk formation, it is well established that the Loyalhanna (Trough Creek) Member at the base of the Mauch Chunk Formation in the Broad Top area 10 miles to the northwest steadily changes from west to east with declining sand fraction, fewer strongly cross-bedded units, and increasing interbedded red shale and siltstone (see Hoque, 1965, p. 45-51; Brezinski, 1984, p. 12-14). In the southwestern part of the Broad Top synclinorium and in the Emmaville syncline to the south, the Loyalhanna interval seems to be largely replaced by red shales, siltstones, and sandstones (Hoque, 1965, p. 45-47). As pointed out by Brezinsky, this trend indicates an eastward shoaling of the Loyalhanna embayment and interfingering with prograding delta plain red clastics from the eastern source area. Where Mauch Chunk conformably succeeds the Pocono, the lower beds are not usually calcareous except for occasional caliche zones or nodules. The interpreted correlation with the closest Mississippian sections is shown in Figure A.

EASTERN LIMIT OF THE EARLY MERAMECIAN ARCH AND UNCONFORMITY

The large hiatus between the Loyalhanna Member of the Mauch Chunk Formation and the underlying Pocono Formation shown on Figure A is part of a widespread unconformity that extends throughout all extant Late Mississippian rocks of Pennsylvania (except possibly those of northern Dauphin and Lebanon Counties), Maryland, Ohio, and West Virginia (except Berkeley County and part of Greenbrier and Monroe Counties). It also extends into westernmost Virginia, easternmost Kentucky, and a small part of Tennessee (Edmunds, 1993a, 1993b). Edmunds also concluded that the erosion surface represents a large tectonic arch or peripheral bulge that developed in early Meramecian time..

The eastern edge of the arch and its associated unconformity presumably lay somewhere across southeastern Pennsylvania and central Maryland prior to the general northwestward translation of the rock sequence during Alleghanian folding and faulting. East of that line, deposition of the Mauch Chunk delta sequence was continuous and the contact with the underlying Pocono Formation was conformable. To the west, most or all of the lower half or more of the Mauch Chunk is missing by erosion and nondeposition. It is clear that almost all of the Mauch Chunk Formation older than late Meramecian is missing across the western half of Pennsylvania, including the Broad Top synclinorium. Throughout eastern Pennsylvania, except possibly the section in northern Dauphin and Lebanon Counties, the unconformity is not as deeply incised. Some lowermost Mauch Chunk remains between the top of the Pocono and the unconformity everywhere south of Scranton where the unconformity cuts down into the Pocono Formation.

If the previously discussed correlation of the Mauch Chunk section in the Meadow Grounds syncline is correct (Figure A), the unconformity is present and all early Mauch Chunk section has been removed. Translating the Meadow Grounds section back to its original pre-Alleghanian location near Waynesboro in southeastern Franklin County (based upon Faill, 1985, Figure 11), the eastern edge of the arch and associated unconformity must have been some distance east of there.

The nearest occurrences of the Mauch Chunk Formation or nomenclatural equivalent along the southeastern outcrop limit are in the southern Minersville syncline (southern "fishtail") in northern Dauphin and Lebanon Counties, 60 miles to the northeast, and in the Meadow Branch synclinorium in Berkeley County, West Virginia, 20 miles to the south. In both places much or all of the middle Osagean to late Meramecian Mauch Chunk sequence is present (Figure A). This indicates that the sections lay beyond the eastern limit of the arch and associated unconformity or just within the area affected so that only a relatively small amount of section is missing by erosion or erosion and non-deposition.

In the southern Minersville syncline the Mauch Chunk Formation is approximately 5,000 feet thick and is conformable and transitional with the underlying Pocono Formation and overlying Pottsville Formation (Wood and others, 1969; Dyson, 1967). It is not certain whether the unconformity is present there or not since exposures of most of the sequence are poor. However, approximately 2,500 feet of Mauch Chunk are lost between this area and Jim Thorpe, 70 miles to the northeast, where about 2,400 feet overlie the unconformity and 400 feet remain below it. Because both top and bottom of the Mauch Chunk are still conformable at Jim Thorpe, the loss is internal to the formation. Most or all of this 2,500-foot loss is believed ascribable to erosion or erosion and non-deposition at the unconformity. One possible negative clue suggests that the unconformity may be present in the southern Minersville syncline area, because if the area lay in the narrowed foreland basin southeast of the arch, it seems reasonable to expect that, in addition to receiving sediments from the normal southeastern orogenic source, it would also have intercalated wedges of clastics eroded from the positive arch to the northwest. No one has found this to occur. In either case, if the southern Minersville syncline is translated back to its approximate pre-Alleghanian position near the border between Dauphin and Lancaster Counties, the original eastern edge of the arch should be somewhere in the Harrisburg-Lancaster area.

In the Meadow Branch synclinorium, Lessing and others (1992) consider the contact between the Pocono equivalent (Rockwell Formation, Purslane Sandstone, and Hedges Shale in ascending order) to be conformable with the Mauch Chunk equivalent (Myers Shale and Pinkerton Sandstone). The presence of *Triphyllopteris* sp. and *Rhodeopteridium* sp. of Read and Mamay (1964) floral zone 2 (as extended by Wagner, 1984) in the Pinkerton Sandstone indicates that the terminal age of the Pinkerton cannot be younger than middle Meramecian. This indicates that the 1,200-foot Myers redbed sequence is probably older than the early Meramecian unconformity. The unique Pinkerton Sandstone could be entirely older than the unconformity, but could also be more-or-less contemporary as well. The gray coarse-grained Pinkerton with a number of thin coal horizons has no lithologic equivalent elsewhere in the central Appalachians. Its climatic implication is also an enigma, being the only indication of well-watered conditions in a region of widespread and long-standing semi-aridity. If the Pinkerton is contemporaneous with the unconformity to the west, it would suggest that the Meadow Branch section was deposited in the constricted foreland basin east of the positive arch. Prior to Alleghanian deformation, the Meadow Branch section was probably located about 30 miles to the southeast, in the area of Brunswick, Maryland (based on Faill, 1985, Figure 11 and Lessing and others, 1992). Speculatively, the Pinkerton clastics might have been derived from the eroding arch to the northwest, at least partially. Conceivably, the Pinkerton is the only remnant of sediments deposited in the south-flowing main stem of the vast fluvial system draining the orogenic highlands to the east and the arch to the west and north. The narrow area occupied by this main channel may have remained well-watered year-round, producing a linear oasis within an otherwise semi-arid region. Studies of cross-bedding and other directional indicators would be enlightening.

It is striking to note that the entire 2,350-foot lower Mauch Chunk (Myers and Pinkerton) section of the Meadow Branch synclinorium is older than any Mauch Chunk rocks of the Meadow Grounds-Emmaville-Broad Top area. In a distance of 20 to 30 miles the entire Meadow Branch section is lost by erosion or erosion and non-deposition below the early Meramecian regional unconformity. It appears that, of the thousands of feet of section missing below the unconformity in Pennsylvania, Maryland, Ohio, and northern West Virginia, most is lost within a few tens of miles along the eastern edge. Probably no more than an additional 400 feet or so disappears by erosion and non-deposition across the remaining 200-mile width of the unconformity to the western edge of Late Mississippian occurrence in Ohio (in Ohio the western edge of the arch and unconformity lies beyond the outcrop edge, if it exists at all and does not simply merge with the east side of the Cincinnati arch). It seems that this northern part of the arch is highly asymmetrical with a steep rise along the eastern edge with only a very slight tilt to the rocks from there on to the northwest.

		RETRACE ROUTE back to SR 1003.
2.6	47.1	**INTERSECTION. TURN LEFT** (N) onto SR 1003.
1.0	48.1	**STOP SIGN** and **INTERSECTION**. **TURN RIGHT** (E) onto SR 1004. On your left is the south end of Little Scrub Ridge, with Tuscarora Formation outcrops extending to the north.
0.5	49.4	**TURN LEFT** (N) onto Peach Orchard Road, SR 1003. Proceed N, observing the knobby crest of Little Scrub Ridge on your left front.
0.5	49.9	Bridge over US Rte. 30.
0.4	50.3	Last house on left.
0.3	50.6	Outcrops of Ordovician Bald Eagle Formation on the left.
0.1	50.7	Crest of Little Scrub Ridge. **Park buses and walk back to the Bald Eagle outcrop of Stop 5.**

STOP 5. STRUCTURE OF THE COVE FAULT ZONE ON LITTLE SCRUB RIDGE

Discussant: Dick Nickelsen.

INTRODUCTION

The most interesting structural feature in the region, a zone of cross faults along the Cove fault, was observed in an overview from Stop 1. We will now take a closer look at a representative part of it at Stop 5. This stop is the only place along Little Scrub Ridge where portions of the ridge top and its good exposures of Tuscarora Formation can be observed without first climbing the ridge from the valley floor. Also, the land owner, John Funk of Waynesboro, has granted permission for members of this field trip to enter his land on both sides of Peach Orchard Road. A small part of this feature was mapped by Pierce (1966) in the NW 9th of the McConnellsburg quadrangle, and the structure of the northwest limb of the McConnellsburg-Big Cove anticline was the subject of a MSc thesis at the University of Oklahoma (Main,1978).

GENERAL GEOLOGIC DESCRIPTION

The knobby topography of Little Scrub Ridge is illustrated in Figure 16, one of the views from Stop 1. The geologic structure that is responsible for the topography is shown on Figure 29. It consists of a number of fault blocks distributed along the ridge that contain stratigraphic units of differing resistance to erosion. Near Stop 5 the ridge trends Az 30° and is cut by a number of steep faults trending Az 50° or 60° that produce right-lateral separations of a stratigraphic section including the Ordovician Bald Eagle Formation and the Juniata Formation, as well as the resistant Silurian Tuscarora Formation that forms the knobs. Stratigraphic markers used to measure the right-lateral separation between adjacent fault blocks are the reddish quartzite at the

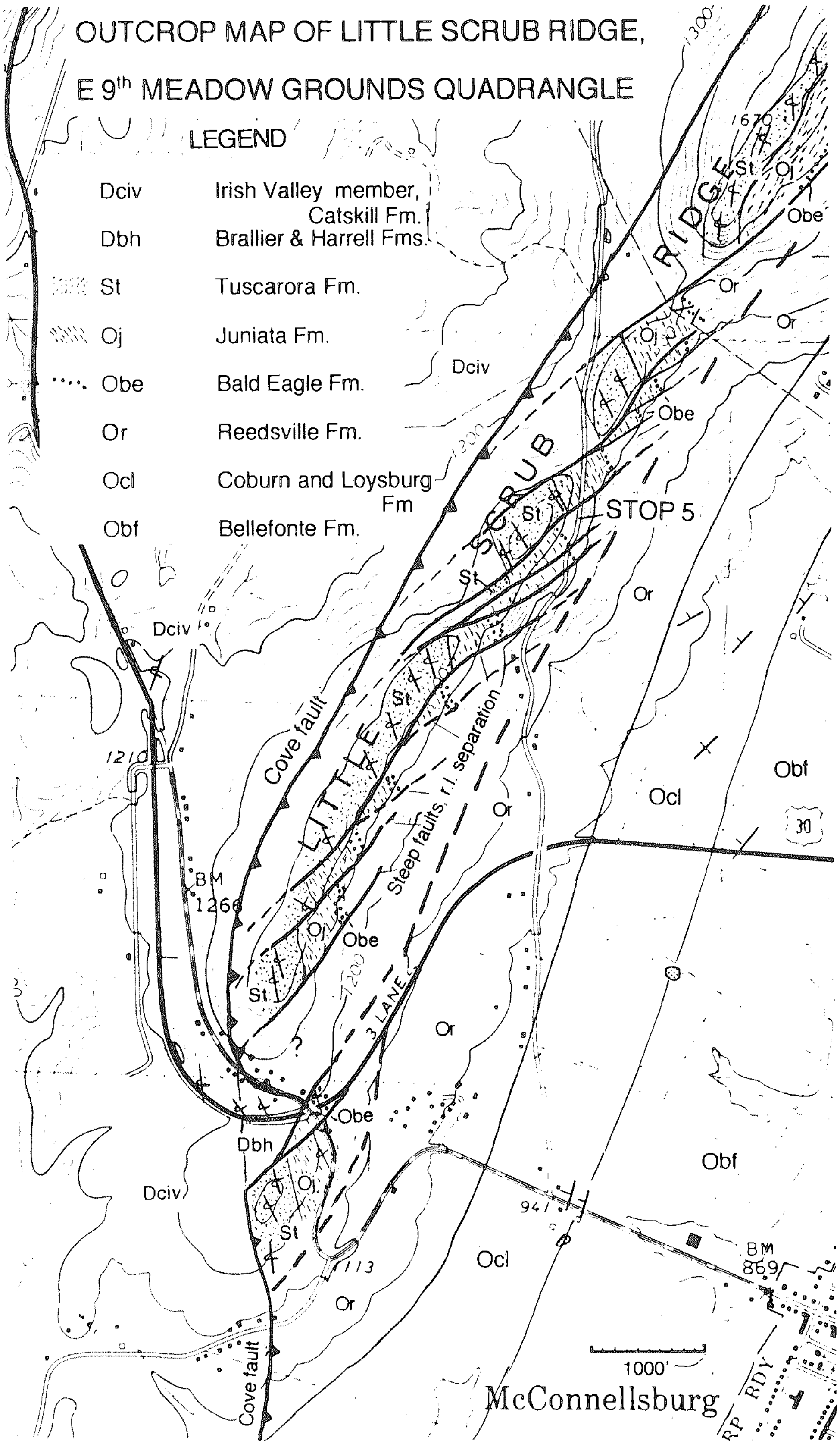


Figure 29. Outcrop map of Little Scrub Ridge near Stop 5, showing the Az 50° to 60° transverse fault set with much right-lateral separation.

base of the Tuscarora where it grades into the underlying Juniata Formation, and the distinctive 10 m bed of resistant, pebbly sandstone near the base of the Bald Eagle Formation. This sandstone may be confused with the Tuscarora because it is quite quartzose, but it is more cross-bedded, more pebbly, and more friable than the Tuscarora, and can be seen to grade up into the red Juniata Formation. Bedding within the fault blocks is commonly overturned and strikes across the ridge at Az 340° to 355°, but some segments of the ridge north of Stop 5 have bedding striking parallel to the ridge with dips either toward the NW or, overturned, toward the SE.

DESCRIPTION OF THE OUTCROP

Figure 30 is a geologic map of Little Scrub Ridge near Stop 5. The buses will park at the place where Peach Orchard Road crosses the ridge and you will walk south, back to an outcrop of pebbly Bald Eagle sandstone, that strikes NW and dips 70° or 80° overturned toward the NE. If you look NW, up slope above the outcrop, you will see that the Bald Eagle sandstone strikes into outcrops of Tuscarora quartzite, that are across one of the Az 50° or 60° faults that crosses the ridge and the road near this point. If you look right (or N) up the road you will see red Juniata float that is also across the same fault. If you turn and face SE and cross the road, you can look down into a dump which, unfortunately, covers the next fault in the Az 50° or 60° system that crosses the ridge and road S of this point.

There are a few examples in the Bald Eagle sandstone outcrop of slickensided and slickenlined faults of the early pre-folding or syn-folding system that will be seen best at Stop 6. In one example, slickenlines parallel the fault-bedding intersection, which indicates that the faulting occurred during early layer-parallel-shortening, prior to folding. The mappable faults which transect the ridge are later faults with different characteristics that are discussed below.

In summary, you are standing on a narrow NE - SW trending fault block that is bounded to the NW and SE by faults of the Az 50° to 60° system. If you were to walk up slope toward the SW you would eventually encounter the Tuscarora Formation, above the overturned Bald Eagle sandstone in front of you. There are different fault blocks to the NW and SE of the block you are standing on, all having the stratigraphic markers that permit quantitative measurement of separation between the same marker in different blocks. This is discussed below in the section entitled "Fault separation along different segments of Little Scrub Ridge/ Scrub Ridge".

Many participants may not want to venture away from the road to see more of this geologic structure, but for those that do guidance will be provided to two different places:

1. You may wish to climb SW up slope diagonally beyond this Bald Eagle outcrop to see an example of one of the Az 50° to 60° faults where it is exposed on large surfaces truncating the Tuscarora Formation. This fault surface, the same one that crosses between the Bald Eagle sandstone and the Tuscarora quartizite at the top of the outcrop, has small patches of fault breccia but no slickensides or slickenlines. General characteristics of these faults are described below under "Description of faults".

2. Another longer walk E and upslope from near where the buses are parked will take you up on outcrops of overturned Tuscarora Formation in the next fault block to the north along Little Scrub Ridge. The Tuscarora strikes northwest and dips 50°, overturned, toward the NE. An overturned section of about 500 feet has been measured in this fault block, but there will not be time for walking all the way along the ridge to the structural marker at the transition to the Juniata Formation. However, you will be able to assess the quality of the exposures along these ridge tops, and will be able to observe the steep cliff dropoff to the SE where one of the Az 50° to

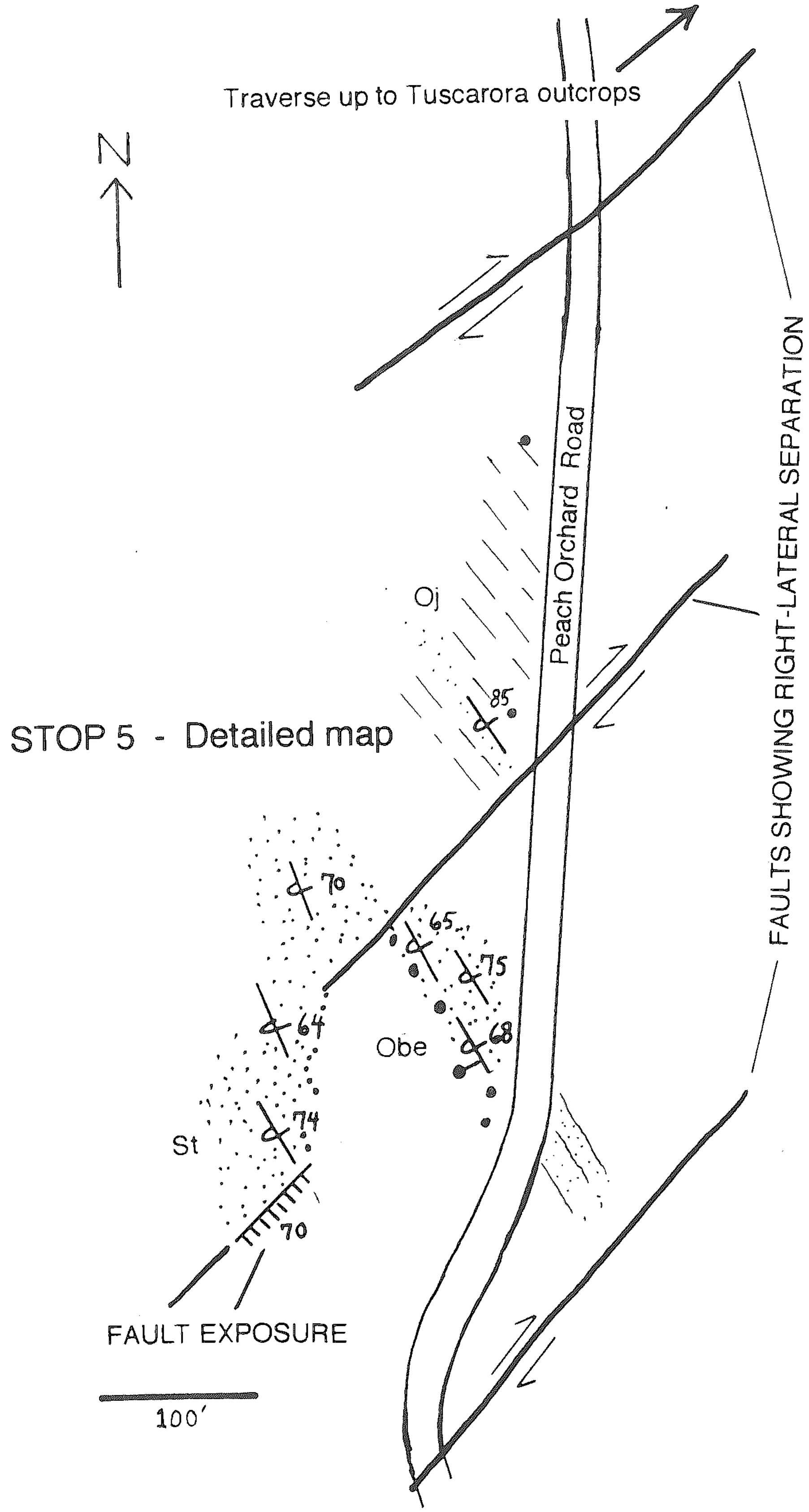


Figure 30. Detailed outcrop map of Little Scrub Ridge at Stop 5, with suggested off-road outcrops for study.

60° faults truncates the bedding of the Tuscarora. Inspection of the geologic map will reveal that there are 4 different slices of Bald Eagle sandstone down there below the cliff, but they will be inaccessible on this trip.

DESCRIPTION OF FAULTS

At a number of places the Az 50° to 60° faults that divide the ridge into fault blocks can be seen, particularly where they terminate Bald Eagle sandstone outcrops, but also at a few places in the Tuscarora. These faults are always similar in their fault fabrics to the fault that was demonstrated on the traverse of Lowery Knob at Stop 3. They have a fractured surface, intersected by many joints that are perpendicular to the surface, but never are marked by slickensides or slickenlines. They don't contain the euhedral quartz fillings that are found on steps or vugs of other faults in these rocks. If these surfaces were not seen terminating outcrops as large planes, perpendicular to the bedding in the outcrops, they would not be judged to be faults. In places they show small traces of a coarse, angular, cohesive breccia or the iron-oxide staining that has become one of their distinguishing features. They are all steeply-dipping surfaces.

In faults of such enigmatic character - no slickenlines that might be used to determine the slip direction - that occur in such complicated, poorly exposed terrain, it is impossible to be certain of their slip direction and sense. Both Pierce (1966) and Main (1978) suggest that they are strike-slip faults related to the Cove thrust fault on the northwest side of Scrub Ridge and Little Scrub Ridge, and this is certainly the most obvious option for their origin. I have sought other options during my detailed mapping of Little Scrub Ridge and Scrub Ridge but none are more acceptable. This will be discussed at greater length below in the summary section.

FAULT SEPARATION ALONG DIFFERENT SEGMENTS OF LITTLE SCRUB RIDGE/SCRUB RIDGE

Little Scrub Ridge and Scrub Ridge, to the north of Knobsville Gap, can be divided into segments of different trend and different frequency of the mappable Az 50° to 60° faults. Figure 31 is a map of Little Scrub Ridge extending from the E 9th of the Meadow Grounds quadrangle to Knobsville Gap in the SW 9th of the Burnt Cabins quad-rangle, and then continuing north along Scrub Ridge to the Central 9th in the Burnt Cabins quadrangle. Segments 1, 2, and 3 of the ridge are marked and all mappable faults have been shown.

Segment 1 of the ridge trends Az 30° and is intersected by many faults of the Az 50° to 60° right-lateral, steeply dipping set.

In the 11,200-foot Segment 1, measured parallel to the ridge, one can also measure strike separation between stratigraphic markers in different blocks. This separation measurement, when made essentially perpendicular to bedding strike and parallel to the Az 50° to 60° faults, is 6,800 feet. When only the component of this right-lateral separation parallel to the trend of the ridge is measured, this separation amounts to 6,000 feet. Original length L_0 = 11,200' - 6,000' = 5,200' and extension - $e = \frac{11{,}200 - 5{,}200}{5{,}200} = 1.15$ or 115%

Segment 2 of Little Scrub Ridge, 6,800 feet long, trends Az 35° but has no mappable faults. Bedding in outcrops along the ridge crest does not always parallel the strike of the ridge, but both the Bald Eagle sandstone and the Tuscarora quartzite outcrops can be mapped parallel to the ridge for over a mile. Outcrops are broken, rotated and probably extended by faulting, but this is not measurable at the scale of mapping. Exposures are inadequate to measure the extension along the ridge within the outcrops.

Segment 3 starts in the center of the NW 9th of the McConnellsburg quadrangle and trends 30° through Knobsville Gap to a fault north of the gap. The mean strike of the transverse faults in this segment is Az 63°. In this 16,000-foot segment of Scrub Ridge, the same procedure was followed and the separation parallel to the trend of the ridge was again 6,000 feet, yielding an L_0 of 10,000 feet and an extension of 0.60 or 60%.

North of Segment 3 the transverse faults disappear so the ridge shows no extension. Farther north, a thrust fault that places shallow, northwest dipping Bald Eagle Formation and Tuscarora Formation against overturned Juniata and basal Tuscarora indicates that the structural regime of transverse faults has ended.

SUMMARY

The extension due to right-lateral separation on map scale faults of Segments 1, 2, and 3, a distance of 7 miles, is .55 or 55%. I know of no other ridge in the Pennsylvana Valley and Ridge Province that has experienced such extension parallel to strike, and this is particularly unusual because nothing about the geology that is mapped here suggests that the NW limb of the McConnellsburg-Big Cove anticline is an area of local spreading that might account for this observation. Also, the SE limb of the anticline has not experienced any of this extension and it is odd that extension on the NW limb was accommodated only by faults showing right-lateral separation and possible dextral slip. Where are the left-lateral separations or sinistral slips that you might expect to see in this extending system? Small scale strain markers such as the nearby oolites of the Great Valley (Cloos, 1947) or deformed reduction spots elsewhere in the Valley and Ridge Province (Nickelsen and Cotter, 1983) show only small amounts of extension parallel to strike, so this limb of the McConnellsburg Big Cove anticline is an anomaly. Large amounts of extension have only been recognized in the principal plane up and down the dip of rock cleavage, perpendicular to strike.

What are some other options? (1) Slip directions are unknown on the Az 50°-60° faults so it is possible that the separations are related to vertical or oblique slip between fault blocks. With the overturned NE dip of most bedding planes, such steep slip directions would require that each successive block to the north has undergone vertical offset with respect to the block to the south. But large amounts of stepping up to the north would result in uplift in that direction, and be incompatible with the general NE plunge of the anticline. (2) If folding preceded the Cove fault, as is suggested by structural relations at Stops 3 and 4, and in the Burnt Cabins vicinity (Stop 6), then it is possible that the transverse faults of Scrub Ridge or Little Scrub Ridge are the product of superimposed faulting upon beds with pre-existing dips of 50° that have been folded more during the growth of the Cove fault. Although a variation of this idea served as an explanation for the map relations on the west limb of the Kishacoquillas Valley (Jacks Mountain) anticline (Nickelsen, 1988) the amount of overturning and change in strike and the rarity of early shortening direction markers makes it impossible to test in this region. (3) The Cove fault is different in its dip and and predominant strike in its different parts. Near its south end at Stops 3 and 4 it is a steep reverse fault that strikes in a more northerly direction (Az 6°) obliquely through the NW limb. As a result, it serves as the connector between footwall exposures of the Tuscarora in the south and hanging wall exposures at Little Scrub Ridge, near Stop 5. At the south end of Little Scrub Ridge along US Rte. 30, the Cove fault is a thrust fault carrying Ordovician and

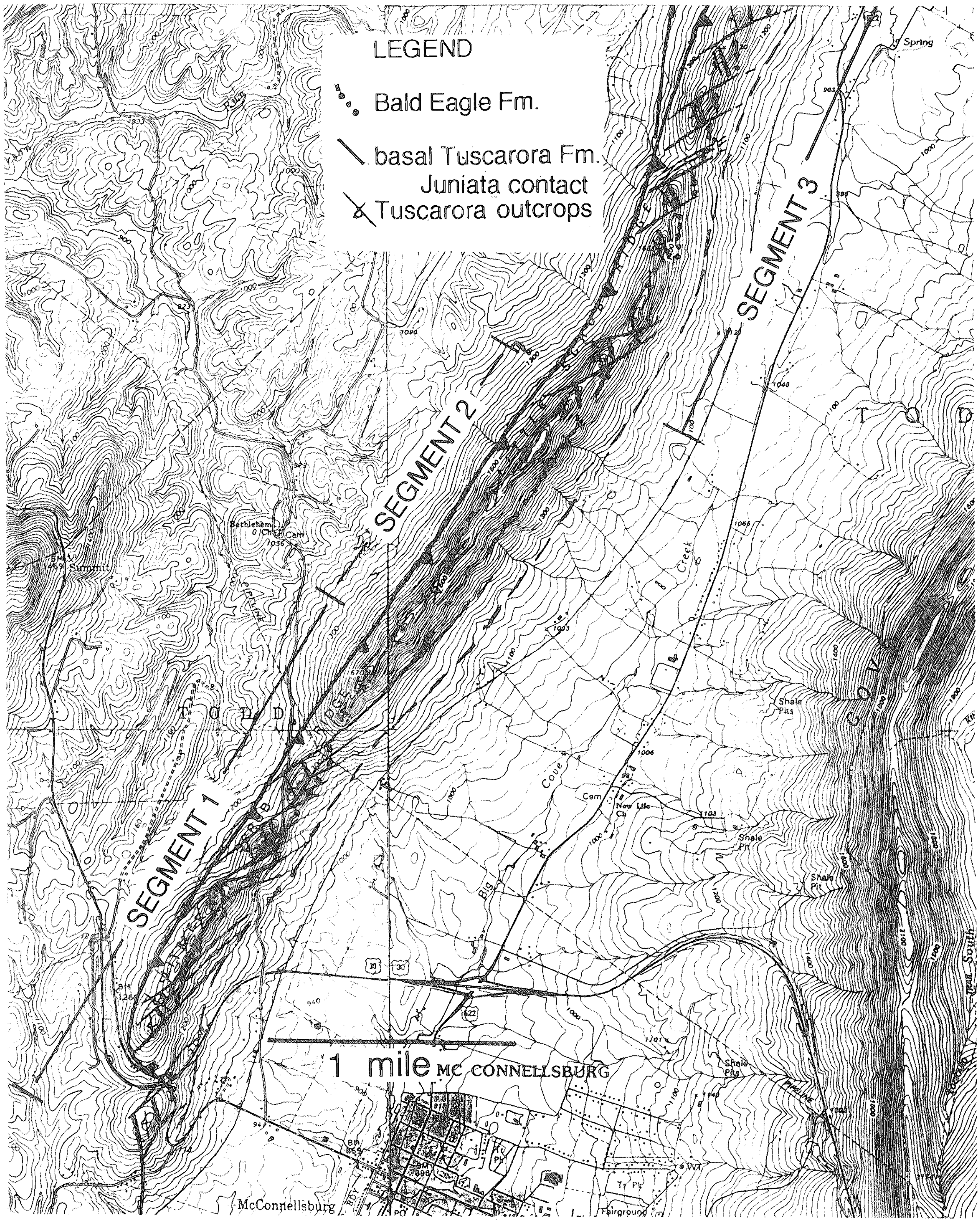


Figure 31A. Geologic map showing transverse faults along three segments of Scrub Ridge and Little Scrub Ridge where extension has been calculated.

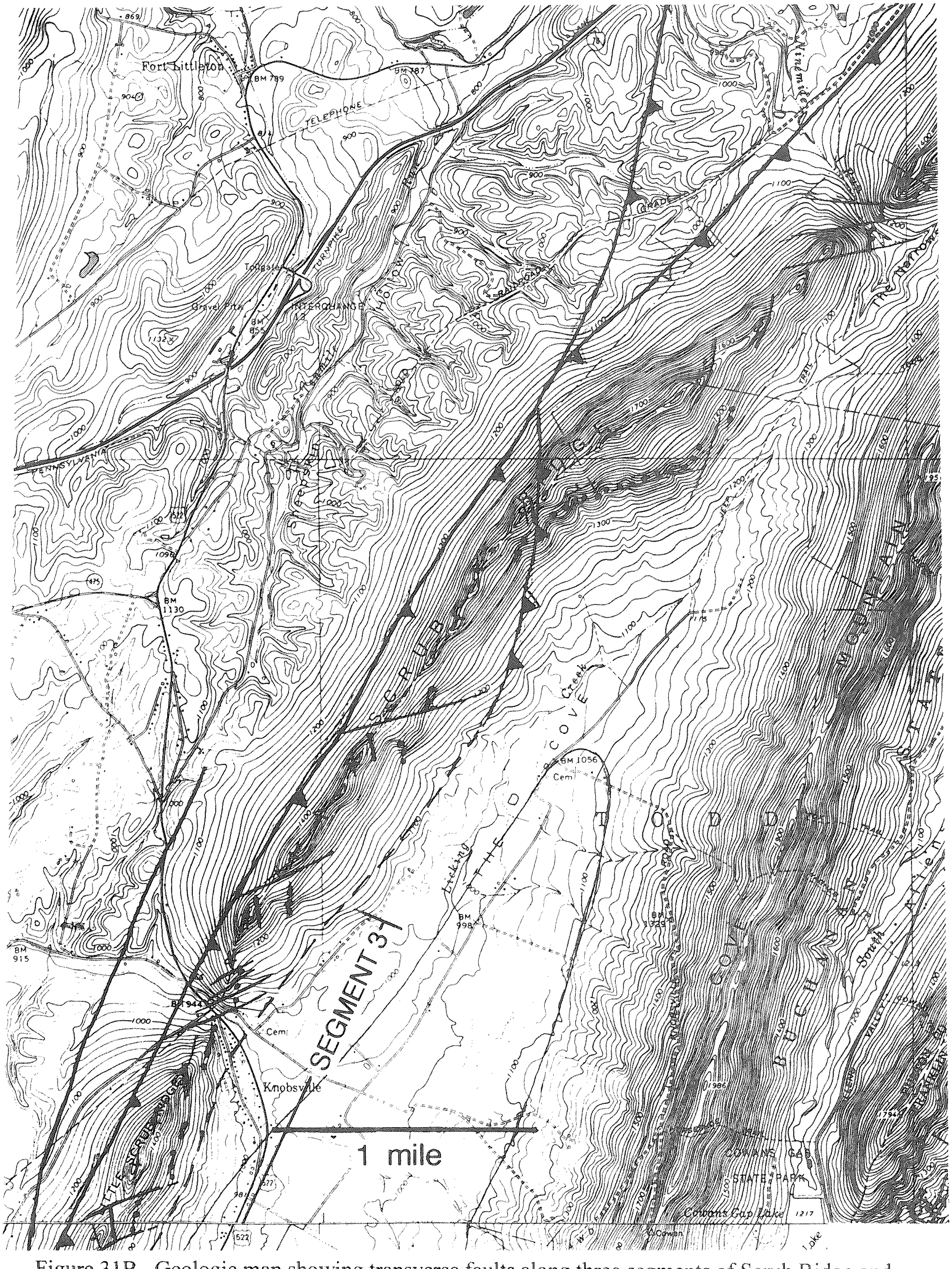


Figure 31B. Geologic map showing transverse faults along three segments of Scrub Ridge and Little Scrub Ridge where extension has been calculated.

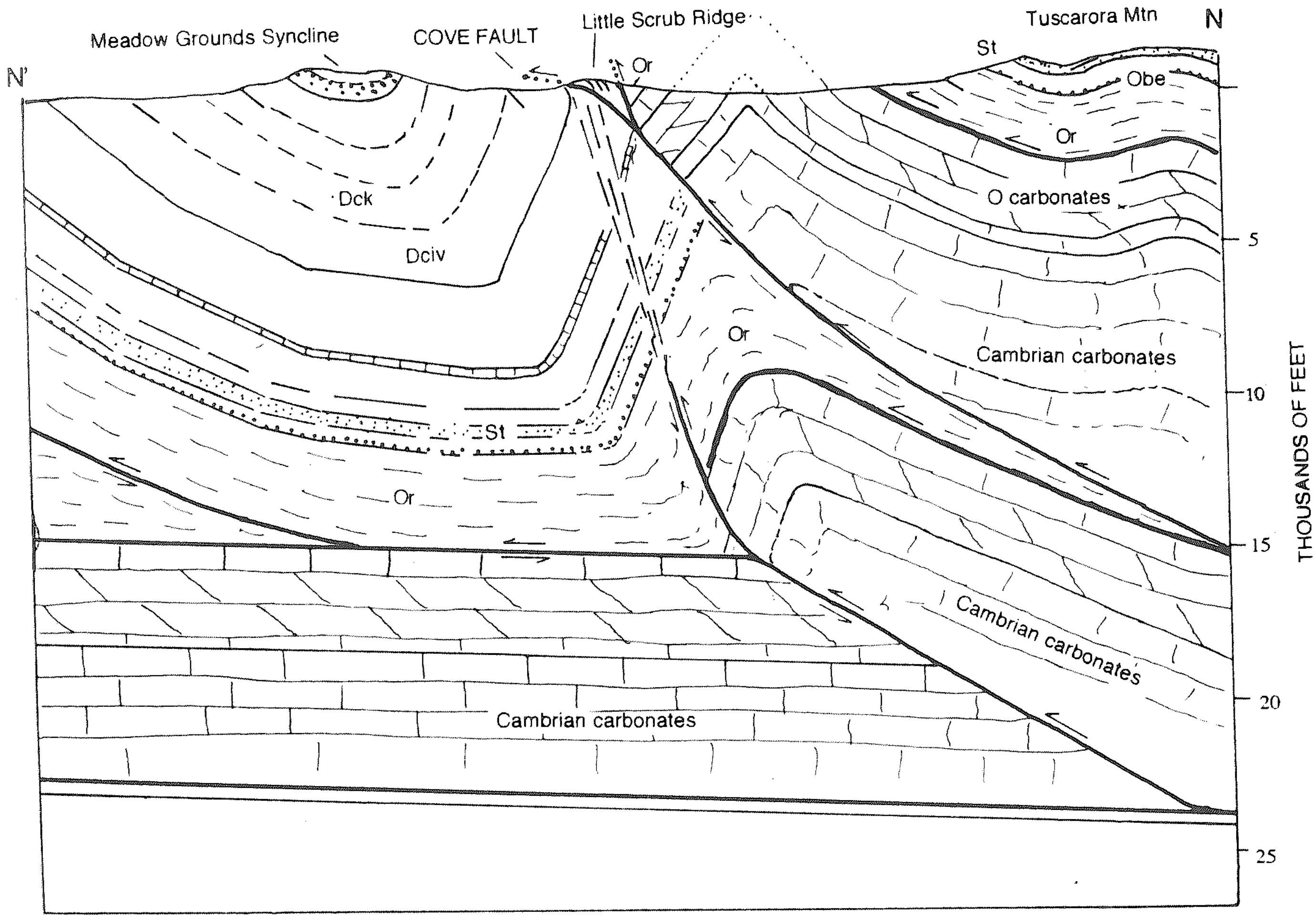


Figure 32. Section N-N' through Little Scrub Ridge.

Silurian rocks above overturned Upper Devonian Brallier-Harrell shales(see section N-N', Figure 32). When the Cove fault changes from the steep reverse fault to the thrust at Little Scrub Ridge, it also changes strike by 24^{0} to Az 30^{0}. Could this bend be related to a component of right-lateral oblique or strike-slip on the steep reverse fault to the south passing under the thrust fault and creating both the right-lateral separation on the Az 50^{0} to 60^{0} fault set and the extension to provide vertical movements of the transverse fault blocks, down to the south, and up to the north?

None of these alternatives are viable with the data at hand at this time, but it is necessary to consider them and other options until the large extension parallel to strike that has been documented here can be integrated with the geology of the region.

SURFICIAL GEOLOGY

When walking from the crest of the hill down to the main outcrop, observe the first outcrop where some redbeds are poorly exposed. The outcrop is mantled with rubble with matrix (boulder colluvium). Note that farther up the slope there is scree and that there is a change in slope between the scree and the rubble with matrix. Note the distinctive color difference between the bedrock and the rubble with matrix. At the north end of the outcrop the rubble comprises only a thin veneer. Has that area been significantly eroded or has the surficial mantle there always been thin?

		Leave Stop 5. **PROCEED** N on SR 1003 along the W side of Little Scrub Ridge.
1.0	51.7	Road bends left.
0.1	51.8	Sharp bend to the right. **CONTINUE** on SR 1003.
1.0	52.8	**ROAD SPLITS** and SR 1003 continues left. **TURN RIGHT** onto T 415, Dutch Corner Road. Good views of knobby Little Scrub Ridge on right.
1.0	53.8	Farm pond on left.
0.6	54.4	Devonian Brallier(?) shale borrow pit on left.
1.3	55.7	**STOP SIGN.** Intersection with US Rte. 522 in Knobsville Gap. **TURN LEFT** (N) onto US Rte. 522 crossing Licking Creek (Potomac drainage). Knobsville Gap is the boundary between Little Scrub Ridge (to the SW) and Scrub Ridge (to the NE) where the Tuscarora Formation has been faulted out.
1.6	57.3	Junction with PA Rte. 475 on the left. **CONTINUE** N on US Rte. 522.
0.7	58.0	Outcrop on the right of Devonian Irish Valley Member of the Catskill Formation.
0.2	58.2	Bridge over Pennsylvania Turnpike, US Route 76.
0.4	58.6	Entrance to the Pennsylvania Turnpike on the right.
0.9	59.5	Fort Littleton, road to left to Clear Ridge.
0.9	60.4	View left to Gobblers Knob, Tuscarora Formation outcrops on the SW plunging nose of the Shade Mountain anticline. Little Aughwick Creek (Susquehanna drainage) on left. Little Aughwick Creek has a well developed floodplain and is a good example of what Pierce mapped as modern alluvium. Between here and Burnt Cabins the road passes by several cuts in shale. Note that there is no surficial mantle on the shale and barely even any shale residuum. Erosion is very effective on shale.
1.9	62.3	View right to Sidneys Knob, the Tuscarora Formation in the NE plunging nose of the McConnellsburg-Big Cove anticline.
0.9	63.2	Entering Burnt Cabins.
0.3	63.5	**ROAD FORKS,** US Rte. 522 bends left, **CONTINUE STRAIGHT AHEAD** toward Cowans Gap State Park and Burnt Cabins Grist Mill.
0.1	63.6	Burnt Cabins Post Office on left.
0.3	63.9	Bridge over South Branch, Little Aughwick Creek. **Buses stop E of bridge and discharge passengers for Stop 6**. Stop 6 is across road, to the N, behind house owned by Carl Brown. Request permission for entry.
0.1	64.0	Buses proceed to the Burnt Cabins Grist Mill parking lot.

STOP 6. EVIDENCE OF PRE-FOLDING LAYER-PARALLEL-SHORTENING AT THE BURNT CABINS PLUNGE-OUT OF THE McCONNELLSBURG ANTICLINE

Discussants: Adam Gooch and Dick Nickelsen.

INTRODUCTION

Exposures at the northeast plunging nose of the McConnellsburg-Big Cove anticline near Burnt Cabins provide the best record in the region of the sequential deformation during the progression from layer-parallel-shortening in horizontal beds to major folding. This area excells as a demonstration of these events because there are good exposures of pre-folding strike-slip faults in the Keefer sandstone around the nose of the fold, and because the axis of later folding can be well defined by a large number of bedding observations. The Keefer sandstone is a much better unit for structural studies than the Tuscarora because it contains more, better defined, faults. Also, the Keefer sandstone is commonly not well exposed along the limbs of the major folds so studies requiring large numbers of observations of structural data must be conducted at the noses of plunging folds such as in the Burnt Cabins area.

DEFINITION OF THE FOLD AXIS

The Keefer sandstone is well exposed at the crest and on both limbs of the plunging fold, but an outcrop on the northwest limb, striking Az 60° or 70° and dipping 50° northwest, will be visited (Figure 33). Large bedding exposures reveal excellent examples of burrows perpendicular to bedding and the trace of strike-slip faults. Poles to bedding orientations on the northwest limb and also the southeast limb, that won't be visited, are shown in the equal area stereographic projection of Figure 34. A more significant plot is Figure 35 which consists of bedding poles measured at all the Keefer outcrops as well as a few Tuscarora outcrops in the area. When all poles are plotted on an equal area stereographic projection they are found to be clustered along a great circle that defines the plane perpendicular to the plunging fold axis. This definition of the fold axis, plunging 20° toward Az 50°, allows comparison between the dominant orientation of strike-slip faults and the fold.

STRIKE-SLIP FAULTS THAT DEFINE THE PRE-FOLDING SHORTENING DIRECTION

Pre-folding strike-slip faults are recognized as fault surfaces that have their slickenlines parallel to the fault-bedding intersection, implying that their major slip occurred parallel to their strike while the adjacent bedding was horizontal. At Stop 6 there are two conjugate sets of these faults, showing, in places, right-lateral and left-lateral slip sense as illustrated in the diagram at LPS on Figure 33. Determination of slip sense is not possible on all faults, but enough examples of slip sense are available in each of the two sets of faults to provide confidence in utilizing the acute bisector of these two sets of faults as the pre-folding shortening direction. The right-lateral faults are more nearly perpendicular to the later fold axis and have been reactivated during folding, with the result that the early, pre-folding slickenlines have been overprinted by nearly horizontal slickenlines that are, in places, related to small strike-slip offsets of bedding. The left-lateral set of early strike-slip faults is difficult to find because it is of an inappropriate orientation for movement during the later folding. The left-lateral set doesn't show the overprinted, horizontal slickenlines.

Poles to the present attitude of the early strike-slip faults from both limbs have been plotted in Figure 36, but a more significant plot is Figure 37, which shows the traces of early strike-slip faults from both limbs after they have been rotated with bedding to the attitude they attain when bedding is horizontal. On the top margin of Figure 37 the acute bisectors of conjugate pairs of faults from the same part of the outcrop have been plotted, and they all lie in the range between Az 340° and 357°. This position on the plot is in the middle of the array of rotated strike-slip fault traces, so both types of data agree that the direction of pre-folding shortening was approximately Az 350°.

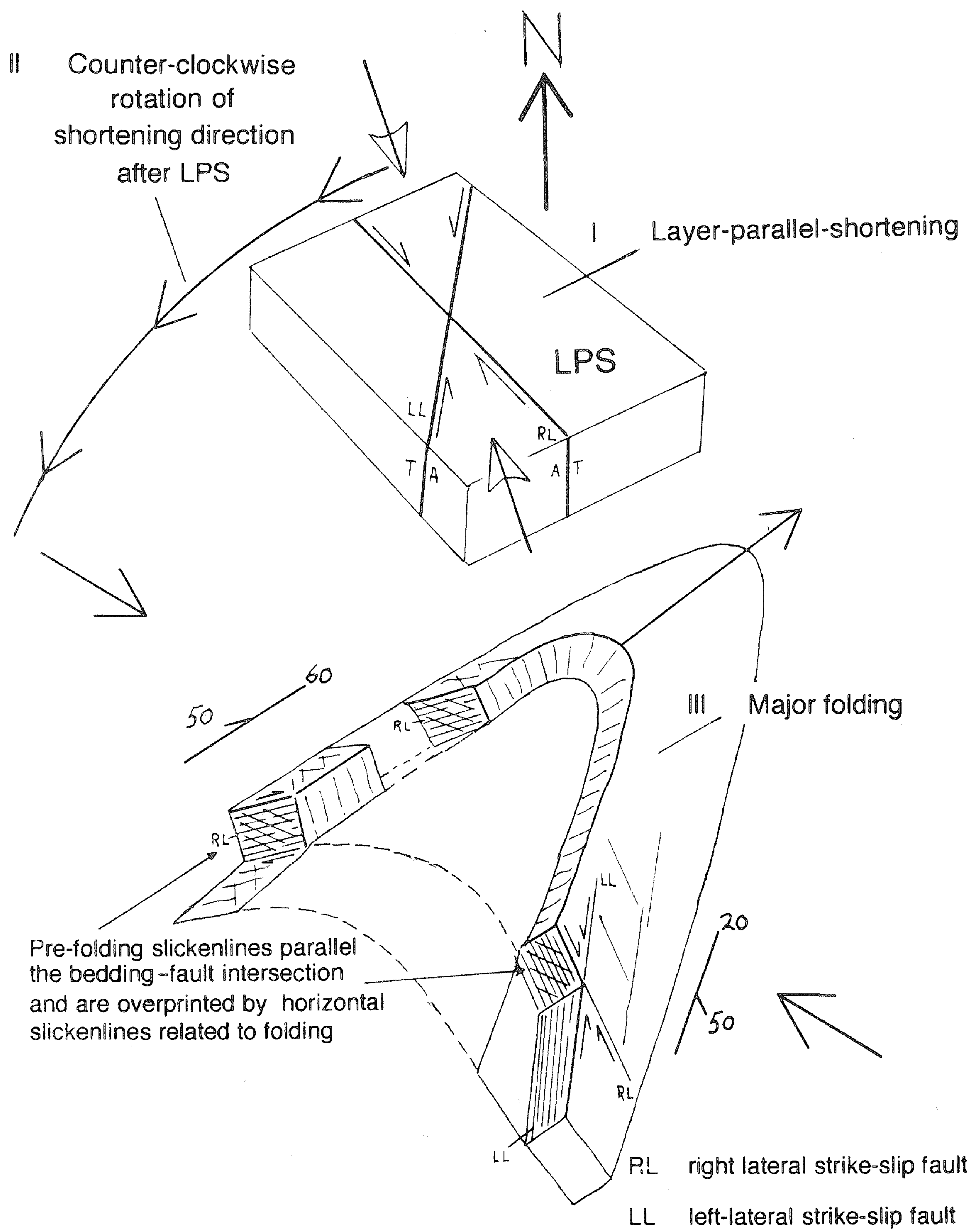


Figure 33. Block diagram of fold/strike-slip fault relations at Stop 6. Layer-parallel-shortening toward the NNW was overprinted by the NE plunging nose of the McConnellsburg-Big Cove anticline.

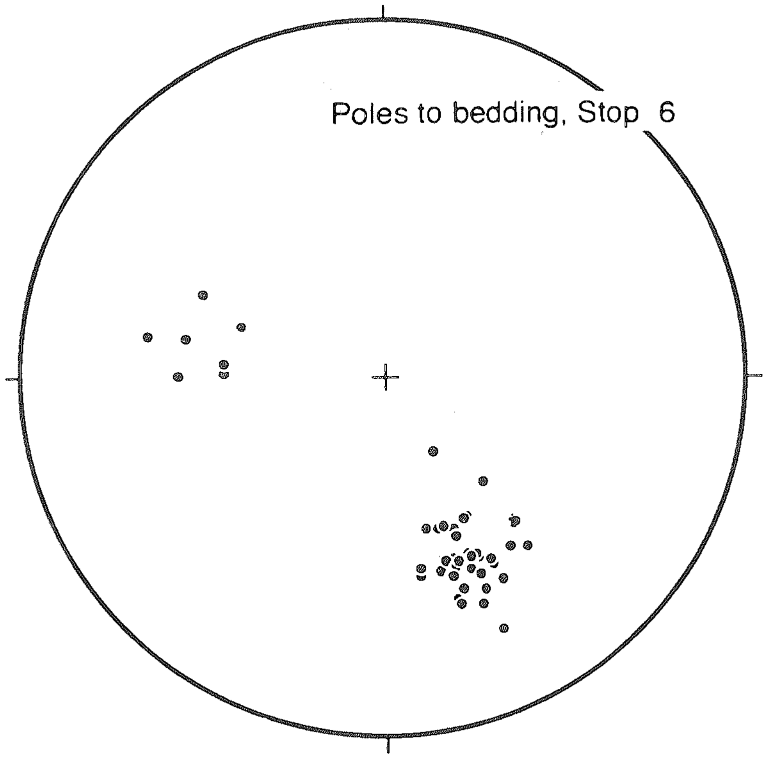


Figure 34. Stereographic projection of the poles to bedding in the Keefer sandstone at Stop 6, NW limb and SE limb.

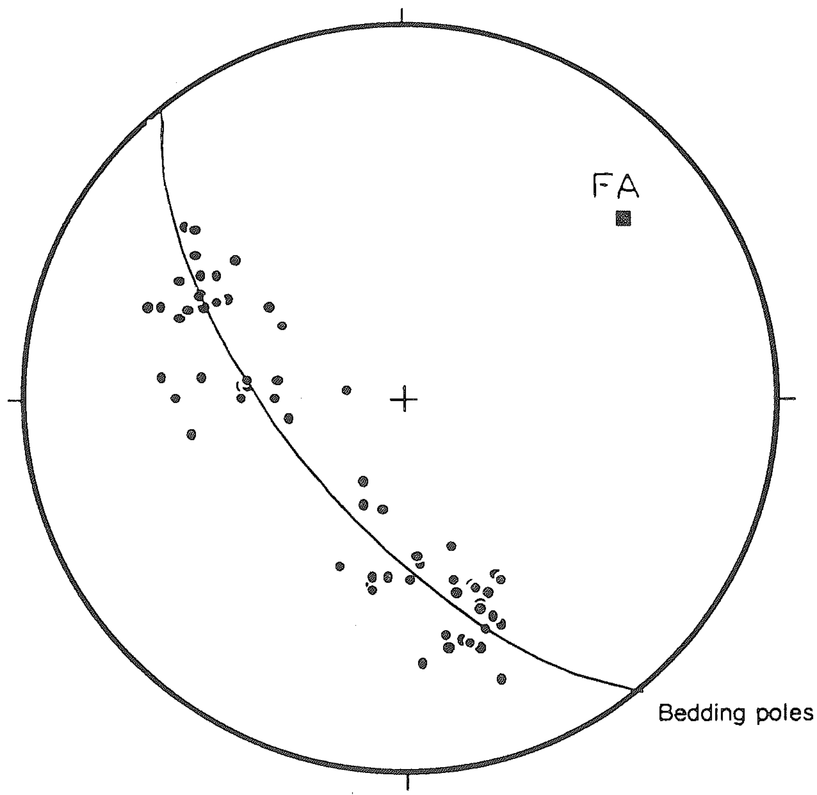


Figure 35. Stereographic projection of the poles to bedding in the Keefer sandstone at all localities around the Burnt Cabins plungeout, used to establish the fold axis.

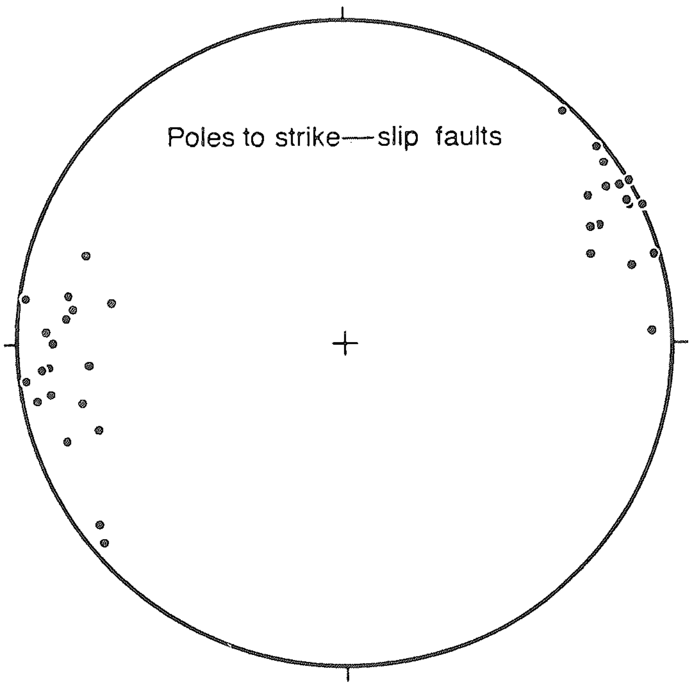


Figure 36. Stereographic projection of poles to unrotated strike-slip faults in the vicinity of Stop 6, NW limb and SE limb.

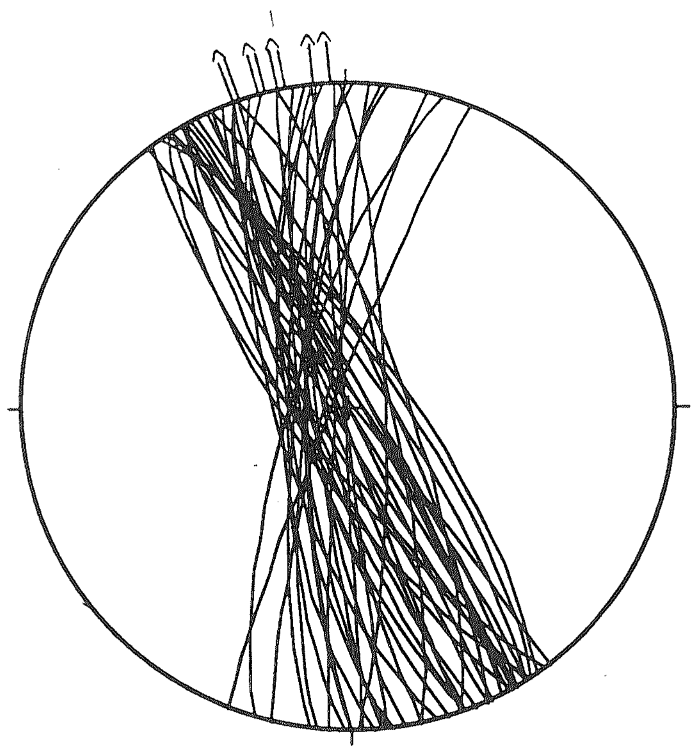


Figure 37. Stereographic projection of the traces of rotated strike-slip faults, showing the inferred shortening direction at Stop 6. It is parallel to the acute bisectors of conjugate right-lateral and left-lateral strike-slip faults or to the mean orientation of the whole array of strike-slip faults.

SUMMARY

Analysis of bedding and early strike-slip fault measurements at the plungeout of the McConnellsburg-Big Cove anticline at Burnt Cabins has established that the direction of pre-folding shortening was NNW at Az 350^{0} , which was overprinted by major folds trending Az 50^{0} that verge toward Az 320^{0}, counter-clockwise of the earlier direction of shortening. At this locality, there is good evidence of the pre-folding relative age of the conjugate strike-slip faults because right-lateral members of the conjugate system have earlier slickenlines that were overprinted by horizontal slickenline during folding.

		Leave Stop 6 by walking E along road and crossing to buses parked at the Burnt Cabins Grist Mill, owners, Jack D.and Sonja Blattenburger. Buses **PROCEED E.**
0.1	64.1	Extensive outcrop of Rose Hill Formation, on left.
0.2	64.3	Pass under Pennsylvania Turnpike.
0.1	64.4	**ROAD FORKS, TURN RIGHT** (S) onto SR 1005 toward Cowans Gap State Park.
0.1	64.5	Cross bridge over Little Aughwick Creek, South Branch and proceed up Allens Valley (Susquehanna drainage). Along this road there is abundant evidence of the rubble with matrix that mantles the landscape. Small exposures along the road show the matrix and the sharpstones are generally present at the surface throughout the area. The mantle is variable in thickness and in many places very thin. From the South Branch Little Aughwick Creek bridge crossing to the second crossing at mileage 67.8 the colluvial and alluvial materials on the east (left) side of the road appear to be relatively thick. From the second bridge crossing to Cowans Gaap Lake at mileage 69.3 the materials are on the west (right) side of the road and the valley bottom is somewhat narrower.
1.4	65.9	Bloomsburg Formation outcrop on the right.
0.7	66.6	Bloomsburg Formation outcrop on the right.
1.2	67.8	Crossing South Branch, Little Aughwick Creek.
1.5	69.3	Cowans Gap Lake on right. Road has crossed a big transverse fault which is responsible for the formation of Cowans Gap. Cowans Gap is the only low pass through Tuscarora Mountain in the middle of a 40 mile, NE to SW line of high ridges, and consequently was used by Forbes Road in its passage to Pittsburgh via early forts at Littleton, Bedford, and Ligonier.
0.1	69.4	Sharp bend to right in Cowans Cap State Park.
0.2	69.6	**LEFT TURN** onto SR 4003 toward PA Rte. 75.
1.4	71.0	Road bends left. Entrance to Mt. Pleasant abandoned, 19th century, limonite (goethite) mine on right. This mine is located on the Path Valley fault.
1.7	72.7	**STOP SIGN. TURN RIGHT** onto PA Rte. 75. For the next half mile the road traverses the toe of Pierce's Pump Run diamicton (Figure 10, p. 27). The road then traverses an interval with several roadcuts made in shale. Note the general absence of roundstone diamicton on the shale. After the shale outcrops have been passed, the road is continuously on roundstone diamicton until crossing West Branch ConococheagueCreek on US Rte. 30. Pierce named the diamicton immediately south of the shale outcrops the Township Run diamicton and the diamicton

		at the intersection of Routes 75 and 30 the Rocky Hollow diamicton. Both named deposits have the topographic form of an alluvial fan and an apex where the namesake streams issue from Cove Mountain.
3.5	76.2	Crossing Main Street, Fort Loudon.
0.3	76.5	Intersection US Route 30, **TURN LEFT** toward Chambersburg.
13.8	90.1	Intersection. US Route 11 (southbound). **TURN RIGHT.**
0.7	90.8	**MERGE LEFT** onto PA Rte. 316 toward the SE
1.3	92.1	**TURN LEFT** into Holiday Inn parking lot.

End Day 1 Field Trip.

ROAD LOG AND STOP DESCRIPTIONS - DAY 2

Mileage		
Inc	**Cum**	**Description**
0.0	0.0	Leave parking lot of Holiday Inn. **TURN RIGHT** onto PA Rte. 316 heading NW toward Chambersburg.
1.3	1.3	Intersection with US Rte. 11, **MERGE RIGHT** (N) onto US Rte. 11.
0.7	2.0	**STOP LIGHT. TURN LEFT** onto US Rte. 30 W.
13.8	15.8	Follow 1st day road log west along US Rte. 30 to Intersection with PA Rte. 75. **TURN RIGHT** onto PA Rte. 75.
2.3	18.1	Start Ordovician Reedsville Formation outcrops on both sides of road.
1.5	19.6	**TURN LEFT** onto SR 4003 to Cowans Gap State Park.
1.8	21.4	Entrance to Mt. Pleasant abandoned limonite mine, on left.
1.3	22.7	**STOP SIGN. TURN RIGHT** onto SR 1005 toward Burnt Cabins.
0.2	22.9	View of Cowans Gap Lake on left. Continue on SR 1005 toward N.
3.7	26.6	Bloomsburg Formation outcrop on the left.
0.6	27.2	Bloomsburg Formation outcrop on the left.
1.5	28.7	**STOP SIGN. TURN LEFT.**
0.1	28.8	Pass under Pennsylvania Turnpike.
0.2	29.0	Rose Hill Formation outcrop on the right.
0.2	29.2	Stop 6 and bridge over South Branch, Little Aughwick Creek.
0.5	29.4	**STOP SIGN. TURN RIGHT** (NE) onto SR 1009.
0.2	29.6	Bridge over Little Aughwick Creek.
0.5	30.1	Farm pond on the left.
1.0	31.1	**INTERSECTION.** Road continues toward NE on T 307, **TURN RIGHT** following SR 2009 toward the E.
1.1	32.2	Intersection Locke Road, TR 300. **CONTINUE** ahead on SR 2009.
4.8	37.0	**STOP SIGN,** town of Neelyton. **TURN RIGHT** (E) onto PA Rte. 641 ascending Tuscarora Mtn.
1.2	38.2	Sharp bend to the right, outcrop of Rose Hill Formation. Ahead on the left abundant exposures of scree can be seen through the trees and at the power line.
0.1	38.3	Tuscarora scree on left.
0.4	38.7	Outcrops of Tuscarora Formation on left. **Park on right side of road.**

STOP 7. TUSCARORA FORMATION WITH BEDDING PLANE EXPOSURES SHOWING, PRE-FOLDING STRIKE-SLIP FAULTS

Discussant: Dick Nickelsen.

INTRODUCTION

This stop is the first of three where structural features that were seen yesterday associated with the McConnellsburg-Big Cove anticline can be found again on the Path Valley anticline. The Path Valley anticline is the next first order anticline to the NE, and it is bordered on its NW side by the Path Valley fault, which shares some of the characteristics of the Cove fault. A glance at Figure 38, which has been modified from the map of Okuma (1970) and the preliminary compilation of data for the Pennsylvania state geologic map by D. M. Hoskins (Berg and Dodge, 1981), will reveal that the structural relationship of an anticline in the Ordovician carbonate rocks of the Path Valley to the Path Valley fault is similar to that observed yesterday at Stops 3 and 4 in the Big Cove Tannery quadrangle near the southern end of the Cove fault. The Path Valley fault obliquely truncates a northeast plunging anticline in the Ordovician carbonates at an angle of 20°, and Stops 7, 8, and 9 will be devoted to demonstrating the evidence for the sequential deformation that produced this relationship.

Before studying the bedrock geology, please observe the magnificent view NW to the ridges of Tuscarora Formation in the Shade Mountain anticlinorium, one of the most continuous mid-Valley and Ridge folds, which can be followed in a number of 2nd-order, en-echelon, structures from the Susquehanna River to the Pennsylvania Turnpike or the Latitude 40°N fault zone of Root and Hoskins (1977). The topography and trellised drainage of the intervening syncline on Silurian and Devonian rocks can also be seen from Stop 7.

The bedrock here consists of about 200 feet of along strike, bedding plane exposure of northwest dipping Tuscarora Formation. It has been cut by many pre-folding strike-slip faults, some of which show overprinted slickenlines that indicate reactivation of the early faults during later folding. Some of the bedding planes show exposures of the trace fossil *Arthrophycus* that is so typical of Tuscarora bedding plane exposures.

PRE-FOLDING STRIKE-SLIP FAULTS

This is the best outcrop in the region for observing pre-folding strike-slip faults in the Tuscarora Formation, much like the faults present in the Keefer sandstone of Stop 6. Figure 39 is an equal-area, stereographic projection of the poles to bedding and strike-slip faults as well as the traces of early strike-slip faults. They have been identified by their slickenlines that are parallel or nearly parallel to the fault/bedding contact. On several of the steeply-dipping fault surfaces, slickenlines that rake 30° from the northwest end of the fault plane are overprinted on the earlier, more steeply raking slickenlines, proving that the fault was a plane of slip during the later folding.

The early strike-slip faults have been rotated with bedding to the attitude they attain when bedding is horizontal, and Figure 40 illustrates how most of the fault traces have changed to a more northerly strike during the rotation. The angle between the mean strike of these faults and the trend of the ridge is 75°. All indicators of slip sense that have been seen along these faults show that they were right-lateral strike-slip faults when they formed in horizontal beds. The only slip sense indicators that seem useful here are gash fractures which are diagonal to the fault trace.

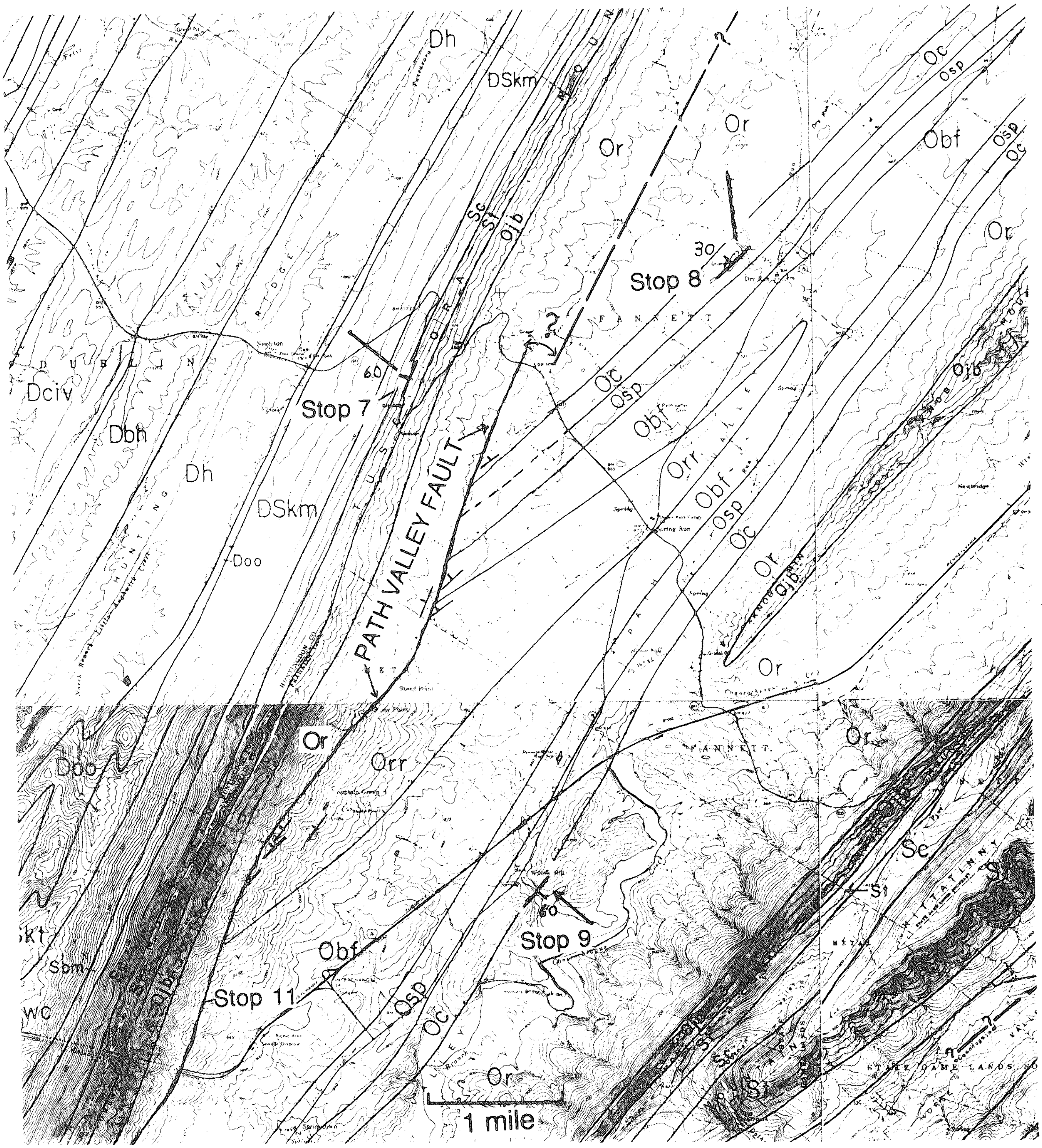


Figure 38. Geologic map of Tuscarora Mtn. and the upper Path Valley showing Stops 7, 8 and 9. At Stops 7 and 8 the mean strike of rotated right-lateral strike-slip faults is a line, north of the Stops. This is inferred to be the pre-folding shortening direction at these outcrops. At Stop 9, the arrow indicates the bearing of slickenlines on the roof of the cleavage duplex of the Tuscarora fault/Antes-Coburn detachment, the inferred vergence direction of this structure.

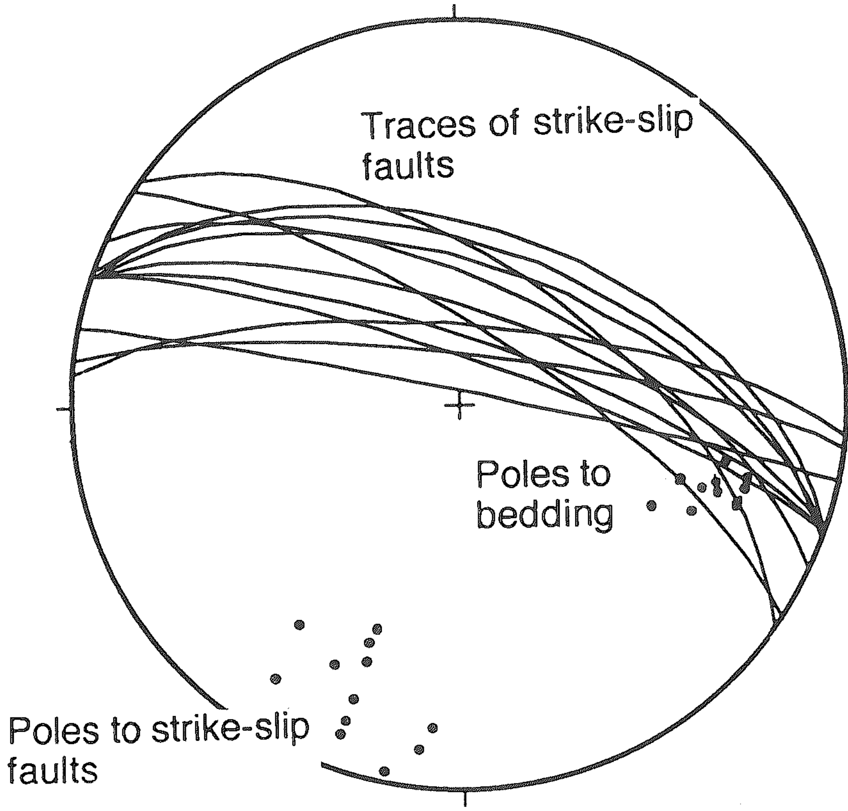


Figure 39. Stereographic projection of the unrotated poles to bedding and the unrotated traces of strike-slip faults at Stop 7.

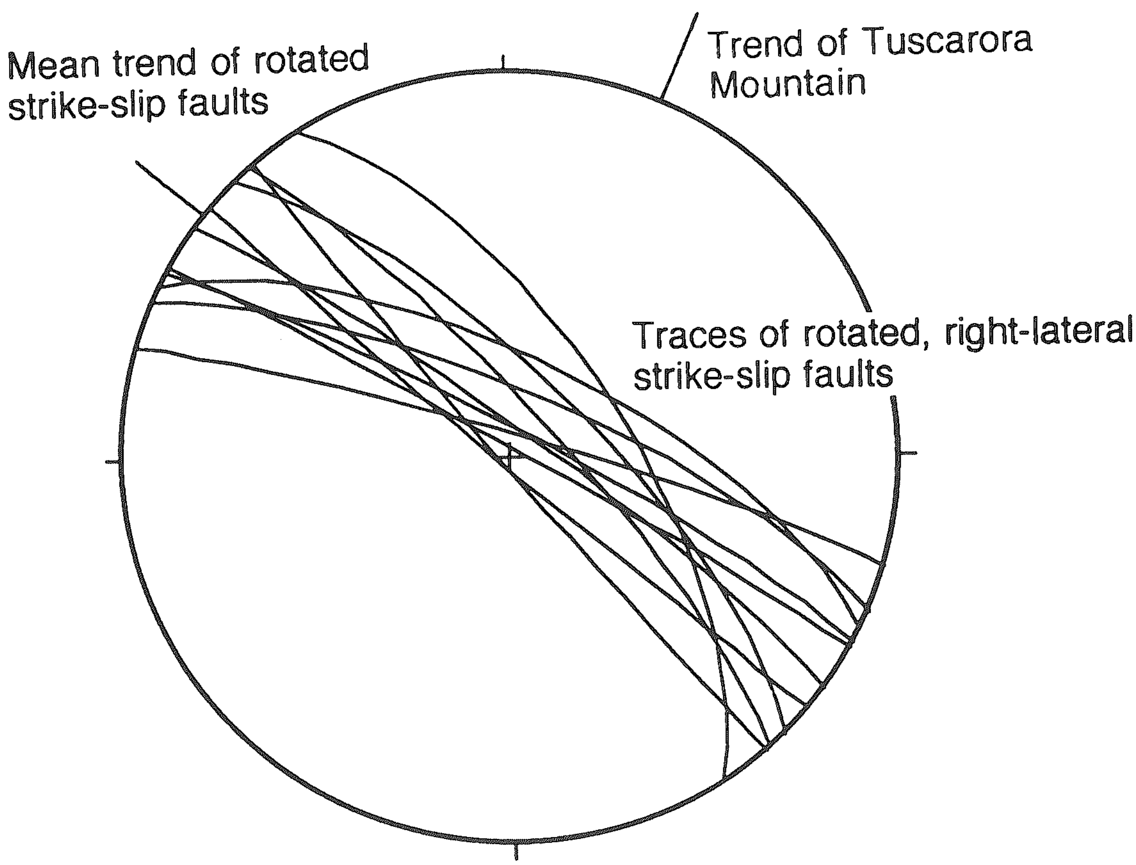


Figure 40. Stereographic projection of the traces of rotated strike-slip faults at Stop 7.

Steps that might indicate slip sense from slickenlines have commonly been damaged by the reactivation of faults during later folding.

If all faults are right-lateral strike-slip faults, then the shortening direction lies somewhere to the north of the direction of the mean strike, and at a smaller angle to the mean strike than 75°. The main point is that the shortening direction is not perpendicular to the strike of the ridge, and that the folding of the ridge verged counter-clockwise of the earlier shortening direction.

LET'S LOOK AT THE ROCKS

A number of stations, starting with A at the SW and ending with H at the NE end of the 200-foot bedding exposure have been marked. You are encouraged to visit them and look for evidence of slip sense on the pre-folding strike slip faults and for the evidence of overprinting during later folding. Briefly:

1. At Station A an early fault shows oblique slip and bed displacement as well as excellent steps on slickenlines that unequivocally establish right-lateral slip.
2. At Station B (85 feet along the outcrop) right-lateral slip on an early strike-slip fault can be seen.
3. At Station C (100 feet along the outcrop) right-lateral slip on a pre-folding fault has been reactivated by later, fold-related slip that produced overprinted slickenlines.
4. At Stations D and E (between 100 and 120 feet along the outcrop) several faults show what is interpreted as a right-lateral slip sense.
5. At Station F and G (130 to 150 feet along the outcrop) several more faults show right-lateral slip sense.
6. At Station H (at 180 feet near the NE end of the exposure) is perhaps the best exposed early strike-slip fault of the outcrop, showing excellent overprinting by later slickenlines. Unfortunately, evidence of pre-folding slip sense is lacking.

SUMMARY

This outcrop was included to demonstrate evidence of pre-folding shortening in the Tuscarora Formation that was overprinted, counter-clockwise by folding. Lack of conjugate right-lateral and left-lateral strike-slip faults, such as were seen at Stop 6, precludes definition of a precise shortening direction, but it is certain that the shortening direction was north of the rotated mean strike of the right-lateral strike-slip faults that has been plotted on Figure 40 and the regional map of Figure 1.

Comparison of this direction with the mean strike of the ridge, plotted on Figure 40 shows that counter-clockwise rotation of the shortening direction occurred between early layer-parallel-shortening and the later folding. Although this is a small angle of 15°, what is striking is its constant rotation sense - counter-clockwise - both here and at Burnt Cabins, where the plunge of inferred early folding was NE, and in the Big Cove Tannery region, where the plunge of early folding was SW.

		PROCEED up PA Rte. 641 to summit of Tuscarora Mtn.
0.4	39.1	Bend to left at crest of Tuscarora Mtn. Outcrops of steep, NW dipping, basal, reddish Tuscarora Formation underlain ahead by Juniata Formation. Note basal reddish Tuscarora at crest of ridge, a typical relationship.
0.2	39.4	Juniata Formation outcrops on left.

0.4	39.8	Bald Eagle Formation outcrops on left.
0.4	40.2	Reedsville Formation outcrops on both sides of road.
1.6	41.8	Beekmantown Formation outcrop on left, dipping NW.
0.2	42.0	Rockdale Run Formation outcrop on left.
0.3	42.3	**STOP SIGN.** Intersection with PA Rte. 75 in Spring Run. **TURN LEFT** (N) onto PA Rte. 75.
0.1	42.4	Beekmantown Formation outcrop. **PROCEED** N on PA Rte. 75.
1.9	44.3	**INTERSECTION. TURN LEFT** onto SR 4007 toward Dry Run..
0.1	44.4	**INTERSECTION. TURN LEFT** in Dry Run onto T 567, Dry Run Road.
0.1	44.5	**TURN LEFT** into entrance road of Dry Run Quarry.
0.2	44.7	Office and weigh scales of the Dry Run Quarry of the New Enterprise Stone and Lime Company, producer of aggregate and concrete, Jim Campbell, quarry superintendent.
0.1	44.8	Floor of Dry Run Quarry.

STOP 8. PRE-FOLDING STRIKE-SLIP FAULTS IN ORDOVICIAN CARBONATES OF THE PATH VALLEY

Discussant: Dick Nickelsen.

INTRODUCTION

The Dry Run quarry produces aggregate, concrete products and agricultural lime from a uniformly, northwest-dipping section of the Middle Ordovician St. Paul Group and Upper Ordovician Chambersburg Formation. The operators of this lonely limestone quarry in the great Path Valley have, several times during the past year, blasted away geological features that were supposed to be seen by the 61st Field Conference of Pennsylvania Geologists. Part of what will be described is not present anymore, but perhaps new features have been exposed by the continuing quarrying.

GEOLOGIC DESCRIPTION

This quarry is on the northwest limb of the well defined, northeast-plunging anticline that trends 20° east of the Path Valley fault and Tuscarora Mountain on the northwest side of the carbonate valley (Figure 41). An equal area stereographic projection of 82 bedding poles measured at the quarry and in the nearby valley defines a horizontal fold axis at Az 42°. Structural features not seen previously are:

1. Consistently oriented, early strike-slip faults exposed on large surfaces at both the NE and SW ends of the quarry and, intermittently, elsewhere;
2. Spaced rock cleavage in the shaly limestones near the top of the section, and in the ash beds;
3. An ash bed that served as a movement horizon in pre-folding, top-to-the-foreland shear toward the NNW.

EARLY STRIKE-SLIP FAULTS

Figure 42 shows the fault traces of rotated, pre-folding, strike-slip faults, all having slickenlines parallel to the fault/bedding intersection. They were all rotated with bedding before plotting on Figure 42. They all plot near north, ranging from Az 340° to 4°. The mean orientation of these strike-slip faults is plotted north of Stop 8 on the map of Figure 38. Within the cluster

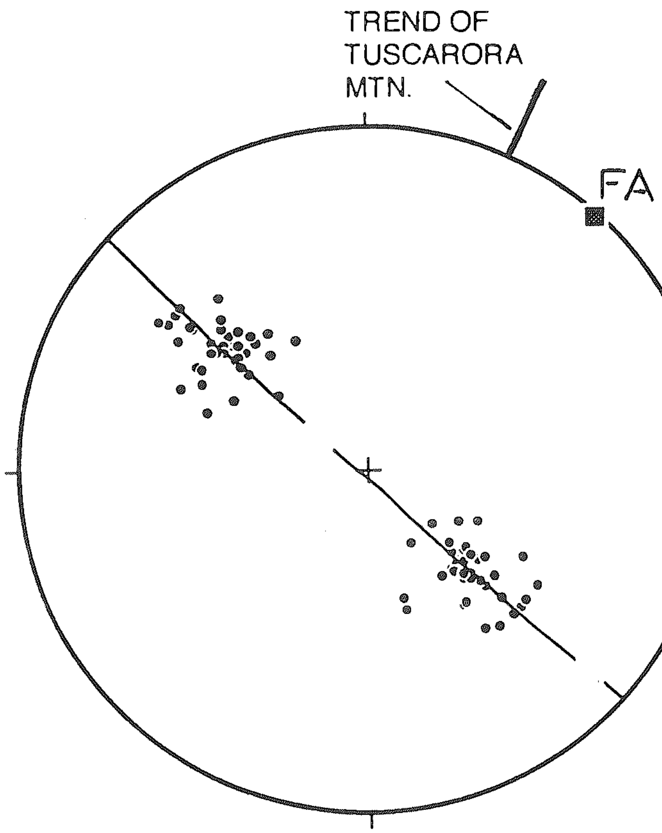


Figure 41. The fold axis of the anticline in carbonate rocks within the upper Path Valley is defined by a stereographic projection of 82 bedding poles in the region.

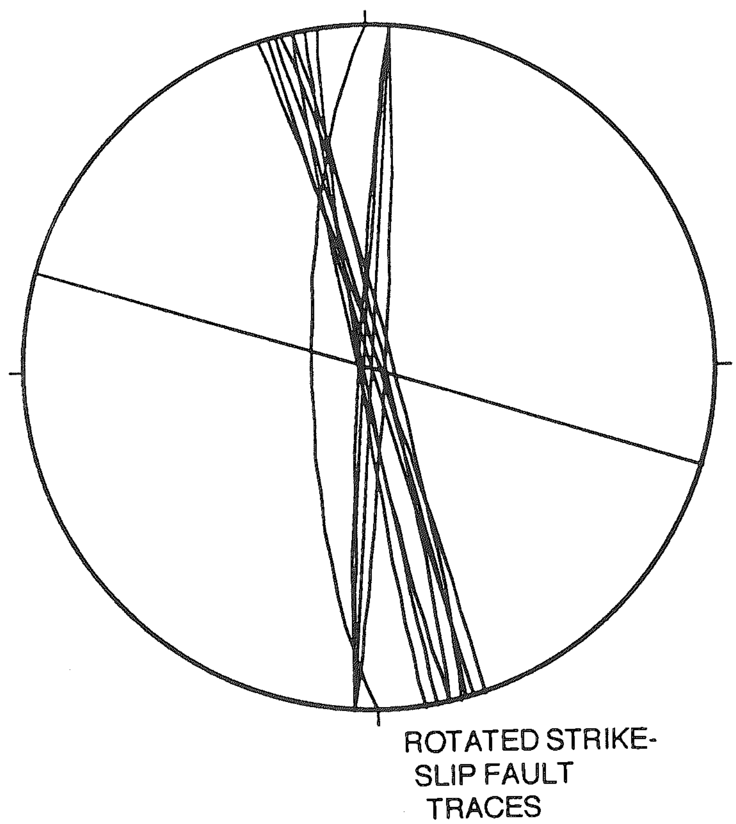


Figure 42. Stereographic projection of the traces of rotated strike-slip faults from the Dry Run quarry, Stop 8.

around north there are faults showing both right-lateral and left-lateral movement senses, although it might be expected that faults of this orientation are left-lateral faults, based upon their orientation with respect to the fold. If they are a cluster of right-lateral and left-lateral faults with a very small dihedral angle, then an early, pre-folding shortening toward north is implied.

THE ASH BEDS

Slickenfibers in ash beds have variable orientations ranging from Az 342° to 2° in different layers within the bed. The fibers show a top-to-the-foreland shear sense. The close similarity of slickenfiber orientations to the strike of rotated strike-slip faults suggests that both structures were formed before the large fold that has been defined by the stereographic projection of Figure 41. This view is supported by the spaced rock cleavage, related to folding, that crenulates the earlier slickenfibers of the ash bed.

ROCK CLEAVAGE IN THE QUARRY

Exposures of the rock cleavage in the upper part of the carbonate section exposed in the quarry will be inaccessible on this field trip, and may not be visible if the ash bed has been completely removed by quarrying. Cleavage is oriented parallel to the fold and was formed during flexural slip or flexural flow folding, so it is not surpising to observe the cleavage crenulations in the pre-existing slickenfibers of the ash bed.

SUMMARY

The cluster of pre-folding strike-slip faults and the slickenfibers in an ash bed that shows pre-folding top-to-the foreland shear both suggest that the Ordovician carbonate rocks of this Az 42° trending fold in the Path Valley were shortened and transported toward the north prior to the formation of the fold. Evidence for the pre-folding orgin of the strike-slip faults is provided by their slickenlines, paralleling fault bedding intersections. Evidence for pre-folding ash bed top-to-the foreland shear is provided by slickenfiber steps and by cleavage crenulations in the ash bed that are related to cleavage formation during later folding.

		RETURN to PA Rte. 75.
0.5	45.3	**STOP SIGN. TURN RIGHT** (S) onto PA Rte. 75.
2.0	47.3	Intersection, PA Rtes. 75 and 641 in Spring Run. **CONTINUE** S on PA Rte. 75.
1.7	49.0	Fannett-Metal High School on right.
0.3	49.3	Pennsylvania Turnpike overpass.
0.5	49.8	**BEAR LEFT** into town of Willow Hill.
0.1	49.9	**TURN LEFT** (E) in town of Willow Hill.
0.1	50.0	Unload buses at outcrop of Tuscarora Fault/Antes-Coburn detachment on left side of road.

STOP 9. ORDOVICIAN CARBONATE- REEDSVILLE SECTION CONTAINING AN EXPOSURE OF THE TUSCARORA FAULT/ANTES-COBURN DETACHMENT

Discussant: Dick Nickelsen.

INTRODUCTION

Complete exposures of the Tuscarora fault/Antes-Coburn detachment are rare and this is one of only 8 that are known for the region of the field conference (see Figure 2). Here you will see a section of the structural feature as well as enough outcrops of the adjacent stratigraphy to understand its place in the boundary zone between the underlying Upper Ordovician carbonate rocks and the overlying clastic wedge of the Upper Ordovician (Figure 43). The exposure leaves a lot to be desired, but is the best one available for a visit by a group of this size in the Path Valley. It was included to demonstrate that the Tuscarora fault/Antes-Coburn detachment is widespread and can be seen throughout the region at the appropriate stratigraphic position. You are now approximately 20 miles (32 km) from Stop 2 where you first saw this feature. **Please don't collect specimens of the fault zone-cleavage duplex at this outcrop.**

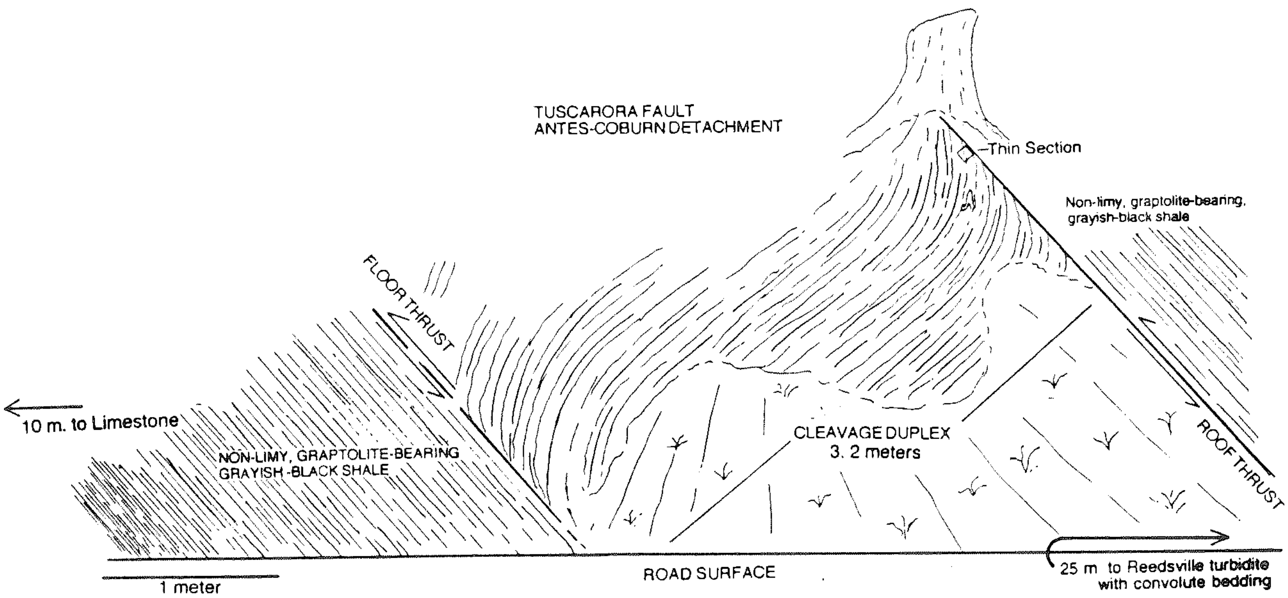


Figure 43. Drawing of a section through the cleavage duplex of the Tuscarora fault/Antes-Coburn detachment at Stop 9.

STRATIGRAPHIC SETTING

The Tuscarora fault/Antes-Coburn detachment is expressed at this outcrop as a 3 m cleavage duplex in a Reedsville shale section. At Stop 2 where it was seen previously, it was emphasized that the structure is restricted in its occurrence to the same grayish black, carbon-rich, non-calcareous, graptolite-bearing clay shale that can be seen here both above and below the cleavage duplex. Though the outcrop is not well-exposed, the position of the graptolite horizon and the relative position of the Reedsville Formation distal turbidite beds, 20 m up section, is well shown. Limestone outcrops don't appear until 10 m down section, but this may be the result of lack of exposure.

TUSCARORA FAULT/ANTES-COBURN DETACHMENT

The cleavage duplex is thought to have propagated toward the foreland as a frontal zone of pure shear created a vertical cleavage ahead of the tip line of a bedding-parallel floor thrust (Nickelsen, 1986). As the floor thrust propagated into the frontal zone of cleavage it produced the basal sigmoidal drag of the cleavage that resulted from top-to-the-foreland shear. The cleavage front had advanced farther toward the foreland by this stage of development. It is less clear how the roof thrust and the top half of the sigmoidal cleavage zone formed, but it seems that the formation of cleavage in this thin zone might have changed rock properties and promoted ramp thrusting from the floor to the roof of the cleavage duplex. After the roof thrust formed, continued top-to-the-foreland shear dragged the vertical cleavage into the top half of the sigmoidal cleavage that can be seen at this outcrop.

Measurements here have included the attitude of slickenlines on both the floor and roof thrust, that indicate transport in the top-to-the-foreland shear toward Az 312^{o} as plotted on Figure 38. A 3x6 cm thin section extending from the slickensided and slickenlined fault surface of the roof thrust down into the penetrative cleavage shows an angle of 30^{o} between the cleavage and the bed parallel fault surface. As at Stop 2, the penetrative cleavage shows detrital phyllosilicates parallel to the foliation but no recognizable new mica growth. What is striking is the total lack of cleavage in the, admittedly, incompletely exposed section through the Reedsville and Chambersburg-St.Paul Group section above and below the cleavage duplex. Clearly this is a unique zone in the stratigraphy and structure of these Upper Ordovician rocks.

There is no estimate of the amount of transport toward the foreland associated with the formation of this fault zone and this study has not proven that it exists on the northwest dipping limb of the Path Valley anticline, because at all places the appropriate part of the stratigraphic section has been faulted out. Nevertheless, it is the only horizon in the Upper Ordovician Reedsville/Martinsburg section where the thrusting toward the foreland or the detachment between different styles or amounts of deformation above and below in the stratigraphic section can be placed (see discussion in "The Tuscarora fault/Antes-Coburn detachment", p. 3). Balanced sections across the whole Valley and Ridge that have been drawn through this region by Gwinn (1970) or Mitra and Namson (1989) show that this is the major thrust or detachment surface above the basal Waynesboro surface which has been used to explain the thrust geometry.

SUMMARY OF STRUCTURAL FEATURES AT STOPS 7, 8, AND 9 IN THE UPPER PATH VALLEY

Remapping has not changed the formation contacts of previous workers (Okuma, 1970; Hoskins, in Berg and Dodge,1981), but has changed the trace of the Path Valley fault, that bends significantly as it brings different Ordovician carbonate units of its hanging wall into contact with the steeply-dipping Reedsville Formation of the footwall. In the area north of Stop 8 the fault cannot be traced accurately because it brings Reedsville of the hanging wall against Reedsville of the footwall. Successful mapping of this fault can only be accomplished where carbonate rocks are in the hanging wall and fracturing, presumably fault induced, has created an environment for massive limestone sink development. The fault can be mapped along the line of sinks, and carbonate exposures in the sinks permit recognition of the diverse carbonate stratigraphy in the fault zone along its length. This will be illustrated at Stop 11.

Inferred directions of pre-folding shortening or transport toward the foreland at Stops 7, 8, and 9 all suggest that this region was shortened either perpendicular to the Az 42^{o} fold axis or in a more northerly direction (Az 340^{o} to 4^{o}) prior to folding of the carbonate rocks of the valley floor. The Path Valley fault is interpreted as a steep reverse fault that truncates pre-existing structures at an angle of 20^{o} and is responsible for the trend of Tuscarora Mountain, on the northwest side of the Path Valley. The sequential Alleghanian deformation recorded here from early pre-folding shortening and transport toward the foreland, through folding and eventual truncation by the Path Valley fault, involves a counter-clockwise rotation.

0.1	50.1	Buses proceed to Creek Road for U-turn, then return to reload before **returning to PA Rte. 75.**
0.3	50.4	Intersection with PA Rte. 75. **TURN LEFT** (S).
1.5	51.1	Willow Hill Pennsylvania Turnpike interchange, right side.
2.2	54.1	**STOP SIGN**. Center of Fannettsburg. **CONTINUE** S on PA Rte. 75.
1.5	55.6	Ordovician St. Paul Group Limestones on right side, dipping SE.
2.6	58.2	Carrick Furnace, on right.
0.3	58.5	Passing through town of Metal. The name comes from iron mining and smelting near here before the middle of the last century.
1.7	60.2	**INTERSECTION.** Stumpy Lane on right. **TURN RIGHT** toward Cowans Gap State Park.
1.1	61.3	Passing entrance to Cowan Village on right.
0.1	61.4	Passing abandoned Reedsville Formations quarries on left and right.
0.2	61.6	**STOP SIGN. TURN LEFT** (S) toward Cowans Gap State Park picnic area.
0.1	61.7	Continue S straight ahead. Passing road to left which goes to Richmond Furnace.
0.2	61.9	**TURN RIGHT** passing Park Office and entering picnic area.
0.1	62.0	**PARK** near pavilion at upper end of Cowan Gap Lake on right. **LUNCH STOP AND A DEBRIS SLIDE-FLOW.** Visit flow after lunch.

COWANS GAP DEBRIS SLIDE-FLOW
Discussant: Helen Delano.

Some time on the weekend of January 19 to 21, 1996, a debris slide-flow moved rapidly down a hillside above Little Aughwick Creek in Cowans Gap State Park (Figure B). It was discovered on Monday morning, January 22 because it had flowed across a park access road in two places, blocking the road with debris and large rocks. Because of the loss of road access and concern about the effect of excess sediment on the already overburdened park lake, the Pennsylvania Geological Survey was contacted and Bill Kochanov investigated the site. It seems unlikely that the slide will move farther or supply significant sediment to the stream beyond its initial contribution. The scar and deposit remain as a very nice example of a steep-mountain debris avalanche, unusual in that it is reasonably accessible by way of Knobsville Road. In the terminology of Cruden and Varnes (1996) this is an "extremely rapid, very wet, debris slide-flow".

The first seventeen days of January, 1996 were notable for two major snow storms. These were followed on the 19th by heavy rain, strong wind, and warm temperatures. The resultant flooding is perhaps best known for the destruction of two spans of Harrisburg's Walnut Street Bridge. Three Springs, Huntington County, is the closest weather station to Cowans Gap State Park reporting hourly precipitation data. Three Springs is approximately 15 miles NNW of Cowans Gap at an elevation of 810 feet ASL. The record there shows 4.8 inches of precipitation between January 1 and 17. This was presumably all as snow and most would have remained on the ground by the 19th. Three Springs received 3.0 inches of rain on the 19th, 2.4 inches of which fell between 4:00 and 7:00 am. It is likely that the landslide site, at an elevation of 1,700 feet (top of slide) may have had even more snow. A rain-on-snow event of this magnitude would

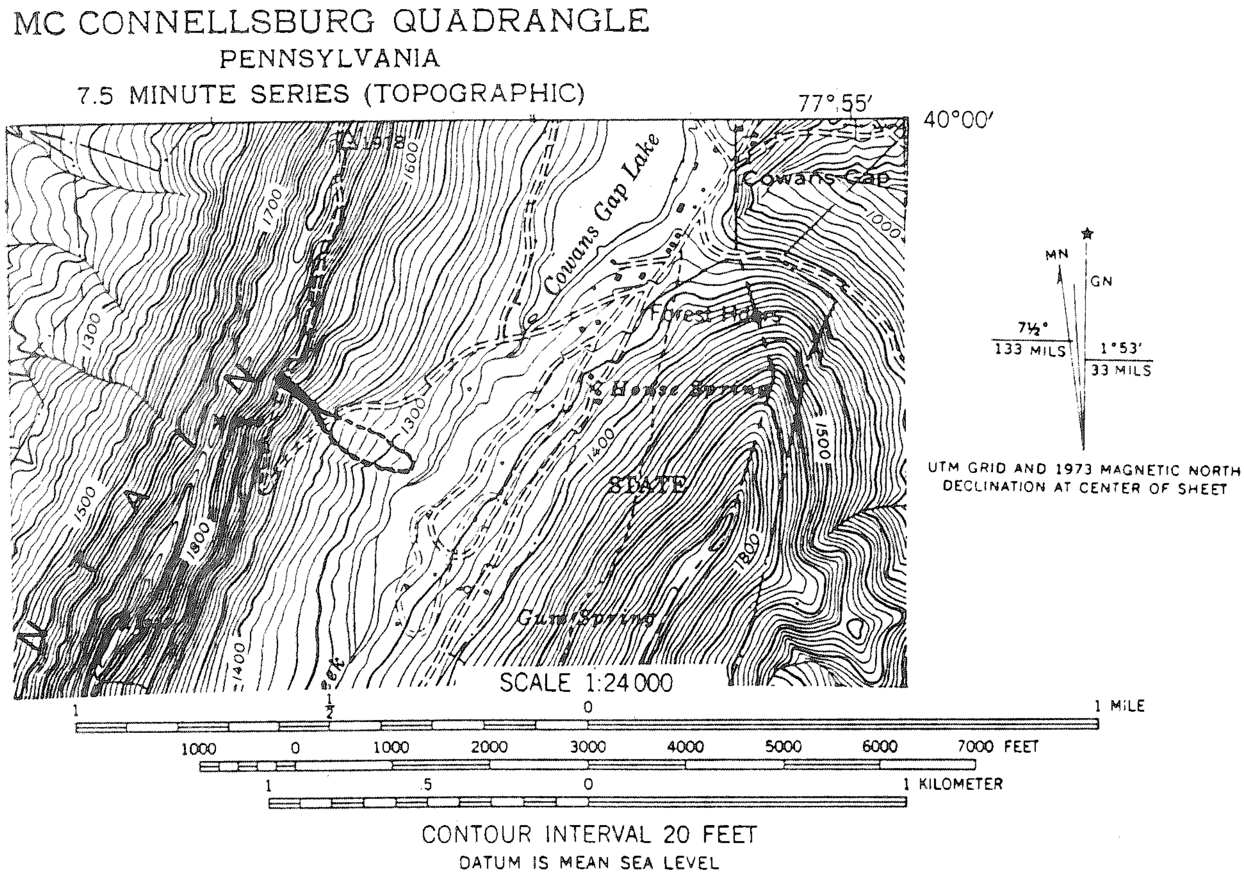


Figure B. Location map of Cowans Gap State Park debris slide-flow.

lead to increased ground water levels and it is easy to imagine the snow cover contributing to confining forces and increased pore-water pressure. When pore-water pressure overcomes stabilizing forces on a slope, failure can occur rapidly. The high water content of the slide debris allows for very rapid movement of the loose material as a fluid with a high specific gravity capable of carrying very large rocks.

Independent evidence for the rapid movement of this slide includes several large trees with bark removed on the uphill side to heights of 7 or 8 feet, removal of soil down to bedrock at several places in the upper "chute", and transportation of very large boulders (one approximately 10x5x1.5 feet) well out onto the gently-sloping toe area.

The slide site is on the steep (approximately 50% near the top of the slide), southeast-facing slope of Cove Mountain on the west limb of the Allen Valley syncline. The upper part of the slide is on a dip slope on the Tuscarora Formation, the lower portion is on the Rose Hill Formation. The upper end of the slide is at approximate elevation 1,700 feet, 160 feet below the ridge crest and 50 feet above the upper part of Knobsville Road, which makes a switchback about 1,000 feet southwest of the slide. The landslide originated as a debris slide along the soil/bedrock contact in the area above the road. Cutting the slope for the road had removed some support in this area. The slide occurred where a preexisting concave slope channeled drainage from an area several hundred feet wide (measured along the upper road), and at a slight bend and low spot in the road.

The Tuscarora here is less well cemented than is usual (R.C. Smith II, personal communication). It is friable, and breaks around, rather than through the grains. The surficial material remaining in the scarp area is a grain-supported boulder colluvium with a sandy matrix (rubble with matrix of Pierce, 1966) and is approximately 3 to 4 feet thick. Boulders are typically blocky, up to 3 feet x 1 foot thick, and are inclined subparallel to the slope. Extensive lichen growth on some boulders suggests that this slope has been stable for many years. The failure surface is a bedding plane dipping southeast at 45°. Remaining roots and soil confirm that it was the soil/bedrock interface. The slide scar is approximately 45 feet wide at the upper road.

The slide moved across the road, depositing some boulders, but not removing any of the road. A substantial trash dump had accumulated below the road here over many years, as indicated by the changing materials in campers' trash. This unique sedimentary deposit was partially eroded by the debris flow, and clasts from it occur mixed throughout the debris flow material. Be careful of broken glass if you walk over the slide. The debris flow appears to have moved over the dump, scouring its upper surface and lower end.

Below the dump, about 50 feet below the road, the channel of the debris flow is scoured to bedrock. Large trees and most soil were removed from an area about 50 feet wide and 800 feet long. A few trees were left standing, but many have had bark severely abraded by fast moving debris. Piles of rock and mud as high as 5 feet on the upstream side of several trees remained in August, 1996.

A debris levee is developed along the north edge of the channel section. This section of the slide is characterized by a mixture of scour and deposition of a thin layer of debris. The Tuscarora-Rose Hill contact is at approximate elevation 1,550 feet (Pierce, 1966). Below this point, on the Rose Hill, the slide is less steep, the area of scour and deposition is wider, and post-slide erosion by running water is apparent in the clayey Rose Hill residuum. The average slope of the channel or chute portion of the slide is 37.5% (measured on the topographic map).

The debris flow crossed the lower section of Knobsville Road at approximate elevation 1,420 feet, and deposited boulders, trees, and other debris on the road and in a widening tongue several hundred feet long on the lower, gentler slope. Total slide width at Knobsville Road is 170 feet, including 110 feet of debris on the north (lower along the road) edge, a 30-foot wide channel, and 30 feet of debris on the south edge. Coarse debris apparently did not reach Little Aughwick Creek, but water and fine sediment must have. There is only a little evidence of scour or erosion by the debris flow below the lower road. The path of the debris through the woods can be traced by following piles of brush and tree trunks piled against standing trees. Patterns of boulders, cobbles, gravel, and sand indicate that the debris flow was diverted around obstacles, but followed a nearly straight path toward the creek. Average slope of the portion of the slide below Knobsville Road is 15.5%. The sediments deposited by the debris flow are clearly evident six months after the event. It will be interesting to see how long they will remain evident.

Debris flows similar to this one are well known in other parts of the Appalachians, where they typically occur in clusters of tens to hundreds during extreme rainfall events (Clark, 1987; Hack and Goodlet, 1960; Jacobson and others, 1987; Pomeroy, 1981; Williams and Guy, 1973). A number of single examples are known in central Pennsylvania, but they seem to be rarer here than in West Virginia and Virginia. The reasons for this difference are unknown, but present climate, lithology, Pleistocene history, and total relief are all different, and the answer is probably a combination of factors (see p. 29 for further discussion).

After lunch and visit to debris slide-flow, **RETURN** N to Park Entrance.

0.4 62.4 **STOP SIGN. CONTINUE** N on SR 1005 toward Burnt Cabins passing Cowan Gap Lake, and along Allens Valley and the South Branch of Little Aughwick Creek, which you have passed previously on this trip (mileage 64.4-69.3, Day 1).

6.0 68.4 **STOP SIGN. RIGHT TURN** on SR 2018 toward the E. **BUSES** must make a **LEFT TURN** on SR 2018 because they can't negotiate the right turn. After turning at the Burnt Cabins Grist Mill parking lot or at the intersections with US Rte. 522, they should return to this spot and proceed E.

0.9 69.3 Outcrop of vertically dipping Bloomsburg Formation on left.

0.1 69.4 Intersection with Locke Road on the left. Beyond the intersection is an outcrop of the steeply-dipping Centre Sandstone member of the Silurian Rose Hill Formation. These steeply-dipping outcrops of the Bloomsburg Formation and Centre Sandstone member are inferred to be at the tip-line of a small thrust sheet, the Allens Valley thrust on the northwest slope of Tuscarora Mountain, that we will visit part of at Stop 10.

0.1 69.5 Outcrops of shallow, NW-dipping Rose Hill Formation on left.

0.2 69.7 End of Rose Hill outcrops. Road curves to right and begins ascent of Tuscarora Mtn.

0.7 70.4 Summit of Tuscarora Mountain with outcrop of Tuscarora Formation on the right. **Buses unload and proceed to parking place near Carrick Valley Road.**

STOP 10. DISCUSSION OF MAPPING THAT DEMONSTRATES OVERPRINTING OF THE LATER PATH VALLEY FAULT UPON PRE-EXISTING STRUCTURES OF TUSCARORA MOUNTAIN AND THE PATH VALLEY

Discussant: Dick Nickelsen.

INTRODUCTION

A five mile length of Tuscarora Mountain, extending from one mile north of Cowans Gap to one mile north of Carrick Valley Gap, has a different topography from the rest of Tuscarora Mountain, and this is believed to result from different structures, not found elsewhere along the mountain. These different structures are two outcrop belts of Tuscarora Formation, one on the crest and the other on the SE flank of the mountain, and two areas of steep to overturned bedding in the Keefer Sandstone, Centre Iron Sandstone, and Bloomsburg Formation at the NW base of Tuscarora Mountain in the Allens Valley. One of these areas of steep to overturned bedding is along the route of the field trip before Stop 10, and the other is 2.5 miles NE of Cowans Gap. The two Tuscarora outcrop belts and the steep to overturned bedding in the Allens Valley seem related to the same structural feature, and have been placed together in the 5-mile-long thrust block shown in Figure 44. This stop is included in the field trip to demonstrate another area where several stages of sequential deformation have been deemed necessary to create the existing structural patterns.

GEOLOGIC DESCRIPTION

The thrust block of Figure 44 is bounded on the SE by the Carrick Valley fault and on the NW by the Allens Valley fault that extends NE from the Cowans Gap transverse fault mapped by Pierce (1966) in the McConnellsburg quadrangle. The Allens Valley fault does not extend far

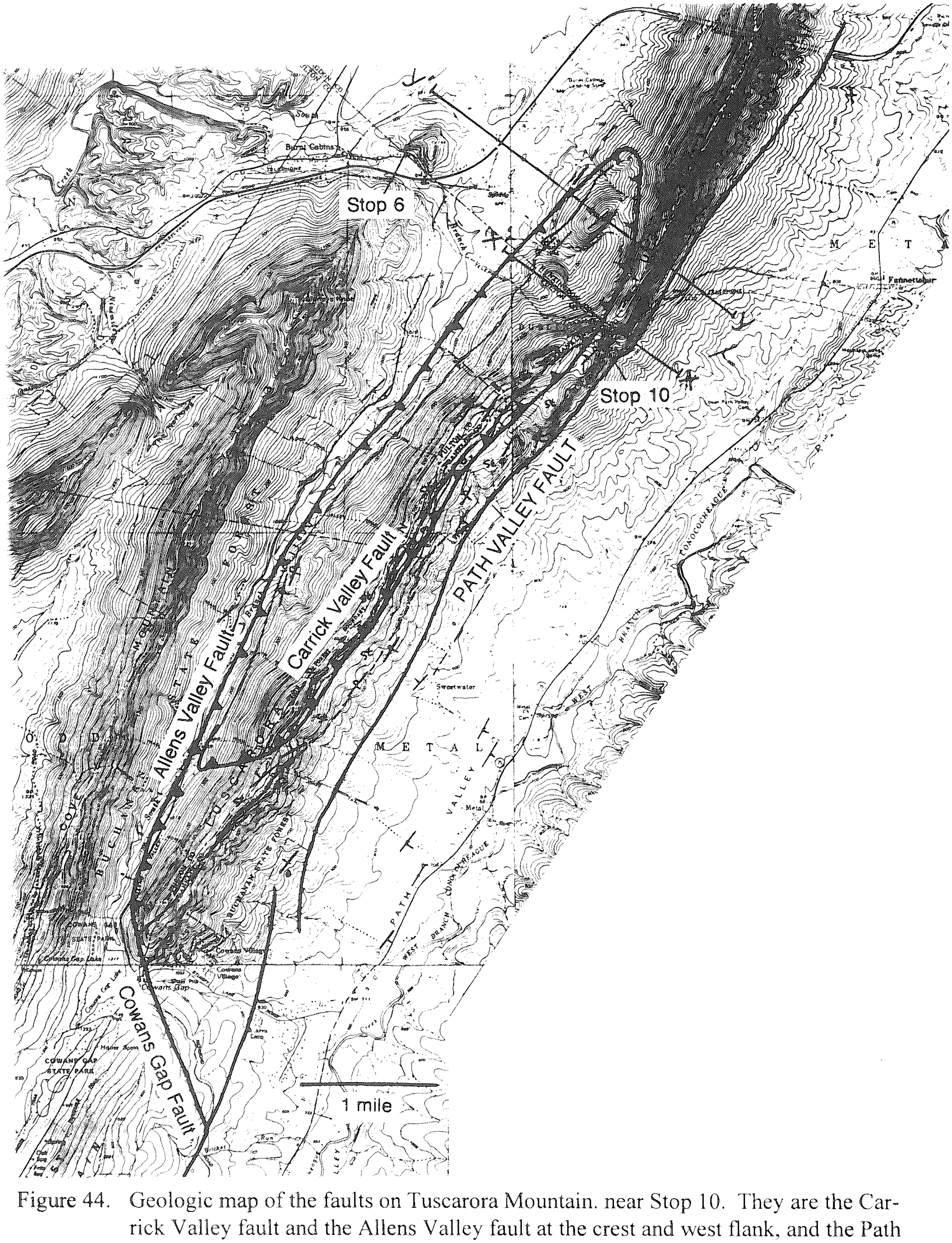


Figure 44. Geologic map of the faults on Tuscarora Mountain. near Stop 10. They are the Carrick Valley fault and the Allens Valley fault at the crest and west flank, and the Path Valley fault on the east flank of Tuscarora Mountain.

beyond the thrust block and is not present at the Pennsylvania Turnpike Tunnel, one mile to the NE. The Path Valley fault, a steep, reverse fault at the SE base of Tuscarora Mountain, places several different Ordovician carbonate formations against a variety of Ordovician and Silurian clastic units including the Ordovician Reedsville shale and Bald Eagle sandstone as well as the Silurian Tuscarora quartzite. It has been interpreted here as a later fault that truncates previous structures, including the Cowan Gap fault. At Stop 10 the base of the upper, NW outcrop belt of Tuscarora Formation will be seen in Carrick Valley Gap.

FEATURES TO BE OBSERVED AT STOP 10

Carrick Valley Gap is at the NE end of the NW, crestal, belt of the Tuscarora Formation, exposed in the outcrop-sized fold that verges SE and plunges NE (See Figure 45, an outcrop map of all the Tuscarora outcrops that can be found in the gap). After observing the outcrop with the fold, turn and look SE to the outcrop of the SE belt of Tuscarora Formation, exposed in the hollow below you, in difficult terrain. It is not suggested that you try to visit this outcrop. A thrust fault has been placed between the two outcrops, striking NE-SW and passing through the gap and just below the road. Note the other outcrops to the NE along Tuscarora Mountain and to the S, both interpreted to be part of the SE belt of Tuscarora which can be traced on Figure 44 all of the way to Cowans Gap. Finally, walk down the road to where buses are parked, noting the sharp topographic drop-off to the SE. The Path Valley fault cuts close to the base of Tuscarora Mountain, juxtaposing Ordovician carbonate rocks of the hanging wall against the Tuscarora Formation of the footwall. This is the only place along the Path Valley where the Ordovician carbonate rocks are directly in contact with the Tuscarora Formation and it is marked by a line of sinks and extensive historic iron mines of the 19th century (Railroad Bank of Figure 11, p. 33). Several float blocks of a Tuscarora Formation breccia found along this slope are thought to represent the rocks of the fault zone but no outcrops remain. Permission to visit the Path Valley fault zone at this stop could not be obtained, but Stop 11 will allow observations of one of the sinks along the faults zone, where, unfortunately, there was no iron mining activity and the fault contact juxtaposes carbonate rocks and Reedsville shale.

GEOLOGIC INTERPRETATION

Figure 46 consists of two structure sections of Tuscarora Mountain: Y-Y', a complete section to a depth of 3,000 feet, extending NW to the axis of the McConnellsburg-Big Cove anticline, and X-X', an abbreviated section showing only the rocks in the hanging wall of the Allens Valley fault. The Carrick Valley fault has been drawn as a backthrust, verging SE because of what was seen in the Tuscarora Formation outcrop-sized fold of Stop 10 in the gap. This section thus interprets the Carrick Valley fault as an early backthrust which was folded and cut off by the later, NW verging Allens Valley fault at its NW limit where vertical to overturned Keefer and Centre sandstones and the Bloomsburg Formation crop out. Finally, in this interpretation, the Path Valley steep reverse fault was imposed along the SE, cutting through various rocks of the footwall and rotating them to vertical, at the same time as it truncated the earlier Cowans Gap fault. In summary, the sequence was: (1) early backthrusting to form the Carrick Valley fault, verging to the SE, (2) later thrusting toward the NW and folding of the Carrick Valley fault on the Allens Valley fault, and (3) steep reverse faulting which truncated and dragged previous structures to vertical along the Path Valley fault.

The Path Valley fault is shown here as a steep reverse fault because of its broadly curving

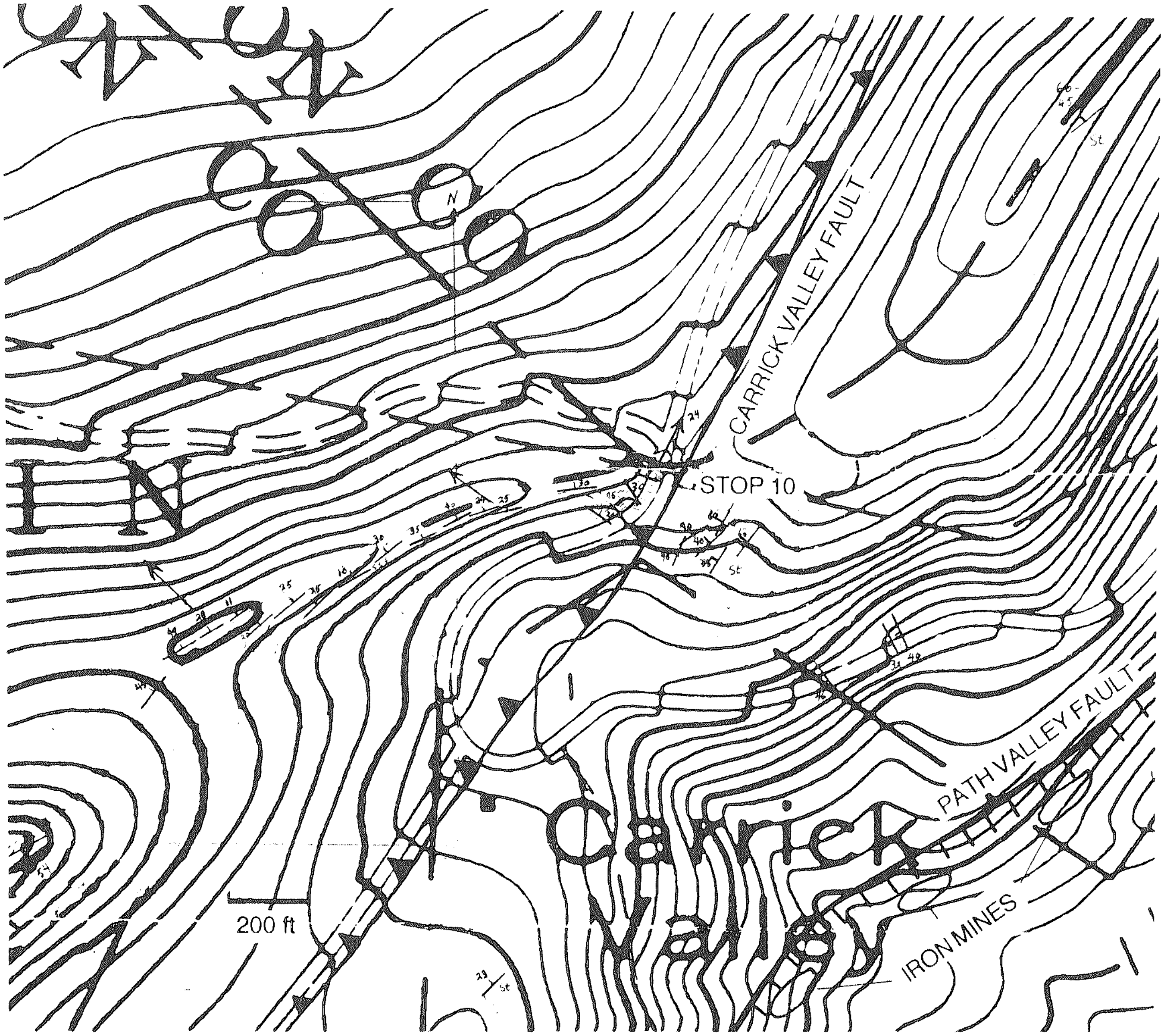
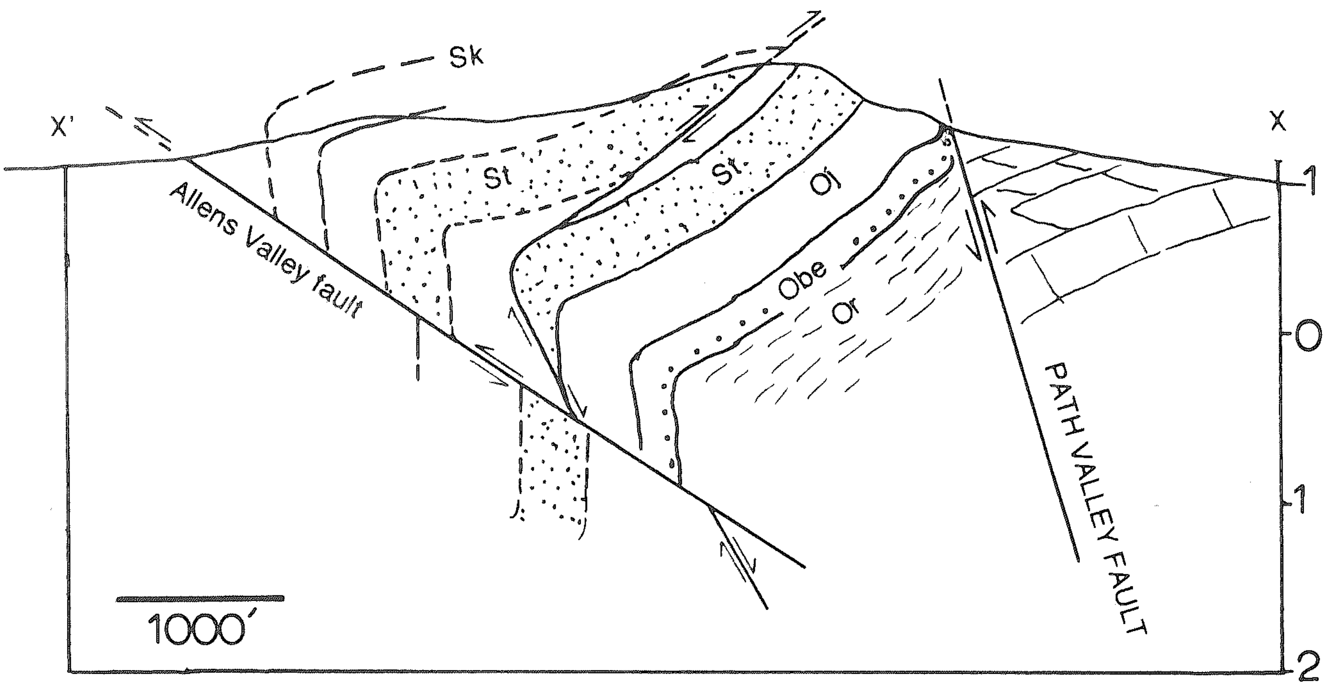


Figure 45. Outcrop map of theTuscarora Formation in Carrick Valley Gap, at the crest of Tuscarora Mountain (Stop 10).

trace through areas of some topographic relief, its rotation of footwall rocks to vertical, not overturned attitudes, and its truncation of pre-existing structures, both folds and faults, to the north and south of Stop 10.

0.2	70.6	Bus parking and reload of passengers. **PROCEED** ahead.
1.0	71.6	Dirt road(with gate) to left. Crossing trace of the Path Valley fault, marked by a line of sinks.
0.2	71.8	Pines Tavern on the left.
0.5	72.3	**INTERSECTION.** Back Road, **TURN LEFT** (N).
0.5	72.8	**STOP SIGN. TURN LEFT** (N) onto PA Rte. 75.



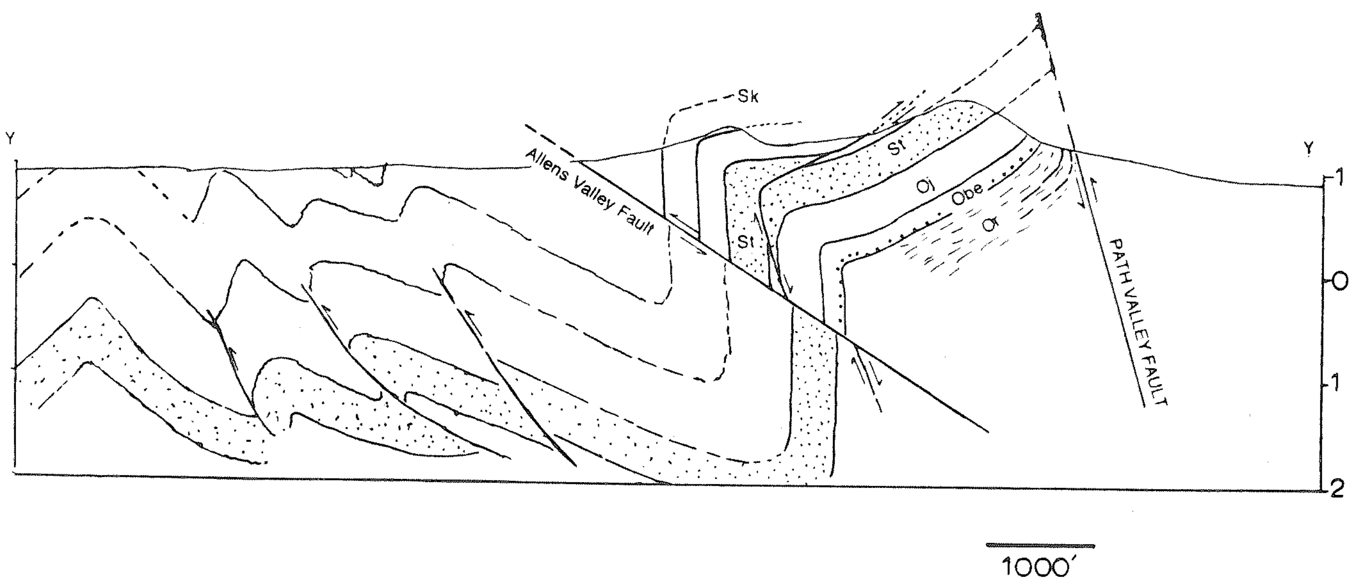


Figure 46. Sections X-X' and Y-Y' through Tuscarora Mountain, showing a structural interpretation of the geologic map.

0.3	73.1	Stone church on left.
0.6	73.7	**TURN LEFT** (W) on unnumbered dirt road. Barn at right labelled "Silverod".
0.7	74.4	Tunnel under Pennsylvania Turnpike.
0.7	75.1	Sink at E border of Elliotts Tree Farm and Nursery. Buses unload and proceed to turning and parking place.
0.1	75.2	Bus parking and turning where we will reload buses.

STOP 11. SINK ON TRACE OF PATH VALLEY FAULT WHERE MIDDLE ORDOVICIAN BELLEFONTE DOLOMITE IS IN CONTACT WITH AND STRIKES INTO UPPER ORDOVICIAN REEDSVILLE SHALE

Discussant: Dick Nickelsen.

INTRODUCTION

This stop will demonstrate several of the sinks that occur along the Path Valley fault where Ordovician carbonate rocks are brought into contact with either the Reedsville Formation or the Bald Eagle, Juniata, or Tuscarora Formations. The location of Stop 11 is shown in the SW corner of Figure 38. There are exposures that would be more interesting because they also are the sites of mid-19th century limonite mines that may have become iron prospects because of exposures of ore in the sinks. They would require a long walk. My purpose in visiting this locality is to demonstrate the availability of outcrops in places where, if the sinks were not present, no bedrock would be exposed. It is clear that downslope movement of colluvium had transported blocks of Tuscarora and Bald Eagle clastics across the sites prior to the opening of the sinks, because they occur on the valley side of the sinks and also as rubble within the sinks. If sinks had not developed at the fault contact between the carbonates and the clastics, it would be difficult to locate the Path Valley fault.

Sinks along this fault zone are undergoing rapid enlargement in the present environment. Local land owners noted massive collapse at several sinks during the heavy snows and rains during January, 1996.

GEOLOGIC DESCRIPTION

Elliotts Nursery and the farm pond are developed on bedrock of the Reedsville Formation and the line of sinks along the fault to the southeast is at the contact with the Ordovician Bellefonte dolomite which strikes into the fault. Perhaps as much as 800 feet of the Chambersburg and St.Paul Group limestones have been faulted out. This is the end of the trip!

		Reload and **RETURN** to PA Rte. 75.
1.7	76.9	**STOP SIGN. TURN RIGHT** (S) onto PA Rte. 75.
1.4	78.3	Fannettsburg intersection. **CONTINUE** S on PA Rte. 75.
8.4	86.7	Cowans Gap State Park access road on right.
3.8	90.5	Intersection. **TURN LEFT** onto US Rte. 30 toward Chambersburg.
13.8	104.3	Intersection. **TURN RIGHT** onto US Rte. 11 S.
0.7	105.0	**MERGE LEFT** onto PA Rte. 316.
1.3	106.3	**TURN LEFT** into Holiday Inn Parking lot.

End of Day 2 and the 61st Field Conference of Pennsylvania Geologists.

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