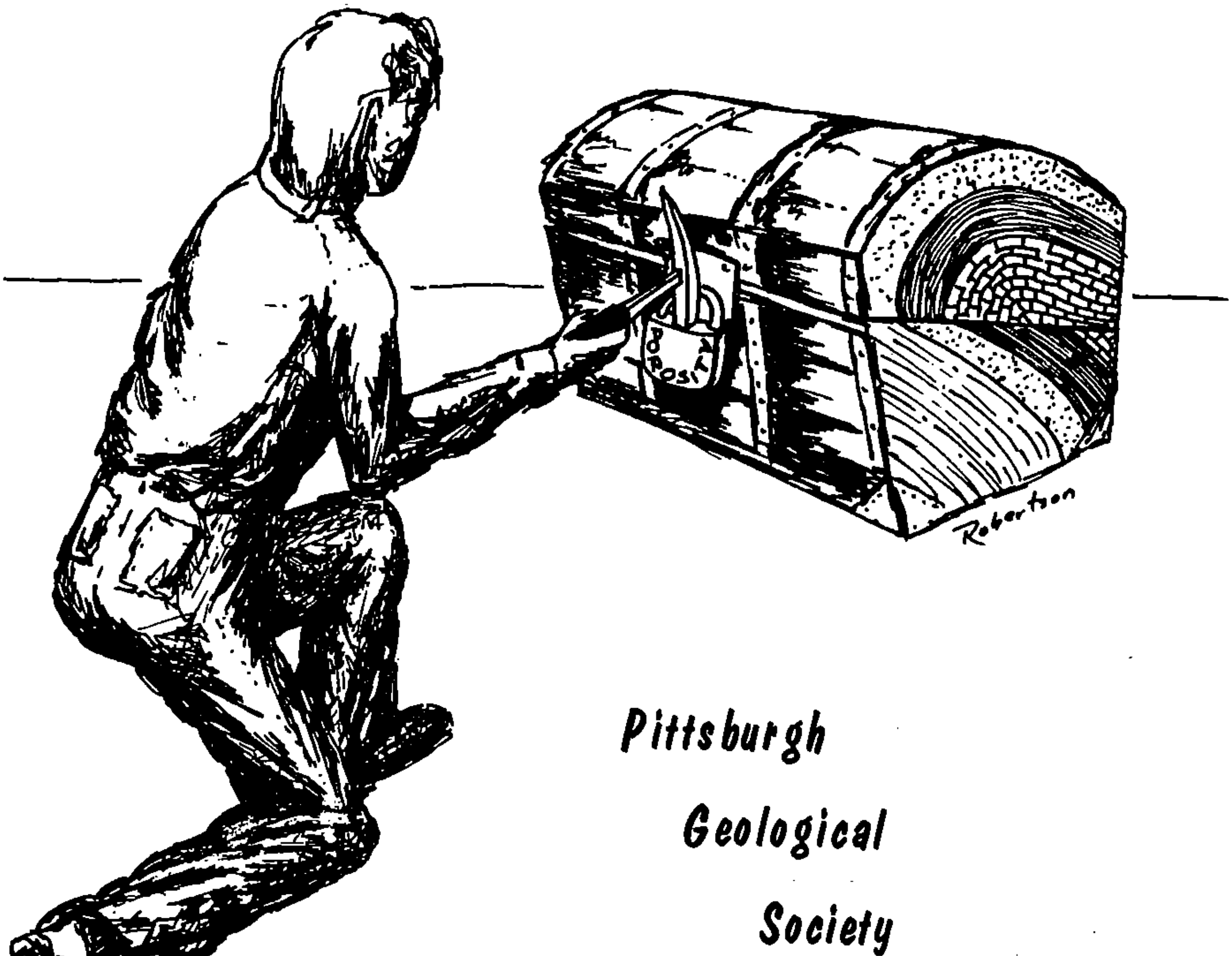
# GUIDEBOOK

## TECTONICS AND CAMBRIAN-ORDOVICIAN STRATIGRAPHY CENTRAL APPALACHIANS OF PENNSYLVANIA




Pittsburgh Geological Society

with the

Appalachian Geological Society

September, 1963

# TECTONICS AND
# CAMBRIAN-ORDOVICIAN STRATIGRAPHY
# in the
# CENTRAL APPALACHIANS OF PENNSYLVANIA

FIELD CONFERENCE

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CONTENTS

ILLUSTRATIONS

# INTRODUCTION

The 1963 Field Conference of the Pittsburgh Geological Society leads us into one of the first studied, yet one of the least understood portions of the Appalachians - the Valley and Ridge Province. From the onset, this conference was intended to provide an opportunity to survey both the tectonics, and the Ordovician and Cambrian stratigraphy of the central Appalachians of Pennsylvania. The facets of geology in this area are varied and numerous, and we have attempted to touch upon a few of them. Obviously we will not be able to cover the vast expanse traversed by this field conference in very great detail. We will, however, during the course of the next two and one-half days be able to observe some of the intricacies which have long challenged field geologists, as well as have an opportunity to gain some new insights into the role this province has played in the geologic past.

Stratigraphically we will attempt to see the Lower Ordovician and Cambrian dolomite facies of the western outcrop belt change to a limestone facies towards the east and southeast. Obviously the actual transition cannot be seen, but during the course of the trip we will see each of these facies and some of the variations within them. Unfortunately, we cannot show the entire section in an orderly sequence. Therefore, it will be necessary to be imaginative, to make numerous mental re-constructions, and to continually think back to what we saw the day before. This should provide a challenge. Perhaps you can find economic applications.

Structurally you will probably have a nightmare, particularly should your experience be from the Mid-Continent or Gulf Coast regions. From the peek we get through the window at Birmingham or the rare glimpses a mile or so into the crust which are provided by an occasional well, we see that thrust-faulting is the basic tectonic element, even in this portion of the Valley and Ridge Province. The surface structures are not unique, but detailed examination of exposures provides valuable clues to the mechanics of deformation which have come into play here. Occasionally, we will cast a longing eye to the Appalachian Front where gentle dips can become monotonously uniform to everyone but a geophysicist with a budget.

Perhaps there is some orderliness to our conference, perhaps even some orderly sequence - we are not certain. We do hope that you will enjoy it. We hope it will create interest and an influx of workers. Who knows, perhaps some new fields will be found!

ACKNOWLEDGMENTS

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Glenn Poulter - Chairman
Page Richardson - Road Log
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Addison Cate - Guidebook

# CAMBRO-ORDOVICIAN STRATIGRAPHY OF CENTRAL AND SOUTH-CENTRAL PENNSYLVANIA

by

W. R. Wagner

## Introduction

The Cambro-Ordovician carbonates discussed in this paper include all the limestones and dolomites from Late Cambrian age up through the lower Middle Ordovician (Chazy). Rocks of Cambro-Ordovician age are exposed in two parallel belts in central Pennsylvania: a northwestern one extending from Lycoming and Clinton counties on the northeast to Bedford County on the southwest, and a southeastern belt in Franklin County, Pennsylvania, which extends into adjacent Washington County, Maryland. Although separated by less than 50 miles the stratigraphic nomenclature of each belt has evolved independently and correlations between the two areas are still subject to controversy, particularly in the Lower and lower Middle Ordovician sections. The purpose of this paper is: 1) to show how the formational units of the two belts may be lithologically related and 2) to suggest that the Chazy-Beekmantown contact may be explained as a lithofacies boundary.

## Upper Cambrian Stratigraphy

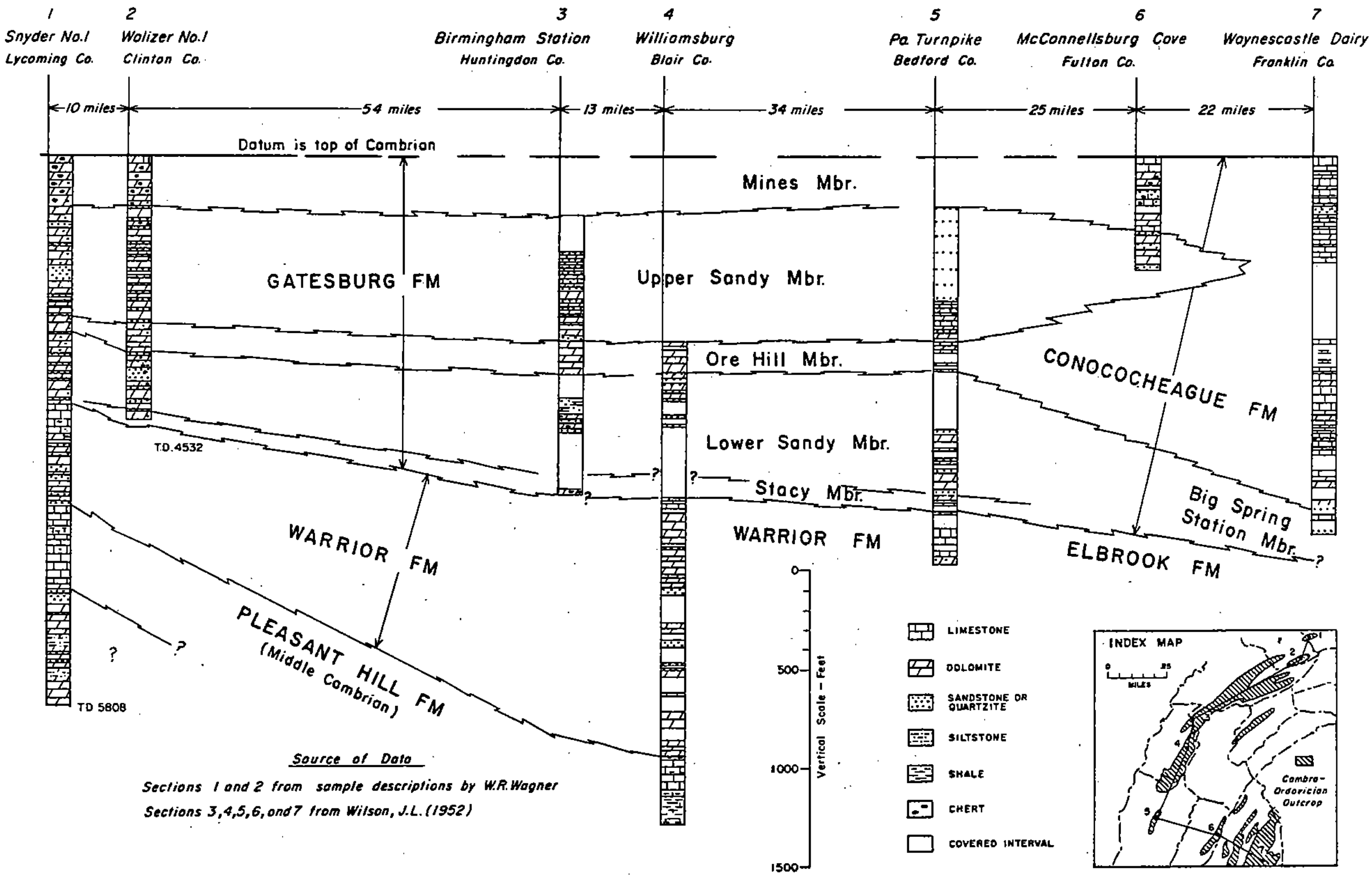
The Upper Cambrian strata of the northwestern belt include two formations: The Warrior below and the Gatesburg above. (Figure 1)

The most complete exposure of the Warrior is just west of Williamsburg (Figure 1, section 4) where it is 1200 feet thick. It is mainly a dolomite with some sandstone in the middle and a little limestone, particularly at the top (Butts, 1945 and Wilson, 1952). In the Snyder well in Lycoming County (Figure 1, section 1) the Warrior thins to 600 feet, the lower two-thirds composed of interbedded sandstone and dolomite and the upper third of limestone and dolomitic limestone.

The Gatesburg Formation is divided into five members which in ascending order are: Stacy dolomite, Lower Sandy, Ore Hill, Upper Sandy, and Mines. The Stacy is a 100 foot unit of dolomite lacking sandstone beds. Comprising most of the Gatesburg are the Lower and Upper Sandy members consisting of alternating beds of sandstone and dolomite. The Lower Sandy varies from 300 feet in the north (Figure 1, secs. 1, 2) to 600 feet in the south (sec. 5). The Upper Sandy maintains a fairly constant thickness of 600 to 650 feet. Between the two sandy members is a limestone or dolomite about 150 feet thick called the Ore Hill Member. It has no sandy beds and is important for its trilobite fauna which suggest assignment of Franconian age (Wilson, 1952). The uppermost member is the Mines dolomite, about 250 feet thick, which is characterized by oolitic chert and lack of sandstone. The amount of sandstone in the Gatesburg varies along the regional strike, becoming sandier to the north and northeast (Wilson, 1952).

Figure 1

STRATIGRAPHIC CROSS-SECTION OF UPPER CAMBRIAN IN CENTRAL AND SOUTH-CENTRAL PENNSYLVANIA



Below the Upper Cambrian Warrior and Gatesburg lies the Pleasant Hill Formation of Middle Cambrian age. Butts (1945) described it as 600 feet thick and consisting of limestone in the upper third and micaceous limestone with interbedded sandstone and siltstone in the lower two-thirds.

The Upper Cambrian of the southeastern belt is also composed of two formations: the lower Elbrook and the upper Conococheague (Figure 1, sec. 7). The upper 800 feet of the Elbrook is a dolomite and a calcareous, dolomitic shale which alternates with limestone (Wilson, 1952). The formation is approximately 3000 feet thick and is of both Middle and Upper Cambrian age. Above the Elbrook is about 2000 feet of dark, silty, laminated limestone called the Conococheague. The Conococheague contains a basal 250 foot dolomite-sandstone unit named the Big Spring Station Member (Wilson, 1952).

The Gatesburg of the northwestern belt is a sequence of sandstone and dolomite which is replaced almost completely in the southeastern belt by limestone and subordinate dolomite of the Conococheague. One tongue of the Gatesburg sandstone-dolomite facies extends from the northwestern belt into Franklin County where it is called the Big Spring Station Member. The top of the Cambrian is placed at the base of the Beekmantown which is also the top of the Mines dolomite in the northwestern outcrop sections in central Pennsylvania and the top of the Conococheague in the southeastern part. The Warrior and upper Elbrook appear lithologically similar, both being more argillaceous than the overlying formations. The Warrior, however, is more sandy than the Elbrook.

The datum of Figure 1 is placed on top of the Cambrian and by definition is a time line. According to Wilson (1952), "the fauna of the Warrior are very similar to those of the Big Spring Station Member and the uppermost Elbrook", so probably the top of the Warrior is nearly contemporaneous with the top of the Elbrook. Because of this time-stratigraphic control at the Gatesburg boundaries it is assumed that the member boundaries are also time-parallel because the members tend to parallel the formational boundaries.

Beekmantown Stratigraphy

For many years the Beekmantown Group in Pennsylvania has been synonymous with Lower Ordovician. In the northwestern belt of the central part of the State the Beekmantown has traditionally been divided into four formations of relatively constant thickness. They are, in ascending order, the Stonehenge limestone (500 feet), Nittany dolomite (1000 feet), Axemann limestone and dolomite (0-500 feet), and Bellefonte dolomite (2000 feet) - see Figure 2. Lithologic correlation of subsurface data with surface exposures indicate that the relationships among these formations may not be as simple as the layer-cake generalizations would presume. Lateral facies changes from limestone into dolomite are more prevalent than much of the published literature indicates.

The Stonehenge Formation at Bellefonte (Figure 2, sec. 3) is about 500 feet of limestone with minor dolomite interbeds. Donaldson (1959) has shown

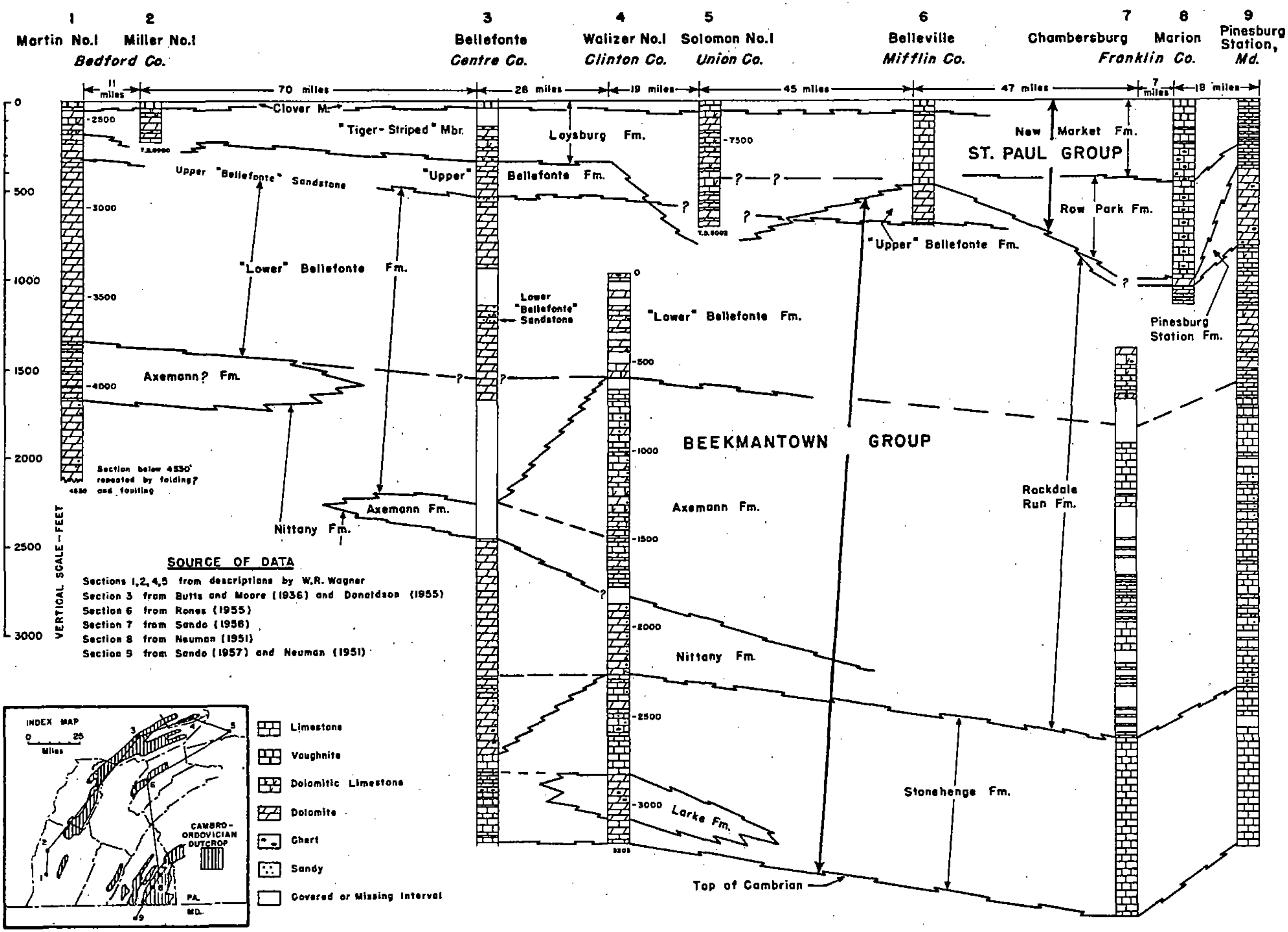



*FIGURE 2*

STRATIGRAPHIC SECTION OF ST. PAUL-BEEKMANTOWN ROCKS IN CENTRAL AND SOUTH-CENTRAL PENNSYLVANIA that southwestward along strike from Bellefonte the Stonehenge disappears by grading into the medium-to coarse-crystalline Larke dolomite. From Bellefonte northeastward into the Walizer well (Figure 2, sec. 4) the Stonehenge interval increases to 950 feet, the thickening taking place at the expense of the overlying Nittany dolomite which thins proportionally. Zones of chert, quartz sand, and oolites found in the lower Nittany at Bellefonte are present in the upper Stonehenge in the Walizer well. A tongue of Larke dolomite occurs in the lower part of the Stonehenge in the Walizer well.

The Nittany Formation is almost exclusively dolomite lying between the limestones of the Axemann above and the Stonehenge below. The formation is variable in thickness because the stratigraphic position of the Axemann and the top of the Stonehenge varies. In the Walizer well (Figure 2, sec. 4) the Nittany is 450 feet of medium- to coarse- crystalline dolomite containing anhydrite and in Bedford County it may range up to a possible maximum thickness of 2000 feet where it is very fine-to coarse crystalline.

The Axemann Formation consists of interbedded limestones, dolomites, and dolomitic limestones. It is about 200 feet thick at Bellefonte (Butts and Moore, 1936 and Figure 2, sec. 3) and 1200 feet thick in the Walizer well (sec. 4). Its position in the stratigraphic column is almost unpredictable; it lies more than 500 feet higher in the Martin well (Figure 2, sec. 1) than at Bellefonte, and in some parts of the Tyrone quadrangle it is reported to be completely missing (Butts, 1939). The Axemann is a limy facies of both the lower Bellefonte and the upper Nittany Formations.

The Bellefonte Formation is a dolomite which, in general aspect, tends to be finer grained than the Nittany. It varies from about 1200 feet thick in the Martin and Walizer wells (Figure 2, secs. 1 and 4) to about 2000 feet at Bellefonte (sec. 3), the thickness depending on the position of the Axemann. In this paper the Bellefonte is divided into an upper and a lower part. The upper part, the "Upper" Bellefonte Formation, is about 150 feet (sec. 1) to 250 feet (sec. 6) of non-cherty, microcrystalline dolomite, and the lower part, the "Lower" Bellefonte Formation, is a very fine-to medium-crystalline dolomite containing traces or small amounts of chert and quartz sand.

There are several thin sandy dolomites or dolomitic sandstone beds in the Bellefonte Formation. The highest one occurs at the boundary between the upper and lower parts and is called the Upper "Bellefonte" sandstone in Figure 2. This sandstone occupies at least part of the stratigraphic position of the sandstone which, in western Pennsylvania and adjacent Ohio, is referred to as the "St. Peter". At the town of Bellefonte another sandy zone is reported to lie about 700 feet below the upper sandstone (Butts and Moore, 1936). The lower sandstone, called Lower "Bellefonte" sandstone in this paper, is probably the sandstone which is exposed at Dale Summit in the Bellefonte quadrangle. Heretofore these two sandy zones have been considered as the same zone.

The top of the Bellefonte marks the upper boundary of the Beekmantown and is placed at the top of the dolomite sequence just underneath the interbedded limestones and dolomites of the Loysburg.

In Franklin County(Pennsylvania) and Washington County (Maryland) Sando (1957, 1958) divided the Beekmantown into three formations which, beginning with the oldest, are: Stonehenge, Rockdale Run, and Pinesburg Station (Figure 2, sec. 9). The Stonehenge consists of 1000 feet of interbedded fragmental and algal limestones. The Rockdale Run is composed of limestone and dolomite, 2500 feet thick, with dolomite dominant in the upper third and limestone in the lower two-thirds. Above the Rockdale Run at section 9 (Figure 2) is approximately 450 feet of cherty dolomite named the Pinesburg Station Dolomite.

The major facies relationship in the Beekmantown is the change from dolomite in the northwestern belt to limestone in the southeastern belt of central Pennsylvania. The Stonehenge has its maximum thickness in Franklin County, Pennsylvania, and decreases westward, its place being taken by the Larke and lower Nittany dolomites. From the northwestern belt eastward the erratically occurring Axemann limestone thickens (at the expense of the Nittany and part of the "Lower" Bellefonte dolomite) to become the dominantly limestone section of the lower two-thirds of the Rockdale Run Formation. The upper dolomitic third of the Rockdale Run is represented in the northwestern belt by most of the "Lower" Bellefonte dolomite, and the Pinesburg Station Dolomite probably occupies a stratigraphic position similar to that of the "Upper" Bellefonte Formation to the west. It is worth noting that the Pinesburg Station is either very thin or absent at Chambersburg (Sando, 1958). The significance of this will be discussed later.

## St. Paul and Loysburg Stratigraphy

In central Pennsylvania the Loysburg Formation has two members: an upper microcrystalline limestone, 40 to 60 feet thick, called the Clover and a lower "Tiger-Striped" member made up of interbedded microcrystalline dolomites and limestones. The "Tiger-Striped" varies from 40 feet near Union Furnace (Kay, 1944) up to 400 feet in the Kishacoquillas Valley (Rones, 1955) (Figure 2, sec. 6). The Loysburg appears to grade conformably into the dolomites of the Beekmantown and disconformably underlies the microcrystalline limestones of the Black River Group.

In Franklin County, Pennsylvania and neighboring Maryland the strata lying between the Black River limestones (Chambersburg) and the Beekmantown are called the St. Paul Group (Neuman, 1951). Neuman separated the group into the Row Park Formation below and the New Market above.

The Row Park is composed of two kinds of limestone, gray vaughnites and dark granular limestones with the granular limestones dominant in Franklin County (Figure 2, sec. 8). At Pinesburg Station, Maryland (sec. 9) the Row Park is 112 feet thick and in adjacent Pennsylvania it ranges up to 680 feet.

The New Market mainly consists of vaughnites with considerable amounts of fine-grained, dark limestone. It varies from 265 feet at Pinesburg Station to at least 710 feet at Welsh Run, Pennsylvania, a few miles north of the state line. Both the New Market and Row Park were assigned to the Chazy by Neuman (1951) and he correlated the New Market with the Loysburg Formation but was in doubt about what strata corresponded to the Row Park in the northwestern belt of central Pennsylvania.

Beekmantown - St. Paul - Loysburg Relationships

It is almost a stratigraphic custom in Pennsylvania to place an unconformity at the top of the Beekmantown at its contact with the Loysburg and the St. Paul. The Beekmantown has been traditionally considered to be of Canadian (Lower Ordovician) age and the Loysburg and St. Paul of Chazy (lower Middle Ordovician) age. Therefore the unconformity supposedly represents the hiatus between the Lower and Middle Ordovician strata. Evidence cited in support of the unconformity is 1) the extremely irregular contact which exhibits as much as 250 to 350 feet of relief in central Pennsylvania, 2) the presence in some localities of dolomite fragments in the basal Row Park limestones, and 3) the absence of Lower Chazyan fauna because the St. Paul and Loysburg contain fauna of Middle and Upper Chazyan age (Neuman, 1951).

There is also an array of evidence indicating that an unconformity may not exist at the boundary being discussed, but instead that the boundary simply defines two adjacent lithofacies, the Row Park and Pinesburg Station Dolomite or the Row Park and "Upper" Bellefonte Formation.

The contact of the Beekmantown with the Loysburg and the Row Park appears transitional. In the Kishacoquillas Valley (Figure 2, sec. 6) the microcrystalline dolomites of the "Upper" Bellefonte Formation grade upward into interbedded microcrystalline dolomites and limestones of the "Tiger-Striped". In the southeastern belt as much as the lowest 50 feet of the Row Park may contain interbeds of dolomitic limestone (Neuman, 1951) and at Pinesburg Station, Maryland, according to Neuman (1951), the dolomite-limestone boundary does not parallel a bedding plane, but the dolomite can be seen to rise about five feet into the horizon of the Row Park vaughnites.

Local dolomitization in the Row Park and Loysburg may cause the appearance of "erosional relief" at the top of the Beekmantown. The combined Row Park-Pinesburg Station interval is 566 feet at Pinesburg Station, Maryland. (Figure 2, sec. 9) and about 585 feet at Marion, Pennsylvania (sec. 8). While the combined interval remains relatively constant the Row Park thickens as the Pinesburg Station thins. At Pinesburg Station the dolomite of the same name is 454 feet thick (Sando, 1957) and the Row Park is 112 feet (Neuman, 1951). At Marion they are 40? feet and 545 feet respectively, and at Chambersburg (sec. 7) the Pinesburg Station Dolomite may be completely missing. The thinning of one lithology accompanied by the thickening of the other, while the total interval remains the same, is indicative of a facies relationship. A facies change will also explain how the lower 300 feet of limestones and dolomites in the Solomon well (Figure 2, sec. 5) appear to have been replaced, at least in part, by the microcrystalline dolomites of the "Upper" Bellefonte Formation at Bellefonte (sec. 3) and Belleville (sec. 6). The lower 300 feet of the Solomon well can be easily assigned to the Loysburg Formation and also perhaps to the Row Park Formation because many of the limestones are very fine-textured and dark and may be lithologically similar to the dark, granular limestones of the Row Park.

The fragments of dolomite in the basal Row Park are not necessarily eroded Beekmantown fragments but may be in some cases local dolomite replacements of limestone.

The absence of Lower Chazyan fauna in the area being discussed does not mean that strata of Lower Chazyan age are not present. These beds may be represented by the dolomites of the uppermost Rockdale Run and the upper part of the "Lower" Bellefonte Formation but the diagnostic fossils have been destroyed by dolomitization.

The arguments above suggest that the Row Park Formation is a limestone facies of the Pinesburg Station Dolomite and of the "Upper" Bellefonte Dolomite. As a result of the Chazy-Canadian boundary may not lie at the top of the Beekmantown in central Pennsylvania but may be several hundred feet lower at least at the base of the Pinesburg Station dolomite in the southeastern belt and at the base of the "Upper" Bellefonte Formation in the northwestern belt. If these ideas are valid, then the Beekmantown as it is now defined in central Pennsylvania is of both Canadian and Chazyan age.

Conclusions

The Cambro-Ordovician rocks in central Pennsylvania are principally dolomites in the northwest and limestones in southeast. The relationship of the formations in the two areas is one of interfingering facies. Relatively continuous deposition may have taken place from Upper Cambrian through Chazyan time because no major break in the sedimentary record seems to be present at either the Cambrian-Ordovician boundary or at the top of the Beekmantown.

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# FOLD PATTERNS AND CONTINUOUS DEFORMATION MECHANISMS OF THE CENTRAL PENNSYLVANIA FOLDED APPALACHIANS

by

Richard P. Nickelsen

## Introduction and Regional Setting

The 1600 mile-long belt of the Appalachians within the United States and southern Canada is divided into three major salients (Billings, 1954, p. 54) separated by recesses in southern New York and central Virginia. From north to south the major salients are: 1. The Gaspe-New England salient, 2. the Pennsylvania Salient, and 3. the Tennessee salient. The Gaspe-New England salient and Tennessee salient differ from the Pennsylvania salient in showing considerably more large scale thrusting toward the northwest than is known to exist in the Pennsylvania salient. Differences in the foreland may account for the different structural behavior of the salients. Both the Gaspe-New England salient and the Tennessee salient are compressed against basement buttresses, the Adirondack uplift and the Canadian shield in the North and the Nashville Dome and Cincinnati Arch in the South, whereas the Pennsylvania salient is bordered on the northwest only by the broad Appalachian Basin of western Pennsylvania, Ohio and West Virginia.

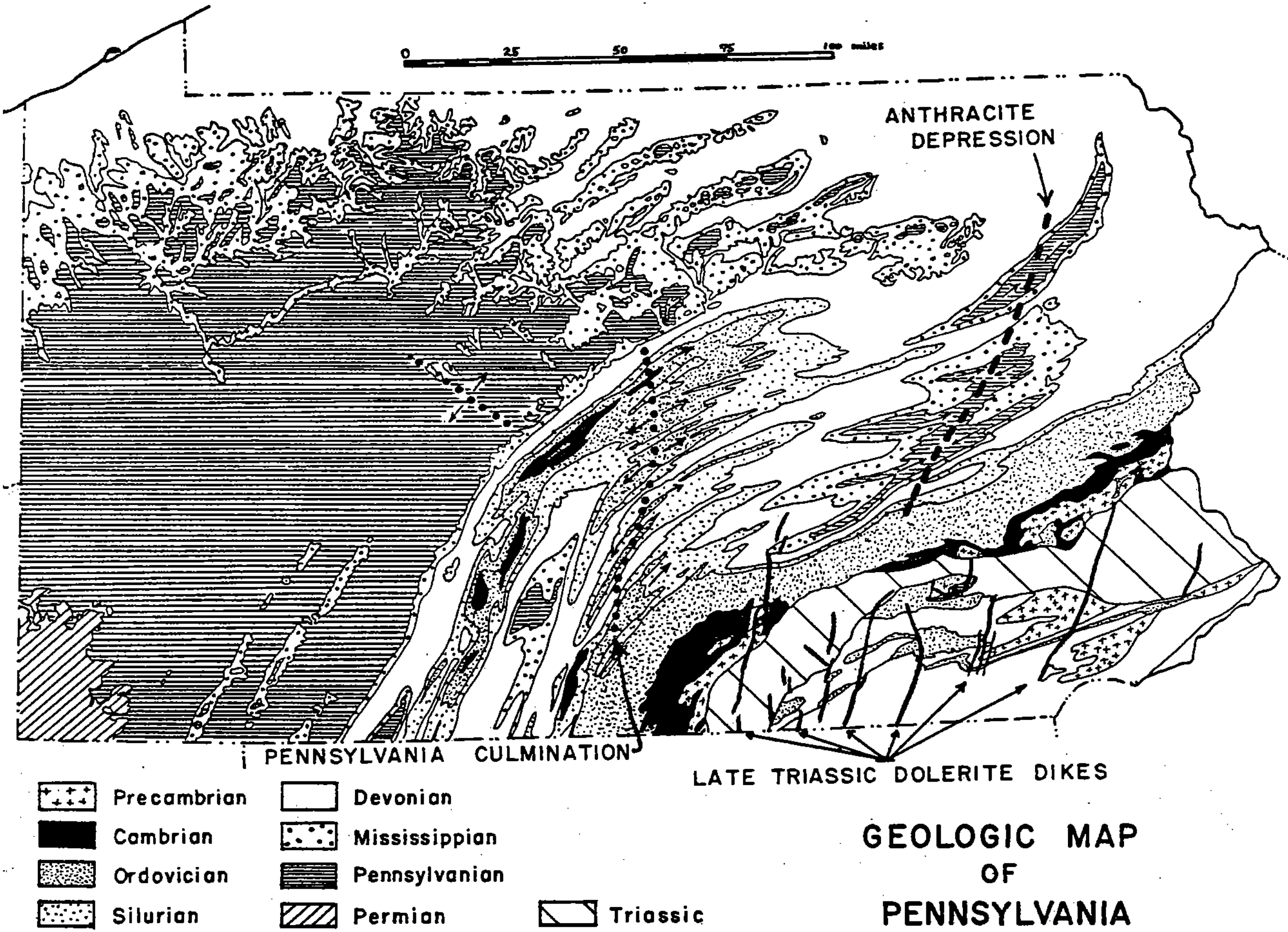
New work by the U.S.G.S. in the anthracite district of northeastern Pennsylvania has revealed a significant steep upthrust (Wood and Kehn, 1961, p. 256) and considerable stratigraphically limited thrusting within the Pennsylvanian section (Coal Investigations Maps, U S.G.S ). Recent reinterpretation of the Birmingham Thrust and Window of south-central Pennsylvania calls for a major sole thrust beneath the Valley and Ridge folds at the Cambrian stratigraphic level (Geologic Map of Pennsylvania, 1960). Significant thrusts also occur in the southeastern Valley and Ridge in the McConnelsburg area (Geologic Map of Pennsylvania, 1960). Despite this new and old evidence of major or minor discontinuities (faults) within the Valley and Ridge Province of the Pennsylvania salient, folding (continuous or semi-continuous deformation) is an important mode of deformation within the province. The rest of this paper will deal with fold patterns and mechanics within the Pennsylvania salient of the Valley and Ridge Province.

## Fold Map Patterns in the Pennsylvania Salient

The map pattern of folds in the Pennsylvania salient is dominated by a culmination (Billings, 1954, p. 54) trending north-south approximately through the axis of the salient but not symmetrically situated within the salient (Fig. 1). The axis of the culmination, here termed the Pennsylvania culmination, is approximately defined by the structurally highest parts of doubly-plunging anticlines or anticlinoria where Cambrian or Ordovician rocks are exposed, from north to south, in: 1. the Nittany Valley Anticlinorium, 2. the Penn Valley Anticlinorium, 3. the Kishacoquillas Valley Anticlinorium, 4. the Blue Mtn. Anticline, and 5. the Blacklog Valley Anticline (Fig. 1). The culmination spreads southwest along the axis of the Nittany Arch (Butts and Moore, 1936, p. 79) with the result that there are at least four structurally high areas shown by Cambrian exposures along the Nittany Arch between Bellefonte, Pennsylvania and central Bedford County. East and northeast of the culmination, virtually all folds plunge east giving rise to the deep synclinal basins of the northeastern Pennsylvania anthracite region. Here the deepest portions of the anthracite synclinoria lie approximately along a north-south axis of a transverse depression (Billings, 1954, p. 54) parallel to the axis of the culmination. This depression is here termed the Anthracite Depression. West and southwest of the culmination the pattern of southwest plunges off the culmination is less perfect but southwest plunges bring the Pennsylvania section beneath the erosion level in the Broad Top coal field. Also the Ordovician rocks of the Kishacoquillas Valley, Blacklog, and Blue Mountain anticlines clearly plunge southwest beneath Devonian rocks in Fulton County in southcentral Pennsylvania. Southwest along the strike of the Nittany Arch both northeast and southwest plunges occur but the structure finally plunges southwest in southern Pennsylvania after passing through four more structurally high areas which bring Cambrian rocks to the surface in Centre, Huntingdon and Bedford counties. In each case these structurally high Cambrian areas, occurring along the southwest extension of the Nittany Arch, are bounded on the northwest by thrusts, possibly locally generated, possibly rising from the sole thrust interpreted to underly parts of the southwest half of the Pennsylvania salient.

In the Appalachian Plateau beyond the Nittany Arch, what may be the extension of the culmination is offset to the southwest and trends northwest, more nearly perpendicular to fold axes. According to Fettke (1954, p. 7) minimum structural relief between adjacent anticlines and synclines occurs in Centre, Clearfield, and northern Cambria and Indiana counties, the region interpreted to lie on the northwest continuation of the Pennsylvania culmination. Anticlines and synclines of this area of the Appalachian Plateau show structural relief of only 500'- 900', whereas structural relief of 1000' - 1500' is found to the northeast and 2000' - 3500' is found to the southwest.

It has been noted (personal communication, D. U. Wise, 1962) that the trend of many late Triassic dolerite dikes (Sanders, 1963, p. 514) both within and outside of the Triassic basin of southeast Pennsylvania approximately parallels the N.-S. to N.-N.E. - S.-S.W. trend of the Pennsylvania culmination and the adjacent Anthracite Depression. This may indicate either: 1. development of the north-south arching responsible for the Pennsylvania culmination and Anthracite Depression during late Triassic, or 2. continuing activity of basement (?) or other controls responsible for Paleozoic development of the culmination and salient into Late Triassic time.



0
25
50
75
100 miles
ANTHRACITE DEPRESSION
PENNSYLVANIA CULMINATION
LATE TRIASSIC DOLERITE DIKES
Precambrian
Cambrian
Ordovician
Silurian
Devonian
Mississippian
Pennsylvanian
Permian
Triassic
GEOLOGIC MAP OF PENNSYLVANIA


Figure 1

Sanders (1963, p. 517) has recently argued that "the arching and faulting that have caused uplift of many areas of Precambrian rocks in the medial parts of the Appalachians, ..... may reasonably be supposed ..... to have resulted from Late Triassic tectonic movements." At the present state of our knowledge, we can only suggest, given the parallelism of the Pennsylvania culmination and the Anthracite Depression with Triassic structural features in Pennsylvania and northward, that we should consider Triassic warping and faulting as a possible mechanism for production of Valley and Ridge culminations and depressions.

Size Orders of Folds and Structural Lithic Units

For purposes of discussion it is convenient to classify the folds of this region into a number of size classes or orders so that the varying behavior of different structural lithic units (Currie, et al, 1962) can be described. On the basis of relative fold sizes in the Ordovician-Middle Devonian section in the northeast plunge of the Penn Valley Anticlinorium, the Seven Mountains Synclinorium and the Kishacoquillas Valley Anticlinorium the following orders of folding are recognized:

1. First Order folds - the largest folds of this region with wave lengths of 7 - 11 miles; usually anticlinoria or synclinoria such as the Penn Valley Anticlinorium, the Seven Mountains Synclinorium and the Kishacoquillas Valley Anticlinorium. Also includes folds of the Appalachian Plateau such as the Chestnut Ridge and Laurel Hill anticlines.

2. Second Order folds - anticlines and synclines with a wave length of 1-1/2 to 2 miles which are most clearly defined in this region at the stratigraphic level of the Tuscarora and Bald Eagle sandstones.

3. Third Order folds - smaller folds with wave lengths of less than 1/2 mile which are best expressed in the Middle Silurian - Middle Devonian sequence above the Rose Hill Shale and below the Hamilton Group.

4. Fourth Order folds - folds of outcrop size with wave lengths of several tens of feet. At the present state of our knowledge these folds cannot always be differentiated from Third Order folds and it is possible that the two orders are transitional.

5. Fifth Order folds - folds of microscopic to hand specimen size.

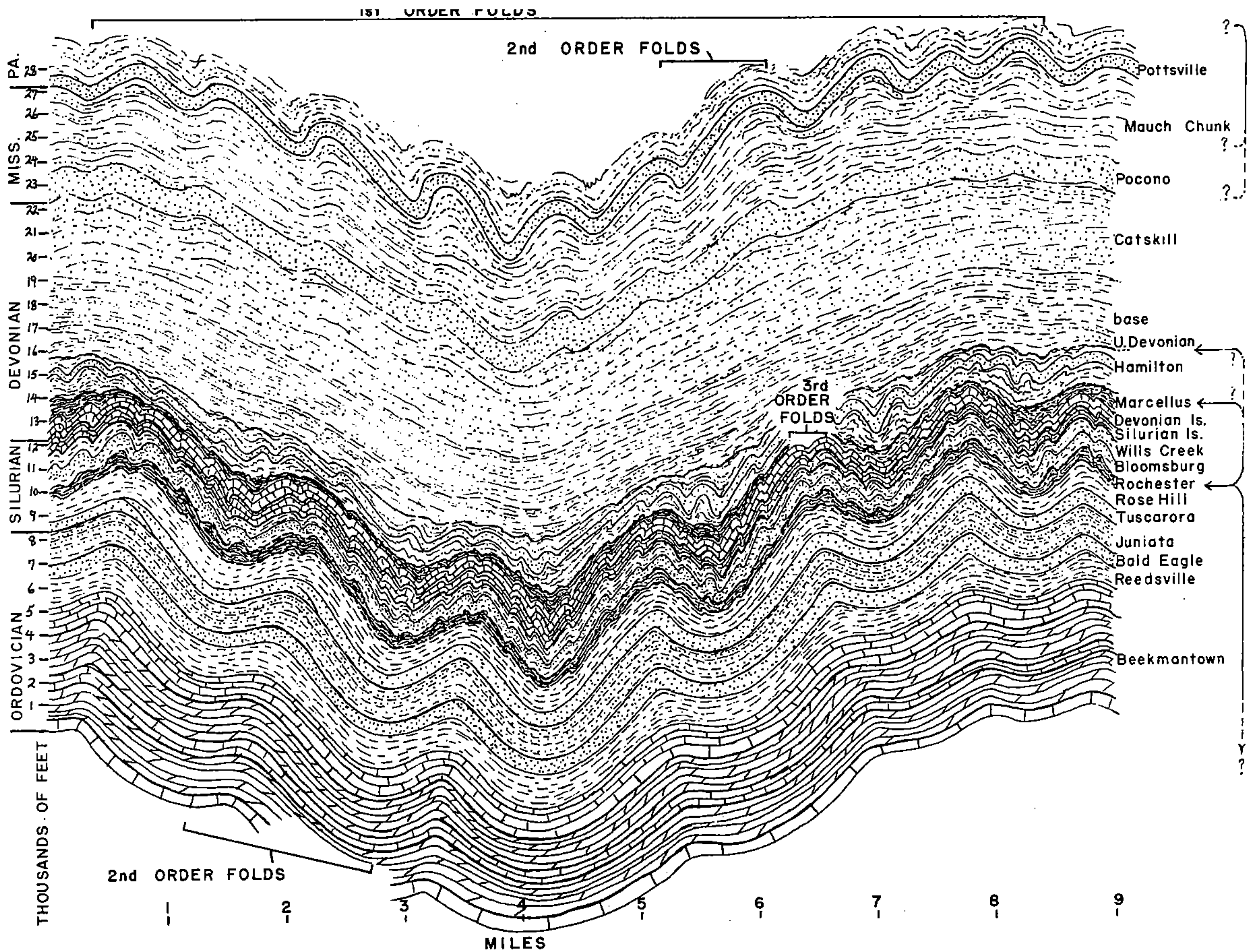
It should be recognized that this classification is a first attempt to place arbitrary fold size class limits on a possibly continuous progression in fold sizes which are related to different thicknesses of structural lithic units and competent members. Size limits given in the description of orders of magnitude of folding are most applicable to the Ordovician-Devonian section and cannot be applied completely to higher parts of the section. The anthracite coal basins are First Order synclinoria corresponding to, and occurring down plunge from, First Order synclinoria at the Ordovician-Silurian stratigraphic level. However, Second Order folds of the Ordovician-Silurian stratigraphic level with wave lengths of 1-1/2 to 2 miles do not occur in the Pennsylvanian coal measures, but are replaced here by Second Order folds with wave lengths of approximately 3/4 to 1-1/2 miles. These coal measure Second Order folds thus fall between the size of Second Order and Third Order folds as defined in the Ordovician-Devonian section.

Generally then, it would appear that First Order folds extend throughout the stratigraphic column from Ordovician to Pennsylvanian but that Second and Third Order folds are controlled by the geometrical and strength properties of the structural lithic units in which they occur (Currie, et al, 1962, p. 670). The large scale structural lithic units of the Appalachian stratigraphic column in central Pennsylvania that can be approximately defined east of the Pennsylvania culmination with presently available information are shown in Fig. 2. They are, from base to top:

1. A structural lithic unit extending from the Silurian Keefer Sandstone at the top of the Rose Hill Shale down through the Silurian Tuscarora Sandstone, the Ordovician clastics (Juniata, Bald Eagle, Reedsville) and including the carbonate rocks at least to the base of the Lower Ordovician Beekmantown Group. The base of this structural lithic unit has not been defined but its top is clearly the Keefer Sandstone, above which the shales and interbedded limestones of the Rochester and McKenzie members of the Mifflintown Formation serve as a boundary zone (Currie, et al, 1962, p. 670).

   Second Order folds which extend essentially harmonically through 10,000 feet of section are characteristic of this structural lithic unit throughout the eastern half of the Pennsylvania culmination. Third Order folds do occur in fold hinges as illustrated at Stops XII and XIII but are not known to occur on fold limbs. Their presence at Stops XII and XIII is ascribed to local crowding due to extreme tightness of folding or lack of sufficient bedding slip during concentric flexural slip folding. The sandstones and limestones that comprise most of the unit are strong and have behaved in a brittle manner with only slight bending and no minor folding or flowage. The more ductile Reedsville shale has locally undergone "flowage" as at Stop XI with the result that it may serve as a boundary zone between fold disharmonies in the upper and lower halves of the structural lithic unit. However, such fold disharmonies are not known to exist. Third Order folds are known to occur in the upper Rose Hill shale indicating that, in places, the upper boundary zone of the structural lithic unit is within the Rose Hill shale.

2. A structural lithic unit extending from the Silurian Bloomsburg Formation, above the boundary zone in the Rochester-McKenzie, to the Devonian Marcellus shale, or perhaps to the shales (Burket, Brallier) at the base of the Upper Devonian. This unit, at least 3000' in thickness and composed of shales, sandstones, limestones,




**STRUCTURAL LITHIC UNITS AND SIZE ORDERS OF FOLDING, PALEOZOIC SECTION, CENTRAL PENNSYLVANIA**

Figure 2

is characterized by Third Order folds which, for the most part, do not extend into the lower structural lithic unit or into the Upper Devonian section. The Third Order folds are present on both hinges and limbs of Second Order folds in the lower structural lithic unit. The upper boundary zone of the unit is not definitely established. Third Order folds in the Montebello Sandstone of the Hamilton Group may either be harmonic with the folds of the underlying Lower Devonian and Silurian rocks or may occur in a separate structural lithic unit bounded at the bottom by the Marcellus Shale and at the top by the shales at the base of the Upper Devonian. In the first case, the upper boundary zone of this structural lithic unit occurs in the shales at the base of the Upper Devonian. In the second case, the Hamilton Group is a distinct structural lithic unit bounded at the base by the Marcellus Shale boundary zone and at the top by the shale boundary zone near the base of the Upper Devonian.

I am unable to define structural lithic units in the Upper Devonian-Pennsylvanian section at this time but the following observations about the distribution of folding are pertinent to the discussion.

(A) As noted above, First Order folds extend throughout this part of the section but less Second and Third Order folding occurs in the Upper Devonian section than is known to occur in the overlying Pennsylvanian and Upper Mississippian sections or in the structural lithic units below.

(B) Pronounced Second Order folds with wave lengths of approximately 3/4 - 1-1/2 miles are present in the Pennsylvanian section and probably extend down through much of the Mauch Chunk Formation. It is possible that the Pennsylvanian and the Mauch Chunk comprise a structural lithic unit with a lower boundary zone within the Mauch Chunk. The Pocono Sandstone does not generally appear to be as tightly folded as the Pennsylvanian agé sandstones.

This preliminary definition of some Paleozoic structural lithic units of central Pennsylvania is probably most applicable to the Susquehanna River region between the Pennsylvania culmination and the Anthracite Depression and will have to be revised and improved both here and in areas where stratigraphy differs. However, it is hoped that this presentation will generate discussion and stimulate interest in the definition of structural lithic units throughout the Pennsylvania salient.

<u>Fold Geometry</u>

Folds of the Valley and Ridge Province of central Pennsylvania do not show the form of either <u>parallel</u> or <u>similar</u> folds (Billings, 1954, p. 56) but rather are more like sine curves with nearly planar limbs and curved hinges (for example see: Third Order folds at Stop XIII, or Arndt, H.H., et al, 1959, p. 16-17). Both examples are Third Order folds from the tightly folded Silurian section and it is possible that folds of more nearly parallel form occur elsewhere in more competent units. Disharmonies in fold form and amplitude are well documented in rocks of different strength and ductility at different stratigraphic levels in the Pennsylvanian anthracite area (Darton, 1940 and Coal Investigation Maps, U.S.G.S.) and different fold forms occur at different depths in the same fold. However, it has been shown experimentally and theoretically that the initial deflection curve of a beam hinged and stressed at the ends until it buckles is a sine curve (Currie, et al, p. 657, 664-667). Theory, experimentation, and field observation of Third Order folds all support the conclusion that elastic buckling produces folds with sinusoidal cross sections. It is assumed that larger folds that are not directly observable also have grossly sinusoidal cross sections. The sinusoidal cross section of folds permits their development with similar form throughout greater thicknesses of section than would be possible were they parallel folds comprised of circular arcs. Indeed, mechanisms discussed below contribute to thickening in fold hinges (limbs, however, maintain original thickness) with the result that the gross fold form commonly approaches that of similar folds, (Billings, 1954, p. 56) with slightly thickened hinges and unchanged limb thicknesses.

In summary then, whereas fold disharmonies may allow different fold forms (similar and parallel) to exist at different stratigraphic levels in one fold the essential form of most folds in the Pennsylvania Valley and Ridge is thought to be a sinusoidal curve commonly showing planar limbs and a concentrically curved crest. At certain stratigraphic levels, thickened hinges are present with the result that the similar fold form is approached.

## Scale and Continuous or Discontinuous Deformation

"The deformation of rock material in faulting is generally considered to be discontinuous; in folding, it is dominantly continuous. But almost every rock outcrop and thin section of deformed rock shows the effect not only of continuous flow but also of movements resulting in discontinuities: cracks, faults, fragmentation, ruptural phenomena of various sorts" (Knopf and Ingerson, 1938, p. 32-33). This discussion will mention some of the small scale discontinuities which contribute to the grossly continuous folding process in the Valley and Ridge Province of Pennsylvania.

Small scale discontinuities so far abundantly recognized occur at the supra-grain level and include slices of internally undeformed rock bounded by bedding planes, rock cleavage planes, joints, or small, stratigraphically limited faults. In local, highly-stressed environments within the Valley and Ridge, intra-granular discontinuities such as deformation twins in calcite and deformation lamallae in quartz have been noted but we do not yet know the quantitative importance of such intra-granular processes. On the other hand, the various inter-granular or supra-granular discontinuities all contribute to the deformation process. These range in scale from inter-granular grain displacements, to relative movement between rock cleavage-bounded-microlithons less than a millemeter in thickness, to relative movement between beds ranging in thickness from millimeters to tens of feet, to stratigraphically limited thrust faulting. Given this range of size of discontinuities, decision as to whether the deformation process is continuous or discontinuous rests largely upon the scale of observation.

At one place (Stop XII) microlithons or other discontinuity-bounded blocks have clearly undergone intra-block changes in shape as proven by deformed fossils. This is an unusual feature in the Valley and Ridge and may be expected to occur only in ductile shales such as the Rose Hill shale at Stop XII. In some cases of apparently ductile deformation of shales it is not clear that the sediments had been transformed into rocks before deformation i.e. distortion may have resulted from viscuous inter-granular adjustments before the grains were cemented together.

Mechanics of Folding

Folding in central Pennsylvania is dominantly flexure folding (Billings, 1954, p. 88), concentric folding (DeSitter, 1956, p. 181-182), or flexural-slip folding (Turner and Weiss, 1963, p. 473-474) where bedding of competent beds is elasticoviscously bent and serves as an important discontinuity or slip surface. Bedding plane slickensides oriented essentially perpendicular to fold axes show the direction of slip between beds. Other features of such folds are tendency for concentric or parallel form in cross-section (DeSitter, 1956, p. 182) and relatively constant bedding thickness throughout the fold. Flexure folds in central Pennsylvania show the following additional features:

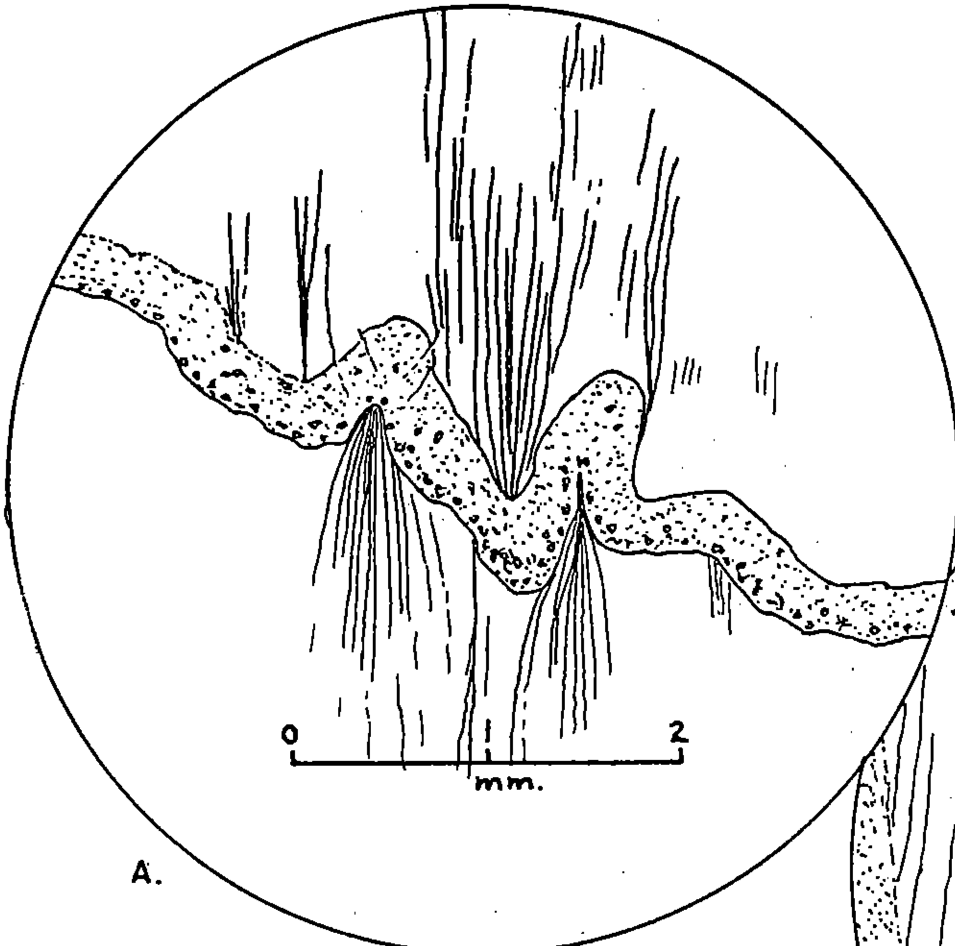
1.) Fold forms of many well-exposed folds are not concentric with respect to some center of curvature but are sinusoidal. Although this fact does not affect the flexural-slip mechanism of their genesis it does allow the fold to extend up and down section with little significant change in fold form or amplitude.

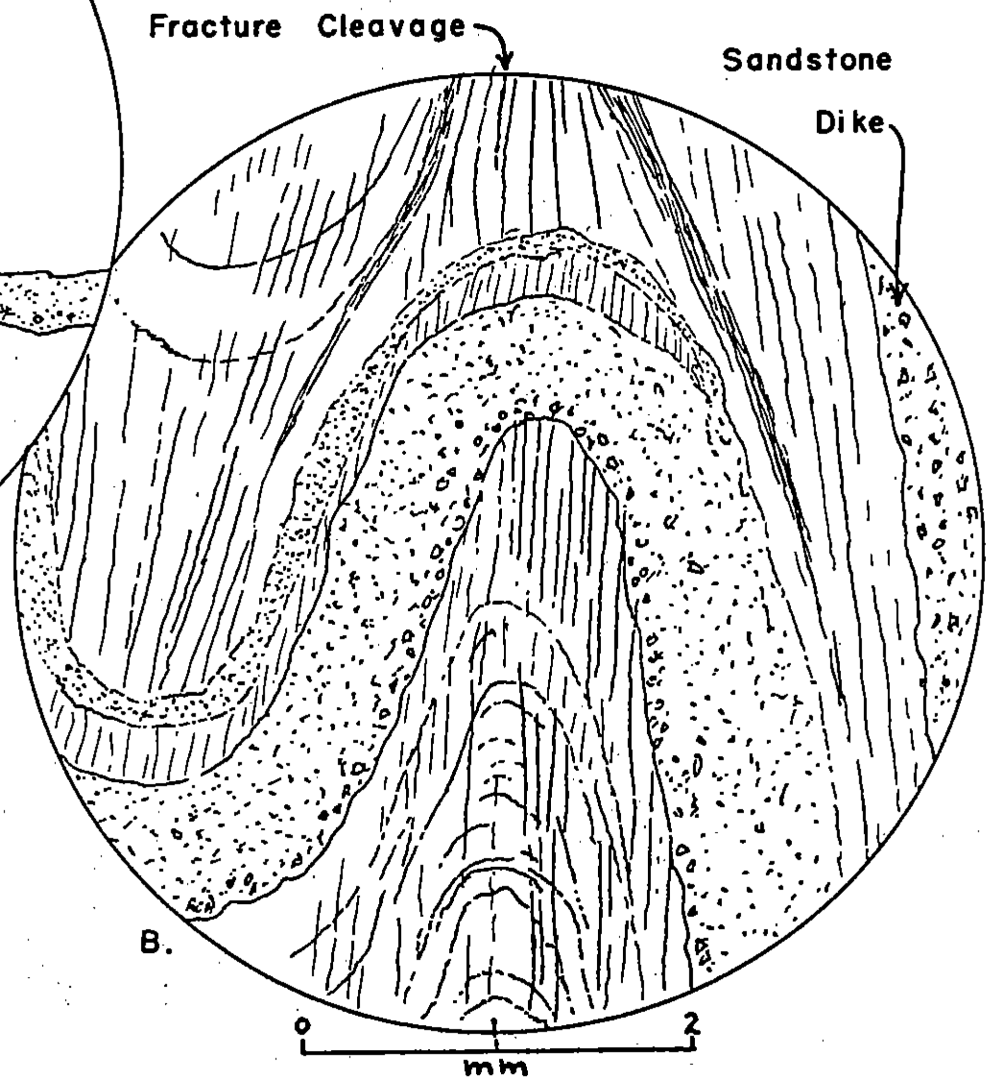
2.) Incompetent beds (shales) in folds commonly show fracture cleavage which initially, in mildly deformed rocks, is oriented perpendicular to bedding and in many cases has been externally rotated in the same sense as bedding during folding, to remain perpendicular to bedding. Cleavage does not remain passive throughout folding, however, but becomes an important plane of slip along which bedding is rotated and folds are created or enlarged. In thick incompetent units, such as at Stop XI, flexure folding gives way to shear folding (Billings, 1954, p. 91) or cleavage folding (DeSitter,1956, p. 182) as slip along cleavage planes becomes more important than bending and bedding plane slip. Fracture cleavage consists of dark, irregular, fractures which divide the rock into microlithons, .05 - .2 m in. thick, which show no internal distortion in any of the thin sections studied. Micas, clays and tabular quartz grains are oriented in their original sedimentary position with long axes parallel to bedding and no discernible minerals have developed in the plane of the cleavage.

Evidence from tectonically oriented flow casts at Stop X and sandstone dikes injected parallel to cleavage in a Bloomsburg Formation outcrop near McAlevys Fort, Pa. (Fig. 3b) suggests that cleavage is initiated early before complete lithification of the sediments (see also Maxwell, 1962). Although evidence is sparse, the origin of cleavage in sedimentary rocks seems to be genetically related to laminar flow of viscous water-sediment mixtures, the laminar flow occurring in vertical planes which intersect bedding in future fold axes and are oriented perpendicular to the regional greatest principal stress axes. In our opinion initiation of cleavage in shales occurs simulatneously with the development of early anistropies recognizable in other sediments only by a variety of physical measurements (Brinkman, et al, 1961). The development of the fine, dark, spaced fracture planes so typical of fracture cleavage in central Pennsylvania occurs later, in some unknown manner, but the orientation of stress axes does not change, for fracture cleavage planes are bent around flow casts at Stop X in a way that can only be explained by greatest principal stress orientation parallel to bedding and perpendicular to cleavage planes. As folding proceeds and the rotations described below occur, cleavage becomes an active slip plane but still appears to maintain orientation perpendicular to principal stress axes. That cleavage has served as a slip plane is demonstrated by small scale displacement of beds shown in thin section (Fig. 3b) and on some bedding planes intersected by cleavage. Within larger fold limbs minor folds (parasitic folds or "drag" folds) originate through reversals of slip sense of fracture cleavage as shown in Figure 3b. Note in Figure 3a that cleavage planes have been pinched or compressed at certain fold hinges by stress acting perpendicular to cleavage planes. Parasitic folds showing similar characters have been ascribed by DeSitter (1958, p. 283) to a later flattening of the fold by cleavage folding after early concentric folding, but whatever the sequence of events it is difficult to escape the conclusion that cleavage is oriented perpendicular to the local greatest principal stress axis and has undergone slip perpendicular to the greatest principal stress axis.

3.) Evidence of bedding slip is completely lacking or rare in many fold limbs and bedding slip may not be as prevalent as is generally thought. Cloos (1961, p. 115-116) following Busk (1929, p. 10) has shown that the maximum differential slip between beds folded concentrically through 180° is approximately 1.6 times the thickness of the bed. If this slip does not occur, crowding of material in the lower parts of anticlines and the upper parts of synclines is bound to occur. Crowding may also occur above and below the center of curvature in a concentric fold (DeSitter 1956, p. 184, 189). Using this fact, DeSitter has shown that the eventual breadth of a fold in a concentrically folded sequence is controlled by the thickness of the sedimentary blanket involved in folding (p. 189). Whether due to lack of sufficient bedding plane slip or position with respect to the center of curvature of concentric folding, axial crowding is a common feature of folds in central Pennsylvania. Such crowding is manifested by:

a) Fracture cleavage "flowage" resulting in axial thickening of incompetent beds.




Camera lucida sketches of fracture cleavage and parasitic folds in incompetent shaly bed, Bloomsburg formation near McAlevys Fort, Penna.

Figure 3

b) Small scale folding or crinkling resulting in local axial thickening of incompetent units.

c) Intra-bed small scale faulting resulting in axial thickening of incompetent beds.

d) Wedging and doubling of beds resulting from bedding thrusts which turn and cut acutely through a bed before returning to a bedding plane above the bed. ("Wedging" of Cloos, 1961). Because displacement on wedges exceed the maximum slip between beds that may be expected due to the geometry of flexure folding, and because wedges show the same directions of displacement on either limb of folds, Cloos (1961, p. 116, 121) has suggested that they proceed folding and control the position of folds. Further work will be necessary to decide whether: 1) anticlines develop where they do because wedging initially is concentrated there before folding, or whether 2) wedging develops after folding has begun to alleviate crowding in anticlines where incomplete bedding slip adjustment has occurred, or whether 3) wedging is effective both early, before folding as an agent for initiating folding and later as a mechanism for alleviating crowding at fold hinges.

Thus there are at least three recent theories regarding the basic controls affecting the spacing of fold hinges in flexure folded sedimentary sequences. All of them recognize the importance of thickness and relative strength of sedimentary units in the folded sequence.

DeSitter, (1956, p. 189) states "that the breadth of the fold is determined from the very beginning, by the thickness of the sedimentary blanket" which is being folded.

Currie, Patnode and Trump have established a simple mathematical relationship between thickness of dominant members of fold wave length in structural lithic units containing competent strata (Currie, et al, 1962, p. 664-666). In their Figure 6 (p. 666) they show, for a number of folds ranging in wave length from less than a foot to 50,000', that $\frac{L}{T} \sim 27$, where

L = wave length of fold from anticline to anticline or syncline to syncline

T = thickness of dominant member.

Application of this relationship requires recognition of the structural lithic unit, and its boundary zones and the size order of folding within the unit. However, experimentally produced fold patterns shown in Plate 2 and 3 (Currie, et al, 1962) look much like what is thought to exist in the central Appalachians (see Fig. 2).

Cloos (1961, p. 121) states, and has shown experimentally, that pre-folding "wedging may have a triggering effect in the location of folds." No data or theory is currently available about the spacing of pre-folding wedges but perhaps their location is fixed at the points of inflection of the initial sinusoidal curves of Currie, Patnode and Trump.

To summarize, if folds are sinusoidal rather than concentric in cross section the effect of thickness of the sedimentary blanket in concentric folding (DeSitter, 1956, p. 189) is probably of lesser importance in establishing fold wave length than the sinusoidal deflection curve of dominant sedimentary members of given thickness (Currie, et al, 1962), or the location of pre-folding wedges (Cloos, 1961). Decision as to the relative importance and possible inter-actions between the three above mentioned controls upon fold wave length will have to await more work in the Appalachians and other flexure folded areas. Whatever the initial control upon the location of hinges, after folding has begun a number of secondary rotations of varying importance are started which continue the flexure folding process and eventually modify the fold form and mechanics of generation.

These rotations, which are shown diagrammatically in Figure 4, are:

I. External rotation[1] of limbs of the fold around the hinges or points if inflection where beds are bent.

II. Internal rotation[2] of lines or planes formerly perpendicular to bedding toward parallelism with axial plane which is accomplished by flexural slip on bedding planes. The slip sense is usually reversed on opposite limbs of folds.

III. Internal rotation of beds by slip along fracture cleavage planes in incompetent horizons. The slip sense is reversed on opposite limbs of folds resulting in upward migration of cores of anticlines and downward migration of synclinal cores (see small scale example in Figure 3b). Where this slip-internal rotation mechanism predominates in thick incompetent horizons such as at Stop V the folding process is shear or cleavage folding. This internal rotation progressively decreases the angle between cleavage and bedding on the limbs

1. Rotation with respect to external axes which are constant in orientation, for example, a parallel to earth's surface and perpendicular to fold axis; b parallel to earth's surface and parallel to fold axial trace, and c perpendicular to earth's surface.

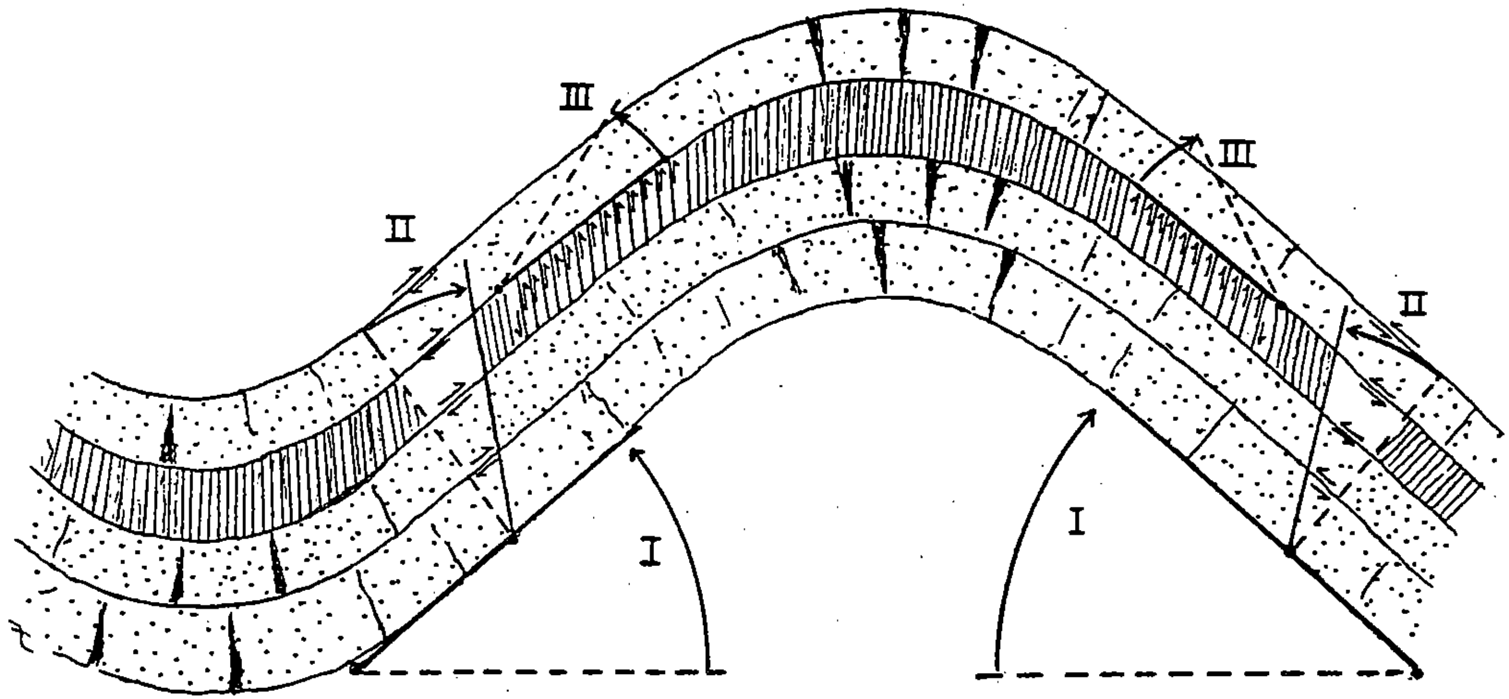
2. Rotation with respect to internal axes within each limb of the fold, for example, a parallel to bedding plane slickensides and bedding plane, b parallel to fold axis and bedding plane, c perpendicular to ab and bedding plane.

> of folds resulting in thickness decrease of incompetent beds measured perpendicular to bedding. Thickness of incompetent beds at fold hinges, where cleavage bedding angle remains 90°, is unchanged. If individual microlithons change shape, as indicated locally by deformed fossils at Stop VI, bedding thickness at hinges may exceed original bedding thickness and fold limbs become further reduced.

In summary, on the right limb of the anticline in Figure 4: a) clockwise external rotation (I) of bedding, cleavage, joints and other early formed features, occurs simultaneously with: b) counter-clockwise internal rotation (II) of cleavage and local stress axes owing to left-lateral bedding slip and: c) clockwise internal rotation (III) of bedding owing to right-lateral slip on fracture cleavage. The importance of different rotation mechanisms varies with intensity of deformation, relative thickness and position of ductile and brittle sedimentary horizons, and stage in the folding process. External rotation (I) and internal rotation (II) are features of flexure folding whereas dominance of internal rotation (III) leads to shear or cleavage folding. Where competent units (sandstone, limestone, dolomite) comprise most of the folded section flexure folding predominates and incompetent layers (shale) tend to accommodate themselves to the spaces between folded competent layers (Turner and Weiss, 1963, p. 472). Where thick sections of incompetent material are folded (example Stop XI) deformation is predominantly by shear folding. That the two folding processes are transitional is indicated by the presence of shear folded incompetent beds containing sandstone boudins in competent flexure folded sequences (Stop XII) and the folding of fracture cleavage by bedding plane slip along certain competent beds in incompetent sequences deformed predominantly by shear folding (Stop XI). The exact mechanism of bending of brittle competent beds at fold hinges is unknown but appears to be a continuous process perhaps involving cleavage "flowage", intergranular adjustment and micro-faulting. Although not particularly abundant in central Pennsylvania wedge-shaped tension cracks on the outer side of the fold hinge probably allow discontinuous bending of separation of fracture-bounded blocks on the outside of folds.

## Conclusions

Folds of at least four different orders of size are believed to exist in the Appalachians of central Pennsylvania. Following Currie, et al (1962), a preliminary attempt has been made to define structural lithic units; stratigraphic sequences that because of their own intrinsic geometrical and strength properties have reacted independently to deformation. Stratigraphic distribution of different size orders of folds has been the main basis for the attempted definition of structural lithic units and boundary zones. Flexure fold wave length is established early in the history of deformation by the thickness of the concentrically folded section (DeSitter, 1956, p. 189), by the thickness of the dominant member of a structural lithic unit, (Currie, et al, 1962, p. 666), by the location of wedges (Cloos, 1961, p. 121) or by a combination of these, and perhaps other factors. Equally early is the beginning of development of rock cleavage, which starts perpendicular to bedding




SCHEMATIC DRAWING OF INTERNAL AND EXTERNAL ROTATIONS IN FLEXURE FOLDS OF CENTRAL PENNSYLVANIA

Figure 4

and to the regional greatest principal stress axis in flat lying beds. With the beginning of buckling at the fold hinges a complex system of internal and external rotations is initiated, effecting or utilizing the bedding and cleavage planes and proceeding somewhat differently in competent, incompetent and interbedded sequences. Since sandstones, limestones and dolomites all behave competently and only shales are incompetent, Valley and Ridge folding is competent folding. The competent units define the folds in each structural lithic unit and the shales accommodate themselves to the spaces between the folded competent layers. The resultant fold form appears to be sinusoidal with concentric, slightly thickened, hinges, and planar limbs. Thickening of hinges is accomplished by crinkling, intra-bed faulting, wedging and, in incompetent beds, by cleavage "flowage" and shear folding.

This attempt to describe and explain the fold patterns and continuous deformation mechanisms of central Pennsylvania has emphasized the need for continuing structural study in a region which has already attracted the attention of several generations of eminent geologists. Future structural work on folding should be directed toward: 1) improving the definition of structural lithic units and testing the relationship between thickness of dominant members and fold wave length, 2) establishing the mechanism of bending at fold hinges in competent lithologies, 3) tracing the development of cleavage and explaining the presence of differential slip along cleavage planes apparently oriented perpendicular to greatest principal stress axis, and 4) delineating the age and trend of major controls affecting to fold pattern and distribution of culminations and depressions in the Pennsylvania salient.

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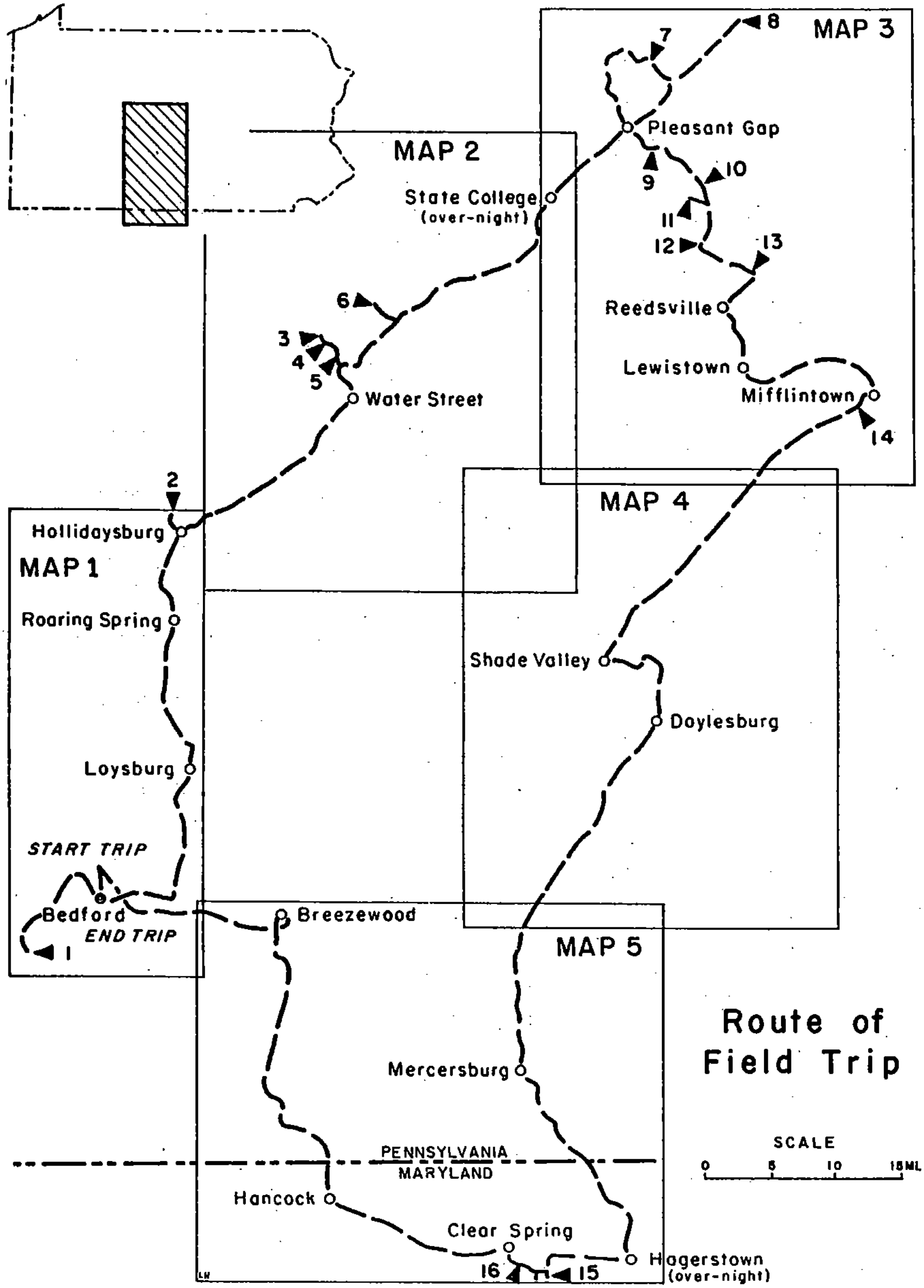

MAP 1
MAP 2
MAP 3
MAP 4
MAP 5
Pleasant Gap
State College
(over-night)
Reedsville
Lewistown
Mifflintown
Water Street
Hollidaysburg
Roaring Spring
Loysburg
START TRIP
Bedford
END TRIP
Breezewood
Shade Valley
Doylesburg
Mercersburg
PENNSYLVANIA
MARYLAND
Hancock
Clear Spring
Hagerstown
(over-night)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Route of
Field Trip
SCALE
0
5
10
15ML

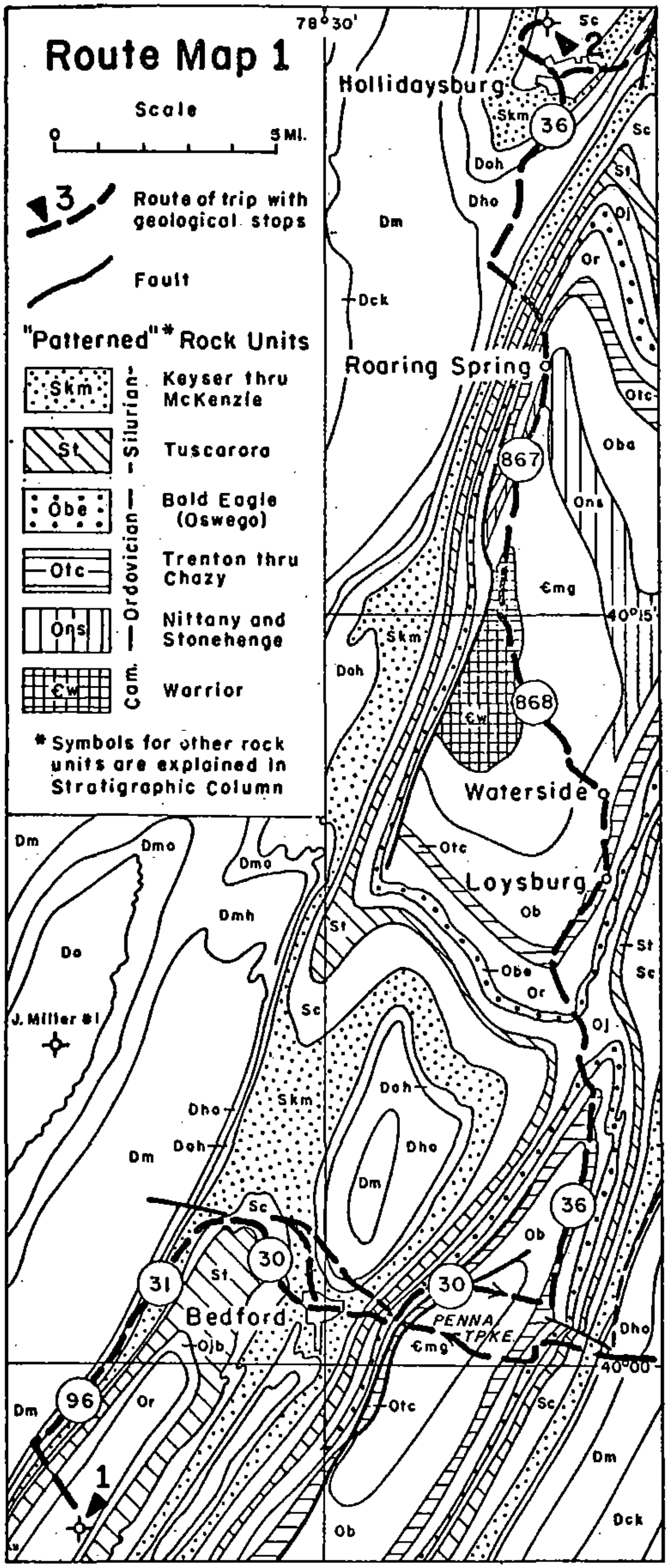
Figure 1

# R O A D   L O G

For

# F I E L D   T R I P

September 19, 20, and 21, 1963



Route Map 1
Scale
0
5 MI.
Route of trip with geological stops
Fault
"Patterned"* Rock Units
Skm
Keyser thru McKenzie
St
Tuscarora
Obe
Bald Eagle (Oswego)
Otc
Trenton thru Chazy
Ons
Nittany and Stonehenge
Єw
Warrior
Cam. — Ordovician — Silurian
* Symbols for other rock units are explained in Stratigraphic Column
78°30'
40°15'
40°00'
Hollidaysburg
Roaring Spring
Waterside
Loysburg
Bedford
PENNA TPKE.
J. Miller #1
36
867
868
30
31
96
1
2
3

FIRST DAY
ROAD LOG, THURSDAY, SEPTEMBER 19, 1963
Mileage - 141.3 miles

Buses will line up in parking space in front of hotel for departure at 8:30 AM.

Mileage

| | | |
|---|---|---|
| 0.0 | | Bedford, Pennsylvania. Main entrance of New Hoffman Hotel. |
| 0.1 | 0.1 | Follow hotel driveway to intersection with Pitt Street (U.S. 30), noting the stone building to the left of the driveway. TURN RIGHT and continue through Bedford business district. Route is now heading west on U.S. 30. (Refer to Route Map 1.) |

Bedford Village

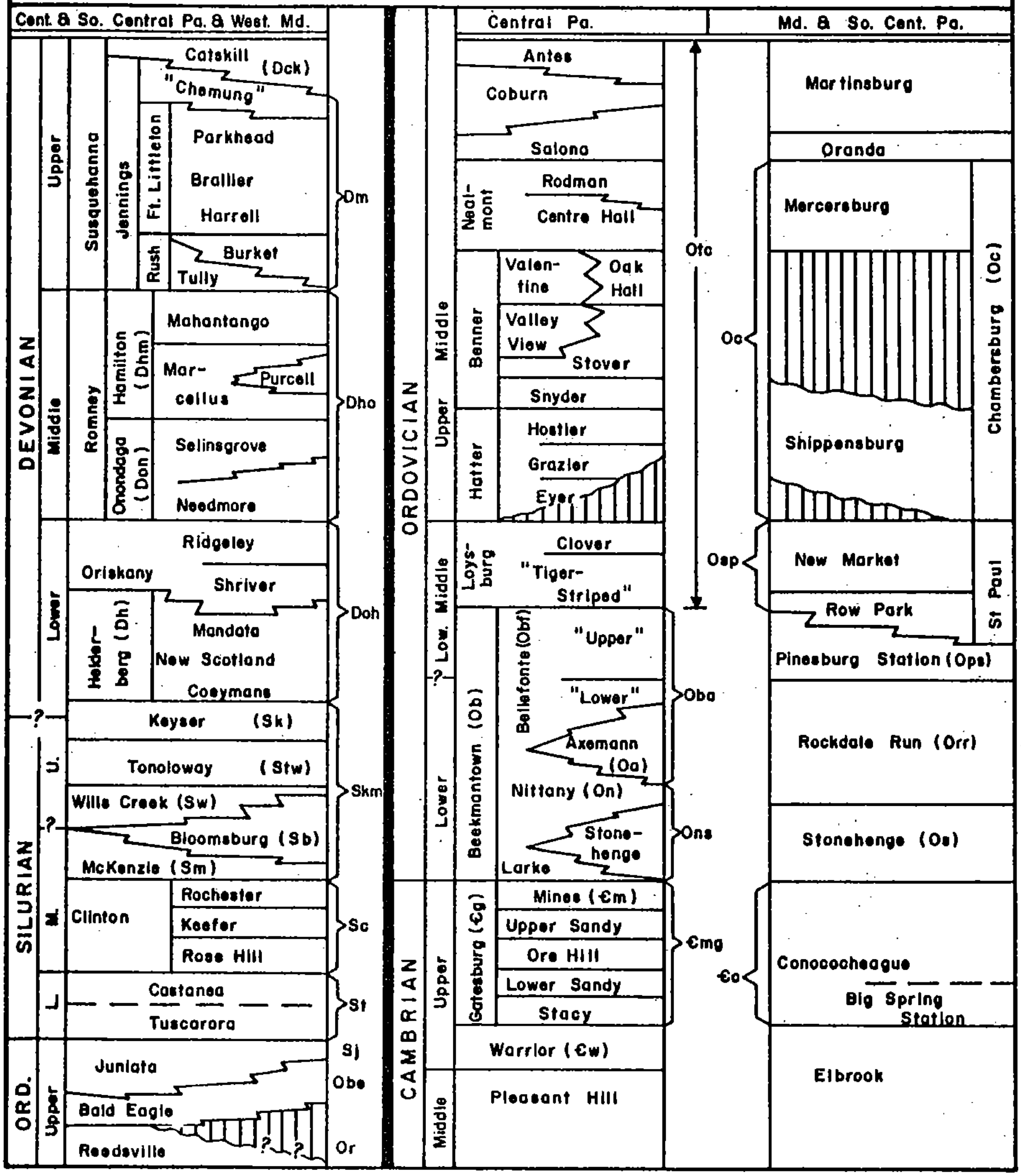
Settled about 1750, known then as Raystown. Site of an early trading post and Fort Bedford, 1758. Base for Forbes and Bouquet expeditions to the west. In 1794 Washington here reviewed forces involved in the Whiskey Rebellion. The stone building in front of New Hoffman Hotel was a powder magazine during Whiskey Rebellion.

Bedford is located on the axis of the relatively shallow Bedford Syncline between Friends Cove (or Roaring Spring) Anticline to the east and Wills Mountain Anticline to the west. Regional structural strike of the Bedford syncline is N 35° E. The route of this field trip cuts diagonally across the regional strike, passing through a poorly exposed Silurian section on the east flank and on the northeast plunging nose of Wills Mountain Anticline in which the following sequence (youngest to oldest) exists:

Keyser Formation
Tonoloway Formation
Wills Creek Formation
Bloomsburg Formation
McKenzie Formation
Rose Hill Formation

FIGURE 2

CORRELATION OF STRATIGRAPHIC UNITS IN CENTRAL AND SOUTH-CENTRAL PENNSYLVANIA AND WESTERN MARYLAND



Mileage

| | | |
|---|---|---|
| 0.5 | 0.4 | Passing obliquely through the Silurian Wills Creek shale, Bloomsburg shale and McKenzie Formation during the next 0.6 miles. |
| 1.1 | 0.6 | Entrance to Bedford County Fairgrounds (at 9 o'clock). |
| 1.4 | 0.3 | Approximate contact Rose Hill (Clinton) shale with overlying McKenzie shale. Poor exposures of Rose Hill shale can be observed in fields and road-cuts in next 2.6 miles around the northeast plunge of Wills Mountain Anticline. |
| 3.0 | 1.6 | Bridge over Raystown Branch of Juniata River. Small Rose Hill shale crops, both sides of road. |
| 3.4 | 0.4 | Crossing the axis of the Wills Mountain Anticline. Sloping topographic ridge at 9 o'clock reflects the rapid northeast plunge. Good exposures of Rose Hill shale in Turnpike road-cuts at 2 o'clock. Attitude N 70 E/24 NW. |

> Colonial iron workings, pits and mounds can be observed in the Rose Hill "iron-rich" sands, north of the Turnpike at 3 o'clock.

The Juniata River provides an excellent example of a structurally-controlled stream adjustment around the northeast plunging nose of the Wills Mountain Anticline.

| | | |
|---|---|---|
| 4.0 | 0.6 | Approximate contact of Rose Hill shale and McKenzie shale, on west flank of Wills Mountain Anticline. |
| 4.2 | 0.2 | Junction Pa. 56. Continue STRAIGHT AHEAD on U.S 30. At 9 o'clock note the profile of Wills Mountain which reveals the rapid plunge of the anticline. The ridge-former on skyline is the Silurian Tuscarora sandstone. |
| 4.3 | 0.1 | Approximate contact of Wills Creek shale with younger Tonoloway argillaceous dolomite. Attitude N 30 E/50 NW. |
| 4.8 | 0.5 | Junction with Pa. 31. Bear to the LEFT at traffic island and continue southwest on Pa. 31, proceeding through Tonoloway rocks. |

The Forks

Monument marks the point where Forbes Road of 1758 diverged from the path cut by Col. Burd in 1755. Forbes Road leads from Fort Bedford to Fort Duquesne (Pittsburgh) via Fort Dewart and Fort Ligonier. The army of General Forbes marching against the French at Fort Duquesne established a camp at this point.

| | | |
|---|---|---|
| 5.0 | 0.2 | Route 31 parallels the strike of beds on the western side of Buffalo Mountain (which is the topographic expression of the west flank of Wills Mountain Anticline). Road follows very close to the Wills Creek-Tonoloway contact; most road-cut crops are Tonoloway. At 3 o'clock are good exposures of Keyser limestone, and of the Coeymans and New Scotland limestone members of the Helderberg Group immediately north of Turnpike underpass. |
| 5.7 | 0.7 | East-dipping exposure (minor synclinal flexure) of Tonoloway is to be seen in road cut at 9 o'clock. The low ridge paralleling the route is comprised of Silurian Keyser limestone, and of Devonian Helderberg limestone and Oriskany sandstone; this secondary topographic ridge can be traced along the west flank of Wills Mountain Anticline southward into Maryland. |
| 6.8 | 1.1 | Bridge. Raystown Branch - Juniata River. |
| 7.9 | 1.1 | We are travelling parallel to strike in Devonian Onondaga and Hamilton beds. |
| 8.1 | 0.2 | Wonderland "Coral" Caverns at 9 o'clock (high). The cave is developed in the Keyser limestone along steeply dipping bedding planes. Attitude N 50 E/80 NW. |
| 8.3 | 0.2 | Entering the village of Manns Choice. Founded 1848. |
| 8.5 | 0.2 | Junction Pa. 31 and Pa. 96. Proceed STRAIGHT AHEAD (southwest) on Pa. 96 South. |
| 9.6 | 1.1 | Highly fossiliferous Lower Devonian Oriskany-Helderberg is exposed in road cuts at 9 o'clock. Onondaga and Hamilton groups lie in the valley of Buffalo Run at 3 o'clock. |
| 10.7 | 1.1 | TURN LEFT (east) at sign directing to White Sulphur Springs hotel. |

| Mileage | | |
|---|---|---|
| | | From this point the route follows the drainage of White Sulphur Run up the west flank of Wills Mountain Anticline. In rapid succession the section from Middle Devonian Hamilton shale to Upper Ordovician Reedsville (Martinsburg) shale will be traversed. |
| 10.9 | 0.2 | At 3 o'clock, Oriskany-Helderberg ridge. |
| 11.2 | 0.3 | Entering the narrows through Buffalo Mountain. |
| 11.4 | 0.2 | At 9 o'clock, vertical to overturned (east-dipping) Silurian Tuscarora sandstone. |
| 11.5 | 0.1 | Caution. One-way bridge over White Sulphur Run. Tuscarora float is abundant at 3 o'clock. |
| 11.6 | 0.1 | Juniata Formation is at 3 o'clock; vertical to overturned (east-dipping). |
| 11.9 | 0.3 | Narrow bridge over White Sulphur Run. |
| 12.1 | 0.2 | Junction; continue STRAIGHT AHEAD over concrete bridge. Zone of *Orthorhynchula* is in left bank at junction; zone occurs in siltstone assigned to Reedsville Formation. |
| 12.2 | 0.1 | The White Sulphur Springs Hotel - built in 1886. The mineral spring is located in the gazebo at 9 o'clock. Analysis of the water from this spring, by F. A. Genth of the University of Pennsylvania, discloses the presence of the following chemical compounds: |

| | |
|---|---|
| Lithium chloride | Trace p/m |
| Sodium chloride | 3.29 p/m |
| Sodium sulphate | 17.10 p/m |
| Potassium sulphate | 3.70 p/m |
| Calcium sulphate | 6.08 p/m |
| Magnesium sulphate | 16.78 p/m |
| Calcium bicarbonate | 154.63 p/m |
| Magnesium bicarbonate | 22.03 p/m |
| Ferrous bicarbonate | 11.29 p/m |
| Silica | 30.96 p/m |
| Total solids | 263.86 p/m |

A Shawnee trail to this spring, and relicts of that tribe, prove that this spring was an Indian "resort" long before white men settled in central Pennsylvania.

Mileage

12.3 0.1 Upper Ordovician Reedsville shale in road-cuts on both sides of road.

12.5 0.2 Proceed southwest along the surface crest of Wills Mountain Anticline. Skyline rim at 9 o'clock is a Tuscarora ridge on the east flank of the anticline; the lower secondary ridge is supported by Oswego (or Bald Eagle) sandstone. The oldest rocks exposed along the surface crest of this structure are Reedsville shale.

12.8 0.3 TURN LEFT, proceed on single-track dirt road. Use caution- - very rough road.

13.1 0.3 Bear to RIGHT at road fork.

13.3 0.2 Bear to LEFT at road fork.

13.8 0.5 STOP I. Group Leader: Walt Skinner, Sun Oil Company
Location: Kerr-McGee Petroleum Industries, No. 1 Mary Martin well.

The No. 1 Mary Martin was spudded in Reedsville shale, probably about 600' below the top of the formation. The section was "normal" until the Nittany Member of the Beekmantown Formation was reached. (It is thought that the well did not penetrate stratigraphically lower than basal Nittany.) The Nittany, expected to be from 800' to 1000' in thickness, actually was 2184' thick and occurred immediately above the major thrust which was encountered at 6174'. The entire lower section of the Nittany is extremely contorted; it is possible that the lowest part of the Nittany was not found by the well.

Below the thrust at 6174', the well re-entered the Reedsville shale, this time in an inverted position. A series of shales and siltstones of varying shades of gray, somewhat calcareous and fossiliferous was penetrated to approximately 6500'. Greenish gray quartzitic siltstones were encountered at 6500' and some red siltstone and shale at 6540'. The section seems to parallel, in inverse order, the upper Reedsville section in the No. 1 Jesse B. Miller well, and also the section exposed in the cut in Buffalo Mountain. The section in the lower part of the Martin well is considered to be the upper Reedsville sandy unit which is exposed in Bedford Narrows. This will be seen later in the trip (at mileage 32.7 on First Day, or mileage 79.2 on Third Day).

Mileage

No significant shows were encountered in the well although some minor indications were noticeable on the gas detector while the Trenton section was being drilled.

(See skeletal log on page 40 , and Figure 3.)

Editor's Note:- The significance of this recent well (Martin No. 1) and the well (Rankey No. 1) at Stop II is the contribution which each makes to our understanding of the regional structure. A detailed interpretation, however, by a geologist familiar with the pertinent facts is not available at the time of this writing. Nevertheless, we feel sure that an informal and lively discussion will ensue at each of these stops at the time of the trip and that mutual educational benefit will result from such a sharing of opinions.

Return to paved road along the axis of the anticline.

| | | |
|---|---|---|
| 14.9 | 1.1 | Dirt road ends at paved road; TURN LEFT, traversing the Reedsville shale southwesterly along crest of Wills Mountain Anticline. |
| 15.0 | 0.1 | Ridge at 3 o'clock supported by Oswego sandstone. |
| 15.5 | 0.5 | Scar low on ridge at 9 o'clock is the No. 1 Mary Martin location. |
| 17.0 | 1.5 | Entering the narrows of Buffalo Run through Buffalo Mountain. Steep-dipping to vertical Reedsville shale and Oswego sandstone in road-cut at 3 o'clock. Prominent Orthorhynchula linneyi zone may be seen 27 feet below the base of the Oswego in the brown and green fossiliferous Reedsville. |
| 17.1 | 0.1 | Oswego (Bald Eagle) sandstone exposure; steep to nearly vertical beds in road-cut at 3 o'clock. |
| 17.3 | 0.2 | Overturned (east-dipping) Juniata beds at 3 o'clock. |
| 17.4 | 0.1 | Overturned (east-dipping) Tuscarora sandstone at 3 o'clock. |
| 17.5 | 0.1 | West-dipping (normal) Tuscarora sandstone is at 3 o'clock; Castanea contact is concealed but float is evident. |

The following are skeletal logs of the three wells in the vicinity of the field trip in Bedford and Blair counties.

(See also Figure 3.)

Stop I.

No. 1. Mary Martin

| | |
|---|---|
| Reedsville | 0-1462 |
| Trenton | |
| Coburn | 1462-1710 |
| Salona | 1710-1898 |
| Rodman | 1898-2000 |
| Centre Hall | 2000-2082 |
| Oak Hall | 2082-2138 |
| Black River | |
| Valley View | 2138-2151 |
| Stover | 2151-2190 |
| Snyder | 2190-2244 |
| Hostler | 2244-2336 |
| Grazier | 2336-2380 |
| Chazy | |
| Clover | 2380-2464 |
| "Tiger Striped" | 2464-2610 |
| Beekmantown | 2610-6174 |
| **Fault** | |
| Reedsville | 6174-6677 TD. |

- - - - - - -

Stop II.

No. 1 Rankey

| | |
|---|---|
| Rose Hill | 0- 775 |
| Thorold-Castanea | 775- 835 |
| Tuscarora | 835-1432 |
| Juniata | 1432-2400 |
| **Fault** | |
| Tonoloway | 2400-2980 |
| Wills Creek | 2980-3623 |
| Bloomsburg | 3623-3667 |
| McKenzie | 3667-4102 |
| Rochester | 4102-4192 |
| Keefer | 4192-4220 |
| Rose Hill | 4220-4896 |
| Thorold-Castanea | 4896-4970 |
| Tuscarora | 4970-5110 TD. |

(Located on Route Map 1.)

No. 1. Miller

| | |
|---|---|
| Shriver | 0- 43 |
| Helderberg | 43- 112 |
| Keyser | 112- 247 |
| Tonoloway | 247-1053 |
| Wills Creek | 1053-1658 |
| Bloomsburg | 1658-1723 |
| McKenzie | 1723-2160 |
| Rochester | 2160-2206 |
| Keefer | 2206-2219 |
| Rose Hill | 2219-2770 |
| Thorold-Castanea | 2770-2881 |
| Tuscarora | 2881-3215 |
| **Fault** | |
| Rose Hill | 3215-3251 |
| Thorold-Castanea | 3251-3350 |
| Tuscarora | 3350-3792 |
| Juniata | 3792-4910 |
| Oswego | 4910-5615 |
| Reedsville | 5615-7810 |
| Trenton | |
| Coburn | 7810-8070 |
| Salona | 8070-8282 |
| Rodman | 8282-8313 |
| Centre Hall | 8313-8343 |
| Oak Hall | 8343-8392 |
| Black River | |
| Stover | 8392-8493 |
| Snyder | 8493-8587 |
| Hostler | 8587-8650 |
| Grazier | 8650-8685 |
| Chazy | |
| Clover | 8685-8727 |
| "Tiger Striped" | 8727-8835 |
| Beekmantown | 8835-8980 TD. |

| | MARTIN | MILLER | RANKEY |
|---|---|---|---|
| BASE REEDSVILLE TO BASE TRENTON | 676 | 582 | |
| BASE REEDSVILLE TO BASE BLACK RIVER | 762 | 777 | |
| BASE REEDSVILLE TO BASE CHAZY | 1146 | 1025 | |
| BASE TONOLOWAY TO TOP ROSE HILL | | 1164 | 1240 |
| TOP ROSE HILL TO BASE TUCARORA | | 1092* | 1333* |
| BASE WILLS CREEK TO BASE ROSE HILL | | 1112 | 1347 |

COMPOSITE *

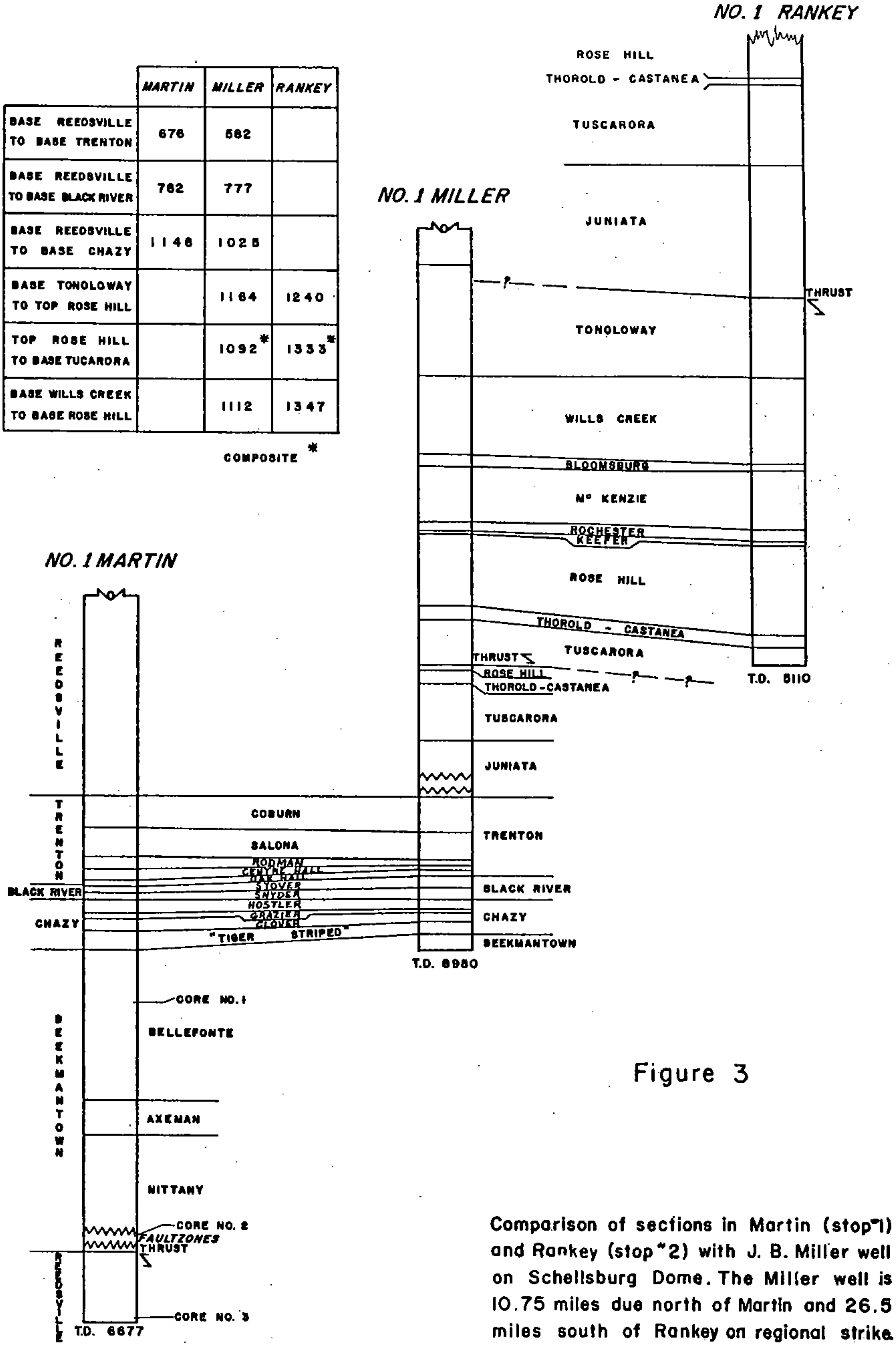



Figure 3

Comparison of sections in Martin (stop #1) and Rankey (stop #2) with J. B. Miller well on Schellsburg Dome. The Miller well is 10.75 miles due north of Martin and 26.5 miles south of Rankey on regional strike.

Mileage

| | | |
|---|---|---|
| 17.6 | 0.1 | Silurian Rose Hill shale outcrops in road-cut at 3 o'clock. |
| 17.8 | 0.2 | Bridge over Buffalo Run. Entering the village of Buffalo Mills. An Oriskany-Helderberg ridge is at 10 o'clock. |
| 18.1 | 0.3 | Junction with Pa. 96 (north). TURN RIGHT. |
| 19.1 | 1.0 | Beds of the Devonian Hamilton group are exposed in road-cut at 9 o'clock. |
| 19.7 | 0.6 | Hamilton rocks are in the road-cut at 9 o'clock. |
| 23.2 | 3.5 | Manns Choice. Junction of Pa. 96 and Pa. 31. Continue STRAIGHT AHEAD on Pa. 31 (east). |
| 26.8 | 3.6 | Junction with U.S. 30. Stop. BEAR RIGHT and continue on U.S. 30 (east). |
| 30.7 | 3.9 | Entering Bedford. Continue on U.S. 30 (east) STRAIGHT through town. |
| 31.5 | 0.8 | Junction with U.S. 220. Continue STRAIGHT AHEAD on U.S. 30 (east). We are now crossing the east flank of the Bedford Syncline. |
| 32.3 | 0.8 | Silurian Rose Hill shale to be seen in cuts at 3 o'clock. |
| 32.7 | 0.4 | Entering the Bedford Narrows where the Raystown Branch of the Juniata River cuts through Evitts Mountain. The highway cut exposes overturned (east-dipping) Silurian and Ordovician sandstone on the west flank of Friends Cove Anticline. The stratigraphic succession shows the oldest beds to be to the east, but dips range from vertical to as low as 35° SE (overturned). |

Numerous slip-planes and faults of small throw, tending to shorten the section, may be found in this exposure and in the Kilcoin Quarry to the north. At the east end of the cut, at the Turnpike underpass, is a section of red sand once thought to be Oswego repeated by faulting; no fault of significant magnitude, however, is evident. This section is now believed to be the upper sandy unit of the Reedsville; the section furthermore, closely matches that encountered in the No. 1 Jesse B. Miller 10 miles to the northwest. The dip and strike of this Reedsville outcrop also is similar to that of the "Tiger-Striped" member of the Loysburg which crops out in the Juniata River beneath the Turnpike bridge to the

| Mileage | | |
|---|---|---|
| | | east. The Turnpike outcrop ties into the section exposed in and below Kilcoin Quarry and appears to be "normal". with the possibility of faulting in the Trenton limestone section, which has been apparently shortened considerably at both the Turnpike and Kilcoin exposures. A similar section may be measured to the east, at the town of Everett. The Reedsville, including the upper sandy unit, measures 1270' at Bedford Narrows, 1320' at Kilcoin Quarry, and 1316' at Everett. |
| 32.9 | 0.2 | Silurian Tuscarora sandstone at 11 o'clock in Turnpike road-cut. |
| 33.0 | 0.1 | Silurian Tuscarora sandstone float at 3 o'clock. |
| 33.1 | 0.1 | Upper Ordovician Juniata formation; best exposures are at 9 o'clock in Turnpike road-cut. |
| 33.2 | 0.1 | Upper Ordovician Oswego (Bald Eagle) sandstone in road-cuts on both sides of highway. |
| 33.3 | 0.1 | Junction of U.S. 30 (east) and Pa. 326 (south). BEAR LEFT, over bridge and continue on U.S. 30. |
| | | Upper Ordovician Reedsville (Martinsburg) shale in Turnpike road-cut at 10 o'clock and in road-cut for secondary road at 2 o'clock *Orthorhynchula* fossils found. |
| 33.5 | 0.2 | Turnpike underpass. Reedsville sand (upper unit of formation) outcrop at 9 o'clock and 3 o'clock. |
| 34.1 | 0.6 | Paralleling Evitts Mountain, the route is over Reedsville shale. |
| 34.8 | 0.7 | Kilcoin Quarry at 3 o'clock. Middle Ordovician Trenton-Black River - Chazy limestones in near-vertical attitude. |
| 35.0 | 0.2 | Trenton-Black River limestone crops in road-cuts on both sides of road. |
| 35.6 | 0.6 | Cambrian Gatesburg sandy dolomite exposed in road-cuts on both sides of road. The Upper Cambrian has been faulted up against the Middle Ordovician here on the west flank of the Friends Cove Anticline. |
| 36.1 | 0.5 | Gatesburg still exposed in road-cuts on both sides of road. This is the approximate axis of the Friends Cove Anticline. |

Mileage

| | | |
|---|---|---|
| 37.0 | 0.9 | Approximate contact between the Cambrian Gatesburg and Lower Ordovician Beekmantown dolomite on east flank of Friends Cove Anticline. |
| 37.7 | 0.7 | Middle Ordovician Trenton-Loysburg limestone can be seen in road-cuts. |
| 37.8 | 0.1 | TURN SHARP LEFT on Pa. 36 (north). Route continues along strike on north plunge of Friends Cove Anticline. Road parallels the Middle Ordovician-Lower Ordovician contact. Beekmantown dolomite is at 9 o'clock and Trenton-Loysburg limestone at 3 o'clock. |
| 38.7 | 0.9 | Bridge over Snakespring Valley Run. Continue STRAIGHT AHEAD on Pa. 36 (north). |
| 39.1 | 0.4 | Tussey Mountain (at 3 o'clock) is the Tuscarora ridge on the east flank of Friends Cove Anticline. Beekmantown crops out at 9 o'clock. Route is traversing progressively younger beds on the north plunge of the anticline. |
| 41.1 | 2.0 | East-dipping Middle Ordovician limestones are exposed. Abundant Silurian Tuscarora sandstone float to be found in soil. |
| 42.3 | 1.2 | Tussey Mountain at 3 o'clock and Dunning Mountain at 9 o'clock are both Tuscarora ridges and they mark the east and west flanks respectively of Friends Cove (Roaring Spring) Anticline. |
| 43.3 | 1.0 | Crossing the north-plunging axis of Friends Cove Anticline. |
| 43.7 | 0.4 | Intersection. BEAR RIGHT and continue on Pa. 36 (north). Reedsville shale is exposed in borrow pits and road cuts on both sides of the road.<br><br>During the next 3.2 miles the route crosses a topographic ridge marking the structural saddle separating Friends Cove and Roaring Springs anticlines. In this interval the route traverses the Upper Ordovician Reedsville shale, Oswego (Bald Eagle) sandstone and Juniata red silty shale to the crest of the divide. Reverse sequence may be observed from the crest into the anticlinal valley ahead. |
| 46.9 | 3.2 | Intersection is in Reedsville shale. BEAR RIGHT. Entering Morrison Cove Valley in the core of Roaring Springs Anticline. The ridge on skyline at 9 o'clock (Dunning Mountain) is Tuscarora-supported, the lower secondary ridge is supported by the Oswego (Bald Eagle) sandstone. |

| Mileage | | |
|---|---|---|
| 47.3 | 0.4 | East-dipping Middle Ordovician limestone is at 3 o'clock along the drainage of Beaver Creek. |
| 48.2 | 0.9 | East-dipping Middle Ordovician limestone is exposed at 1 o'clock (near bridge abutment) and along the drainage of Beaver Creek. |
| 49.4 | 1.2 | Tuscarora talus slope at 2 o'clock (high) in Yellow Creek Gap through Tussey Mountain. Reedsville shale is at 3 o'clock (low). |
| 49.7 | 0.3 | Slow, sharp RIGHT TURN. |
| 49.9 | 0.2 | Intersection of Pa. 868 (north). TURN LEFT. Village of Loysburg. |
| 50.0 | 0.1 | Reedsville shale crops out at base of ridge at 3 o'clock. |
| 50.5 | 0.5 | Middle Ordovician Trenton-Black River-Chazy limestones are to be seen in road-cuts. |
| 51.4 | 0.9 | Northern Bedford County High School. Black River-Chazy limestone exposed here. |
| 51.5 | 0.1 | Approximate Middle Ordovician-Lower Ordovician contact. Route enters upon Beekmantown dolomite here. |
| 52.2 | 0.7 | TURN LEFT on Pa. 868 (north), following drainage of Potters Creek. Almost continuous exposures of Beekmantown dolomite are to be seen in road-cuts at 9 o'clock. (Waterside Section) |
| 53.3 | 1.1 | TURN RIGHT. In Cambrian Gatesburg sandy dolomite. |
| 53.6 | 0.3 | Settlement of Maria. We are crossing a nearly continuous exposure of Gatesburg dolomite. Best exposures are in road-cuts at 3 o'clock. This is on the east flank of Roaring Springs Anticline. |
| 55.4 | 1.8 | Approximate contact of Upper Cambrian Warrior dolomite and shale. |
| 55.6 | 0.2 | Cambrian Warrior is exposed at 3 o'clock in road-cuts. |
| 56.9 | 1.3 | Route parallels the Warrior-Gatesburg contact; road is on Warrior dolomite; wooded area ("the Barrens") at 3 o'clock is underlain by Gatesburg sandy dolomite. |

| Mileage | | |
|---|---|---|
| 57.7 | 0.8 | Junction with Pa. 867 (north). TURN RIGHT. |
| 57.8 | 0.1 | Approximately 1500 feet to the west and parallel to the road is the Bakers Summit (Halter Creek) Fault with Cambrian Warrior dolomite thrust up (on the east) into contact with Ordovician Reedsville shale. |
| 58.6 | 0.8 | Settlement of Bakers Summit. Road parallels the axis of Roaring Spring Anticline. |
| 59.3 | 0.7 | Warrior outcrops at 3 o'clock. |
| 60.5 | 1.2 | Junction. BEAR LEFT and continue on Pa. 867 (north); in Gatesburg dolomite. |
| 61.1 | 0.6 | Cambrian Gatesburg is here in contact with the Lower Ordovician Beekmantown. Mines Dolomite Member of the Gatesburg Formation may be seen. |
| 63.0 | 1.9 | Route Parallels the strike in Beekmantown - an outcrop is at 3 o'clock. |
| 63.7 | 0.7 | Entering Borough of Roaring Spring. Continue through town on Pa. 867 (north). |
| 64.5 | 0.8 | Beekmantown dolomite is exposed in road-cut at 3 o'clock, Middle Ordovician limestone at 9 o'clock. |
| 64.8 | 0.3 | Junction with Pa. 36 (north); TURN LEFT on Pa. 36. |
| 65.1 | 0.3 | New Enterprise Stone and Lime Co. at 3 o'clock. Near-vertical Middle Ordovician Limestone (Trenton, Benner and Hatter limestone formations). |
| 65.2 | 0.1 | Upper Ordovician Reedsville shale at 9 o'clock. |
| 65.5 | 0.3 | Entering McKee Gap through Evitts Mountain. We are on the steep west flank of Roaring Spring Anticline. In rapid succession the route will pass through a normal stratigraphic section from Ordovician Reedsville shale to Upper Devonian shales which occupy the center of the Reservoir Syncline. |
| 66.4 | 0.9 | Lower Devonian Ridgeley sandstone is exposed in borrow pit at 3 o'clock. Continue on Pa. 36 (north). |

Mileage

| | | |
|---|---|---|
| 67.3 | 0.9 | Junction. BEAR RIGHT and continue on Pa. 36 (north). |
| 67.4 | 0.1 | Middle Devonian Hamilton Group in road-cuts at 3 o'clock. |
| 67.7 | 0.3 | Short Mountain (a Tuscarora ridge) can be seen on skyline at 3 o'clock; the lower secondary ridge is supported by Oriskany sandstone (Ridgeley Formation). |
| 68.3 | 0.6 | Exposure of Middle Devonian Hamilton rocks at 9 o'clock; this is close to the axis of the Reservoir Syncline. |
| 70.0 | 1.7 | Middle Devonian Marcellus shale is exposed in road-cut at 9 o'clock. Our route is now traversing the east flank of the southwest-plunging nose of the Sinking Valley Anticline, the westernmost structural feature of the Nittany Anticlinorium (or Arch) at this latitude. |
| 70.5 | 0.5 | Lower Devonian Oriskany sandstone exposure. |
| 70.6 | 0.1 | Lower Devonian Helderberg limestone outcrop. |
| 70.8 | 0.2 | Silurian Tonoloway limestone exposure. |
| 71.2 | 0.4 | The Allegheny Front can be seen at 9 o'clock. |
| 71.8 | 0.6 | Upper Silurian Keyser limestone outcrops ("The Chimneys") stand out on skyline at 12 o'clock (high). |
| 72.1 | 0.3 | Entering Borough of Hollidaysburg. Continue on Pa. 36 (north); watch highway signs carefully. |
| 72.6 | 0.5 | Bridge over Beaverdam Branch of the Juniata River. |
| 73.2 | 0.6 | Route crosses south-plunging axis of Sinking Valley Anticline. |
| 73.8 | 0.6 | Junction. BEAR RIGHT and continue on Pa. 36 (north). |
| 74.1 | 0.3 | State Hospital at 9 o'clock. Route parallels Silurian Bloomsburg-McKenzie contact on west flank of Sinking Valley Anticline. Bloomsburg redbeds are to be seen at 9 o'clock, McKenzie Formation at 3 o'clock. |
| 74.7 | 0.6 | TURN RIGHT on unmarked dirt road. Traversing Silurian McKenzie Formation and Silurian Rose Hill shale. Continue straight up hill. |

Mileage

| | | |
|---|---|---|
| 75.1 | 0.4 | BEAR LEFT at road fork up slight rise to clearing. |

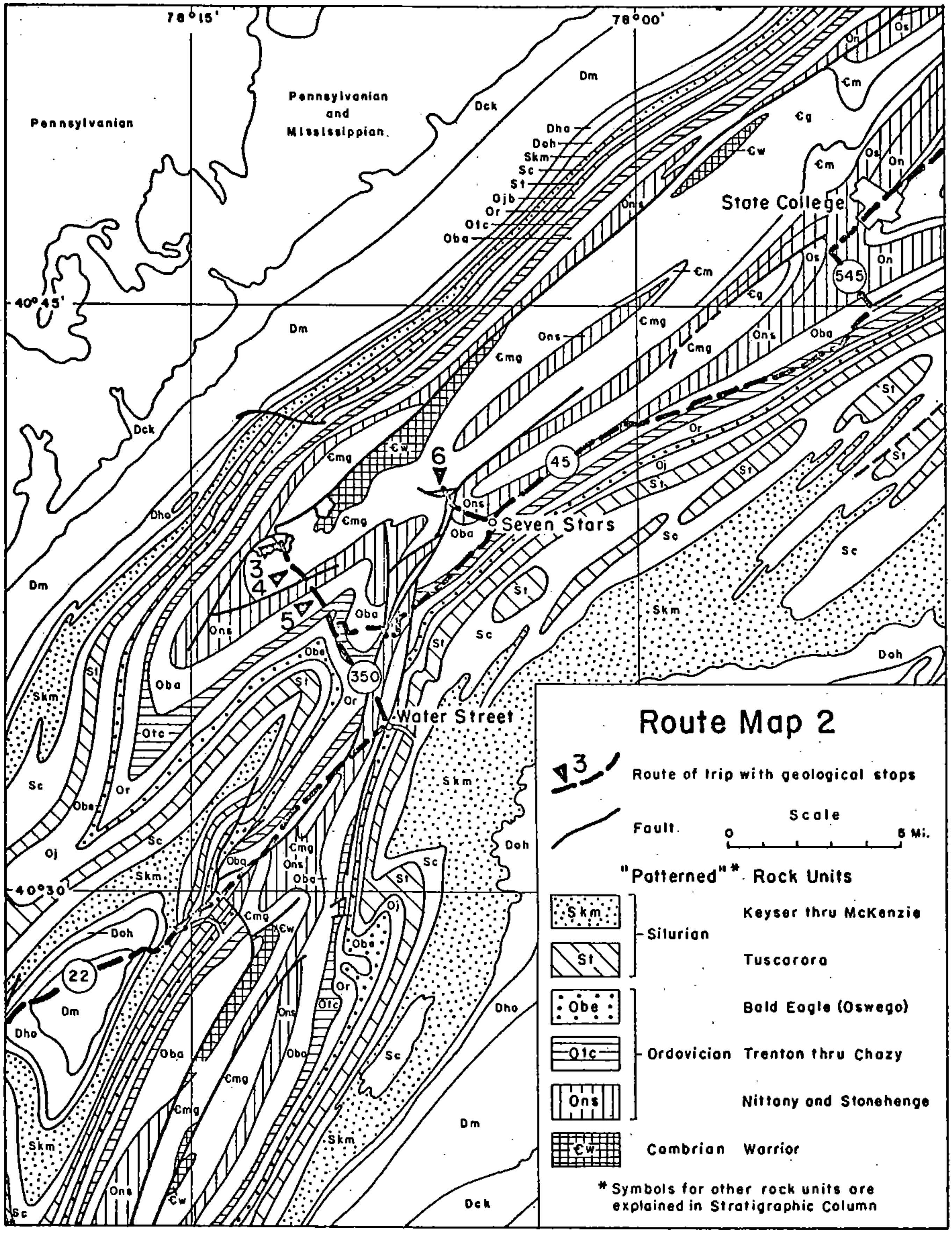
STOP II. Group Leader: Walt Skinner, Sun Oil Company
Location: Hollidaysburg Oil and Gas Company No. 1 Rankey well.

Hollidaysburg Oil and Gas Company intended the No. 1 Rankey well as a test of the Trenton on the northwest flank of the Sinking Valley Anticline. The well was spudded in the Rose Hill shale in October of 1961. Considerable difficulty was encountered with the 8" casing and water problems until a string of 7" was run in the Tuscarora at 1298'. A major thrust was encountered at 2400' and the well entered Upper Silurian Tonoloway at this depth. The Tonoloway is here an intertonguing limestone, shale, and dolomite with large calcite and anhydrite crystals, probably fracture-fill. Below the fault the well appeared to penetrate a "normal" section to the total depth of 5110' in the Tuscarora.

The well encountered no commercial shows of gas and was abandoned. (See skeletal log on page 40, and Figure 3.).

Return to paved road.

| | | |
|---|---|---|
| 75.6 | 0.5 | Junction with Pa. 36 (the paved road). TURN LEFT and retrace route previously travelled. |
| 76.5 | 0.9 | Junction. TURN LEFT around traffic island and continue on Pa. 36 (south), returning to Hollidaysburg. |
| 77.6 | 1.1 | Continue to Stop light, proceed one block straight ahead to junction with US. 22 (east) and TURN LEFT. |
| 78.2 | 0.6 | Bloomsburg redbeds in borrow pits at 3 o'clock. |
| 79.2 | 1.0 | In road-cut (Bald Hill Section) at 9 o'clock we pass, in rapid succession, southeast dipping Silurian Tonoloway and Keyser limestone, Devonian Helderberg limestone, Oriskany sandstone, limestone, and shale, Onondaga and Marcellus shale. Oriskany sandstone quarries may be seen across the river at 4 o'clock. |
| 80.4 | 1.2 | Entering the village of Frankstown. |


Route Map 2
Route of trip with geological stops
Fault
Scale
0
5 Mi.
"Patterned"* Rock Units
Skm
Keyser thru McKenzie
Silurian
St
Tuscarora
Obe
Bald Eagle (Oswego)
Otc
Ordovician
Trenton thru Chazy
Ons
Nittony and Stonehenge
Ꞓw
Cambrian
Warrior
* Symbols for other rock units are explained in Stratigraphic Column
78°15'
78°00'
40°45'
40°30'
Pennsylvanian
Pennsylvanian and Mississippian
State College
Seven Stars
Water Street
545
45
350
22

Mileage

Frankstown

The site, prior to 1748, of a Delaware-Shawnee village called Assunepachla. Here the trader, Frank Stevens, had a fur post as early as 1734. The Kittanning Path led through here.

Frankstown has lent its name to an "ore bed" of hematitic and fossiliferous sandstone once mined nearby (in the Rose Hill Formation).

Route here crosses northern termination of both the Reservoir Syncline and Roaring Spring Anticline.

| | | |
|---|---|---|
| 80.6 | 0.2 | Crossing the Frankstown Fault. (Turn to Route Map 2.) |
| 80.7 | 0.1 | At 9 o'clock, by fault repetition, is exposed the same Silurian-Devonian sequence as was seen at mile 79.2. |
| 80.9 | 0.2 | Entering village of Geeseytown. |
| 81.4 | 0.5 | Middle Devonian Hamilton shale can be seen in road-cuts. Route crosses diagonally the west flank of Scotch Valley Syncline. |
| 82.0 | 0.6 | Upper Devonian Brallier shale is exposed in road-cuts on both sides during next 2.6 miles. The type locality for the Upper Devonian Harrell shale is close by to the southeast. |
| 84.6 | 4.6 | Route crosses axis of Scotch Valley Syncline; Sinking Valley Anticline is to the west and Woodbury Anticline to the east. |
| 85.2 | 0.6 | Bridge over Canoe Creek; entering village of Canoe Creek. |
| 86.3 | 1.1 | We are now following the drainage of the Frankstown Branch of the Juniata River and the exposures are, in tight succession, from the Middle Devonian Hamilton shale to the Silurian Clinton shales. |
| 87.6 | 1.3 | Junction of US. 22 (east) and Pa. 866. BEAR LEFT and continue up the hill on US. 22 (east). |
| 87.7 | 0.1 | Crossing Jackson Fault (upthrown on east - we cross from Clinton to Bloomsburg). |

Mileage

| | | |
|---|---|---|
| 88.4 | 0.7 | Approximate Juniata-Oswego contact (to the west of the Jackson Fault). Our route moves from one side to the other of a complex fault system for the next few miles. |
| 88.6 | 0.2 | Crossing Jackson Fault into the Silurian Bloomsburg, McKenzie, and Clinton shales. |
| 89.3 | 0.7 | Crossing the West Henrietta Thrust -- we go from Silurian Clinton shale to Lower Ordovician Bellefonte dolomite. |
| 90.0 | 0.7 | Approximate contact of the Lower Ordovician Bellefonte dolomite with Nittany dolomite. |
| 91.0 | 1.0 | Approximate contact of Lower Ordovician Nittany dolomite with Cambrian Mines and Gatesburg dolomites. |
| 91.3 | 0.3 | Crossing Yellow Spring Thrust Fault -- Gatesburg (on the southeast) is thrust over Bellefonte (to the northwest). Spring at 9 o'clock marks the fault trace. |
| 91.9 | 0.6 | Etna Furnace<br>Built in 1809 by the firm of Canan, Stewart & Moore, and operated until 1877, the furnace produced some of the "Juniata iron" for which this region was famous. The furnace stack and some of the stone buildings may be seen about 1 mile to the east on a side road at 3 o'clock. |
| 94.2 | 2.3 | Road parallels Bellefonte dolomite - Axemann limestone contact. Axemann limestone is at 3 o'clock, Bellefonte dolomite at 9 o'clock. |
| 94.6 | 0.4 | Crossing Yellow Spring Thrust Fault. Nittany is thrust over Bellefonte. Route continues along on Nittany dolomite, with the Mines-Gatesburg dolomite in the paralleling ridge at 3 o'clock. |
| 96.1 | 1.5 | Approximate contact of the Nittany dolomite and the Bellefont dolomite in a fault block between the Yellow Spring Thrust Fault and the Water Street Fault which is 3 miles to the east; Bellefonte outcrops in road-cuts. |
| 96.8 | 0.7 | Crossing Water Street Fault (normal), we go from Lower Ordovician Bellefonte to Upper Ordovician Reedsville shale and Oswego sandstone. East side of fault is down relative to west side. |

| Mileage | | |
|---|---|---|
| 96.9 | 0.1 | Junction of US. 22 (east) and Pa. 350 (north). TURN LEFT at traffic island and proceed northwest on Pa. 350 (north) |
| 97.0 | 0.1 | Crossing Water Street Fault again, this time from Reedsville shale back into Bellefonte dolomite. The latter crops in road-cuts. |
| 97.7 | 0.7 | Junction of Pa. 350 (north and Pa. 45. Continue STRAIGHT AHEAD (left) on Pa. 350 (north). |
| 97.8 | 0.1 | Approximate contact of southeast-dipping Bellefonte with Nittany dolomite. |
| 98.4 | 0.6 | Crossing Yellow Spring Thrust Fault; Lower Ordovician Nittany dolomite has been thrust onto Upper Ordovician Reedsville shale. |
| 99.0 | 0.6 | Route is diagonally across the axis of a minor south-plunging anticlinal nose; Reedsville shale is beneath us here. |
| 99.2 | 0.2 | Middle Ordovician Trenton-Black River limestones, dips here are to the west off the anticlinal nose. |
| 100.1 | 0.9 | Route passes onto the new highway (Pa. 350-north) and is underlain by Reedsville shale. |
| 100.6 | 0.5 | Crossing drainage of Sinking Run; we are still in Reedsville shale; this is the approximate axis of the Scotch Valley Syncline. |
| 100.8 | 0.2 | Contact of Reedsville shale with Trenton limestone. |
| 101.0 | 0.2 | Top of Black River-Chazy group. |
| 101.2 | 0.2 | Top of Lower Ordovician Bellefonte dolomite. |
| 101.5 | 0.3 | Bridge over Little Juniata River. Junction Pa. 45. Continue STRAIGHT AHEAD. |
| 101.7 | 0.2 | Top of Nittany dolomite. |
| 102.3 | 0.6 | Crossing Shoenberger Thrust Fault - Nittany is thrust over Lower Ordovician Stonehenge. |
| 102.6 | 0.3 | Cambrian Gatesburg is exposed in cut at 3 o'clock. |
| 103.1 | 0.5 | Crossing the axis of Sinking Valley Anticline - in Gatesburg dolomite. |

Mileage

| | | |
|---|---|---|
| 103.4 | 0.3 | Crossing Birmingham Thrust Fault; Gatesburg dolomite is thrust north over Middle Ordovician limestones. |
| 103.7 | 0.3 | Birmingham Junction. |
| 103.8 | 0.1 | TURN LEFT onto bridge over Little Juniata River; proceed on dirt road through railroad underpass. |
| 103.9 | 0.1 | BEAR RIGHT and stop at railroad tracks. |

(Buses will stop prior to railroad underpass and passengers will follow group leader on foot.)

STOP III.

Proceed southeast along railroad right-of-way approximately 1500 feet to observe Birmingham Thrust Fault.

The following description has been taken from a paper written by Moebs, N. N. and Hoy, R. B., in 1959 ("Thrust faulting in Sinking Valley, Blair and Huntingdon Counties, Pennsylvania", Geol. Soc. Amer. Bull., v. 70, p. 1079-1088).

GEOLOGY OF THE SINKING VALLEY AREA

The stratigraphy and the general structural relationships of the Sinking Valley area are described by Butts, et al. (1939, p. 1-78). The formations are included in the Cambrian, Ordovician, and Silurian systems. The oldest formation is the Upper Cambrian Warrior Limestone exposed along the axis of the Sinking Valley Anticline extending northwestward from a point about amile northeast of Birmingham. The youngest formation is the Silurian Tuscarora Sandstone which forms the summits of the mountains that surround the valley. The older units, up through the Ordovician Trenton Group, consist mainly of dolomites with subordinate formations and members of limestone. The younger units, the Ordovician Reedsville Shale, Oswego Sandstone and the Juniata Formation, consist of shale and sandstone.....

STRUCTURES

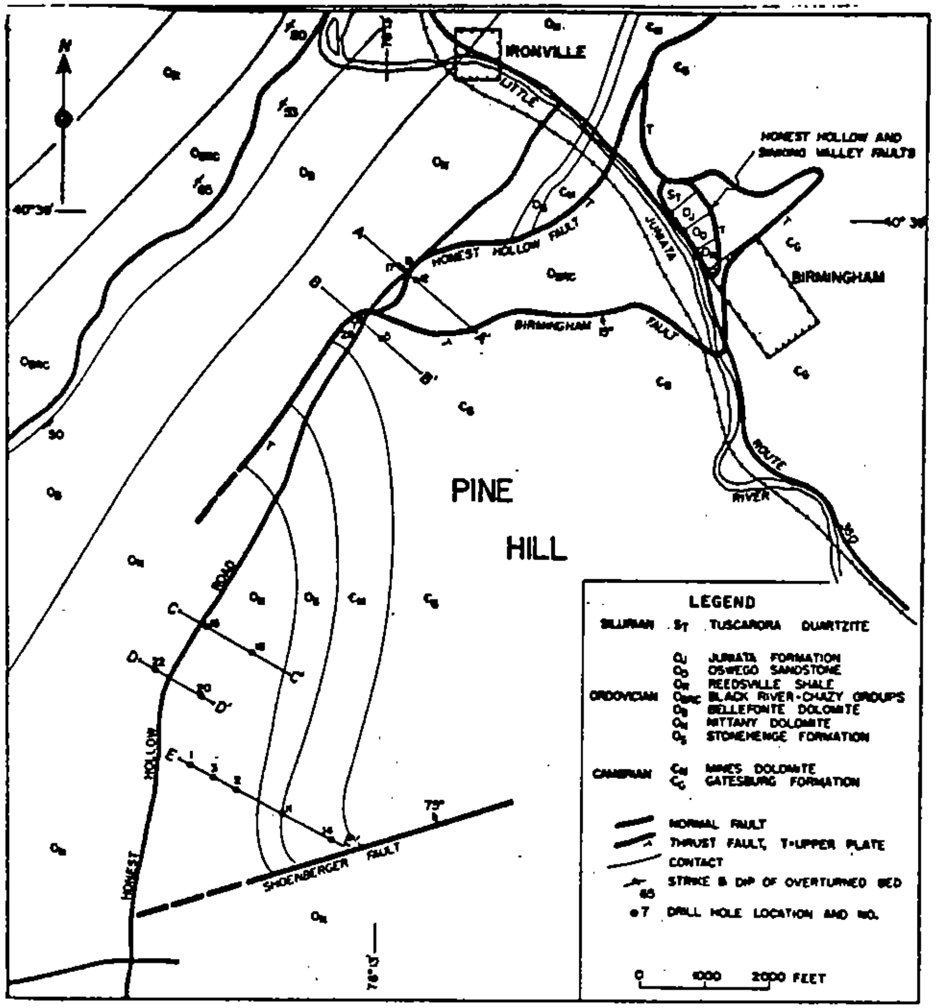
Butts et al. (1939, p. 75-78) point out that the area is located on the summit and flanks of the Nittany Arch, which is an anticlinorium extending for more than

80 miles northwestward. (See Route Map 2.) In cross section the arched form is modified by faults and minor undulation superposed on the major structures. The Sinking Valley Anticline represents the southwest extremity of the apex of the Arch. It is asymmetrical, overturned to the northwest. It is complicated by faulting along its axis where the Birmingham fault thrusts older formations to the northwest. The exposures of younger rocks at Birmingham and at the Knarr fenster, a little more than a mile northeast of Birmingham, indicate that additional faulting of considerable magnitude took place, but as Butts et al (1939, p. 78) stated, ".... no satisfactory explanation of the entire situation has yet been reached."

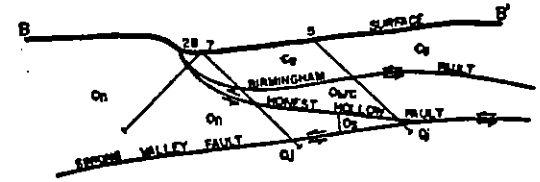
## ANALYSIS OF DRILLING INFORMATION

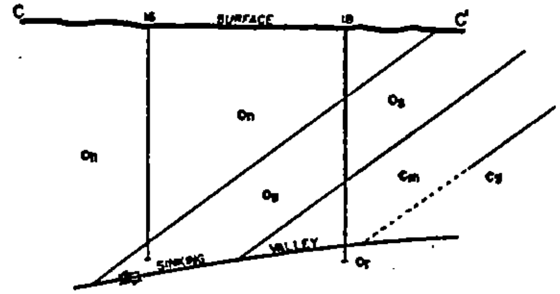
A series of exploration holes drilled west and southwest of Birmingham in 1956 provided information revealing the existence of a gently arched fault under the area (Fig. 4), which the authors named the Sinking Valley Fault. Eight holes reached sufficient depth to penetrate the fault, which is evidenced by abundant fracturing and recementation, grooving, polishing, and abrupt change in stratigraphy. Each hole cored black shale or red and green sandstone and shale under the fault in contact with Nittany dolomite or Stonehenge limestone above. The rocks cored under the fault have been tentatively identified as Reedsville shale and Juniata Formation on the basis of color and composition. These rocks correspond to the two formations observed in the Birmingham exposures, which have been identified by Butts, Zeller, and others as Reedsville and Juniata.

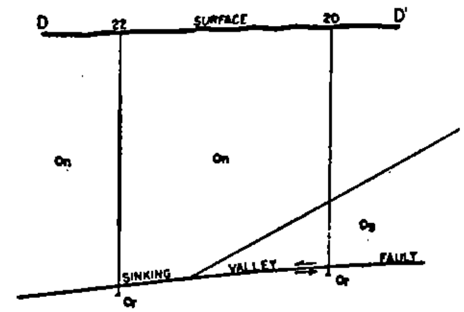
Recognition of the Sinking Valley Fault permits a relatively simple explanation for the presence of the younger rocks in the Birmingham area. The two exposures are fensters through an upwarped thrust fault which has an axis nearly coincident with that of the Sinking Valley Anticline. A net displacement of 2 miles on the Sinking Valley Fault would account for the position of the Tuscarora in the fenster relative to the Tuscarora of the upper block northwest at Brush Mountain. The other thrusts are lesser southeast-dipping branches of the main break. The Birmingham Fault has relatively little displacement and can logically die out to the southwest as mapped by Butts et al. (1939, p. 78). The slice under the Birmingham Fault, consisting largely of brecciated limestone, is probably the Black River-Chazy sequence, or possibly Stonehenge, in a horse dragged

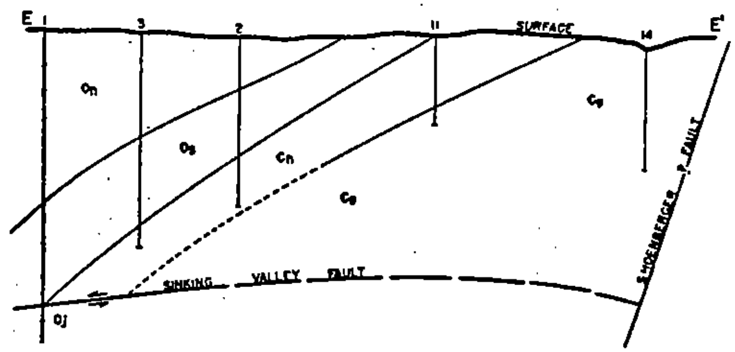


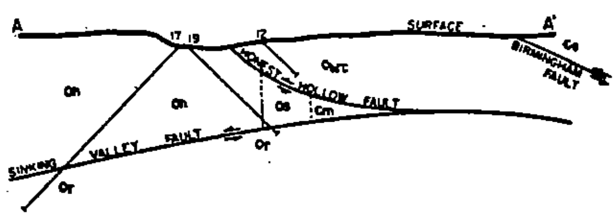

Geologic Map of Sinking Valley Showing Diamond-Drill-Hole Locations




|–300 Ft.–|

## STOP III

Diamond-Drill-Hole Sections Showing Structure at Sinking Valley, Pennsylvania

Taken from figures 6 & 7 in Moebs and Hoy (G.S.A. Bulletin; 1959; Vol. 70; PP. 1085-86)

Figure 4

along between the Birmingham and the lower branch-fault, which was recognized by Zeller (1949, M.S. thesis, Pa. State Univ., p. 19) and is here named the Honest Hollow Fault. This slice has been thrust between the Gatesburg above and the Mines, Stonehenge, and Nittany below. The relatively large volume of limestone in the slice compared to the narrow trace of the Black River-Chazy sequence against the fault requires either that another thicker limestone unit is involved (for example, the Stonehenge) or that the Black River-Chazy sequence was intercepted where the dip is more gentle than indicated on the sections. Little is known regarding the structure of the under block. The strike component of the thrust offset may be so large that a gently dipping part of the structure is present under the Sinking Valley Fault. Section A-A' (Fig. 4) illustrates the Sinking Valley Fault, below and the Honest Hollow Fault branching therefrom to the surface, overlain by the Black River-Chazy sequence, and, near A' the Birmingham Fault overlain by Gatesburg. Section B-B' is similar, except that it illustrates the manner in which the Black River-Chazy block pinches out where the Honest Hollow and Birmingham faults rejoin near the surface.

Comparison of sections shows that the trace of the Sinking Valley Fault becomes progressively deeper to the southwest, which indicates that the "arch" of the fault, like the axis of the anticline, plunges southwest. The fault also dips northwestward from the fensters without causing any recognized stratigraphic breaks; it must continue subsurface under the Bald Eagle Valley and, unless it steepens or dies out along bedding, under the Allegheny Plateau.

This type of fault, having no apparent surface expression except that of the accident of erosion at the fensters, is unusual but not unique, because Rodgers described (1950, p. 680) and illustrated (p. 678, Fig. 3) an almost identical fault in the Sequatchie Anticline area of Tennessee. He states:

> "If they are windows, they have been eroded through a thrust fault that disappears northwestward, its displacement having been taken up in the arching along the Sequatchie Anticline and the folds farther northwest."

Mileage

Hayes (1891, p. 141-152) was the first to describe low-angle thrust faults in the southern Appalachians of great lateral displacement with the fault surfaces commonly warped. Rodgers (1949, p. 1649) noted that faults such as Hayes described have been found in many parts of the southern and northern Appalachians, whereas in the folded middle Appalachians, where the structure is simpler, large low-angle faults have nowhere been recognized. Rodgers was notably perceptive when he stated:

> "....the faulted area on the Nittany Anticline at Birmingham, Pennsylvania,.... strongly suggests low-angle faulting to a geologist who has worked among the low-angle thrust faults of east Tennessee."

Sterns (1955, p. 620-625) describes a number of low-angle thrust faults in the Cumberland Plateau of Tennessee. These differ from the Sinking Valley Fault in that they commonly show a low angle of faulting relative to bedding, and the beds above the fault planes are characteristically crushed, whereas at the Birmingham fenster the rocks below, as well as above, the Sinking Valley Fault are intensely crushed and thinned, and the angle of faulting relative to the bedding is large.....

104.1 0.2 Junction again with Pa. 350 (south). Stop. Exposure ahead, starting at 10 o'clock, is an overturned sequence from Silurian Tuscarora sandstone through the Upper Ordovician Juniata and Oswego, to the Reedsville shale. (This is in the over-ridden block).

TURN RIGHT and proceed on Pa. 350 (south).

104.7 0.6 Pull off highway to left and park on berm. Follow group leader to observe Gatesburg crop in curve straight ahead. Please observe extreme CAUTION and remain off the highway. Heavy and high-speed traffic area.

STOP IV. Group Leader: Dick Frost, Shell Oil Company

The Middle and Upper Cambrian in the Tyrone Quadrangle are composed of four formations (Butts, 1939). From older to younger these are the Pleasant Hills Formation (thickness unknown), the Warrior dolomite (1200'), the Gatesburg dolomite (1750'), and the Mines dolomite (250').

Mileage

The upper 1000 feet of the Gatesburg dolomite crops out in this exposure on the east flank of the Sinking Valley Anticline. (See Wagner paper, Fig. 1, sec. 3, page 4.

The lower part of the outcrop is composed of cyclic sequences of partly cross-bedded quartz sandstone, sparry oolite, and extremely fine-grained stromatolitic dolomite (dolomitized lime mud). A depositional environment of shallow water and the presence of currents are indicated by the sandstone and oolite; shallow water or subaerial exposure are suggested by the presence of intraformational conglomerates, stromatolites, burrowing, and mud cracks.

Overlying this unit is an interval of very fine to fine-grained dolomite containing some surface porosity. It is massive, lacks sedimentary structures, contains questionable relicts of shells, pellets, and ooliths.

The upper third of the outcrop is again interbedded sandstone, oolite, and dolomitized mud, containing shallow water sedimentary features.

105.3 0.6 Top of Gatesburg dolomite.

105.5 0.2 Basal Nittany dolomite is exposed in road-cut.

105.7 0.2 Pull off highway to right and park on road shoulder. Follow group leader to observe continuous section through Lower Ordovician Nittany dolomite, Bellefonte dolomite, and Middle Ordovician limestones to Reedsville shale. Please observe extreme CAUTION and remain off the highway. Heavy and high-speed traffic area. Buses will proceed ahead and pick up group at end of section.

STOP V. Group Leader: Dick Frost, Shell Oil Company

The Beekmantown in the Tyrone Quadrangle (Butts, 1939) is made up (from older to younger) of the Stonehenge limestone tongue (400'), the Nittany dolomite (1250'), the Axemann limestone tongue (0-200'), and the Bellefonte dolomite (1500'). It is overlain by about 1200' of Middle Ordovician limestones which have a complex nomenclature.

We will start at the base of the Nittany and walk up through a monotonous 3800' section of lithified carbonate mud. The main visible difference between the Nittany

Mileage

and the Bellefonte is a small change in grain size--the Nittany having a slightly less fine texture, on the average, than the Bellefonte. The lower half of the Nittany is extremely fine-grained dolomite (dolomitized lime mud), with interbeds of darker colored very fine to fine-grained dolomite containing relicts of pellets and shells. The frequency of these latter beds decreases upwards, and the upper half has an increasing amount of extremely fine-grained to sublithographic, featureless dolomite. Burrowed layers, occasional stromatolites, and clast zones indicate shallow water deposition.

The Bellefonte is composed of the extremely fine-grained to sublithographic dolomite with only rare interbeds of the larger-grained type. Several hundred feet at the top consist of light-colored sublithographic dolomite with conchoidal fracture. Sedimentary features are hard to find in this outcrop because of its freshness, and are more evident on weathered exposures elsewhere in the general area. Shallow water deposition is indicated by occasional stromatolites, clast zones, and mud cracks.

The contact of the Bellefonte and the Middle Ordovician is placed at the change from dolomite to limestone. In this exposure the change is gradational, and a bentonite bed is present at the approximate contact. Several weathered layers with a total of 10 to 15 feet of vuggy porosity are present in the upper 100 feet of the Bellefonte.

The lower 700 feet (Chazy-Black River) of the Middle Ordovician consist mainly of gray to light tan, sublithographic lithified lime mud, with common layers of fossiliferous intraformational conglomerate. There are several bentonite beds near the top of this unit.

The upper 400 feet (Trenton) are composed of dark gray, sublithographic to extremely fine-grained lithified lime mud. The limestones are thin-bedded, the lower half being featureless, the upper half containing shell fragments and an occasional intraformational conglomerate. Shale interbeds increase near the top, and the contact with the Reedsville shale is at the southeast end of the outcrop.

106.9 1.2 End of divided portion of highway.

107.4 0.5 TURN LEFT on unnumbered road.

| Mileage | | |
| --- | --- | --- |
| 107.7 | 0.3 | TURN RIGHT - route is in Reedsville shale on axis of Scotch Valley Syncline. |
| 107.9 | 0.2 | Middle Ordovician limestone exposed here is on east flank of Scotch Valley Syncline. |
| 108.2 | 0.3 | Village of Union Furnace; BEAR LEFT (at road fork) toward Spruce Creek. |
| 108.4 | 0.2 | Lower Ordovician Bellefonte dolomite on west flank of the minor south-plunging anticlinal nose which was seen earlier (at "mile 99"). |
| 109.2 | 0.8 | Approximate axis of the unnamed anticline - in Bellefonte dolomite. |
| 109.4 | 0.2 | Bellefonte dolomite crop at 3 o'clock. |
| 109.6 | 0.2 | Railroad underpass. Crossing through an imbricate zone of the Yellow Spring Thrust Fault -- Nittany dolomite on east thrust over Bellefonte dolomite on west. |
| 109.8 | 0.2 | Junction; stop, and then continue STRAIGHT AHEAD on Pa. 45 (north), crossing the second zone of the Yellow Spring Thrust Fault -- Stonehenge limestone is thrust to the west over Nittany dolomite. |
| 109.9 | 0.1 | Nittany dolomite outcrop. |
| 110.1 | 0.2 | Entering village of Spruce Creek. Caution, sharp left turn onto narrow bridge over Little Juniata River; continue on Pa. 45 (north) travelling in Nittany dolomite. |
| 110.7 | 0.6 | Nittany dolomite is in road-cut at 9 o'clock. |
| 111.3 | 0.6 | Crossing Water Street Fault (normal); we cross from Nittany dolomite to Reedsville shale (down to the east). |
| 112.2 | 0.9 | Middle Ordovician limestone crops at 9 o'clock. |

## Coleraine Forges

Nearby are sites of two forges, built in 1805 and 1809 by Samuel Marshall. "Juniata iron" became famous as a high-grade of "charcoal iron" during the era from 1790 to 1850. Spruce Creek was noted for its iron works.

Mileage

| | | |
|---|---|---|
| 112.9 | 0.7 | Middle Ordovician limestone quarry at 9 o'clock. Southeast dip on flank of Pennsylvania Furnace Anticline. |
| 113.5 | 0.6 | Bridge over Warriorsmark Creek; road parallels Spruce Creek. |
| 113.7 | 0.2 | Ridge on the skyline at 2 o'clock is one formed by the Tuscarora; lower secondary ridge is Oswego-supported. The Tuscarora dips to the southeast into the topographically high Barree Syncline. Route continues in Middle Ordovician limestone. |
| 114.3 | 0.6 | Entering village of Franklinville. Indian Cavern at 3 o'clock. The cave is developed along bedding planes and parallel joints at right angles to the bedding in Middle Ordovician Trenton limestone. Bedding dips 40° to the southeast. |
| 115.3 | 1.0 | Contact of Middle Ordovician limestones with Bellefonte dolomite. |
| 115.6 | 0.3 | Seven Stars Junction. TURN LEFT around traffic island and continue on unnumbered country road toward Warriorsmark. Route passes over poor outcrop area of Bellefonte dolomite, Axemann limestone and Nittany dolomite on the southeast flank of the Pennsylvania Furnace Anticline. |
| 116.5 | 0.9 | Approximate axis of southwest-plunging Pennsylvania Furnace Anticline - in Nittany dolomite. |
| 116.9 | 0.4 | Crossing the Grazier Mill fault complex; we cross from Nittany dolomite to a slice of Middle Cambrian Pleasant Hill limestone which is caught in a horst. |
| 117.0 | 0.1 | Upper Cambrian Gatesburg dolomite - to the west of the horst block. |
| 117.5 | 0.5 | Approximate southern termination of the Gatesburg Anticline and the Marengo Syncline. We are still in Gatesburg dolomite. |
| 118.1 | 0.6 | Gatesburg outcrops in road-cut at 9 o'clock. |
| 118.8 | 0.7 | Pull off highway to right and park on shoulder. Follow group leader to observe a partial section of the Upper Cambrian Warrior dolomite exposed along the crest of Sinking Valley Anticline. Exposures are in road-cuts at right of road. |

Mileage

STOP VI. Group Leader: Dick Frost, Shell Oil Company

The Warrior is about 1200 feet thick (Butts, 1939). The top 500 feet are exposed in this outcrop. These rocks were deposited in an environment of shallow water that may, at times have been subaerially exposed, and they are composed mainly of extremely fine-grained, dark gray dolomite (dolomitized lime mud). Cyclic interbeds of quartz, sandstone, oolite, and extremely fine-grained algal dolomite are present in the lower part of the exposure. Stromatolites and intraformational conglomerate are common, with occasional burrowings, mud cracks, thin layers of dark gray shale, and some lithified lime mud.

119.0 0.2 TURN LEFT on old highway and make a U-turn. Return to Pa. 45 (east) at Seven Stars Junction.

122.5 3.5 Seven Stars Junction "stop sign". TURN LEFT on Pa. 45 (east) heading toward State College. In Bellefonte dolomite. Road parallels the strike (here in the Beekmantown Group) on the east flank of Pennsylvania Furnace Anticline.

125.8 3.3 Southeast-dipping Nittany dolomite in road-cuts on both sides of the route.

126.2 0.4 Entering village of Graysville. Lower Ordovician Stonehenge "ribboned" limestone is exposed in road-cuts on both sides of highway.

The Stonehenge is a limestone tongue which thickens toward the east and southeast, and is correlated with the Stonehenge of the Great Valley. It is derived from lithographic to sublithographic lime mud, deposited in shallow water with subaerial exposure, and contains abundant flat pebble conglomerate, stromatolites, fossiliferous layers, and occasional mud cracks. Laminations and thin beds of buff-weathering dolomite give it a characteristic banded or ribbon-like appearance. Toward the southwest it changes, becoming a fine to medium-grained dolomite called "Larke". (See Wagner paper, Fig. 2, page 6.

127.0 0.8 Stonehenge-Nittany contact. Route continues in Nittany dolomite.

128.1 1.1 Junction to village of Pennsylvania Furnace.

| Mileage | | Pennsylvania Furnace |
|---|---|---|
| | | Some of the remaining buildings here were part of the ironworks established about 1810. Operating first as a charcoal iron "manufactory", the furnace later used coke. Iron was made here as late as 1888. |
| 128.8 | 0.7 | In southeast-dipping Bellefonte dolomite. |
| 130.5 | 1.7 | Bellefonte dolomite. |
| 131.1 | 0.6 | Route continues across typical Beekmantown "no-crop" area (in Nittany dolomite). Mountain at 3 o'clock is Tussey Mountain, a Tuscarora ridge; secondary ridge is supported by Ordovician Oswego sandstone and Juniata Formation. |
| 132.1 | 1.0 | Middle Ordovician Black River-Chazy limestone interval. |
| 134.7 | 2.6 | Entering the village of Pine Grove Mills. Continue on Pa. 45 (east). In Black River-Chazy limestone. |
| 135.6 | 0.9 | Approximate contact of Middle Ordovician Black River-Chazy limestone with Lower Ordovician Bellefonte dolomite. |
| 136.4 | 0.8 | Junction Pa. 45 and Pa. 26 (north). TURN LEFT and continue on Pa. 26. Route proceeds up southeast flank of Penn Valley Anticline in Bellefonte dolomite. |
| 136.6 | 0.2 | Bellefonte-Axemann contact. |
| 136.8 | 0.2 | Axemann-Nittany contact. |
| 137.5 | 0.7 | Approximate axis of Penn Valley Anticline, in Nittany dolomite. |
| 138.0 | 0.5 | Approximate axis of Nittany Mountain Syncline, in Nittany dolomite. Route continues up the southeast flank of the northeast plunging Pennsylvania Furnace Anticline. |
| 138.5 | 0.5 | Continue on Pa. 26 (north). Route parallels strike in the Nittany dolomite. Nittany Mountain Syncline at 3 o'clock, Pennsylvania Furnace Anticline at 9 o'clock. |
| 139.5 | 1.0 | Entering Borough of State College. Continue straight through town to intersection with South Garner Street. |

| Mileage | | |
|---|---|---|
| 141.0 | 1.5 | Intersection with South Garner Street. TURN LEFT onto Pennsylvania State University campus. Continue straight ahead to stop sign in front of McElwain Hall. |
| 141.3 | 0.3 | TURN RIGHT and proceed to Pollock Hall. You'll be sleeping on Nittany tonight. |

END OF FIRST DAY'S TRIP

SECOND DAY

ROAD LOG, FRIDAY, SEPTEMBER 20, 1963

Mileage - 180.6 miles

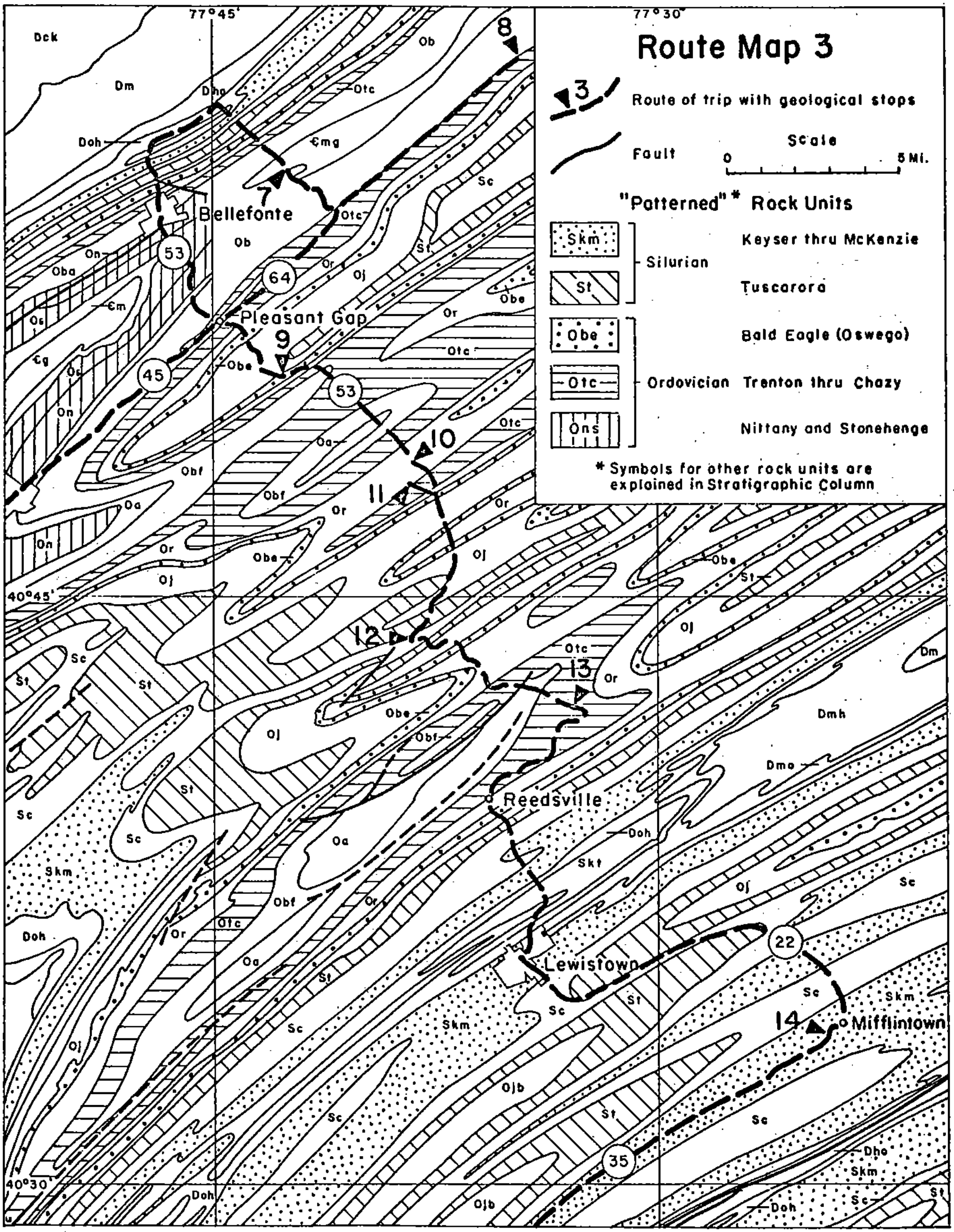
Buses will line up in parking space in front of Pollock Hall #5 for departure at 8:30 AM.

| Mileage | | |
|---|---|---|
| 0.0 | | Mileage check begins at "Stop" sign in front of Pollock Hall #5. (Turn to Route Map 3.) TURN RIGHT. |
| 0.1 | 0.1 | Intersection. BEAR LEFT. |
| 0.2 | 0.1 | Penn State Nuclear Lab. Facility at 3 o'clock. |
| 0.3 | 0.1 | Stop sign. TURN RIGHT. |
| 0.6 | 0.3 | TURN RIGHT on Pa.-26 (North). This is the cloverleaf approach at the far end of overpass, to join Pa.-26 (North) heading toward Bellefonte. |
| 0.9 | 0.3 | Lower Ordovician Axemann limestone in road-cuts at 9 o'clock. Good view of Nittany Mt. at 2 o'clock. It is a synclinal mountain with the Oswego sandstone forming the resistant rim. |
| 1.2 | 0.3 | Centre Furnace at side of road at 9 o'clock. |

CENTRE FURNACE

Here Cols. John Patton and Samuel Miles operated the first charcoal iron furnace in the region (1792-1809). Present stack was used from 1825 to 1855. In this era, Centre County led in the making of "Juniata iron."

| | | |
|---|---|---|
| 1.3 | 0.1 | Contact of Axemann limestone with Bellefonte dolomite. Route parallels strike of southeast dipping Bellefonte between Gatesburg Anticline (at 9 o'clock) and Nittany Mountain Syncline at 3 o'clock. |


Route Map 3
Route of trip with geological stops
Fault
Scale
0
5 Mi.
"Patterned"* Rock Units
Skm
St
Silurian
Keyser thru McKenzie
Tuscarora
Obe
Otc
Ons
Ordovician
Bald Eagle (Oswego)
Trenton thru Chazy
Nittany and Stonehenge
* Symbols for other rock units are explained in Stratigraphic Column
77°45'
77°30'
40°45'
40°30'
Bellefonte
Pleasant Gap
Reedsville
Lewistown
Mifflintown
53
64
45
22
35
7
8
9
10
11
12
13
14

| Mileage | | |
|---|---|---|
| 2.3 | 1.0 | Bellefonte dolomite in road-cuts on both sides of highway. |
| 2.9 | 0.6 | Crossing over Spring Creek. |
| 3.8 | 0.9 | Junction of Pa.-26 (North) with Pa.-64 (North). BEAR RIGHT and continue on Pa.-64 (North). Route continues in Bellefonte dolomite. |
| 6.1 | 2.3 | Front entrance of Rockview State Penitentiary. Buildings are underlain by the upper part of the Bellefonte dolomite which forms a subdued ridge within the valley. |
| 6.7 | 0.6 | Route parallels the contact between the Lower Ordovician Bellefonte dolomite and the Middle Ordovician Loysburg (Chazy) limestone. Loysburg limestone is at 9 o'clock, Bellefonte dolomite at 3 o'clock. |
| 8.0 | 1.3 | Standard Lime and Cement Company's Whiterock quarries (Middle Ordovician Limestone) at 3 o'clock. |
| 8.1 | 0.1 | Junction of Pa.-64 with Pa.-53. TURN LEFT on Pa. -53. Village of Pleasant Gap. Route proceeds northwest on Pa.-53 over the southeast flank of the Gatesburg Anticline. |
| 8.6 | 0.5 | State Fish Hatchery at 9 o'clock in Bellefonte dolomite. |
| 9.1 | 0.5 | East-dipping Axemann Limestone. |
| 9.3 | 0.2 | Nittany dolomite. |
| 9.9 | 0.6 | Village of Axemann, in Nittany dolomite. |
| 10.3 | 0.4 | Concealed contact between Stonehenge limestone and Nittany dolomite. |
| 10.4 | 0.1 | Stonehenge crops at 3 o'clock. |
| 10.8 | 0.4 | Stonehenge crops at 3 o'clock. |
| 10.9 | 0.1 | Cambrian Mines dolomite in cuts at 3 o'clock. |
| 11.4 | 0.5 | Crossing axis of Gatesburg Anticline. |

Mileage

| | | |
|---|---|---|
| 11.6 | 0.2 | Gatesburg at 3 o'clock. |
| 11.8 | 0.2 | Outcrop of steep northwest-dipping Stonehenge limestone. |
| 12.0 | 0.2 | Entering Borough of Bellefonte. |
| 12.1 | 0.1 | Crossing the approximate trace of the Birmingham Fault, in Nittany dolomite. |
| 12.4 | 0.3 | Junction. Leave Pa.-53 and continuing STRAIGHT AHEAD to "Stop" at West Lamb Street. |
| 12.7 | 0.3 | "Stop" sign at West Lamb Street. TURN LEFT and proceed one block to "Stop" sign. |
| 12.8 | 0.1 | "Stop" sign. TURN RIGHT and continue to junction with Pa.-53 (West). |
| 13.0 | 0.2 | Junction Pa.-53 (West). Stop and proceed STRAIGHT AHEAD in Bellefonte dolomite. |
| 13.2 | 0.2 | Middle Ordovician limestone quarry at 3 o'clock. |
| 13.4 | 0.2 | Upper Ordovician Reedsville shale at 3 o'clock. |
| 14.1 | 0.7 | Upper Ordovician Oswego sandstone at 3 o'clock. |
| 14.2 | 0.1 | Upper Ordovician Juniata Formation at 3 o'clock. |
| 14.5 | 0.3 | The Lower Silurian Tuscarora sandstone can be seen high on the ridge of Bald Eagle Mountain at 8 o'clock, but is not apparent along the road. |
| 14.7 | 0.2 | Entering Borough of Milesburg. |
| 15.2 | 0.5 | Junction of Pa.-53 with U.S.-220. TURN RIGHT and continue on U.S.-220. |
| 15.8 | 0.6 | Bald Eagle Mountain on skyline at 12 o'clock paralleling highway is a Tuscarora-supported ridge. Low ridges at 9 o'clock are in Upper Devonian Harrell and Brallier shales and mark the base of the Allegheny Front. |

Mileage

| | | |
|---|---|---|
| 17.7 | 1.9 | Lower Devonian Helderberg limestone is to be seen in road-cut at 3 o'clock. |
| 18.1 | 0.4 | Lower Devonian Oriskany sandstone quarry at 9 o'clock. |
| 18.2 | 0.1 | TURN RIGHT on dirt road at northeast end of bridge. (Very tight turn for buses). Route proceeds south through Bald Eagle Mountain, following the drainage of Nittany Creek through Curtin Gap. We are moving up the west flank of the Gatesburg Anticline, passing through section from Lower Devonian Oriskany sandstone to Lower Ordovician Stonehenge limestone. |
| 18.8 | 0.6 | Crossing poor outcrop area underlain by Lower Devonian, Upper and Middle Silurian rocks. |
| 19.8 | 1.0 | Bridge over Nittany Creek. |
| 20.1 | 0.3 | Overturned Reedsville shale can be seen behind the shed at 3 o'clock. |
| 20.2 | 0.1 | Middle Ordovician limestone quarry at 9 o'clock; dip is 85° NE (overturned). |
| 20.3 | 0.1 | Junction with paved highway. Stop. TURN LEFT. Route parallels Middle Ordovician-Lower Ordovician contact. |
| 20.6 | 0.3 | Tree-covered hill at 2 o'clock, Sand Ridge, is upper Cambrian Gatesburg sandy dolomite and displays a typical Gatesburg outcrop and associated vegetation, referred to as "the barrens." |
| 21.0 | 0.4 | TURN RIGHT on unmarked paved road. |
| 21.1 | 0.1 | Bellefonte dolomite is in road-cut at 9 o'clock. |
| 21.2 | 0.1 | Nittany dolomite in road-cut at 3 o'clock is dipping 85° northeast (overturned). |
| 21.3 | 0.1 | Stonehenge limestone is dipping 85° northeast (overturned). |
| 21.6 | 0.3 | Stonehenge limestone outcrops in road-cuts. |

Mileage

21.7 0.1 Lower Ordovician Stonehenge in contact with Upper Cambrian Mines-Gatesburg.

21.8 0.1 Mines dolomite crops out in road-cut at 3 o'clock. It is a gently dipping black oolitic dolomite; localized porosity development has been noted in this section.

22.0 0.2 Crossing Sand Ridge which marks the axis of the Gatesburg Anticline.

22.2 0.2 STOP VII. Group Leader - Dick Frost, Shell Oil Company. Follow group leader to observe crops of oolitic chert in the Mines dolomite, and quartzose and dolomitic sands of the Gatesburg Formation.

Approximately 125 feet of weathered dolomite are exposed here on the southeast flank of the Gatesburg Anticline. The outcrop is dominated by sparry oolite and fine-grained "relict?" dolomite, with interbeds of extremely fine dolomite (dolomitized lime mud). Approximately half of the exposure has intercrystalline and vuggy porosity. Oolitic chert, cross-bedded quartz sandstone, and intraformational conglomerates are present. Gatesburg sandstones crop out at the base of the exposure.

22.5 0.3 That was the last Cambrian exposure that we will se in the Nittany Arch region. We are now passing over Stonehenge limestone.

22.9 0.4 Stonehenge limestone is in road-cut outcrop at 9 o'clock. Route continues over weak outcrop area in the Beekmantown dolomite.

24.2 1.3 Entering the village of Zion. TURN LEFT at "Stop" sign onto Pa.-550 (North).

24.7 0.5 Junction of Pa.-550 with Pa.-64. Stop. Continue STRAIGHT AHEAD on Pa.-64 (North). Route continues along strike, in Beekmantown dolomite, roughly parallel to the Middle Ordovician contact at 3 o'clock.

| Mileage | | |
|---|---|---|
| 26.6 | 1.9 | Cross road to Mingoville; continue STRAIGHT AHEAD. |
| 28.7 | 2.1 | Cross road to Hublersburg; continue STRAIGHT AHEAD on Pa.-64 (North). |
| 29.4 | 0.7 | Junction of Pa.-64 with Pa.-445; continue STRAIGHT AHEAD on Pa.-64. |
| 30.0 | 0.6 | Beekmantown dolomite outcrops in road-cut at 9 o'clock. |
| 31.5 | 1.5 | STOP VIII. Group leader - Dick Frost, Shell Oil Company. Follow group leader to observe well developed porosity in Bellefonte dolomite. |

About 300 feet of section (near the top of the formation) are exposed 150 feet on the northwest side of the road, and 150 feet above this on the southeast side. Approximately 100 feet of this outcrop contain intercrystalline and vuggy porosity. Very fine to fine-grained dolomite with relicts of pellets, ooliths, and shells, is interbedded with extremely fine to sublithographic dolomite, and occasional limestones.

Retrace route and continue south toward Pleasant Gap via Pa.-64 (South).

| | | |
|---|---|---|
| 38.2 | 6.7 | Junction of Pa.-64 with Pa.-550. BEAR LEFT and continue on Pa.-64. |
| 38.7 | 0.5 | Route parallels the strike in Middle Ordovician limestone near the contact with the Lower Ordovician Bellefonte (at 3 o'clock). Oswego (Bald Eagle) sandstone holds up the Nittany Mountain (a syncline) at 9 o'clock. |
| 40.9 | 2.2 | Standard Lime and Cement Company rotary kilns can be seen at 3 o'clock. |
| 42.8 | 1.9 | Standard Lime and Cement Company's Whiterock Quarries at 9 o'clock. |
| 43.2 | 0.4 | Entering village of Pleasant Gap. |

Mileage

43.7 0.5 Junction of Pa.-64 with Pa.-53. TURN LEFT and proceed southeast on Pa.-53 (South). Route will pass rapidly through weak exposures of Trenton Reedsville and Oswego (Bald Eagle) formations along the drainage of Gap Run. The center of Nittany Mountain Syncline (on this route) is occupied by the Upper Ordovician Juniata Formation.

46.0 2.3 Upper Ordovician Juniata road-cut exposures.

46.3 0.3 Tuscarora sandstone ridge on skyline at 10 o'clock marks axis of Nittany Mountain Syncline. A bit beyond the skyline the Clinton Formation is the youngest unit in the syncline.

46.8 0.5 STOP IX. Group leader - Dr. Richard P. Nickelsen, Chairman of the Department of Geology and Geography, Bucknell University.

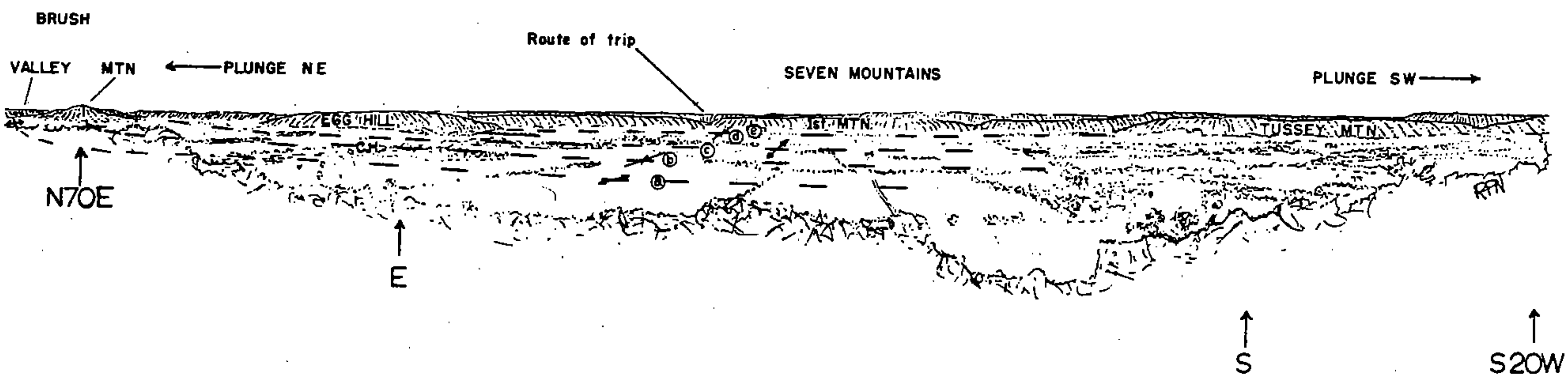
At lookout atop Nittany Mountain, follow group leader to observe the regional structure in Penn Valley. Elevation, 1809 feet. View is toward the southeast across Penn Valley to Seven Mountains (see Figure 5).

General

The floor of Penn Valley at approximately 1300 feet is the Harrisburg surface, developed upon folded Lower and Middle Ordovician carbonate rocks and upper Ordovician Reedsville shale. The Schooley surface is represented by synclinal and homoclinal ridges of Ordovician Oswego (Bald Eagle) sandstone and Tuscarora sandstone such as Egg Hill, Brush Mountain, and the complex of ridges in the Seven Mountains area. These ridges have summit elevations of 1800-2000 feet. Beneath your feet is the outcrop belt of the Oswego or Bald Eagle sandstone. Outcrops of this unit containing quartz, chert, and metamorphic rock pebbles are present across the road and extend downhill toward Centre Hall.

Structure

The purpose of this stop is to acquaint you with two of the major structural units of the region that the field trip will cross--the Penn Valley Anticlinorium and the Seven




STOP IX NITTANY MTN. ABOVE CENTRE HALL (1809')

**View toward southeast across Penn Valley anticlinorium to Seven Mountain synclinorium.**

a. axial trace of anticline through Brush Valley and Centre Hall

b. axial trace of Brush Mountain syncline

c. axial trace of anticline between Old Fort and Centre Hall

d. axial trace of Egg Hill - Tussey Mountain syncline

e. approximate position of anticline between Egg Hill - Tussey Mountain syncline and First Mountain (Axial trace not indicated on sketch)

C.H. - Centre Hall

Figure 5

Mountain Synclinorium. At this latitude the Nittany Arch of Butts and Moore (1936, p. 79) is separated along strike into two anticlinoria by the Nittany Mountain Syncline. You are standing on the southeast flank of the Nittany Mountain Syncline looking across the southeast half of the Nittany Arch, the Penn Valley Anticlinorium, a first order anticlinorium of this region. Second order anticlines and synclines comprising the Penn Valley Anticlinorium are labeled "a," "b," "c," "d," and "e" on the sketch for Stop IX (Figure 5). Topographic expression of structure is present wherever resistant stratigraphic units such as the Tuscarora and Bald Eagle sandstones are present in synclines beneath the Schooley surface. Examples are the Nittany Mountain Syncline, the Brush Mountain Syncline and the Tussey Mountain-Egg Hill Syncline. Egg Hill is present because a sag, or northeast plunge, in the southwest-plunging axis of the Tussey Mountain-Egg Hill Syncline has locally brought Bald Eagle sandstone beneath the level of the Schooley surface.

Ridges in the Seven Mountains area are all developed on Tuscarora or Bald Eagle sandstone while valleys are underlain by Silurian Rose Hill shale or Ordovician Juniata Formation and Reedsville shale. The Seven Mountains is structurally a complex first order synclinorium, and is the result of the up-plunge manifestation of the synclinoria of the Broad Top Coal Field to the southwest and the Northern Anthracite basin to the northeast. It is bounded on the southeast by the Kishacoquillas Valley Anticlinorium which brings Ordovician carbonate rocks to the surface.

The route of the trip to the south across Penn Valley, the Seven Mountains, and Kishacoquillas Valley will follow approximately the nearly north-south axis of the culmination of the Pennsylvania salient of the Central Appalachians. Fold axes to the east and northeast of this culmination typically plunge northeast into the anthracite coal fields, whereas fold axes to the south and southwest plunge southwest. Examples of both plunges are to be seen from this vantage point:

1. The Tussey Mountain synclinal nose is developed on a southwest-plunging syncline;

2. The Brush Mountain synclinal nose is developed on a northeast-plunging syncline;

3. Penn Valley bifurcates to the northeast into two valleys developed upon northeast-plunging anticlines;

4. The axial sag responsible for the preservation of Egg Hill as an isolated erosional remnant of Bald Eagle sandstone probably results from conflict between northeast and southwest plunges in this area.

Mileage

Route continues through Juniata Oswego (Bald Eagle), Reedsville and Trenton formations on the east flank of Nittany Mountain Syncline.

| | | |
|---|---|---|
| 47.7 | 0.9 | Entering the Borough of Centre Hall located on the northeast-plunging nose of Penn Valley Anticline and on the Bellefonte dolomite. |
| 48.1 | 0.4 | Junction with Pa.-192 (East). Continue STRAIGHT AHEAD on Pa.-53. Route continues on east flank of Penn Valley Anticline in Middle Ordovician limestone. |
| 49.0 | 0.9 | Cross synclinal axis in Middle Ordovician Trenton limestone. |
| 49.3 | 0.3 | Junction of Pa.-53 with Pa.-45 at Old Fort. |

POTTER'S FORT

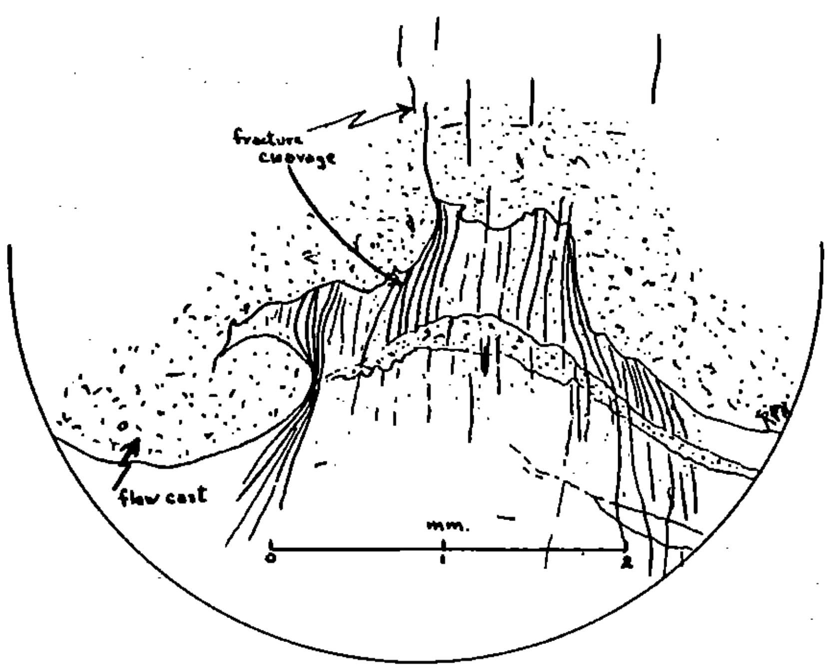
Built in 1777 by General James Potter.
A stockaded fort refuge for the settlers of the valley region.

Continue straight ahead, riding on Black River, Chazy limestones.

| | | |
|---|---|---|
| 49.8 | 0.5 | Approximate contact with Bellefonte dolomite. |

Mileage

| | | |
|---|---|---|
| 50.6 | 0.8 | Cross minor anticlinal axis; Axemann limestone is exposed in core. |
| 51.3 | 0.7 | Middle Ordovician Trenton limestone can be seen in road-cut at 3 o'clock. |
| 51.5 | 0.2 | Egg Hill at 9 o'clock. A synclinal topographic high, with Oswego (Bald Eagle) sandstone in the core. |
| 51.6 | 0.1 | Reedsville shale at 3 o'clock. |
| 52.0 | 0.4 | <u>STOP X</u>. Group leader - Dr. Richard P. Nickelsen, Bucknell University. Follow group leader to observe Reedsville shale in Tussey Mountain-Egg Hill syncline. |




STOP X

Camera lucida sketch of Reedsville shale from Tussey Mountain-Egg Hill syncline, showing sandstone flow casts and fracture cleavage.

Figure 6

## General

This stop, in flat-lying, interbedded, shale and graywacke sandstone of the Reedsville formation in the trough of the Egg Hill-Tussey Mountain Syncline, a Second order feature, was planned to demonstrate the character of small-scale structures in a simple structural setting. The accompanying camera lucida sketch (Figure 6) of a thin section cut perpendicular to the cleavage-bedding intersection shows fracture cleavage and flow-casts at a sandstone-shale contact.

From the upper part of the exposure, the nose of the southwest-plunging Tussey Mountain Syncline may be seen.

## Description of Outcrop

Small scale structures to be seen here are horizontal bedding, vertical fracture cleavage, vertical cross-joints perpendicular to the cleavage-bedding intersection, and flow-casts and other sole marks on the bottoms of sandstone beds. Cleavage-bedding intersections are emphasized by excellent development of "pencil shales", where elongated, pencil-like, fragments produced by cleavage-bedding intersections are aligned parallel to the fold axis. Cleavage and bedding also provide the fractures favoring the development of the spheroidal weathering present throughout the outcrop.

The bottoms of many thin sandstone beds and laminae show small scale (1 - 2 mm.) flow-casts which indent the tops of the underlying shale beds and appear to be tectonically oriented parallel to the strike of fracture cleavage or fold axes. The fracture cleavage appears in thin section as fine, dark, irregular lines, spaced at intervals of .05 to .2 mm. Micas, clays and tabular quartz grains are oriented in their original sedimentary position with long axes parallel to bedding. No discernible minerals have developed in the plane of the cleavage. This cleavage fits the definition of fracture cleavage in that it is a spaced cleavage, not paralleled by mineral orientation. The rock cannot be split into cleavage flakes less than the thickness of the cleavage slices and the only mineral orientation is a relic of the original sedimentary orientation. Cleavage has been compressed and bent around flow-cast projections on the base of the sandstone beds as shown in the camera lucida sketch. I believe that this indicates that cleavage has developed perpendicular to the principal stress axis operating

NW - SE parallel to bedding during a period of flattening which may have been initiated prior to folding. The apparent tectonic orientation of flow-casts (parallel to fold axes and shale pencils ?) suggests that the flattening may have been initiated while the sediments were in a soft state. The cleavage may have begun forming at this time and developed its present character during succeeding lithification of the sedimentary sequence. More work is needed here to clarify the origin of this cleavage. Work by Maxwell (1962) on origin of cleavage in Martinsburg slate of northeastern Pennsylvania has indicated a similar early development of cleavage.

Summary

Important features of this outcrop are:

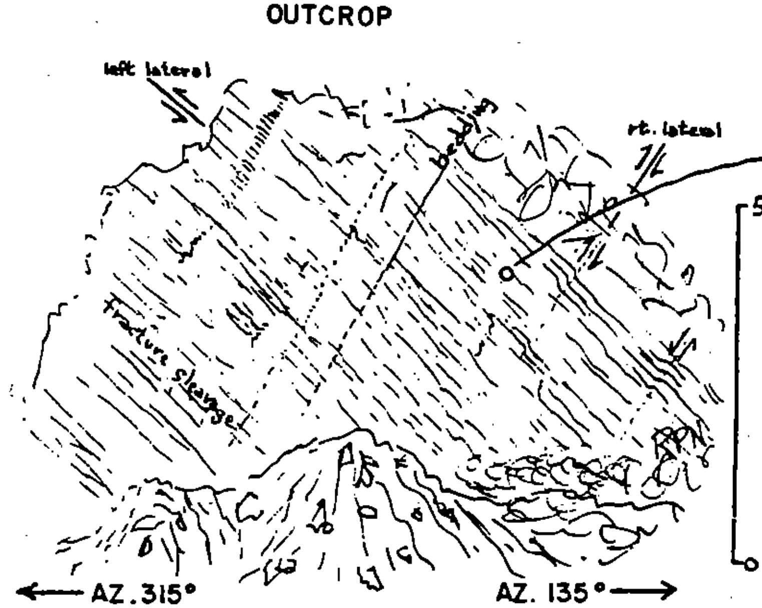
1. Cleavage is preserved in its initial attitude, perpendicular to bedding, and has undergone no internal or external rotation as a result of later folding. Neither has it served as a plane of differential slip. This outcrop thus represents what I infer to be the initial state of cleavage in the area.

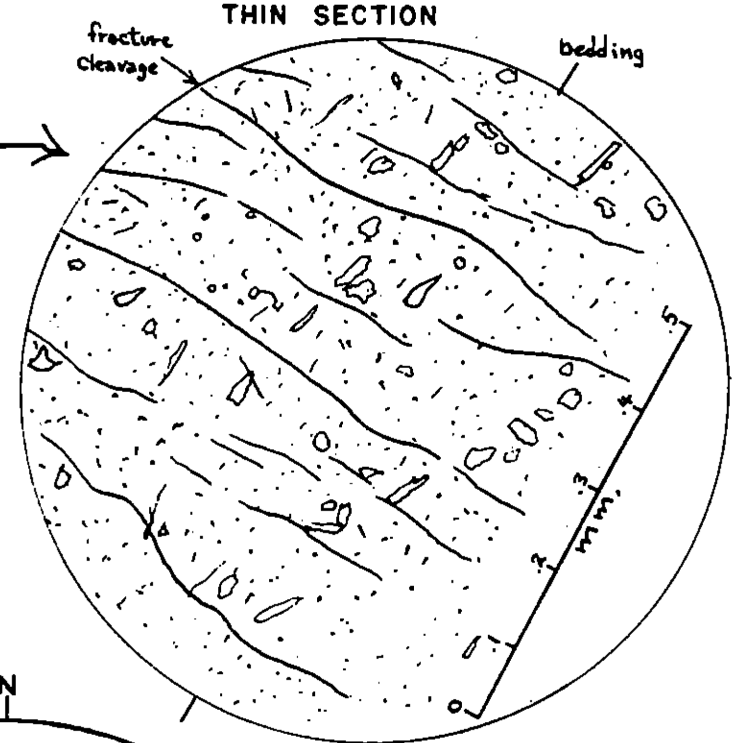
2. Fracture cleavage in shales throughout the region appears under the microscope as it does in this outcrop.

3. Cleavage is interpreted as having developed perpendicular to the greatest principal stress axis as indicated by compression and bending of cleavage against sandstone flow-casts.

4. Relations between sandstone flow-casts along the base of sandstone beds and cleavage suggest that cleavage may have been initiated before complete lithification of the sediment.

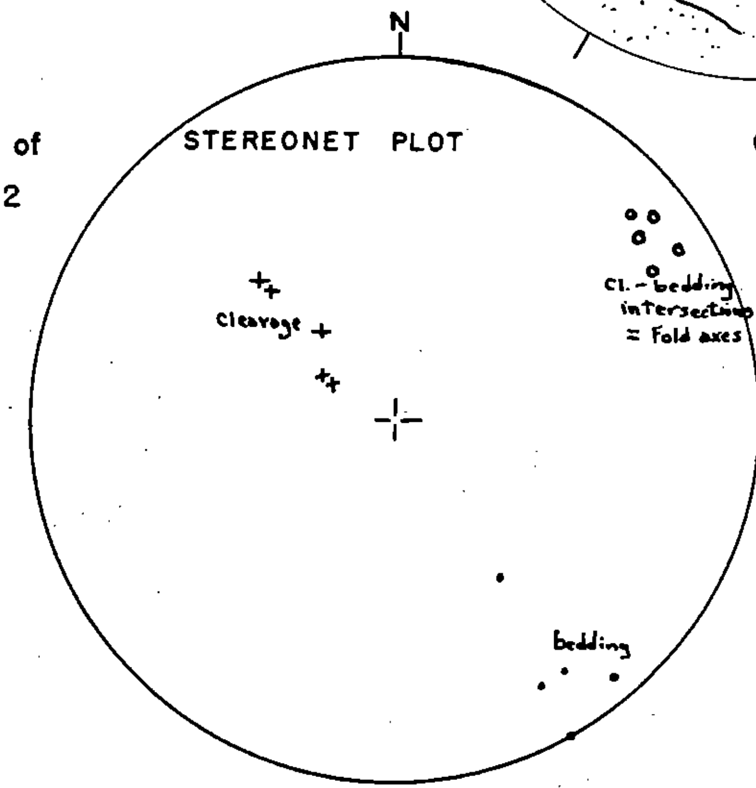
5. The composition and significance of the dark matter along cleavage planes is unknown at the present time.




# STOP XI

Outcrop of Antes Gap member of Reedsville shale along Route 322 south of Potters Mills.




CLEAVAGE Λ BEDDING

68°, 72°, 65°, 68°, 52°

Figure 7

Mileage

52.5 0.5 Reedsville shale outcrop in cut at 9 o'clock.

52.8 0.3 Entering village of Potter Mills. Extremely tightly folded anticline in the Trenton limestone can be seen at 8 o'clock near bridge over Potter Stream.

This anticline is core of the structure exposed at STOP XI ahead.

53.4 0.6 Junction of Pa.-35 with U.S.-322. TURN RIGHT and proceed on U.S. 322.

54.2 0.8 STOP XI. Group leader - Dr. Richard P. Nickelsen, Bucknell University.

Follow group leader to view excellent development of fracture cleavage in a tight anticline of Reedsville shale.

General

This exposure is in the Antes Gap Member of the Reedsville shale on the northwest limb of the tight anticline (Second order) exposed at 52.8 miles. Features to be seen here are well-developed fracture cleavage, shear folding, obscure bedding, and bending of cleavage along certain bedding planes. (See sketch for STOP XI-Figure 7).

Description of Outcrop

At this exposure the incompetent, black, clay shale of the Antes Gap Member shows perhaps the best developed fracture cleavage of the region. Fracture cleavage, dipping 25 to 55 degrees southeast, is the most prominent structure in the outcrop. Bedding dips vertically to steeply northwest. This outcrop is important for the following reasons:

1. It has not been folded predominantly by concentric folding with slip between bedding planes. The bedding planes are merely passive designs and have not served as important slip planes. Rather the Antes Gap Member has deformed by shear folding with slip along fracture

cleavage planes across bedding planes. Such folds are not generally developed in the central Appalachians west of the Blue Ridge and Great Valley.

2. Fracture cleavage is no longer perpendicular to bedding because bedding has been internally rotated by left-lateral* affine slip along fracture cleavage planes (*left-lateral sense of slip when viewed as in sketch of outcrop for Stop XI).

3. Fracture cleavage viewed microscopically appears similar to fracture cleavage of Stop IV except that it is no longer perpendicular to bedding. It has served as a slip plane along which bedding has been internally rotated. Tabular minerals have not been rotated out of their initial bedding attitude; cleavage is spaced similarly and shows no discernible parallel mineral orientation.

4. Certain bedding planes have served as planes of right-lateral and left-lateral slip with the result that cleavage planes are warped in places. Right-lateral bedding slips are most abundant and are evidence of some small-scale concentric folding in a section which is being deformed predominantly by shear along fracture cleavage planes. The fact that both shear and concentric folding are represented here would seem to be good evidence that the two kinds of folding are transitional, the importance of one or the other being a function of lithology and structural position. The Antes Gap shale in this particular tight anticline is probably the only lithic unit that is undergoing appreciable shear folding in the whole Ordovician section. The same shale in adjacent broad anticlines and synclines show no evidence of appreciable slip along cleavage planes.

## Summary

This somewhat anomalous outcrop shows excellent fracture cleavage and obscure bedding as well as evidence of shear folding with minor concentric folding. The best evidence for shear folding is the lack of a right-angle relationship between cleavage and bedding, indicating internal rotation of bedding planes along cleavage. Most important, the outcrop demonstrates the ultimate development of small-scale and continuous processes of deformation in the central Valley and Ridge Province.

Mileage

Continue AHEAD to first junction.

| | | |
|---|---|---|
| 54.4 | 0.2 | At junction, make a U TURN and return to intersection with Pa.-35. |
| 55.4 | 1.0 | Junction of Pa.-35 with U.S.-322. Proceed STRAIGHT AHEAD on U.S.-322. Reedsville outcrop is in bank at 3 o'clock (dip is to the southeast). |
| 55.6 | 0.2 | Entering State Forest Lands - Seven Mountains Area. |
| 55.7 | 0.1 | Talus blocks of Oswego (Bald Eagle) sandstone may be seen at 3 o'closk. |
| 55.9 | 0.2 | Juniata Formation exposed in long road-cut at 3 o'clock - this is near axis of small anticline. |
| 56.3 | 0.4 | Upper Ordovician Oswego (Bald Eagle) conglomeratic sandstone is exposed at 9 o'clock. |
| 56.6 | 0.3 | Reedsville shale crops out at 9 o'clock. |
| 56.9 | 0.3 | State Forestry Experiment Station at 9 o'clock. |
| 57.6 | 0.7 | Oswego sandstone float is to be seen in cuts at 9 o'clock. |
| 58.2 | 0.6 | Juniata crops out at 3 o'clock on small southwest plunging syncline. |
| 58.7 | 0.5 | Mifflin County line. |
| 59.2 | 0.5 | Juniata Formation exposures are obvious at 9 o'clock (rather steep southeast dip). |
| 59.4 | 0.2 | Contact of Juniata Formation with Tuscarora sandstone occurs at 3 o'clock. |

Mileage

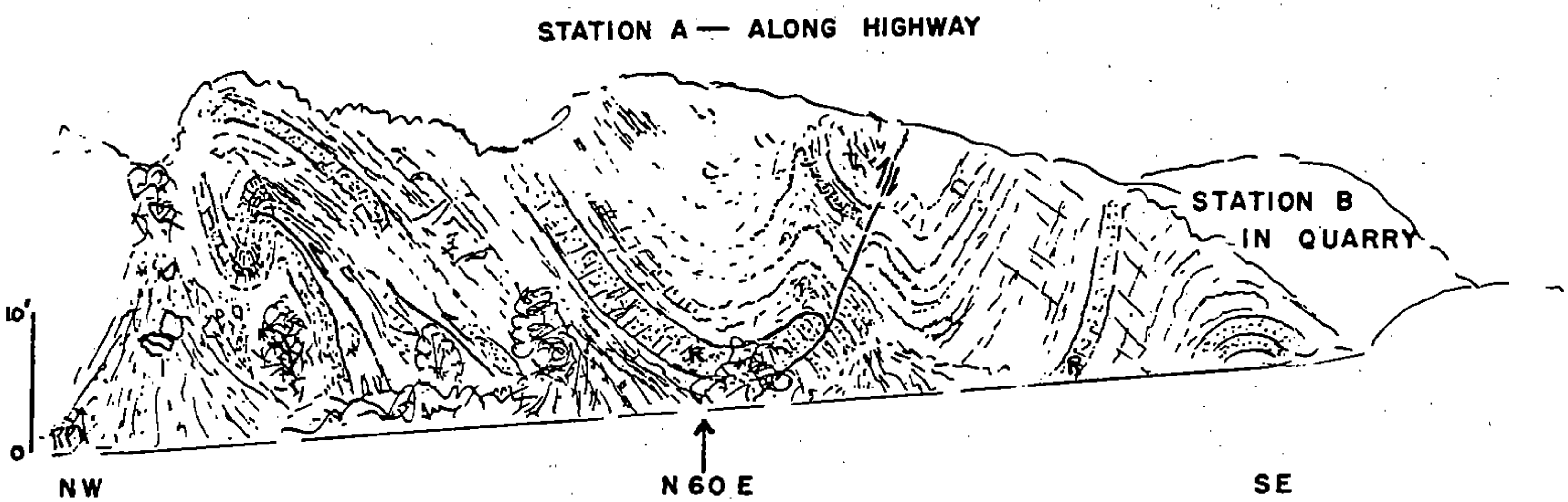
| | | |
|---|---|---|
| 59.9 | 0.5 | Southeast-dipping shaly beds in the upper part of the Tuscarora sandstone are exposed at 3 o'clock. |
| 60.6 | 0.7 | Hairpin curve is on the axis of a tight syncline developed in an outcrop-belt of Rose Hill shale. |
| 61.1 | 0.5 | STOP XII. Group leader - Dr. Richard P. Nickelsen, Bucknell University. Park as far off the highway as possible beyond the east end of the bridge over Laurel Creek. This is a high-speed, heavily traveled road, so please exercise EXTREME CARE and good judgment by staying off the road. Follow group leader to study minor structures and folds in tight syncline developed in the upper Tuscarora-Castenea sandstone and the basal Rose Hill shales. |

## General

This exposure lies on the axis of the southernmost syncline (second order) in the Seven Mountains Synclinorium. Ridges held up by Tuscarora sandstone on opposite limbs of the strucutre rise to north and south. Rocks in the outcrop include the uppermost Tuscarora (or Castenea) red, hematitic sandstone and the basal Rose Hill shale. The stop has been divided into two stations: Station A (see Figure 8), along the highway, shows complexly folded and faulted interbedded sandstone and shale; Station B, in a small quarry off the road, shows fine development of minor structures and flowage in shales of the Rose Hill Formation. Parts A and B of the exposure thus illustrate respectively competent folding and incompetent deformation in the same tectonic setting.

## Description of Outcrop

Station A (see Figure 9) shows several third or fourth order folds and associated faults developed here in the tightly squeezed trough of the large second order syncline. It is typical of the axial crowding that may be expected in such structures in this area. It should be




# STOP XII

Outcrop of Tuscarora-Castanea sandstone and Rose Hill shale along Route 322 in Seven Mountains area.

Figure 8

emphasized that the complex structures shown here are by no means typical of what is usually seen in broad folds and on fold limbs in this area.

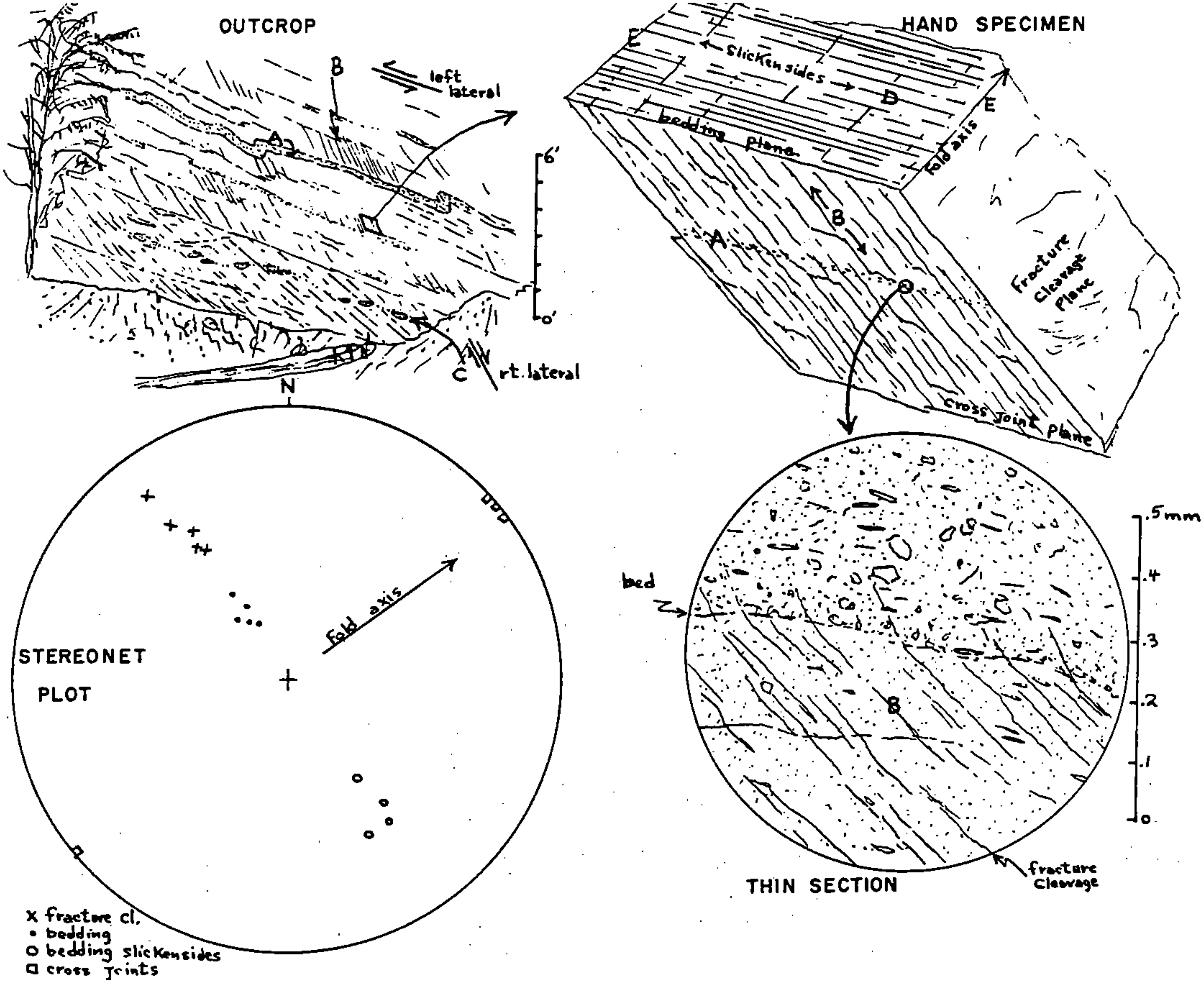
Bent sandstone beds show joints and fracture cleavage parallel to axial planes of folds in the fold hinges but fanning nearly perpendicular to bedding on the limbs. Shaly beds show fracture cleavage more nearly parallel to axial planes on both hinges and limbs of folds. Most bedding planes show slickensides denoting bedding slip during concentric folding. Such bedding slip is probably responsible for internally rotating fracture cleavage from its original attitude perpendicular to bedding to its present attitude, intersecting bedding at less than 90° on fold limbs. The intense folding of the competent units in this part of the exposure contrasts with the simple structure and extensive intra-bed flowage to be seen at Station B.

Station B (see Figure 9) shows unusually good development of small-scale structures which illustrate the essential small-scale deformation mechanisms of the region. Rarely are these structures as well developed as in this outcrop and at Stop XI, and their strong development here must be ascribed to the extreme squeezing in the trough of the second order syncline.

Small-scale structures to be seen are:

A) bedding with parasitic or "drag" folds,
B) fracture cleavage intersecting bedding at less than 90°,
C) sandstone boudins in "plastically" deformed shale,
D) bedding slickensides oriented perpendicular to bedding-cleavage intersections, and
E) bedding-cleavage intersections parallel to fold axes.

(Letters are keyed to sketch, Figure 9, for Stop XII, Station B.)




STOP XII — STATION B

Outcrop of Rose Hill shale in small quarry off Route 322 in Seven Mountains area.

Figure 9

Deformation by differential slip among two different sets of planes has occurred in this outcrop. Between bedding planes, particularly at sandstone-shale contacts, there has been left-lateral slip congruent with the normal bedding slip on the limb of a fold. The direction of slip is shown by bedding slickensides. Within shale beds both right- and left-lateral slip has occurred along fracture cleavage planes. Right-lateral slip dominates but left-lateral slip occurs in the vicinity of small parasitic folds. The amount of "plastic" deformation accomplished by the fracture cleavage-slip mechanism is well illustrated by the sandstone boudins in the thick shale bed at the base of the outcrop. They appear to represent the vestige of a once-continuous sandstone bed which has been pulled apart and now "floats" as a number of isolated boudin fragments in the surrounding "plastically" deformed shale. Further evidence of "plastic" deformation is provided by deformed brachiopods from shaly beds.

## Summary

At this stop an opportunity is provided to compare and contrast the deformation of a competent-incompetent interbedded sequence (Station A) with a predominantly incompetent sequence (Station B) under the same stress environment. In the competent sequence, concentric folding and faulting is the predominant mechanism of deformation but shales show some flowage parallel to fold axial planes along fracture cleavage. In the incompetent sequence distinct beds show bedding plane slip, an expression of concentric folding, but shales have been deformed internally along fracture cleavage planes in a manner similar to the shear folding at Stop XI. The amount of internal "flowage" is shown by sandstone boudins and deformed fossils. The cleavage-bedding angle is considerably less than 90$^{\circ}$ and results from the interplay of two affine slip mechanisms affecting cleavage and bedding. It is entirely possible the cleavage did not start perpendicular to bedding but, on the basis of relations in less deformed localities (e.g., Stop X), I believe that it did. The slip mechanisms, visible in this outcrop, which probably played a role in changing the cleavage-bedding angle are:

a) left-lateral internal rotation by slip between bedding planes which tends to rotate cleavage in a counterclockwise direction,

b) predominantly right-lateral internal rotation between fracture cleavage planes which tends to rotate bedding in a clockwise direction.

Added to these rotations is the external rotation of the whole fold limb which rotates cleavage and bedding in a clockwise direction but does not change their angle of intersection except to the extent that it reorients the cleavage and bedding with respect to regional principal stress axes.

<u>Mileage</u>

| | | |
|---|---|---|
| 61.3 | 0.2 | Loose blocks of Tuscarora sandstone are exposed on southeast limbs of a syncline; dip in this area is nearly vertical to overturned. |
| 61.4 | 0.1 | Juniata Formation at 9 o'clock dips to the south (overturned) on the south limb of a syncline. Route continues along strike of beds. |
| 62.1 | 0.7 | Juniata Formation at 9 o'clock. |
| 62.3 | 0.2 | Leaving Seven Mountains area. |
| 62.4 | 0.1 | Oswego (Bald Eagle) sandstone at 9 o'clock across the road from American Legion Post. Beds are overturned to the north and dip south about 75 to 80 degrees. |
| 62.7 | 0.3 | Approximate position of an anticlinal axis. |
| 63.1 | 0.4 | A southwest-plunging synclinal ridge is at 3 o'clock; ridge is supported by the Oswego (Bald Eagle) sandstone. |
| 63.5 | 0.4 | Entering village of Milroy. |
| 63.6 | 0.1 | <u>BEAR LEFT</u> at stone house onto North Main Street to center of Milroy - route is not numbered. |

Mileage

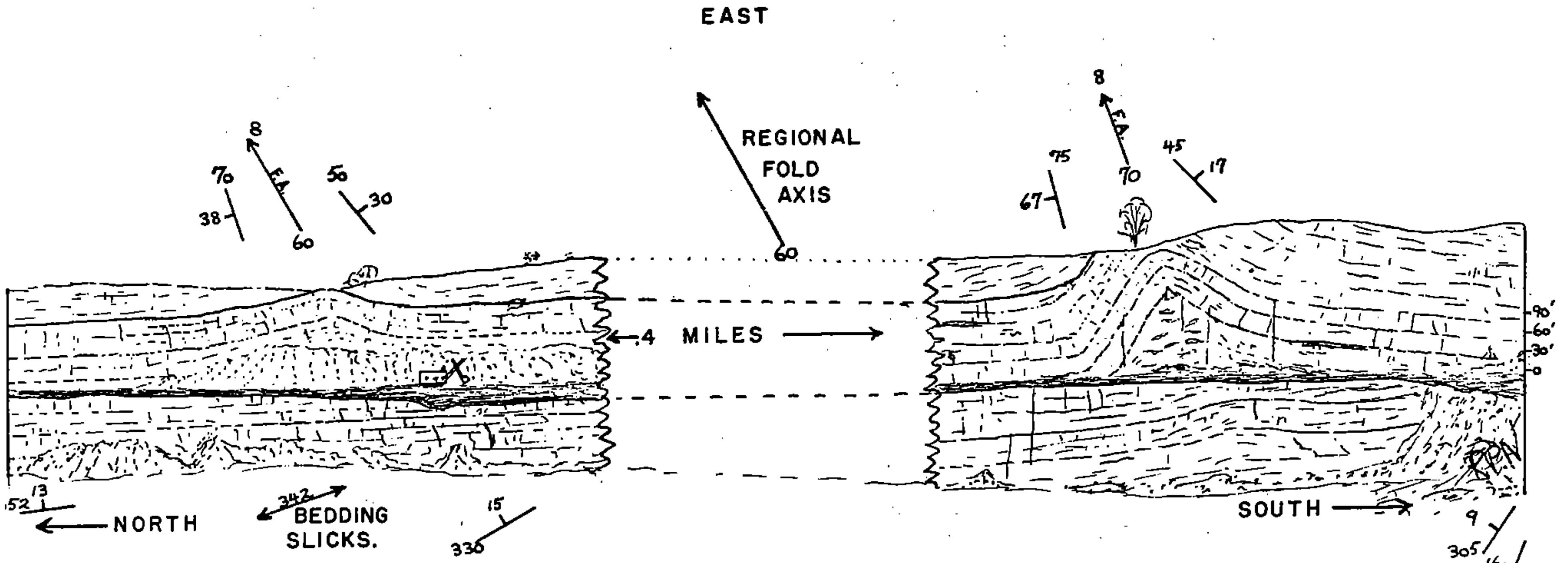
| | | |
|---|---|---|
| 64.2 | 0.6 | In the center of Milroy, BEAR LEFT on road to Siglerville. |
| 64.5 | 0.3 | Bridge over Laurel Run. |
| 64.9 | 0.4 | At "Y" intersection BEAR RIGHT. |
| 65.4 | 0.5 | Intersection; continue STRAIGHT AHEAD to Naginey. We are crossing an anticlinal axis in Bellefonte dolomite. |
| 66.2 | 0.8 | BEAR LEFT at entrance to quarry where sign announces: "Faylor Paving Materials Company, Naginey Plant." Quarry is owned by Bethlehem Limestone Company. |
| 66.3 | 0.1 | STOP XIII. Group leader - Dr. Richard P. Nickelsen, Bucknell University. Park at the top of small rise near operations offices to view structure in the Trenton-Black River limestones exposed in the Naginey Quarry. Follow group leader to observe broadly folded synclinal nose and anomalous development of two flanking and rootless anticlines. |

## General

This exposure, oriented approximately N-S, shows about 1/2 mile of structure section in a quarry of the Bethlehem Limestone Company across the noise of a N60° E plunging, second order, syncline within the Kishacoquillas Valley Anticlinorium. Important geologic features at this stop are illustrated in the sketch for Stop XIII (Figure 10); they are two rootless, third order anticlines which are developed at approximately the same stratigraphic horizons in the Black River and Trenton Limestones at the north and south ends of the exposure. Only the southern anticline will be studied.

## Description of Outcrop

The quarry offers an unusual opportunity to observe the development of third order folds which are not the direct result of general shortening of section but rather develop due to increased axial crowding at higher stratigraphic levels




STOP XIII

Quarry Exposure in Bethlehem Limestone Company quarry at Naginey, Pa.

Figure 10

in a major second order syncline. Features, present in the quarry, that are pertinent to the interpretation of these structures are:

1. decreasing fold amplitude downward in the section; (The fold near the south end of the quarry does not completely die out within the quarry but its amplitude diminishes rapidly downward within the exposed face. The fold of lesser amplitude at the north end of the quarry disappears completely before the quarry floor is reached.);

2. both folds have axes approximately paralleling the regional fold axis and thus are related to folding of first and second order folds;

3. bedding slickensides at a number of places on the large bedding surface making up the floor of the quarry trend 80° or 90° to regional and local fold axes (azimuth trend of slickensides is 342°), indicating that bedding plane slip is in a direction congruent with concentric folding of the limestones; and

4. limestones in the southern, third order, anticline have been bent with some fracturing and faulting in the upper part of the structure but in the lower part the beds have been thickened mechanically, with accompanying shattering and calcite veining. (There is little megascopic evidence of plastic deformation of limestones here or elsewhere in central Pennsylvania, for they behave as brittle, competent units.)

Summary

This stop was included in the trip to dramatically demonstrate third order folds that have developed as a secondary result of bending in the noise of a very broadly folded second order syncline. These structures are rootless, increase in amplitude upward, are probably restricted to the hinges of larger order anticlines and synclines, and are fundamentally different in origin from the folds of varying orders of magnitude that develop in different structural lithic units in response to mechanical and geometric characteristics of dominant members subjected to a general shortening of section. More important, in a broadly folded syncline such as this where the center of curvature is probably more than 10,000 feet above the quarry floor, they indicate insufficient bedding slip adjustment between beds to alleviate crowding in even the outer arc of fold curvature. Features such as these have lead me to question the efficiency of bedding plane slip in the concentric folding process. That differential bedding plane slip does occur is proven by slickensides oriented perpendicular to fold axes on the bedding plane floor of the quarry. Whether such bedding plane slip is generally sufficient in magnitude to allow the theoretical maximum of bedding plane adjustment to occur above and below the center of fold curvature in complete concentric folding (DeSitter, 1958, p. 283) of anticlines and synclines, is questionable.

Mileage

| | | |
|---|---|---|
| 66.4 | 0.1 | Rejoin paved highway at quarry entrance, TURN LEFT. |
| 66.6 | 0.2 | At 3 o'clock the business offices of the Bethlehem Limestone Company, Naginey Plant. |
| 67.2 | 0.6 | Intersection; TURN RIGHT over Honey Creek bridge toward Reedsville. Road parallels Jacks Mountain at 9 o'clock, with Tuscarora ridge on skyline and Oswego (Bald Eagle) sandstone forming the secondary ridge. Jacks Mountain is the southeast flank of Kishacoquillas Valley Anticlinorium. |
| 67.9 | 0.7 | Northwest-dipping Middle Ordovician limestone is exposed in road-cut at 9 o'clock. |
| 68.2 | 0.3 | Bridge over Honey Creek. |
| 68.3 | 0.1 | Southeast-dipping Middle Ordovician limestone can be seen in abandoned quarry at 10 o'clock. |
| 69.4 | 1.1 | Southeast-dipping Upper Trenton limestone at 3 o'clock. |

Mileage

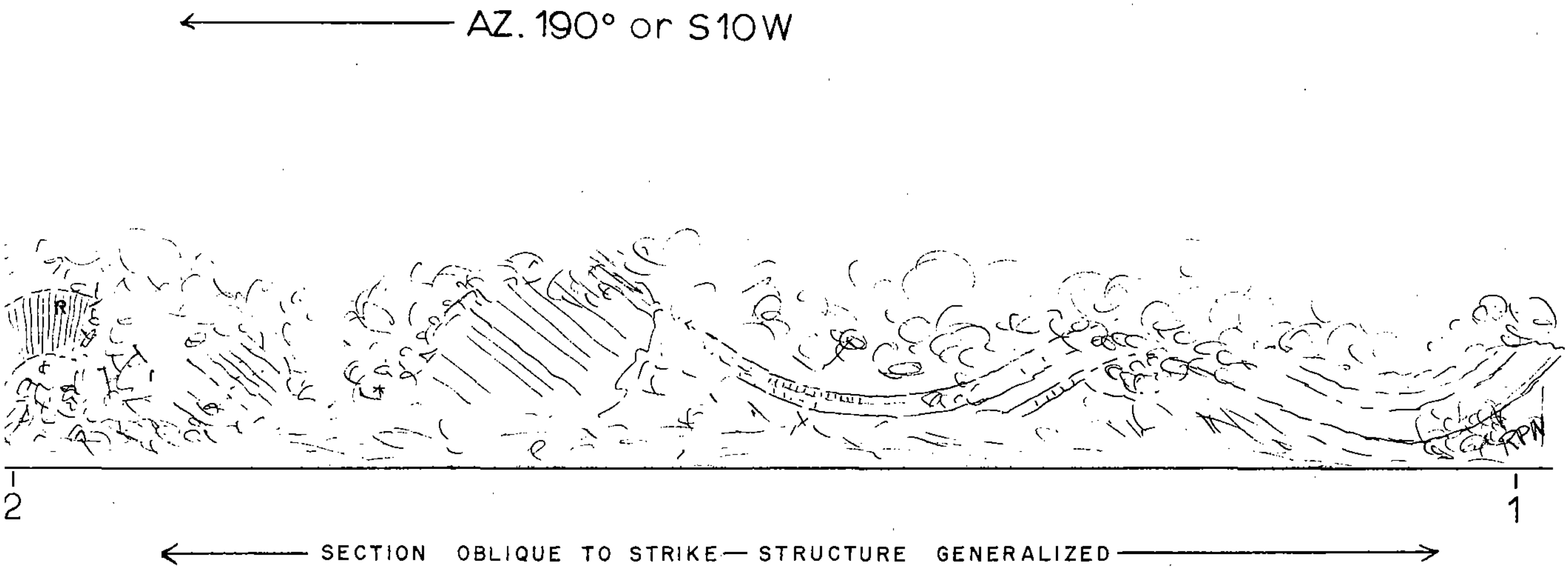
| | | |
|---|---|---|
| 70.1 | 0.7 | Several tight minor folds are exposed in southeast-dipping Upper Trenton limestone in road-cupts at 3 o'clock. |
| 71.3 | 1.2 | Entering the village of Reedsville. |
| 71.8 | 0.5 | At signal, TURN LEFT onto U.S.-322 (East). Route continues southeast on U.S.-322. At Mann Narrows the Kishacoquillas Creek cuts through Jacks Mountain. At the present time road construction exposes as excellent section of Silurian and Ordovician rocks. |
| 72.1 | 0.3 | Southeast-dipping Reedsville shale in Jacks Mountain. This is the type locality of the Reedsville shale. |
| 72.2 | 0.1 | Reedsville shale is in contact with Oswego (Bald Eagle) sandstone. Oswego is sandstone and conglomerate and approximately 600 feet thick. |
| 72.3 | 0.1 | Lost Run conglomerate member of the Oswego (Bald Eagle) sandstone is exposed here. Juniata Formation is 1500 to 1600 feet thick at this spot. |
| 72.9 | 0.6 | Bridge over Kishacoquillas Creek. Tuscarora sandstone forms a large ledge on mountain side above road at 9 o'clock; Tuscarora sandstone is about 400 feet thick here. |
| 73.0 | 0.1 | Entering the village of Yeagertown. |
| 74.4 | 1.4 | Entering the Borough of Burnham. |
| 74.8 | 0.4 | Abandoned Keyser limestone quarry may be seen at 10 o'clock in the distance. |
| 76.2 | 1.4 | Lewistown Bypass; BEAR RIGHT. |
| 76.4 | 0.2 | An abandoned Keyser limestone quarry is at 10 o'clock. |
| 76.8 | 0.4 | Devonian black shales are at 3 o'clock. |
| 78.1 | 1.3 | Approximate contact of Silurian Wills Creek shale and Bloomsburg Formation occurs here. |

Mileage

| | | |
|---|---|---|
| 78.4 | 0.3 | Silurian Rose Hill shale is exposed in road-cuts on both sides; limestones of the overlying McKenzie Formation are present but not visible in this same cut. |
| 78.7 | 0.3 | Route passes over the southwest-plunging nose of Shade Mountain Anticline. In road-cuts at 9 o'clock are outcrops of Silurian Castanea sandstones and upper Tuscarora sandstone. |
| 79.3 | 0.6 | Castanea and Tuscarora sandstones on the southwest plunge of Shade Mountain Anticline occur at 9 o'clock. At 12 o'clock are near vertical cliffs of Tuscarora sandstone on the northwest flank of Blue Mountain Anticline. Excellent exposures of Tuscarora sandstones float may be seen in files of periglacial material. |
| 79.7 | 0.4 | Entering Lewistown Narrows, the valley of the Juniata River which is structurally a syncline, with the Rose Hill shale lying on top of the Tuscarora sandstone in the trough between Shade Mountain and Blue Mountain anticlines. Blue Mountain Anticline is at 3 o'clock and Shade Mountain Anticline is at 9 o'clock. |
| 81.7 | 2.0 | Contorted but essentially vertical upper Tuscarora outcrops at 9 o'clock. |
| 82.0 | 0.3 | Large periglacial block field of Tuscarora sandstone scree is at 9 o'clock. |
| 83.6 | 1.6 | Silurian Rose Hill shale can be seen at 9 o'clock. |
| 84.1 | 0.5 | Decreasing height of Blue Mountain anticlinal ridge at 3 o'clock indicates the northeast plunge. |
| 85.7 | 1.6 | Blocks of Tuscarora sandstone on the plunging nose of Blue Mountain Anticline. |
| 86.4 | 0.7 | Silurian Keefer sandstone can be seen above road level at 9 o'clock. |
| 88.1 | 1.7 | Crossing Lost Creek at village of Cuba Mills. |

| Mileage | | |
|---|---|---|
| 88.6 | 0.5 | Southeast-dipping Silurian Rose Hill shale outcrops at 9 o'clock behind the service station. |
| 88.7 | 0.1 | Blacklog Mountain Anticline is at 3 o'clock. |
| 89.0 | 0.3 | Rocks of the southeast-dipping Rochester-McKenzie Formations are at 9 o'clock. |
| 89.1 | 0.1 | Southeast-dipping Bloomsburg Formation can be seen in road-cuts at 9 o'clock; it is 367 feet thick here. |
| 89.3 | 0.2 | Contact of Silurian Bloomsburg Formation with Wills Creek shale occurs in road-cuts at 9 o'clock. |
| 89.5 | 0.2 | Entering the Borough of Mifflintown. |
| 89.7 | 0.2 | Junction of U.S.-322 (and 22) with Pa.-35 (South) at the traffic signal. TURN RIGHT and proceed on Pa.-35 (South). |
| 89.8 | 0.1 | Bridge over the Juniata River. |
| 89.9 | 0.1 | Entering Mifflin. Continue STRAIGHT AHEAD to dead-end at Penna. R.R. track. |
| 90.1 | 0.2 | At dead-end, TURN LEFT on Railroad Avenue and continue to Pennsylvania Railroad depot. |
| 90.2 | 0.1 | STOP XIV. Group leader - Dr. Richard P. Nickelsen, Bucknell University. Starting at the Pennsylvanian Railroad depot, follow group leader approximately 1/2 mile south along railroad tracks to view excellent exposures of third order structures in the Wills Creek Formation. |

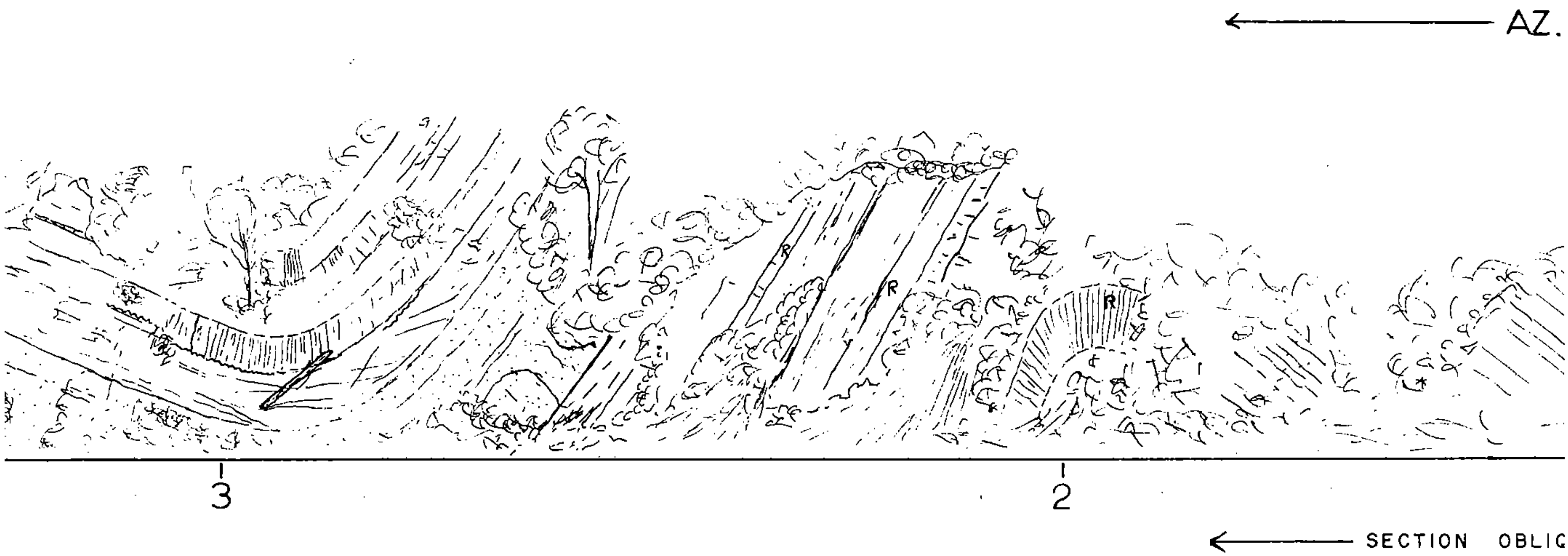
Maintain continued caution and BE ALERT FOR TRAINS.

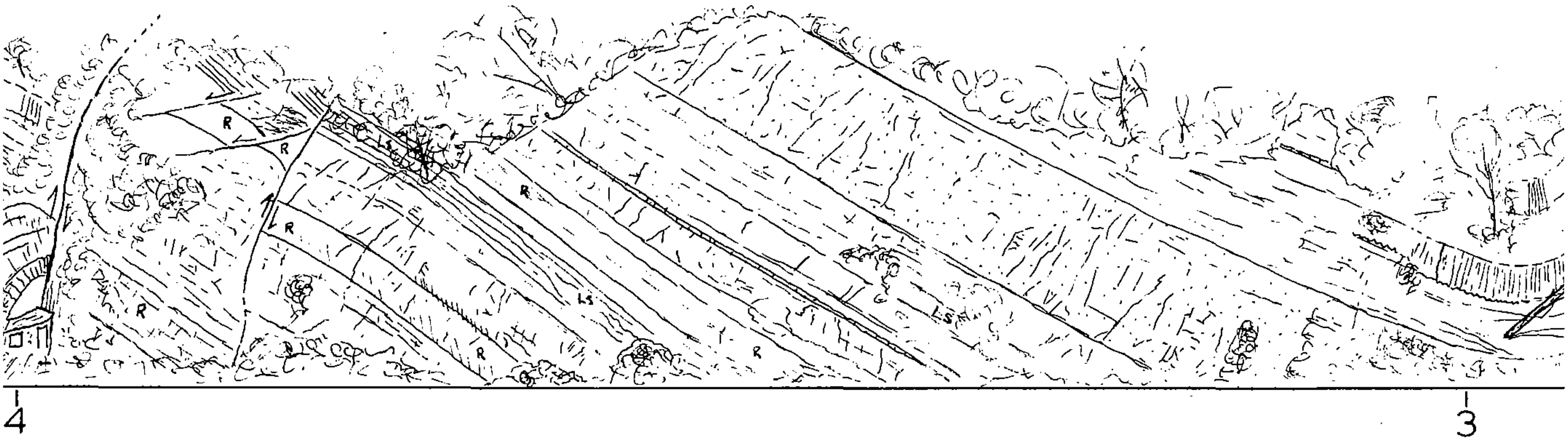


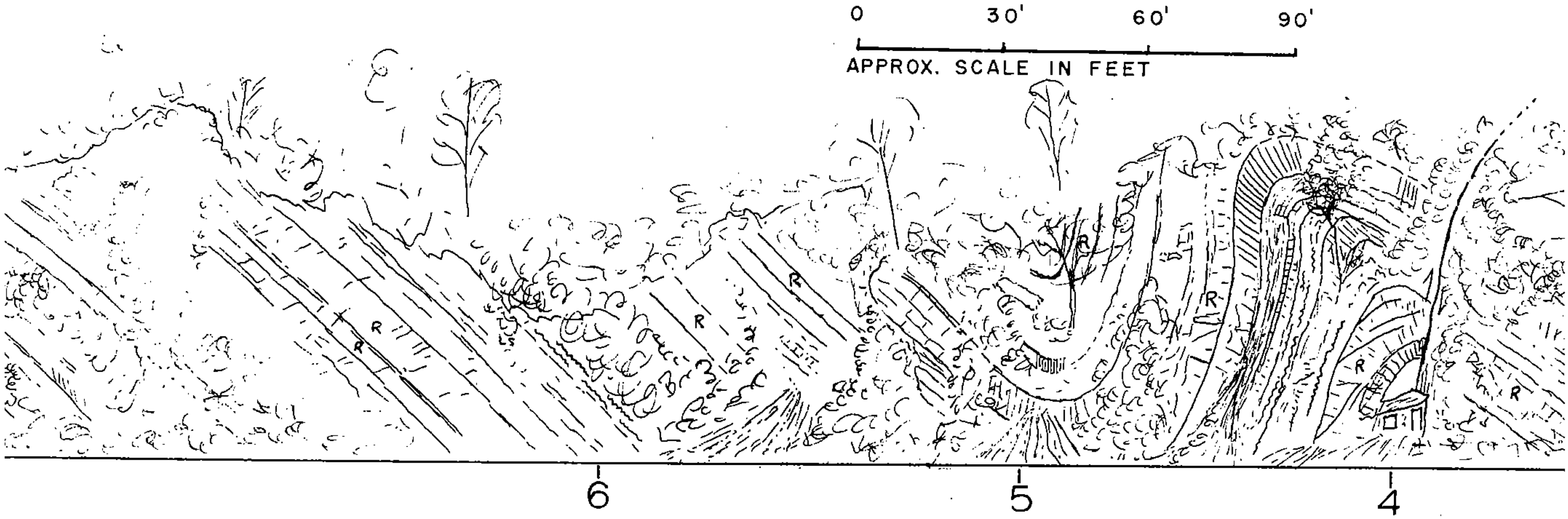

## STOP XIV

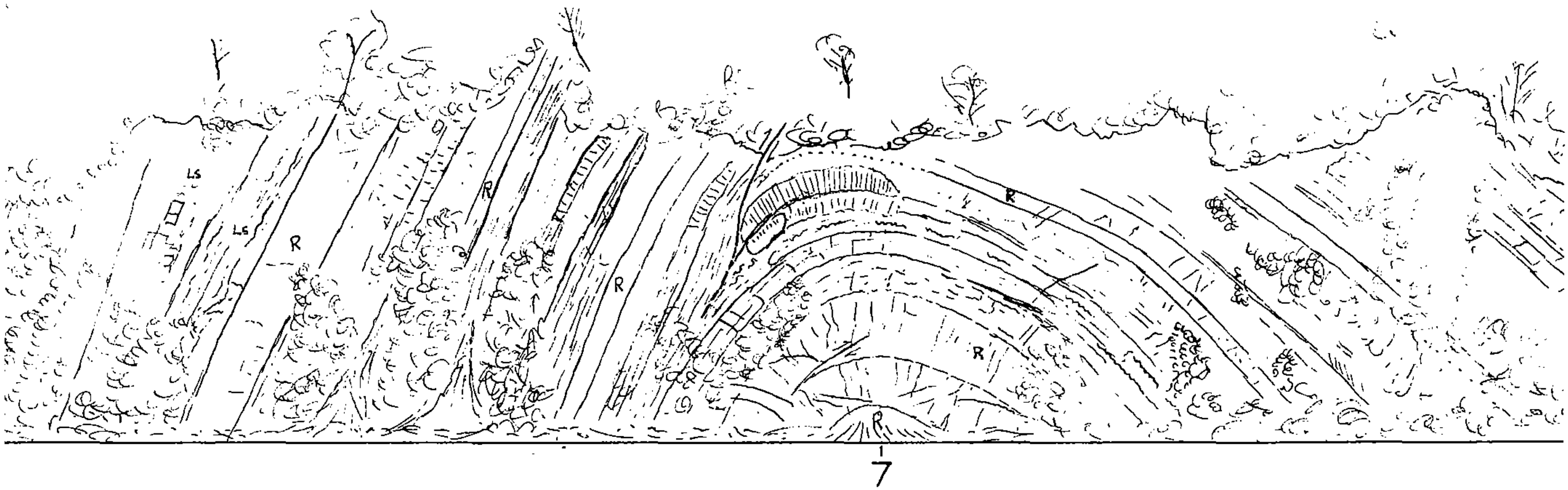
Folds along Railroad tracks and Juniata River south of Mifflin, Pa.

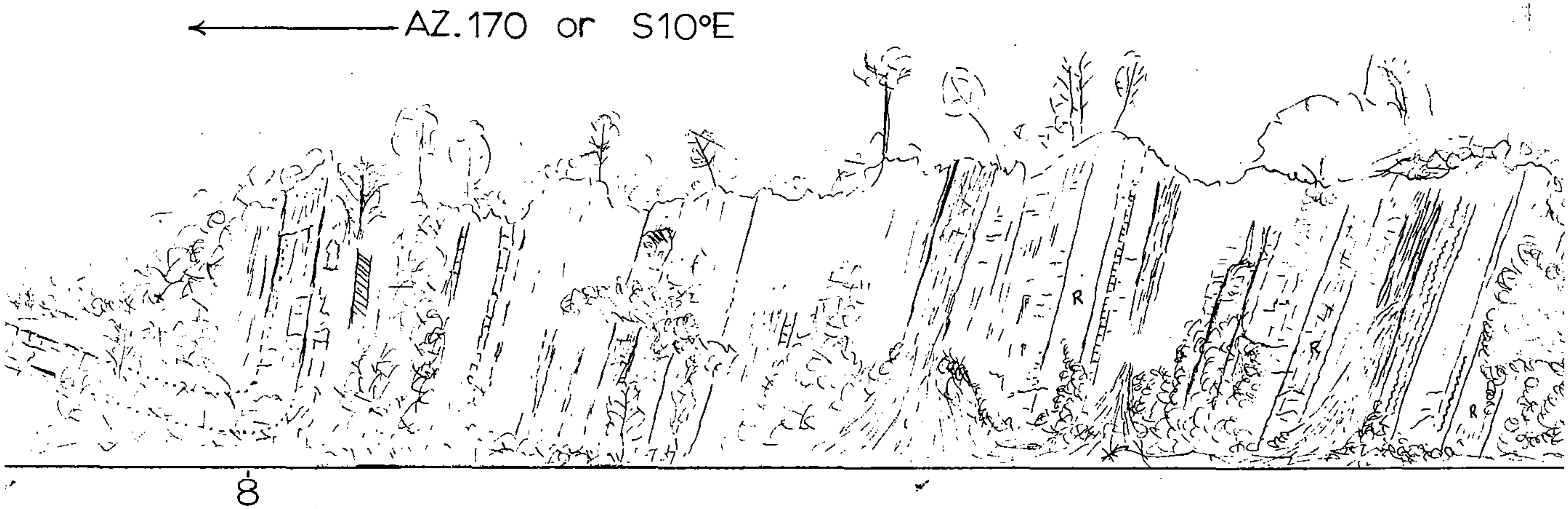
Figure II


AZ.
R
R
R
3
2
SECTION OBLIQ


R
R
R
R
LS
R
R
LS
R
R
LS
4
3


0
30'
60'
90'
APPROX. SCALE IN FEET
6
5
4


LS
LS
R
R
R
R
R
R
7




Folds along Railroad tracks and Juniata River south of Mifflin, Pa.

General

This exposure of several Third order anticlines and synclines in the Upper Silurian Wills Creek Formation is one of the best in central Pennsylvania for illustrating concentric folds and their mechanics of formation. These folds lie just east of the culmination of the Pennsylvania salient, within a bundle of Second order folds that plunge east into the Middle Anthracite field.

Folds in the section are all asymmetric to the southeast because of their position on a Second order fold. However, bedding wedges and an important upthrust within the section indicate over-riding toward the northwest.

The following descriptions of features to be seen have been keyed by numbers to the accompanying sketch of the exposure. (See Figure 11).

Essentially, the structure sections consist of a major Third order syncline at #3, separated, by a fault and anticline-syncline combination at 4 and 5, from a major Third order anticline at #7. The syncline at #8 is the last major fold exposed in the section.

Description of outcrop

(1) Start of section - structure generalized between (1) and (2) because poorly exposed and oblique to RR tracks and thus difficult to represent.

(2) Start detailed consideration of structure. Tightly compressed anticlinal axis in red mudstone with well-developed fanning fracture cleavage.

(3) Broadly folded synclinal axis, asymmetric to the south.

Note particularly a thick (30'), massive, sandy mudstone which is the most competent unit in the whole section and perhaps controls the wave length of folding (see discussion in Summary). Mudstone above log in the core of the fold shows excellent axial-plane fracture cleavage on the axis of the fold. Cleavage becomes less prominent and "fans" approximately perpendicular to bedding on limbs. In this bed, intra-bed deformation has taken place by flattening in fracture cleavage planes perpendicular to bedding. Perpendicular flowage of material along fracture cleavage has probably thickened bed.

Directly below cleaved bed is thin-bedded shaly limestone which has deformed by crinkling into minor folds (amplitude ± 1") in response to the same lateral stress (directed along bedding plane) which produced cleavage-flowage in overlying bed.

Beneath crinkled bed is another mudstone which has been slightly thickened in the trough of the fold by failure along intra-bed thrust faults with acute intersections directed along the bedding plane. Thus, three different processes contribute to the small-scale intra-bed continuous, or semi-continuous, deformation occurring in the trough of this fold:

a) fracture cleavage flowage was oriented perpendicular to bedding and was produced by a stress acting parallel to bedding;

b) symmetrical crinkling, or micro-folding, with axial planes perpendicular to bedding; produced by a stress acting along bedding plane; and

c) intra-bed, small-scale thrusting along planes acutely intersecting with bedding planes.

All of these processes lead to local small-scale thickening of the section and were perhaps initiated before complete lithification and before major folding.

(4) Tightly folded and complexly faulted anticline above small watchman's shack.

The steep upthrust rising above the shack is the largest fault exposed in the section and brings older parts of Wills Creek Formation to the north of the fault. I do not believe that any of the section exposed north of the fault is present in this section south of the fault, with the possible exception of some of the beds at the extreme southern end of the section. A small fault with same sense of displacement is well-exposed 30' north of the shack.

The anticline south of the shack at #4 is asymmetric to the south and shows fanning fracture cleavage, crinkled shaly limestone beds, and a prominent red-bed in the core of the fold is a bed which has been duplicated by a bedding thrust which turns and cuts acutely through the bed. This feature has been termed "wedging" by Cloos (1961). It is a less continuous mechanism of producing section thickening than the three intra-bed mechanisms described above.

(5) Syncline, asymmetric to the south.

Note the well-developed fracture cleavage parallel to the axial plane of fold in trough which decreases in importance and fans out on the limbs. Bedding planes to the upper right show bedding and strike joints intersecting to form "logs" elongated in fold axis.

(6) Crinkled fine-grained shaly limestone beds on the limb of the fold show that microfolds are not restricted to fold hinges but occur throughout the section in lithologies that are receptive.

(7) Major Third order anticline, faulted, thickened and asymmetric to the south.

South limb has ridden up and over the crest and north limb along a bedding fault which breaks through the crest of the anticline. This would appear to be the incipient phase of development of larger fault such as is exposed at (4). The well-cleaved bed in the upper part of the anticline is apparently doubled in thickness by "wedging" along a branch of this fault.

Fracture cleavage flowage and intra-bed faulting have both contributed to thickening of beds in the core of fold.

Beyond #7 nothing of significance is exposed that has not been seen already. The last fold hinge, a syncline, asymmetric to the south, is exposed at #8.

## Summary

The form of folds more closely approximates a sine curve than a series of circular arcs. However, these folds have to be classified genetically as concentric, or flexure folds. The limbs of the folds are typically nearly planar and show few minor structures such as parasitic folds, boudins, etc. At this structural level in the section most complications such as minor folds, faults and wedges are encountered in anticlinal axes; the synclinal axes are typically uncomplicated. In the tight syncline at #5, upper, poorly exposed, parts of the section do seem to show minor complications. From these observations it is perhaps safe to conclude that we are standing at approximately the level of the centers of curvature of the anticlines and somewhat (50' or 100' ?) below the centers of curvature of the synclines. Presumably, at higher structural levels synclinal troughs become complicated due to crowding of material in the hinge of the folds by the bending process. Our best candidate for the dominant member establishing the wave length of Third order folding in this part of the section is the thick sandy mudstone at #3. However, using the relationship between thickness of the dominant member and fold wave-length established by Currie, et al, (1962, p. 666):

$$\frac{\text{Wave length}}{\text{Thickness}} \sim 27$$

we do not arrive at a wave length-thickness ratio anything like the magic number of 27. I am unsure of the exact reason for the discrepancy but it probably hinges upon one or more of the following:

a) the sandy mudstone at #3 is <u>not</u> the dominant member controlling fold wave length but the dominant member occurs in a higher, unexposed part of the section; alternatively the sandy mudstone is the competent member but more than the 30' measured behaves competently;

b) the fault at #4 is of such magnitude that it badly distorts wave length measurements;

c) wave length in the upper part of section (between synclines at 3 and 8, wave length is 1080') appears different from the wave length in lower part of section (wave length between anticlines at 4 and 7 is 360'); different parts of the section are thus controlled by different dominant members, folding is somewhat disharmonic, and no measurements of wave length should be attempted until structural lithic units are established.

Although the folds would appear to be concentric folds, no bedding plane slickensides perpendicular to fold axes have been found. Evidence of bedding plane slip is therefore lacking, but such slip should have occurred to allow material to slip out of anticlinal and synclinal hinges and elleviate the crowding which results in the lower part of anticlines and upper part of synclines. Alternatively, it is possible that fracture cleavage flowage, intra-bed faulting, small scale crinkling, wedging and doubling of beds and relatively major faulting originating in anticlines as at (4) and resulting in local thickening of the section in the hinge of folds, may have alleviated the axial crowding that must occur during the folding process. Even though direct evidence of bedding slip is lacking, I do not believe that the section shows sufficient adjustment by these other processes to remove the necessity of accepting some bedding plane slip.

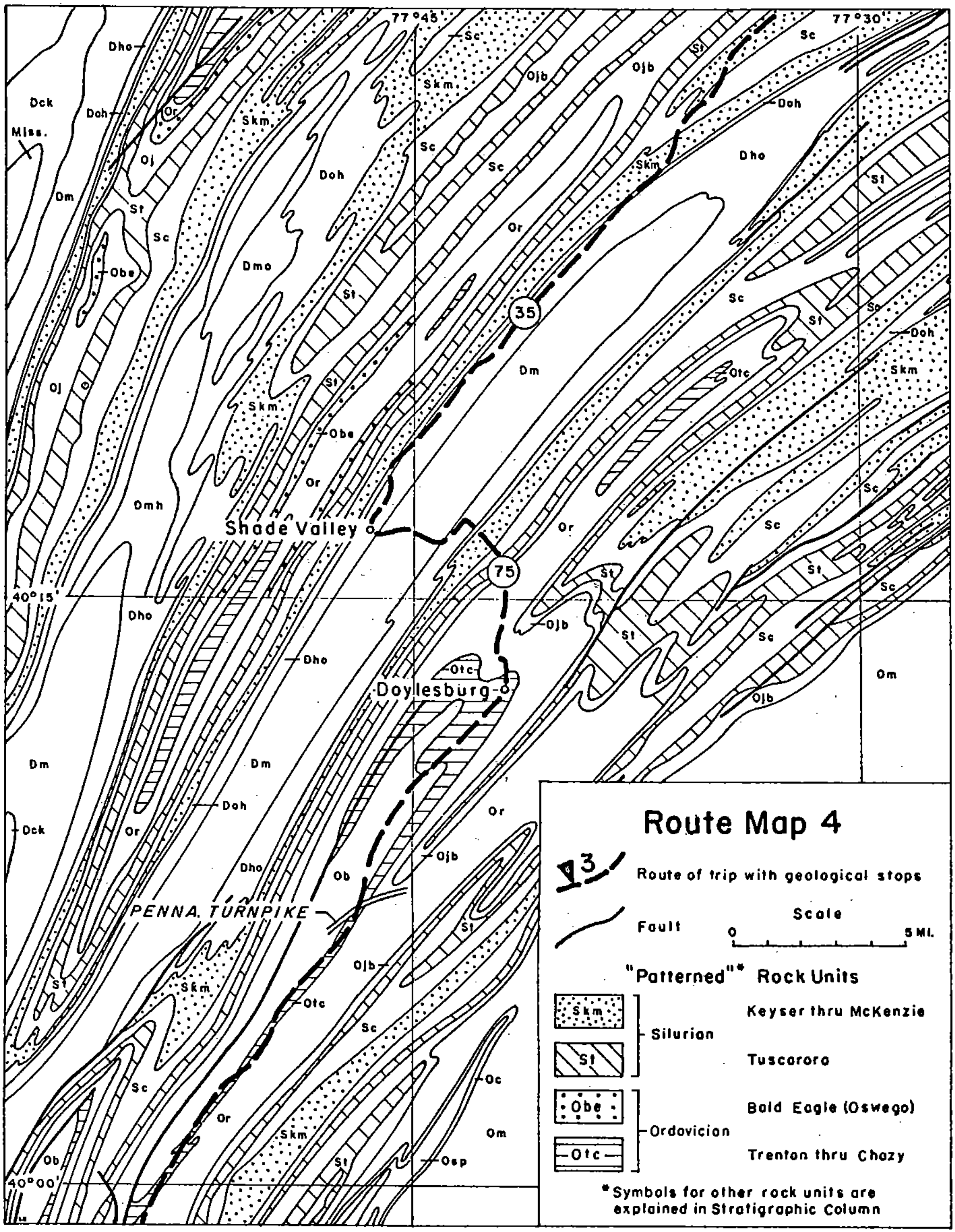
Certain thin-bedded shaly limestones are crinkled into minor folds throughout the section on fold hinges and limbs alike. These are not normal parasitic, or "drag" folds in that they are symmetrical with axial planes which are perpendicular to bedding. My present prejudice is that these minor folds, as well as some fracture cleavage and intra-bed faulting are developed early in the deformational history during a general NW-SE squeezing before the major folding starts. This squeezing and flattening may have occurred prior to lithification of all sediments and different sediments may have behaved differently - some by the plastic flow of water-sediment mixtures (Maxwell, 1962), others by crinkling of partically lithified sediment (most typical of limestones which might be expected to be lithified before other sediments in this section) and others by intra-bed faulting. Cloos (1961) has suggested that bedding slips and wedges may develop early and that wedging may initiate anticlines. Note that anticlines at (4) and (7) both show wedging. It is possible that "wedging" (small scale thrusting limited by bedding planes) occurs at the time of early squeezing and flattening or slightly later, and is responsible for initiating anticlines. If so, it is incorrect to infer that wedges are produced to alleviate crowding at fold hinges. The problem then is deciding whether: (1) Third order anticlines develop in the places that they do because wedging and flattening processes initially are concentrated there before folding; or whether: (2) wedging and flattening develop after folding has begun to alleviate crowding in anticlines where incomplete adjustment by bedding slip has occurred; or whether: (3) wedging and the various flattening processes are effective both early, before folding and as an agent for initiating folding, and later, as a mechanism for alleviating the crowding in fold hinges.

Mileage

Return to buses and proceed via Railroad Street to Pa.-35.

| | | |
|---|---|---|
| 90.3 | 0.1 | Junction with Pa.-35 (South) at "Stop" sign TURN RIGHT and proceed on Pa.-35 (South). |
| 90.5 | 0.2 | Bridge crosses Pennsylvania Railroad tracks. |
| 90.7 | 0.2 | In Silurian Tonoloway limestone. |
| 90.9 | 0.2 | In Silurian Wills Creek shale. |
| 91.8 | 0.9 | Bridge crosses Licking Creek. Route parallels strike in poor exposures of Silurian Tonoloway limestone and Wills Creek shale in synclinal valley. |
| 92.9 | 1.1 | Silurian Tonoloway limestone is exposed in road-cuts. |
| 94.0 | 1.1 | Blacklog Mountain Anticline - Tuscarora sandstone in core at 3 o'clock. Secondary flank ridge is supported by Silurian Keefer sandstone. Keefer sandstone also supports low ridge at 9 o'clock. |

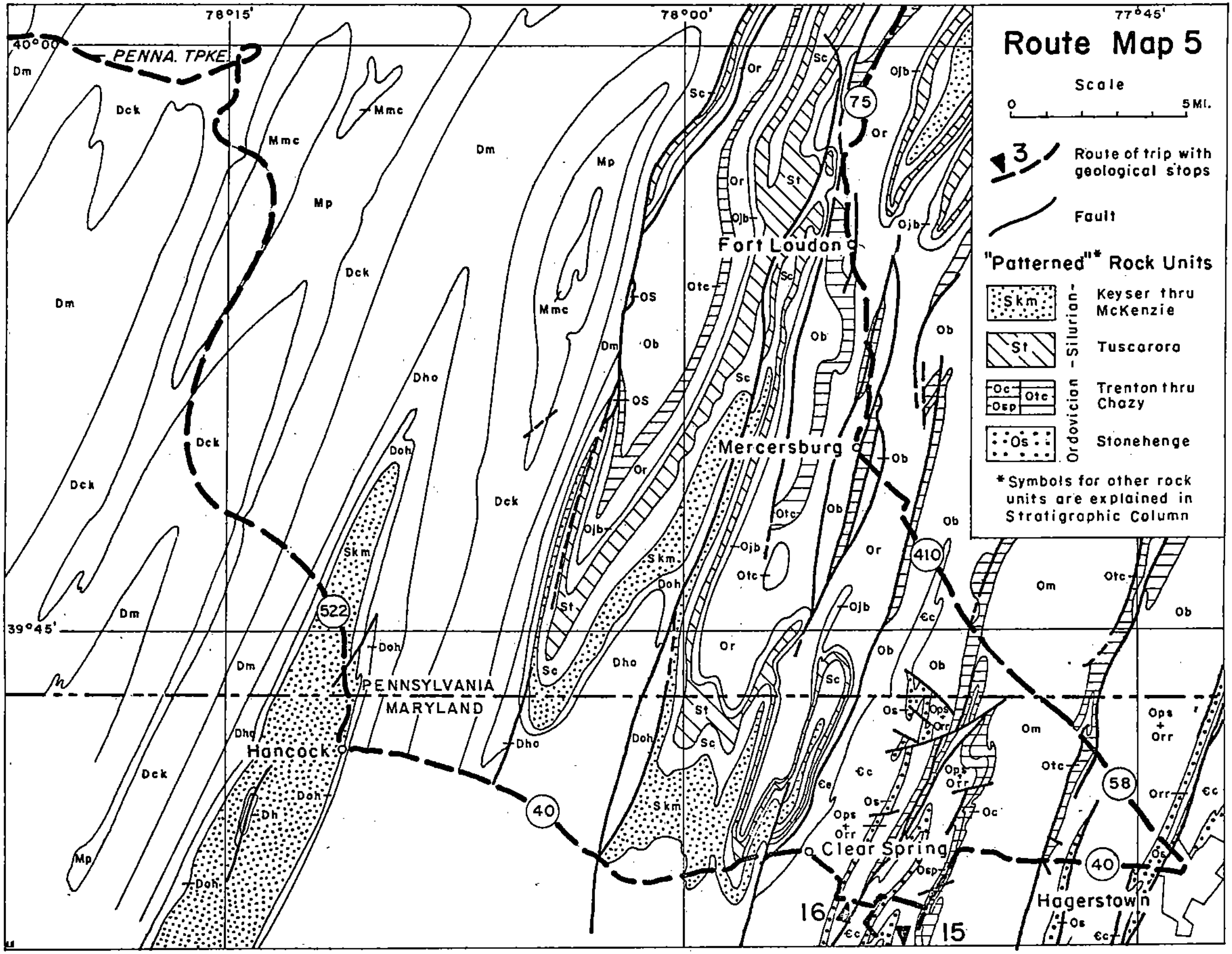
| | | |
|---|---|---|
| 94.2 | 0.2 | Tonoloway limestone can be seen in road-cut at 3 o'clock. |
| 95.9 | 1.7 | Entering village of Walnut. We continue in synclinal trough. |
| 98.2 | 2.3 | Tonoloway-Wills Creek contact; continue, traveling on Wills Creek. |
| 98.7 | 0.5 | Entering the village of Nook; we are in the Silurian McKenzie Formation. |
| 100.5 | 1.8 | Silurian Bloomsburg exposure in small road-cut at 3 o'clock. |
| 101.5 | 1.0 | Bloomsburg is exposed in road-cut at 3 o'clock. (Turn to Route Map 4). |
| 103.1 | 1.6 | At this road junction Keefer sandstone crop can be seen at 9 o'clock.<br>Shade Mountain, the east flank of Blacklog Anticline is at 3 o'clock. |
| 104.6 | 1.5 | East-dipping Keefer sandstone is in road-cut at 3 o'clock. |
| 105.3 | 0.7 | Rocks of the Silurian Bloomsburg Formation can be seen along road.<br>Lower Devonian Oriskany sandstone ridge is at 9 o'clock. |
| 105.7 | 0.4 | Entering the village of Reeds Gap. Shade Mountain at 3 o'clock is the east flank of Blacklog Anticline. |
| 108.2 | 2.5 | Crossing an Oriskany sandstone ridge. |
| 108.7 | 0.5 | Middle Devonian sandstone in the Hamilton Group (Middle Devonian) is at 9 o'clock in a low ridge. Road continues along an Oriskany-Helderberg ridge to Shade Valley. |
| 110.8 | 2.1 | Hamilton shale in road-cut at 3 o'clock. |
| 111.6 | 0.8 | Entering settlement of Peru Mills. |
| 112.9 | 1.3 | Hamilton shale in road-cut at 3 o'clock. |
| 113.4 | 0.5 | Entering settlement of Cross Keys. |


Route Map 4
Route of trip with geological stops
Fault
Scale
0
5 MI.
"Patterned"* Rock Units
Skm
Silurian
Keyser thru McKenzie
St
Tuscarora
Obe
Ordovician
Bald Eagle (Oswego)
Otc
Trenton thru Chazy
*Symbols for other rock units are explained in Stratigraphic Column
77°45'
77°30'
40°15'
40°00'
Shade Valley
Doylesburg
PENNA. TURNPIKE
35
75
Miss.
Dck
Dho
Doh
Dm
Dmo
Dmh
Oj
Ojb
Or
Ob
Oc
Om
Osp
Sc
St
Skm
Obe
Otc

| | | |
|---|---|---|
| 114.4 | 1.0 | Route parallels contact between the Middle and Lower Devonian series. |
| 116.2 | 1.8 | Tuscarora Mountain appears briefly on the distant skyline at 11 o'clock. Sandstone of Hamilton Group supports the ridge at 9 o'clock. |
| 116.5 | 0.3 | Hamilton-Marcellus shales outcrop in cuts on both sides of highway. |
| 116.7 | 0.2 | Hamilton-Marcellus shales in road-cuts on both sides of route. |
| 117.9 | 1.2 | Oriskany sandstone is exposed in road-cuts. |
| 118.7 | 0.8 | Hamilton-Marcellus shales in road-cuts at 3 o'clock. |
| 120.5 | 1.8 | Entering the settlement of Shade Valley (Richvale). TURN LEFT toward Blairs Mills on an unmarked road following the drainage of Trough Spring Branch of Tuscarora Creek. Sands of the Hamilton Group (in the northwest flank of topographically high syncline) are exposed here. |
| 122.1 | 1.6 | Very gentle reversal at synclinal axis - in Upper Devonian marine shales. Road continues through similar stratigraphic section on the east flank of the syncline. |
| 123.1 | 1.0 | Intersection. TURN LEFT |
| 123.5 | 0.4 | Middle Devonian sandstone ridge at 9 o'clock. |
| 124.2 | 0.7 | Middle Devonian sandstone outcrop at 3 o'clock. |
| 124.3 | .01 | Middle Devonian sandstone outcrop at 3 o'clock. |
| 124.5 | 0.2 | Entering Blairs Mills. TURN LEFT at Tuscarora State Bank on unmarked road. |
| 124.6 | 0.1 | TURN RIGHT. Tuscarora Mountain is at 12 o'clock. |
| 125.8 | 0.2 | Junction with Pa.-75 (South) at Spears Grove. Route (Pa.-75) follows the drainage of Narrows Branch of Tuscarora Creek through Concord Narrows of Tuscarora Mountain--Tuscarora Mountain is on the north-west flank of Tuscarora Anticline. |

| | | |
|---|---|---|
| 126.3 | 0.5 | Tuscarora talus slope at 9 o'clock. |
| 126.5 | 0.2 | An exposure of nearly vertical Tuscarora sandstone. |
| 126.8 | 0.3 | Conocheague Mountain is at 9 O'clock. Reedsville shale is in the core of this anticlinal valley here. |
| 127.3 | 0.5 | Entering the village of Concord. Continue on Pa.-75 along strike in the Reedsville shale. |
| 128.8 | 1.5 | Knob Mountain is at 12 o'clock. Continuation of Tuscarora sandstone ridge describes a "fish-tail" pattern for the bifurcating north-plunging axes of Tuscarora Anticline. |
| 129.6 | 0.8 | Junction with Pa.-274; continue on Pa.-75 (South). |
| 129.9 | 0.3 | Village of Doylesburg; bypass and continue in Reedsville shale. Tuscarora Mountain is at 3 o'clock and Knob Mountain is at 9 o'clock; both are Tuscarora sandstone - supported ridges and represent the northwest and southeast flanks, respectively, of Tuscarora Anticline. |
| 131.7 | 1.8 | Abandoned Middle Ordovician limestone quarry at 3 o'clock. |
| 132.1 | 0.4 | Abandoned Middle Ordovician limestone quarry at 9 o'clock. |
| 132.7 | 0.6 | Middle Ordovician limestone exposed in road-cut at 3 o'clock. |
| 133.1 | 0.4 | Beekmantown dolomite exposed in road-cuts on both sides. |
| 134.5 | 0.6 | Entering the village of Dry Run; in the Beekmantown dolomite. |
| 134.9 | 0.4 | West-dipping Middle Ordovician limestone is being quarried in an active quarry (at 3 o'clock) of the New Enterprise Stone and Lime Company (Trenton and St. Paul limestones). |
| 136.0 | 1.1 | Beekmantown exposed in a road-cut at 3 o'clock. |
| 136.5 | 0.5 | Entering village of Spring Run; take bypass. |
| 136.7 | 0.2 | Beekmantown outcrops on both sides of road. |

| | | |
|---|---|---|
| 136.9 | 0.2 | Junction of Pa.-75 with Pa.-433; continue on Pa.-75 (South) STRAIGHT AHEAD. |
| 137.4 | 0.5 | Beekmantown dolomite is in road-cuts at 3 o'clock; we are continuing in an anticlinal valley. |
| 138.1 | 0.7 | Beekmantown outcrops. |
| 139.0 | 0.9 | Underpass beneath Pennsylvania Turnpike. |
| 139.3 | 0.3 | Village of Willow Hill. Route parallels strike in southeast-dipping Middle Ordovician limestone and Lower Ordovician Beekmantown dolomite along the southeast flank of the Tuscarora Anticline. Tuscarora Mountain is at 3 o'clock and Kittatinny Mountain at 9 o'clock. |
| 141.3 | 2.0 | A turnpike entrance is at 3 o'clock. Route is over dolomites of the Beekmantown Group; this is our first encounter with the predominantly limestone facies in the Beekmantown. A low ridge at 9 o'clock marks the approximate contact of the Middle Ordovician limestone and the Reedsville shale. |
| 143.4 | 2.1 | Entering the village of Fannettsburg; in Reedsville shale. |
| 144.5 | 1.1 | A Reedsville shale quarry is at 9 o'clock. |
| 144.8 | 0.3 | An abandoned Middle Ordovician limestone quarry is at 3 o'clock; outcrops continue into field. |
| 145.1 | 0.3 | Middle Ordovician limestone (southeast-dipping) is in road-cuts on both sides of road. |
| 147.1 | 2.0 | Limy dolomites of the Beekmantown group are in road-cut at 3 o'clock. |
| 148.1 | 1.0 | Entering the village of Metal. Route continues, as it has since before the Turnpike underpass, along the West Branch of Conococheague Creek which has been flowing in the Reedsville outcrop belt. |
| 148.8 | 0.7 | Dolomite and dolomitic limestone of Beekmantown Group outcrop in road-cuts on both sides of highway. |


Route Map 5
Scale
0
5 MI.
3
Route of trip with geological stops
Fault
"Patterned"* Rock Units
Skm
Keyser thru McKenzie
St
Tuscarora
Oc
Otc
Osp
Trenton thru Chazy
Os
Stonehenge
Ordovician - Silurian -
* Symbols for other rock units are explained in Stratigraphic Column
78°15'
78°00'
77°45'
40°00'
39°45'
PENNA. TPKE.
Fort Loudon
Mercersburg
Hancock
Clear Spring
Hagerstown
PENNSYLVANIA
MARYLAND
75
410
522
40
58
16
15
Dm
Dck
Dho
Doh
Dh
Mmc
Mp
Skm
St
Sc
Or
Ojb
Otc
Ob
OS
Om
Oc
Osp
Os
Ops + Orr
Єc

| | | |
|---|---|---|
| 150.2 | 1.4 | Reedsville shale is in road-cut at 3 o'clock. (Turn to Route Map 5). |
| 151.8 | 1.6 | Reedsville shale is in cuts on both sides of road. |
| 152.2 | 0.4 | Cowans Gap State Park turnoff - to the right; continue on Pa.-75 (South) paralleling the strike in Reedsville shale. |
| 153.4 | 1.2 | Reedsville shale outcrops in road-cuts. |
| 154.5 | 1.1 | Bridge over Township Run. |
| 155.8 | 1.3 | Village of Fort Louden at 9 o'clock. |
| 156.2 | 1.4 | Intersection of Pa.-75 with U.S.-30; continue <u>STRAIGHT AHEAD</u> on Pa.-75. Rattlesnake Ridge of Cove Mountain is on the skyline at 3 o'clock. Very calcareous Reedsville shale can be found in quarry at 9 o'clock. We are entering the Great Valley of Pennsylvania (a physiographic province), which to the south becomes the Cumberland Valley of Maryland and eventually the historical Shenandoah Valley of Virginia. The southern terminations of Kittatinny, Little, North and Front Mountains are at 9 o'clock distant. |
| 157.9 | 1.7 | Reedsville shale in cuts on both sides of road. |
| 159.3 | 1.4 | Middle Ordovician limestone quarry on both sides of road. Chambersburg and St. Paul Group is exposed in a small fault block. |
| 159.9 | 0.6 | Crossing Buck Creek. |
| 160.0 | 0.1 | Beekmantown dolomite is in road-cut at 3 o'clock. |
| 160.9 | 0.9 | Beekmantown dolomite can be seen in road-cuts. |
| 161.2 | 0.3 | Junction of Pa.-75 with Pa.-416. <u>BEAR RIGHT</u> Route continues on Pa.-416 (South) over Beekmantown dolomite. |
| 162.4 | 1.2 | Junction of Pa.-416 with Pa.-16. <u>BEAR LEFT</u> onto Pa.-16. Entering the Borough of Mercersburg, the boyhood home of James Buchanan, 15th President of the United States. |

| | | |
|---|---|---|
| 163.0 | 0.6 | BEAR LEFT and continue on Pa.-16. |
| 163.4 | 0.4 | Beekmantown dolomite is in road-cut at 3 o'clock. |
| 164.0 | 0.6 | Reedsville shale is in road-cut at 3 o'clock. |
| 164.7 | 0.7 | Bear Pond Mountains are in distance at 3 o'clock. |
| 165.3 | 0.6 | TURN RIGHT on Pa.-416 (South) and travel on Middle Ordovician limestones of the St. Paul Group. West Branch of Conococheague Creek is at 9 o'clock. |
| 165.4 | 0.1 | Approximage contact of Middle Ordovician with Lower Ordovician. |
| 165.7 | 0.3 | Reedsville shale is in road-cuts at 3 o'clock. |
| 166.3 | 0.6 | Reedsville shale - St. Paul limestone fault contact - east side is "up". |
| 166.6 | 0.3 | Crossing Licking Creek; in Beekmantown Group. |
| 167.5 | 0.9 | Beekmantown Group in road-cuts. |
| 167.7 | 0.2 | Upper Cambrian Conococheague Formation is in crest of Welsh Run - Edenville Anticline. |
| 168.7 | 1.0 | Excellent exposures and fairly complete section of the Rockdale Run Member of the Beekmantown Group can be seen along drainage of Welsh Run at 9 o'clock. Entering village of Welsh Run. |
| 170.7 | 2.0 | We are on Martinsburg-Reedsville shale which here "floors" the Massanutten Syncline. |
| 171.9 | 1.2 | Entering the village of Nova. Route continues in Martinsburg shale, paralleling a reach of a meander of the Conococheague Creek. The Conococheague Creek stays within the Martinsburg shale in the core of the Massanutten Syncline. |
| 172.9 | 1.0 | Maryland State Line. Route number changes to Maryland-58; still in Martinsburg shale. The Middle Ordovician subdivisions of Neuman and the Lower Ordovician subdivisions of Sando will be used beyond this point. (See correlations on Figure 2, Wagner paper, page 6.) |

| | | |
|---|---|---|
| 173.8 | 0.9 | Bridge over Conococheague Creek. Good Martinsburg outcrop at 9 o'clock in ramp up river bank; dip is northwesterly (and steep) back into Massanutten Syncline. |
| 174.8 | 1.0 | Fault contact of Martinsburg shale with Chambersburg limestone - eastern (limestone) block is overthrust ot the west. |
| 175.2 | 0.4 | Entering Cearfoss; approximately at the contact of the Middle Ordovician Chambersburg limestone with the St. Paul limestone. |
| 175.4 | 0.2 | Fault contact; Middle Ordovician St. Paul limestone with Lower Ordovician Rockdale Run Member of the Beekmantown Group. Route continues in Rockdale Run Formation for next 3.3 miles. |
| 178.1 | 2.7 | Join 4-lane highway (Cearfoss Pike). |
| 178.9 | 0.8 | Hagerstown city limits. Approximate contact with Lower Ordovician Stonehenge limestone. |
| 179.5 | 0.6 | Fault contact; Upper Cambrian Conococheague Formation is in eastern (up-thrown) block. |
| 180.0 | 0.5 | Pass under railroad underpass. In Lower Ordovician Stonehenge limestone. |
| 180.4 | 0.4 | TURN RIGHT on North Potomac Street (one-way street) and proceed two blocks to Washington Street. |
| 180.6 | 0.2 | TURN LEFT and park at southeast entrance to Hotel Alexander (You will be sleeping on Stonehenge tonight.) |

END OF SECOND DAY

THIRD DAY

ROAD LOG, SATURDAY, SEPTEMBER 21, 1963

Mileage - 86.0

Buses will load at southeast entrance (Washington Street) of Hotel Alexander for departure at 8:30 a.m.

| Mileage | | |
|---|---|---|
| 0.0 | | Hotel Alexander; proceed on Washington Street (one-way street) for one block. |
| 0.1 | 0.1 | TURN LEFT on Locust Street and proceed one block. |
| 0.2 | 0.1 | TURN LEFT on Franklin Street (US 40) and proceed straight ahead. |
| 0.8 | 0.6 | Railroad underpass. Approximate contact of Lower Ordovician Stonehenge limestone with Upper Cambrian Conococheague Formation. |
| 1.6 | 0.8 | US 40 (west) joins Interstate 81; CONTINUE ON EXPRESSWAY; in Lower Ordovician Stonehenge limestone. |
| 2.7 | 1.1 | Poor exposures of the Rockdale Run Formation on the Beekmantown Group. |
| 4.0 | 1.3 | End of Expressway. Straight ahead is a Conococheague synclinal valley. Continue on US 40 (west) |
| 4.4 | 0.4 | Fault contact of Rockdale Run formatuon with Stonehenge limestone. |
| 4.5 | 0.1 | Rockdale Run is exposed. |
| 5.0 | 0.6 | Contact of Rockdale Run with Pinesburg Station Formation (of the Beekmantown Group). |
| 5.1 | 0.1 | Intersection of US 40 with Md. 63 at Huyett; in Pinesburg Station dolomite. |
| 5.2 | 0.1 | Middle Ordovician St. Paul limestone Group in fields at 3 o'clock. |
| 5.3 | 0.1 | Fault contact; we go from Middle Ordovician St. Paul in eastern "up" block to Martinsburg shale of western "down" block. Route continues in Martinsburg shale for next 3.4 miles across the Massanutten Syncline. |

Mileage

5.5 0.2 Martinsburg shale in road cuts on both sides. The meanders of the Conococheague Creek are wholly contained in this belt of Martinsburg shale. As a result of the difference between the mechanical erosion of the Martinsburg and the solution rate of the bounding limestone, at no place does the Conococheague Creek transgress the contact.

6.5 1.1 Bear Pond Mountains at 1 o'clock.

7.9 1.4 Bridge over Conococheague Creek. Chambersburg limestone exposures can be seen at west end of the bridge.

7.9 0.0 TURN LEFT 500 feet west of bridge.

8.1 0.2 Quarry in the Middle Ordovician St. Paul limestone at 3 o'clock (Wilson Quarry).

8.6 0.4 At Y intersection BEAR RIGHT; we are in Chambersburg limestone.

8.7 0.1 Crossing Meadow Brook at contact of Chambersburg limestone with St. Paul Group. Route continues in the St. Paul Group, paralleling strike.

9.3 0.6 Approximate contact of Middle Ordovician St. Paul Group with Chambersburg limestone. Route continues in Chambersburg limestone with excellent exposures in field at 3 o'clock.

10.0 0.7 T intersection. TURN LEFT.

10.1 0.1 Martinsburg shale crops at 3 o'clock.

10.3 0.2 Entering settlement of Pinesburg; TURN RIGHT. Route continues in the Chambersburg limestone.

11.4 1.1 Entering Pinesburg Station, Western Maryland Railroad. TURN RIGHT, park in yard of Fry Coal and Stone Company's Pinesburg Station quarry.

STOP XV Group Leader: Dick Frost, Shell Oil Company

Exposures of the Beekmantown Group and the St. Paul group will be seen along the Chesapeake and Ohio Canal between Pinesburg Station quarry and Millers Bend. Neuman (1951) described the St. Paul Group section exposed in the quarry. A detailed description of the excellent Beekmantown section to the south and west of the quarry has been published by Sando (1957). We will proceed on foot to Millers Bend, where buses will pick us up. (See Wagner's papers Fig. 2, page 6)

The Beekmantown in this area is about 4000 feet thick (Sando, 1957). It is about 70% limestone, being regionally intermediate in the eastward change from dolomite in the Nittany Valley to limestone along the east side of the Great Valley. It has been broken down by Sando into three formations, the Pinesburg Station dolomite at the top (400 feet), the Rockdale Run interbedded limestone and dolomite (2500 feet), and the Stonehenge limestone at the base (1000 feet).

We will start at the Fry Coal and Stone Company's quarry, where the Middle Ordovician Row Park, New Market, and Trenton limestones are exposed, and walk westward through the upper 3000 feet of the Beekmantown, continuously exposed along the canal. In this exposure the upper 1000 feet is extremely fine to sublithographic dolomitized mud, with interbeds of lithified lime mud. The 400 foot dolomite unit at the top is the Pinesburg Station Formation, the Rockdale Run contact being picked at the occurrence of the uppermost limestone interbed. The middle 2000 feet is mainly lithified lime mud with interbeds of extremely fine to sublithographic dolomite. The lower 1000 feet (Stonehenge) is lithified lime mud, the contact with the Rockdale Run Formation being picked at the lowermost dolomite interbed, which occurs near the dirt road across the canal at the west end of the exposure.

The section is rather monotonous except for the limestone-dolomite interbedding. Shallow water to intertidal depositional conditions are indicated by occasional intraformational conglomerates, stromatolitic layers, burrowing, pelletal layers, and oolitic fossiliferous conglomerate. Stromatolites, intraformational conglomerates, and oolitic fossiliferous conglomerate layers are more common in the Stonehenge.

The following log is for "buses only". Buses will retrace route to Pinesburg.

<u>Mileage</u>

| | | |
|---|---|---|
| 12.6 | 1.2 | Entering Pinesburg; <u>TURN LEFT</u> on Md. 68. Route crossing same section seen at STOP XV. |
| 12.9 | 0.3 | Intersection at right, in Chambersburg limestone. Route continues through Chambersburg limestone and the St. Paul Group. |
| 13.1 | 0.2 | Approximate contact of Lower Ordovician Pinesburg Station dolomite (of Beekmantown Group) with St. Paul limestone. |
| 13.2 | 0.1 | Approximate contact of Rockdale Run limestone and dolomite with the Pinesburg Station dolomite (both of the Beekmantown Group). |
| 14.0 | 0.8 | "Y" junction with Md. 56. <u>BEAR LEFT</u>. In Stonehenge (limestone) Formation of Beekmantown Group. |
| 14.3 | 0.3 | Approximate contact of Upper Cambrian Conococheague Formation with Stonehenge. |

Mileage

14.6 0.3 Junction with Charlton Road; TURN LEFT.

14.8 0.2 Entering Charlton, in Stonehenge limestone once again.

15.2 0.4 TURN LEFT on dirt road. End of log for "buses only".

* * * * *

15.8 0.6 People will rejoin (and get back on) buses near Millers Bend (at abandoned railroad bed) and return to Charlton Road.

16.5 0.7 Intersection with Charlton Road; TURN RIGHT.

16.8 0.3 Railroad Crossing at Charlton; in the Stonehenge limestone.

17.0 1.2 Junction with Md. 56; TURN LEFT . In the Upper Cambrian Conococheague Formation.

17.4 0.4 Narrow arch bridge over Little Conococheague Creek. BE CAREFUL. In Conococheague Formation.

19.0 1.6 TURN LEFT on dirt road and proceed to railroad crossing.

19.2 0.2 At Western Maryland railroad crossing.

STOP XVI Group Leader: Dick Frost, Shell Oil Company.

The Conococheague is the limestone equivalent of the Gatesburg, and is about 2300 feet thick in this area (Sando, 1957). It is mostly limestone here, and intermediate in the eastward change from dolomite in the Nittany Valley to limestone on the east side of the Great Valley.

The lower third is well exposed here on the east flank of an anticline. It consists of the following interbedded lithologies: sublithographic to extremely fine-grained lithified mud, extremely fine-grained dolomite (dolomitized "lime mud"), sparry oolitic limestone, and a few layers of shale and quartz sandstone. The amount of oolite and sandstone is much less than in the Nittany Valley. The amount of dolomite decreases upward, and the upper two thirds of the formation is mainly "lime mud."

A shallow water to intertidal environment is indicated by the presence of common stromatolites, abundant flat-pebble conglomerates, cross-bedding in the sandstones, fossiliferous layers, and occasional mus cracks.

Proceed over railroad tracks and turn around at farmhouse. Return to paved road.

Mileage

| | | |
|---|---|---|
| 19.6 | 0.4 | TURN LEFT onto Md. 56. Route continues in the Conococheague Formation and then crosses a fault ("down" to the west) into the Beekmantown rocks. |
| 20.0 | 0.4 | Junction. TURN RIGHT and proceed to village of Clear Spring on US 40. Route crosses a normal contact of Beekmantown with Conococheague. |
| 21.7 | 1.7 | Entering Clear Spring, Maryland; still in Conococheague Formation. |
| 21.9 | 0.2 | Junction with US 40. TURN LEFT and proceed west on US 40. |

(The following road log, from Clear Spring to Hancock, is from the 1958 Pennsylvania Field Conference Guide Book prepared by Cloos and Pettijohn.)

| | | |
|---|---|---|
| 22.8 | 0.9 | Elbrook limestone in old quarry in hill north of highway (3 o'clock). |
| 23.0 | 0.2 | Crossing fault which throws Elbrook and Conococheague against Oriskany sandstone and Romney shale. The fault dies out northward and becomes more prominent southward; it also determines the western edge of the Great Valley in this section. A second, northeast-trending, strike fault separates Elbrook limestone from Martinsburg shale. |
| 24.3 | 1.3 | Summit of Fairview Mountain. Good view of Massanutten Mountain to the south. |
| 24.6 | 1.3 | Silurian Keefer sandstone is exposed in road cuts at 3 o'clock. Crossing south-plunging anticlinal nose. |
| 26.2 | 1.6 | Indian Springs; Stores and intersection with a road to the north. |
| 28.6 | 2.4 | Road cuts in Helderberg limestone. Fossils weather out and can be gathered in quantity. |
| 28.8 | 0.2 | Bridge across Licking Creek. |
| 30.1 | 1.3 | Upper Devonian Parkhead Sandstone (type locality) is exposed here. Excellent exposures of mostly Upper Devonian rocks along road for next 1.1 miles. Road parallels strike of formations most of the way. Jennings Formation (Upper Devonian), with many fossiliferous beds, is exposed along most of the route. |
| 30.9 | 0.8 | Scenic overlook at 9 o'clock. |

Four routes of travel can be seen from this point: Potomac River, Chesapeake and Ohio Canal, Baltimore and Ohio Railroad, and the "National Pike"; all played vital roles during the Civil War.

General W. W. Averell (U.S.A.) with 2800 cavalrymen passed this point in pursuit of McCausland (C.S.A.) after the raid and burning of Chambersburg. McCausland was caught and defeated near Moorefield with all plunder taken from Pennsylvania recaptured.

Mileage

34.4 3.5 Intersection of US 40 with Md. 615. Continue straight ahead on Expressway US 40.

35.1 0.7 Devonian Catskill beds with excellent cross-bedding at 3 o'clock.

36.6 1.1 City limits of Hancock, Maryland.

37.3 0.7 Hancock Post Office at 9 o'clock.

37.5 0.2 Junction. TURN RIGHT and follow directions to US 522.

37.7 0.2 Junction US 522. TURN RIGHT and proceed on US 522 (north).

38.2 0.5 Southeastward-dipping Helderberg limestone crops out here on the southeast flank of Cacapon Mountain Anticline. Parallel ridge 1/8 th. mile to east of highway represents Oriskany sandstone outcrop.

39.6 1.4 Mason-Dixon line. Exposures for next five miles represent Keyser and Wills Creek formations of Silurian age on north plunge of Cacapon Mountain Anticline. The southward extension of this anticlinal feature exposes the Tuscarora sandstone of Silurian age west of Berkeley Springs.

40.2 0.6 Enter limited-access Interstate Route 70.

41.6 One-fourth mile to east of highway may be seen H. B. Millot limestone quarry in Keyser Formation.

42.3 2.1 McConnelsburg Exit - Village of Warfordsburg on left.

42.5 0.2 Crossing axis of Cacapon Anticline.

43.2 0.7 Large road cut on left side of road exposes Northwestward dipping Helderberg, Shriver chert, and Oriskany sandstone of Early Devonian age. Immediately to the east of road, outcrop continues through Onondaga limestone, Marcellus shales, and Hamilton

Mileage

shales of Middle Devonian age.

44.3 1.1 Road cuts expose contorted Chemung beds which evidence faulting on this flank.

46.2 1.9 Red shale and siltstone interbeds marking transitional character of Catskill - Chemung contact. Dip is northwestward. Red rocks of Catskill Formation exposed for next mile.

47.4 1.2 Deneen Gap Interchange marking approximate axis of Sideling Hill Syncline whose youngest rocks are of the Pocono Group of Mississippian age. Continue through gap, the rocks for next 5.7 miles represent those of Catskill Formation exposed over the Paw Paw Anticline. Several distinct Anticlinal trends are displayed in the attitudes between the framework of the Pocono on the east and the west. Approximately forty miles southwest near Romney, West Virginia, Oriskany gas production has been found on this structure at the Whip Cove Gas Field (or Augusta Pool).

53.1 5.7 Pocono-Catskill contact dipping northwestward on Town Hill. Base of Pocono Group contains much red coloration.

55.3 2.2 Summit of Town Hill; Northwestward-dipping resistant Pocono.

57.8 2.5 Mauch Chunk-Pocono contact; Dip is northwestward into Town Hill Syncline whose youngest exposures are of the Mauch Chunk.

59.9 2.1 Southeastward-dipping Mauch Chunk sandstones and shales on northwest flank of Town Hill Syncline.

60.2 0.3 Large road cut in gap of Rays Hill exposes southeastward-dipping Pocono Group; Contact of Mauch Chunk and Pocono is at this point.

61.2 1.0 Approximate contact of Pocono-Catskill on west flank of an unnamed anticlinal complex. Eight miles southwest of this point, Oriskany production has been established on a local anticline; the pool is known as the Purcell Pool. The oldest exposures over the gas pool are of Chemung "age." Continuing northward from this mileage point, all exposures are of the Catskill Formation. Local folding accounts for apparent erratic attitudes.

64.7 3.5 Intersection Interstate Rt. 30 and 126 - TURN RIGHT on Rt. 30 into Village of Breezewood.

65.1 0.4 TURN RIGHT at entrance to Turnpike.

Breezewood Toll Booth - Pennsylvania Turnpike.

65.3 0.2 Joining Pennsylvania Turnpike heading toward Pittsburgh and the west.

(Road log from Breezewood to Bedford is, with minor revision, from Guidebook to the Geology of the Pennsylvania Turnpike, Cleaves and Stephenson, Pa. Geological Survey, 1949)

66.8 1.5 Catskill Formation; red sandstone and shale.

68.7 0.9 Catskill Formation; sandstone and red shale.

70.7 2.0 Catskill Formation, at bridge over the Turnpike, near the axis of a minor syncline.

71.2 0.5 Catskill Formation is exposed in all cuts from Rays Hill westward to Clear Ridge. Considerable folding is evident in many cuts, hence numerous minor synclines and anticlines can be mapped in this area.

71.7 0.5 Clear Ridge Cut. This was the deepest highway cut in eastern United States when it was made in the late 1930's, being 153 feet deep and 2475 feet long. Benches collect rock falls from higher parts of the walls to protect traffic. The strata strike across the Turnpike at this place, and there has been no trouble with slides.

In the Clear Ridge Cut the strike is N 32 E, and the dip 53 SE. The cut continuously exposes 1,800 to 1,900 feet of Upper Devonian Chemung shale and sandstone with some Catskill shaly red sandstone at the east end. The Chemung beds at the Allegheny Front are about 2,000 feet thick, with purplish shales in the higher portion; they are marine and contain the Cyrtospirifer disjunctus fauna with Dalmanella tioga in the lower quarter. At Clear Ridge cut, the purplish tongues of the higher Chemung become more prominent, red, and Catskill-like and give witness to the eastward change taking place in the Chemung as it transforms into the red continental (Catskill) facies; to the east, this change (in correlative strata) from the gray-brown and brachiopod-rich Chemung to red continental Catskill is completed and denotes the proximity to the old land region from which these sands and clays were worn by Late Devonian river systems. From the hilltop there is a fine view of the regional structure.

72.8 1.1 Chemung is exposed in a cut 25 to 30 feet deep; green shales and interbedded chocolate-red sandstone and shale; Pterinea chemungensis present.

72.9 0.1 Fort Littleton Formation shales - soft, olive-drab shales, barren - can be seen here. Tully and Harrell beds are concealed in the valley to the west. In this cut the strata are folded into a syncline, the east limb dipping 47 W and its west limb dipping 44 E. There is an overhead bridge in the middle of the cut.

73.4 0.5 Hamilton Group. In a 40-foot-deep cut, brownish weathering gray sandstones, thin-bedded except for the massive unit near the center of the cut, are overlain by Hamilton shales in the eastern end of

Mileage

the cut. Locally, these beds are very fossiliferous (large "Spirifer's", Chonetes, and Tropidoleptus). (Turn once again to Route Map 1).

73.7 0.3 Lower Devonian strata are exposed here in a deep cut in Warrior Ridge. The sequence of the strata in this cut, from east to west, is:

- Needmore (Onondaga) black, fissile shale
- 114' Ridgeley sandstone, fossiliferous
- 76' Shriver chert, weathered, fragmentary. No fossils found.
- 15' Keyser limestone, crystalline, very fossiliferous limestone.

Across the Juniata River, from the town of Everett north, continuous exposures of Oriskany occur. It was extensively quarried at Tatesville, 3 miles north of Everett, by the Pittsburgh Silica Sand Company.

74.0 0.3 Everett Maintenance Building and shops for the Pennsylvania Turnpike. Site of Everett-Saxton iron works. Note slag piles to the north. Everett was a former "iron town."

74.3 0.3 Rose Hill (Clinton) is covered but under the houses on the south side (9 o'clock) of the road there exists a filled shaft used in colonial days for mining the "Clinton" iron ore.

74.6 0.3 Aliquippa Gap in Tussey Mountain (the nose of which at this point is called Mt. Dallas). In this gap a sequence of strata is exposed from the Tuscarora quartzite at the east through the Bald Eagle (Oswego) on the west - same as in the Bedford Narrows, but with the sequence reversed. The strata strike N22E and the dip varies from 44 to 64 SE. Some faulting and shearing is apparent. The Tuscarora white quartz sandstone and quartzite (ganister) contain Arthrophycus (worm trails). The Bald Eagle, a rusty speckled sandstone, is strongly shattered and faulted. Near the west end of the cut, the contact between the sandy Upper Martinsburg and the Bald Eagle may be seen. All contacts can be observed although are not always clear.

76.2 1.6 New Enterprise limestone plant (north) and quarry (south) of the Turnpike. Quarry is in Chazyan-Black River (Middle Ordovician) limestone.

76.3 0.1 Lower Ordovician Beekmantown dolomites, largely whitish and of Bellefonte type. The Axemann limestone, which separates the Bellefomte dolomite above from Nittany dolomite below in the State College region, tends to disappear southward, making distinction of the two dolomites difficult.

77.5 1.2 Fields south of the Turnpike yield chert fragments with much sil-

Mileage

iceous oolite of the type characteristic of the Mines dolomite (which is 250 feet thick and found at top pf Gatesburg formation). The contact between the Mines and Gatesburg occurs about at the woods line at the west edge of the field.

77.6 0.1 Additional cuts expose Gatesburg sandy dolomite.

78.1 0.5 Beds below the middle of the Upper Cambrian Gatesburg sandy dolomite are exposed in a cut on the south side of the highway. The Gatesburg is about 1,600 feet thick; it contains interlayers of sandy dolomite and quartz sandstone, the sand forming about 10 per cent of the mass; it weathers to a loose sandy-soil mantle of considerable thickness.

The middle part of the Gatesburg contains the 50- to 100-foot Ore Hill characterized by trilobites of the same sort as those found near Chambersburg below the middle of the Conococheague limestone. The sandy Gatesburg of central Pennsylvania grades southeastward into the Conococheague limestone, giving evidence that the Gatesburg sands were transported to central Pennsylvania from the north and northwest.

78.5 0.4 Scattered crops of Upper Cambrian Warrior Formation dip about 30 SE. Cryptozoan heads provide evidence that these beds are not overturned. The Warrior strata at first appear to overlie the Bellefonte (Beekmantown) of the last cut to the west (-their trilobites show that they are early Upper Cambrian in age) but they belong about 4000 feet below the Beekmantown and have been carried to their present position by the Friend's Cove Overthrust. The thrust plane forms a rather low angle to the bedding, and, if so, the actual slip may have been of the order of several miles. This fault was first identified by James Wilson.

78.7 0.2 Long cut in light-weathering Bellefonte dolomite of Lower Ordovician Beekmantown Group. The beds dip about 45 SE and lie in the southeastern limb of the anticlinal fold.

79.0 0.3 Juniata River Crossing. The contact of the Reedsville with the Upper Ordovician limestones was observed in the core borings for the foundations of this bridge, but is no longer exposed. The Cambro-Ordovician limestone does not reappear again to the west until brought to the surface on the Cincinnati Arch, hundreds of miles west of here.

79.2 0.2 Bedford Narrows where Raystown Branch of the Juniata River cuts through Evitts Mountain. (See Mileage point 32.7 on log for First Day)

The section exposed is as follows (in descending order) according to measurements of F. M. Swartz assisted by Doris Bye:

Mileage

Bedford Narrows Section

Lower Silurian:

Tuscarora Sandstone: thick-bedded, resistant, white silica-cemented quartz sandstone or quartzite, making main ridge of Evitts Mountain. Used as ganister rock for silica brick in central Pennsylvania, the Tuscarora extends westward and northwestward into the gas-producing Medina sand ("Clinton" Sand of Ohio), and is represented in part (?) by the Whirlpool Sandstone in Niagara Gorge. Total thickness +400 feet; exposed in west end of cut . . . . . . . . . 165 feet

Upper Ordovician:

Juniata Red Beds: Upper reddish quartzitic member: dark red quartzitic sandstone, with thin partings of red silty shale increasing below . . . . . . . . 60 feet

Red siltstone member: red siltstone or mudstone and interbedded red sandstone . . . . . . . 610 feet

Lower Sandstone Member: thick-bedded, red, medium-grained sandstone and some interbedded red mudstone; some minor interbeds of greenish sandstone in lower part . 380 feet

(The Juniata correlates with the Queenston of the Rochester and Niagara gorges.)

Total thickness Juniata red beds . . . . 1,050 feet

Bald Eagle Sandstone: (intertonguing with Juniata facies)

"Ridge-making" member: thick-bedded, cross-bedded, greenish and much interbedded reddish sandstone (graywacke), with a few thin partings of gray or reddish shale; shale chips are common; a few 1/4 to 1/2-inck pebbles of milky quartz occur in three thin lenses. These beds make subsidiary ridge of the mountain . . 215 feet

Lower shaly member: interbedded greenish and reddish sandstone (graywacke) and greenish and reddish silty mudstone that forms about a third of mass . . . . 320 feet

Total thickness of Bald Eagle Sandstone . . 535 feet

Reedsville Shale:

Upper sandy member containing Orthorhyncula stevonsoni fauna; carbonate-bearing greenish siltstone and some interbedded sandstone . . . . . . . . . . 47 feet

Mileage

Bald Eagle red and green shaly sandstone duplicated by faulting at east end of cut; about 60 feet. (See comments at mileage point 32.7 of First Day).

79.7 0.5 Viaduct over Dunning Creek at its junction with the Juniata River. Foundations for this structure are placed on Rose Hill (Clinton) strata which are no longer exposed.

80.4 0.7 Oriskany (Ridgeley sandstone); yellowish-brown sandstone and chert; Platyceras and Spirifer arenosus common. This is the east limb of a shallow syncline; dips are to the west.

80.6 0.2 Needmore shale (Onondaga); weathered black shale.

80.9 0.3 "Midway" Service Stations and restaurants.

81.2 0.3 Oriskany (Ridgeley sandstone); yellowish-brown, weathered into a loose sand; occasional fossils. This is the west limb of a shallow syncline.

81.6 0.4 A bridge over the Turnpike. Oriskany, decomposed, is exposed.

81.7 0.1 Keyser limestone: massive, and in part cherty limestone; prominent Stromatoporoid bed. Cherty beds rest on top of the Keyser, but no Coeymans or New Scotland fossils have been reported.

82.0 0.3 Tonoloway limestone is exposed to the north in 60-foot cut.

82.6 0.6 Underpass for US Route 220 to Bedford.

Bedford Springs, two miles south of Bedford, has been famous for many years as a health resort. Medicinal value of these springs was discovered about 1796 and it soon became a leading resort. President James Buchanan used the Springs as his summer White House.

82.8 0.2 Bedford interchange. The strata on the west side are Wills Creek, consisting of greenish-yellow shale interbedded with dove-gray calcareous shale. Some cherty limestone occurs near the top of the 40-foot cut. Near the ticket booth is a blue limestone replete with veins of calcite, quartz veins and vugs; some ostracoda are present. Strike N 11° W, dip 12° NE.

(End of log extracted from "Guidebook to the Geology of the Pennsylvania Turnpike")

Mileage

| | | |
|---|---|---|
| 83.1 | 0.3 | Bedford Toll Booth, Pennsylvania Turnpike. Proceed to US 220. |
| 83.2 | 0.1 | Junction US 220. TURN RIGHT and continue south towards Bedford. |
| 85.4 | 2.2 | Bridge over Raystown Branch, Juniata River. Continue straight ahead. Keyser limestone and Uppermost Tonoloway are exposed in bluff at 9 o'clock on north side of bridge. |
| 85.6 | 0.2 | At second signal, TURN LEFT and proceed one block. |
| 85.7 | 0.1 | TURN LEFT and proceed one block. |
| 85.8 | 0.1 | TURN LEFT onto Pitt Street. |
| 86.0 | 0.2 | Entrance of New Hoffman Hotel. |

END OF LOG

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