

GUIDEBOOK

# 31st. ANNUAL FIELD CONFERENCE OF PENNSYLVANIA GEOLOGISTS

*October 7 & 8, 1966  
Harrisburg, Pa.*

*Host*

*Pennsylvania Geological Survey*

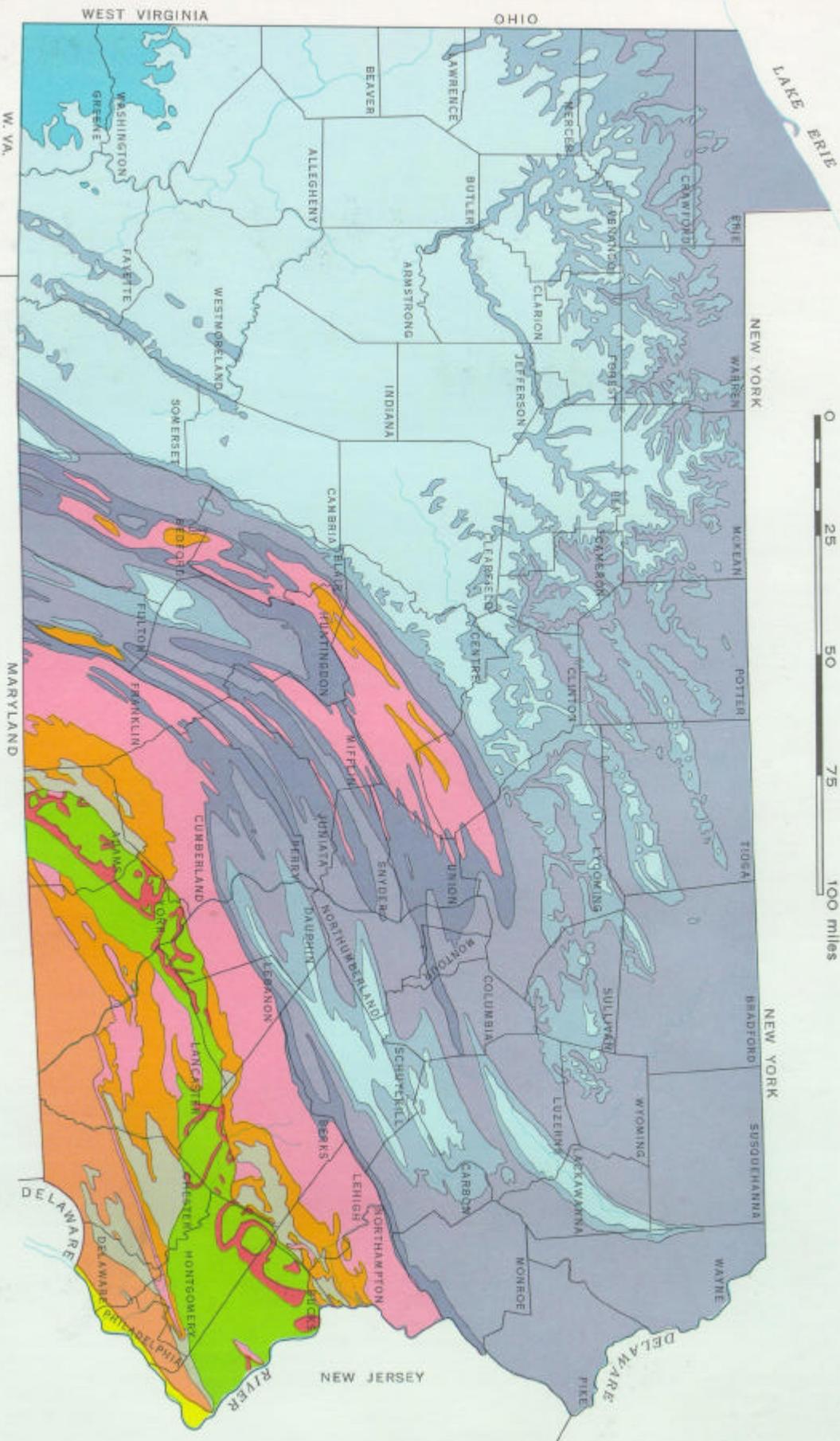




# GEOLOGIC MAP OF PENNSYLVANIA

COMMONWEALTH OF PENNSYLVANIA  
DEPARTMENT OF ENVIRONMENTAL RESOURCES  
TOPOGRAPHIC & GEOLOGIC SURVEY

Arthur A. Socolew, State Geologist



- QUATERNARY** (4-1 million yrs.)  
Sand and gravel, some soil gravel.
- TELUSIC** (180-600 mil. yrs.)  
Shales and sandstones, some dolomite, some chert, some fossiliferous.
- PERMIAN** (260-280 mil. yrs.)  
Carboniferous of sandstone, shale, limestone, and coal.
- PENNSYLVANIAN** (280-310 mil. yrs.)  
Carboniferous of sandstone, shale, limestone, and coal.
- MISSISSIPPIAN** (310-360 mil. yrs.)  
Carboniferous of sandstone, shale, limestone, and coal.
- DEVONIAN** (360-410 mil. yrs.)  
Carboniferous of sandstone, shale, limestone, and coal.
- SILURIAN** (410-440 mil. yrs.)  
Silurian of sandstone, shale, limestone, and coal.
- ORDOVICIAN** (440-500 mil. yrs.)  
Silurian of sandstone, shale, limestone, and coal.
- ORDOVICIAN and/or CAMBRIAN** (500-600 mil. yrs.)  
Cambrian of sandstone, shale, limestone, and quartzite, including quartzite.
- CAMBRIAN** (600-660 mil. yrs.)  
Cambrian of sandstone, shale, limestone, and quartzite, including quartzite.
- PRECAMBRIAN** (Older than 660 mil. yrs.)  
Gneiss, schist, amphibolite, and other rocks, including quartzite, gneiss, schist, amphibolite, and other rocks.

Guidebook for the 31st Annual Field Conference of Pennsylvania Geologists

October 7 - 8, 1966

COMPARATIVE TECTONICS AND STRATIGRAPHY OF THE CUMBERLAND AND LEBANON VALLEYS

By

David B. MacLachlan and Samuel I. Root  
Pennsylvania Geological Survey

Host: Pennsylvania Geological Survey

Headquarters Hotel: Penn Harris, Harrisburg

Guidebook Distributed by:

Bureau of Topographic and Geologic Survey  
Department of Environmental Resources  
Harrisburg, Pennsylvania 17120

## ERRATA

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- iv Fig. 8. Thrust zone on north side of Bethlehem Steel Company quarry, Steelton.
- 8 Martinsburg Formation - Allochthonous elements probably present east of Carlisle.
- 22 Fig. 4. (Lambert Azimuthal Equal-Area Projection [Schmidt net] )
- 34 Fig. 8. Thrust zone on north side of Bethlehem Steel Company quarry, Steelton.
- 38 Fig. 9B The lineation  $L_{1.5 \times 2}$  should appear at the intersection of the two dashed great circles.
- 39 Table 4. second line of text (as in  $B'_1$ )
- 40 lines 14 and 15 for  $A'_1 A_1$  read  $A_1 - A_1$
- 43 first line four S surfaces (not  $S_1$  surfaces)
- 47 line 6 Reading
- 54 line 8 for Figure 8 read Figure 5
- 72 mile 6.7 St. Paul Group outcrop
- 73 mile 13.7 Cross Yellow Breeches Thrust
- 79 mile 22.3 line 4 for shale read swale

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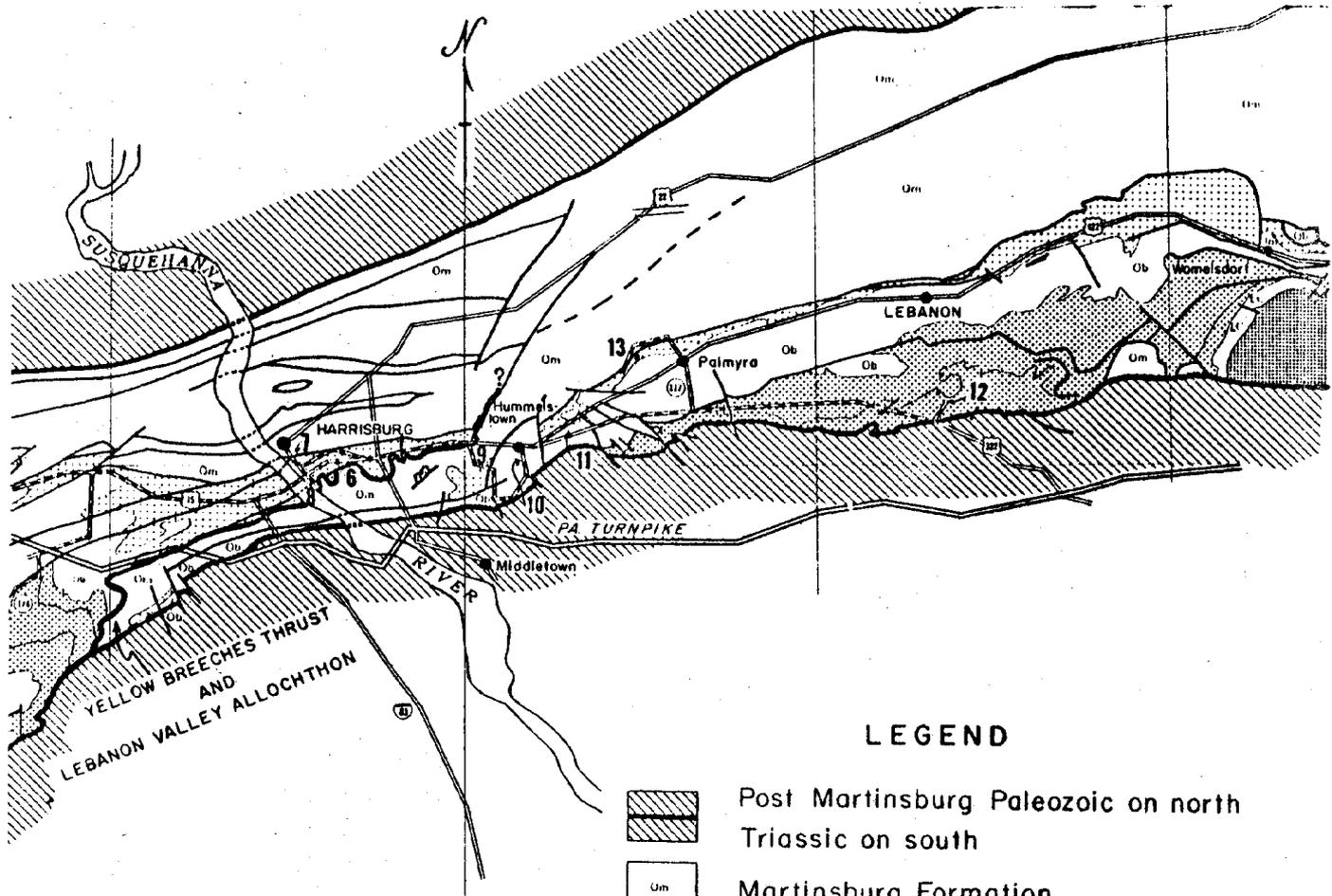
INTRODUCTION

In the early 1950's the Pennsylvania Geologic Survey initiated a program of detailed geologic mapping in the carbonate rocks of the Great Valley. The first published quadrangles (Gray, Geyer, et al, 1958 and 1963) showed general stratigraphic inversion and considerable low angle thrusting in the Lebanon Valley, but the exact relationship of these features to the simpler structures of the Cumberland Valley was not established. Continuation of this program by MacLachlan and Root provides a basis for resolving this problem. Root's mapping in Franklin County yields a stratigraphic column and portrays a tectonic style which reconnaissance shows to be applicable to the vicinity of the Susquehanna River. MacLachlan's mapping in Dauphin County demonstrates a low angle thrust separating Cumberland Valley type lithologies and structures from those of Lebanon Valley.

The 31st Annual Field Conference is intended to characterize the Cumberland and Lebanon Valley sequences and demonstrate the discontinuity between them (Figure 1).

The rocks here referred to as the Cumberland Valley sequence are Cambro-Ordovician rocks of the Great Valley which have been traced from south of Maryland to the Susquehanna River area with little overall variation. The rocks of comparable age in Lebanon Valley sequence, emplaced by the Yellow Breeches thrusting, have been traced from the Susquehanna River area at least to the vicinity of Reading without much more overall variation. Stratigraphic differences between correlative units across the thrust, however, are large with respect to lithofacies variation within either sequence. This leads to the inference that thrusting has juxtaposed distant segments of the depositional basin.





**LEGEND**

-  Post Martinsburg Paleozoic on north  
Triassic on south
-  Um Martinsburg Formation
-  Middle Ordovician limestones
-  Ob Beekmantown Group
-  Upper & Middle Cambrian carbonate
-  L.L. Lower Cambrian clastics
-  Precambrian
-  Field trip route
- 13** Stop

The Cumberland Valley sequence is structurally included in the extensive South Mountain anticlinorium. The tectonic style of this sequence is characterized by regularly oriented axes of elongated asymmetric folds and many steep thrusts. This regular fold system is truncated by the Yellow Breeches thrust. The overlying Lebanon Valley sequence is regionally overturned and constitutes the Lebanon Valley nappe. The tectonic style of this nappe is characterized by multiple deformation axes and syngenetic crossfolds. The latter arise from the situation referred to as restricted tectonic transport, which in thrust geometry has been found to indicate large displacement.

Optimistically, this trip will blend what appears to be two disparate regions into a single element vital to deciphering the complexities of Appalachian geologic history. We hope that interest will be stimulated by some of the problems we have endeavoured to resolve and that our ideas may be relevant to other areas of study.

## PHYSIOGRAPHY

The Great Valley, a feature some 900 miles in length, extends from Alabama to New York. From the vicinity of Carlisle southward, the Great Valley is bordered on the east by the Blue Ridge Mountains, which rise only 1,500 feet above it in Pennsylvania but several thousand feet further to the south. The northern limit of the Blue Ridge physiographic province (South Mountain) is south of Carlisle. Here the Blue Ridge plunges beneath limestones. Tracing these mountains south, they broaden, attaining a width of about 11 miles near Chambersburg and maintaining this width into Maryland. In Maryland erosion splits the Blue Ridge into Catoctin Mountain on the east and South Mountain on the west. South of the Potomac River these mountains merge with the classic Blue Ridge Mountains which increase in width and height to the south. From Carlisle to Reading the valley swings more easterly and "hills of the Triassic Lowland Province" form the southern margin. The northern and western boundary is marked by the first ridge of the Valley and Ridge province, everywhere in Pennsylvania formed by the Silurian Tuscarora or Shawangunk Formation.

The valley has a width of 23 miles at Greencastle but decreases northeastward to 12 miles at Shippensburg and a minimum of 8 miles at the Susquehanna River. It then broadens gradually to about 18 miles in eastern Pennsylvania. Elevations in the valley are generally from 400-600 feet above sea level, and maximum local relief is about 200 feet, typically with gently rolling terrain.

The valley is the result of a thick sequence of Cambrian and Ordovician carbonates and shales which have proved substantially more erodible than the adjacent rocks. The main shale mass lies at the top of the sequence to the north and west. This shale has proved somewhat more resistant than the adjacent limestone, so that a distinct step follows most of the length of the valley. As both lithologies have been denuded to fairly even surfaces, classical geomorphologists suggested that the surfaces were the result of reduction to two distinct base levels. They were

accordingly designated the Harrisburg and Somerville "peneplanes" for the shale and limestone levels respectively. Modern work in dynamic equilibrium suggests that both levels are the natural consequence of a single continuous process working on the diverse lithologies.

## STRATIGRAPHY

### INTRODUCTION

Lower Ordovician and Cambrian carbonates extend with little change in lithology and thickness throughout the Cumberland Valley. Equivalent strata in the Lebanon Valley, although also of considerable internal regularity, do not have formational identity with the Cumberland Valley sequence.

Middle Ordovician carbonates show considerably more lateral variation in both sequences, but the facies trends are not convergent. These stratigraphic differences provide considerable evidence for substantial transport of the Lebanon Valley autochthon.

### CUMBERLAND VALLEY STRATIGRAPHY

The stratigraphic column of the Cumberland Valley is shown in Table 1. Stratigraphic changes northeast along the valley are also shown in this figure. Significant lateral changes in lithology and thickness occur only in rocks of the Pinesburg Station Dolomite, St. Paul Group, and Chambersburg Formation. Although all contacts appear conformable, there are probably diastems within the Chambersburg Formation.

### LEBANON VALLEY STRATIGRAPHY

Generalized stratigraphy of the Lebanon Valley is shown in Table 2. Except as noted the units appear to be depositionally persistent though various units are thinned or deleted by thrusting, especially in the western part of the valley.

Depositional contacts are apparently conformable through the carbonate section through the Middle (?) Chazyan Annville Limestone. The overlying Myerstown Formation is paraconformable but separated by a substantial diastem. The Myerstown also seems fairly uniform in lithology and thickness. The Myerstown passes gradationally up into overlying units.

TABLE 1  
Stratigraphic Column of the Autochthonous Rocks in Southeastern Franklin County

System	Series	Group	Formation	Description	Thickness in feet	Comments on Stratigraphic Changes to the Northeast Part of the Cumberland Valley
ORDOVICIAN	Middle Ordovician	St. Paul	Martinsburg Formation	Black, carbonaceous and fissile shale, weathers buff with yellow-green to dark-gray, fine-grained graywacke beds.	> 1,000	Allochthonous elements probably east of Carlisle.
			Chambersburg Formation	Dark-gray, cobbly limestone, argillaceous, with abundant irregular shaly partings. Some metabentonite beds present.	750	Thins northeast to 250 feet at Susquehanna River, probably by unconformity at base.
ORDOVICIAN	Lower Ordovician	St. Paul	New Market Row Park	Vaughanitic limestone at top. Granular fossiliferous limestone, black chert, and sparse dolomite. Vaughanitic limestone at base.	1,000	Thins to about 700 feet near Carlisle. Dolomite content increases threefold. Tripartite division present. Gains section at base by replacement of Pinesburg Station.
			Pinesburg Station Dolomite	Light-colored, thick-bedded, finely-laminated dolomite.	450	About 100 feet of dolomite with occasional limestone interbeds referred to this formation.
ORDOVICIAN	Lower Ordovician	Beekmantown	Rockdale Formation	Mostly limestone, dolomite interbeds in mechanical and stromatolite limestones. Some chert. Mechanical and stromatolitic limestones in middle part. At base ± 500 feet pinkish marbleoid limestone and chert.	+2,500	Continuous to here with only minor lateral variations. Thickness probably similar.
			Stonehenge Formation	Stromatolitic and fine mechanical limestones that become predominantly mechanical toward the north.	775	About 1,000 feet of similar limestone. Staufferstown probably passes into lithology similar to Stonehenge.
ORDOVICIAN	Upper Cambrian	Conococheague	Staufferstown Formation	Coarse mechanical limestones with dark-gray siliceous seams, prominent ridge former.	260	Continues with little change into this area.
			Shadygrove Formation	Pure light-colored limestones, stromatolitic in part. Abundant pinkish limestones and cream-colored cherts.	650	Continues with little change into this area.
CAMBRIAN	Middle Cambrian	Conococheague	Zullinger Formation	Cyclically-bedded stromatolitic-mechanical limestone, interbedded limestones and dolomite, interlaminated limestone and dolomite, thin dolomite. Several thin local quartz sand beds.	2,500	Continues with little change into this area. May thin slightly.
			Elbrook Formation	Light-colored, calcareous shale and argillaceous limestone, blue limestone and dolomite in middle-ridge former. Pure dark limestone at base.	estimated ±3,000	Continues with little change into this area.
CAMBRIAN	Lower Cambrian	Chilhowee	Waynesboro Formation	Thin basal and upper ridge forming sandy units. Middle portion is blue limestone.	±1,000	Units truncated before reaching northeast portion of Cumberland Valley.
			Tomstown Formation	Dolomitic limestone to limestone in upper part. Mottled silty dolomite in middle part. No exposures at base.	estimated 1,000 - 2,000	
CAMBRIAN	Lower Cambrian	Chilhowee	Antietam Formation	White quartzite with bluish-cast in places, coarse grained, pure, with many scolithus tubes.	500 - 800	
			Harpers Formation	Dark-banded, hackly schist to slate with prominent middle member of massive hard, white quartzite that thickens to the north.	2,750	
PRECAMBRIAN	?	?	Weverton Formation	Gray felspathic sandstone, coarse. Some white quartzites. Conglomerate at base.	1,250	
PRECAMBRIAN	?	?	Catoctin Formation	Altered rhyolitic flows, finely-laminated, red- to purple color. Altered basalt with chlorite and epidote.		

TABLE 2

Stratigraphic Column of the Allochthonous Rocks in Dauphin County

System	Series	Stage	Group	Formation	Description	Thickness in feet
ORDOVICIAN	U.	Middle Ordovician		"Martinsburg" Formation	Dark-gray phyllitic shales, calcareous in part, red and green phyllites, limestone beds, siliceous argillites or chert, lithic quartzite, gray-wacke, and conglomerate. Pre-Trenton faunal elements presumably included in exotic blocks.	probably 3,000 - 5,000
				Hershey Formation	Very dark-gray, impure shaly carbonaceous limestone. Usually strongly cleaved with bedding obscure. Conglomeratic in lower part in east and in isolated exposures in west. Wedges out along strike of main exposures in valley but slices included in thrust zone to west.	1,000 feet east to 0 west 200 feet maximum in Dauphin County ± 200
ORDOVICIAN	Middle Ordovician	Chazy		Myerstown Formation	Regularly thin- to medium-bedded dark-gray, dense limestone, conspicuously carbonaceous near base. Up to four 1½ to 8-inch metabentonite beds recognized in some places.	180
				Annville Limestone	Thick bedded, light- to medium-gray, crystalline high calcium limestone	600 - 800
ORDOVICIAN	Lower Ordovician	Beemantown		Ontelaunee Dolomite	Upper pure dolomite member - medium, dark-gray, heavy bedded, micro-crystalline pure dolomite with rare Annville-like limestone interbeds. Lower member - heavy bedded dolomite generally similar to above with subordinate interbeds of typical Beemantown limestone, gradational to Epler Formation at base.	1,300 thins to 800 feet in east part of valley
				Epler Formation	Heavy bedded, distinctly laminated, finely crystalline limestone with subordinate medium to heavy interbeds of faintly laminated to massive, finely crystalline dolomite. Very light gray to pink limestone appears in lower part.	1,500 ? interval thins to ± 800 feet in east
CAMBRIAN	Upper	Conococheague		Richland Milbach Shaefferstown Snitz Creek	Limestones of Stonehenge Formation only present in Dauphin County. Dolomites of Rickenbach Formation progressively replace entire Stonehenge from top down to the east. Heavy bedded, medium-gray, finely crystalline limestone with dark weathering clastic laminae. Thin calcarenites common and dolomite rare in upper part. Lower portion contains more dolomite and some nodular chert. Group tectonically absent in Dauphin County. It essentially consists of an upper (in part cyclic) and lower dolomite formation separated by a predominantly limy interval in which there is locally a lower impure facies.	(2,000)
				Buffalo Springs Formation	Predominantly light-colored heavy bedded, finely crystalline limestone with subordinate dolomite interbeds. Shaly to silty laminae are conspicuous on weathering. Frequently very high insoluble residue content even in purer looking rocks.	1,000 +
CAMBRIAN	Middle			Leithsville Formation	Platy beds of crystalline dolomite with occasional thin oölitic limestones in upper part; lower part is predominantly light-colored, finely crystalline, sandy dolomite. Predominantly fine- to medium-grained medium- to heavy-bedded quartzitic sandstone, conglomeritic in basal 20 feet.	(± 1,000?)
				Hardyston Quartzite	Granitic, hornblende, graphitic, and quartz diorite gneisses of New England province affinities. Grenville metamorphic ages.	(± 400)
	Lower			Precambrian Gneisses of Reading Prong	Exposed in the Reading Prong	

## RELATION BETWEEN THE CUMBERLAND AND LEBANON VALLEY SEQUENCE

Correlation between the autochthonous carbonates of the Cumberland Valley and allochthonous carbonates of the Lebanon Valley is shown in Table 3. Difference in tectofacies between the two sequences give a different texture to generally similar lithofacies.

As stated previously, stratigraphic differences between correlative units across the Yellow Breeches thrust are large with respect to lithofacies variation within either sequence. For example, the two limestone formations of the Conococheague Group, from Maryland to the north end of South Mountain, a distance of 60 miles, vary little in thickness and lithology. However, 25 miles to the east, at the closest complete exposure of time equivalent allochthonous rocks, the Conococheague Group is divisible into four units of which the upper and lower units are predominantly dolomites that thicken eastward markedly.

The amount of dolomite in the Beekmantown of the Cumberland Valley progressively decreases to the northeast. Across the Yellow Breeches thrust there is an abrupt though fairly subtle increase in dolomite content which increases eastward until the Beekmantown is all dolomite in eastern Pennsylvania. The trend of dolomite content thus also reverses across the thrust. Evaluation of differences in limestone lithofacies that might be expected to exist across a thrust of this magnitude is complicated by the tectofacies difference.

Changes in Middle Ordovician carbonates across the thrust are much more conspicuous. In Franklin County the St. Paul Group is about 1,000 feet of micritic limestone with sparse dolomite (Stop 1). To the northeast the St. Paul Group gradually thins to about 700 feet with 20 percent interbedded dolomite (Stop 6). The only correlative strata in the Lebanon Valley sequence are the pure high calcium limestones of the Annville Formation, which is less than 180 feet thick in the western Lebanon Valley (Stops 9, 11, 13).

C A M B R I A N		O R D O V I C I A N																								
Basement	Lower	CONOCOCHEAQUE GP.	Volcanics Loudon Fm. Weaverston Fm. Harpers Fm. Antietam Ss. Tomstown Fm.	LEBANON VALLEY	"Martinsburg Fm."* Hershey Fm.* Myerstown Fm.* Annville Ls.* Ontelaunee Fm.* Epler Fm.* Rickenbach Dol. Stonehenge Ls.* Richland Fm. Millbach Fm. Schaefferstown Fm. Snitz Creek Fm.	LEHIGH VALLEY	Martinsburg Fm. "Cement rock" "Cement ls." Ontelaunee Epler Fm. Rickenbach Dol.	NORTHERN LANCASTER VALLEY	Cocalico Fm. Myerstown Fm. Annville Ls. Ontelaunee Fm. Epler Fm. Stonehenge Ls. Richland Fm. Millbach Fm. Snitz Creek Fm.	CENTRAL PENNSYLVANIA	Antes Sh. Coburn Ls. Salona Ls. Neadmont Ls. Hunter Ls. Hatter Ls. Loysburg Fm. Bellefonte Dol. Axemann Ls. Nittany Dol. Stonehenge Ls. Lorke Dol.															
												Upper	CONOCOCHEAQUE GP.	Big Springs Station Zullinger Fm. Shadygrove Fm.	BECKMANTOWN GP. Rockdale Run Fm. Stonehenge Ls. Staufferstown Fm.	BECKMANTOWN GP. Buffalo Springs Fm.* Leithsville Fm. Hardyston Qtzite	BECKMANTOWN GP. Allentown Fm. undivided Leithsville Fm. Hardyston Qtzite	BECKMANTOWN GP. Buffalo Springs Fm. Ledger Dol. Kinzers Fm. Vintage Fm. Antietam Ss. Harpers Fm.	BECKMANTOWN GP. Gatesburg Fm. Minns Fm.							
																				Middle	CONOCOCHEAQUE GP.	Elbrook Fm.	BECKMANTOWN GP. Stonehenge Ls.	BECKMANTOWN GP. Buffalo Springs Fm.* Leithsville Fm.	BECKMANTOWN GP. Buffalo Springs Fm. or Elbrook Fm.	BECKMANTOWN GP. Pleasant Hill Fm.
Canadian	CONOCOCHEAQUE GP.	Big Springs Station Zullinger Fm.	BECKMANTOWN GP. Rockdale Run Fm.	LEBANON VALLEY	"Martinsburg Fm."* Hershey Fm.* Myerstown Fm.* Annville Ls.* Ontelaunee Fm.* Epler Fm.* Rickenbach Dol. Stonehenge Ls.* Richland Fm. Millbach Fm. Schaefferstown Fm. Snitz Creek Fm.	LEHIGH VALLEY	Martinsburg Fm. "Cement rock" "Cement ls." Ontelaunee Epler Fm. Rickenbach Dol.	NORTHERN LANCASTER VALLEY	Cocalico Fm. Myerstown Fm. Annville Ls. Ontelaunee Fm. Epler Fm. Stonehenge Ls. Richland Fm. Millbach Fm. Snitz Creek Fm.	CENTRAL PENNSYLVANIA	Antes Sh. Coburn Ls. Salona Ls. Neadmont Ls. Hunter Ls. Hatter Ls. Loysburg Fm. Bellefonte Dol. Axemann Ls. Nittany Dol. Stonehenge Ls. Lorke Dol.															
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												Black River	CONOCOCHEAQUE GP.	Big Springs Station Zullinger Fm.	BECKMANTOWN GP. Rockdale Run Fm.	LEBANON VALLEY	"Martinsburg Fm."* Hershey Fm.* Myerstown Fm.* Annville Ls.* Ontelaunee Fm.* Epler Fm.* Rickenbach Dol. Stonehenge Ls.* Richland Fm. Millbach Fm. Schaefferstown Fm. Snitz Creek Fm.	LEHIGH VALLEY	Martinsburg Fm. "Cement rock" "Cement ls." Ontelaunee Epler Fm. Rickenbach Dol.	NORTHERN LANCASTER VALLEY	Cocalico Fm. Myerstown Fm. Annville Ls. Ontelaunee Fm. Epler Fm. Stonehenge Ls. Richland Fm. Millbach Fm. Snitz Creek Fm.	CENTRAL PENNSYLVANIA	Antes Sh. Coburn Ls. Salona Ls. Neadmont Ls. Hunter Ls. Hatter Ls. Loysburg Fm. Bellefonte Dol. Axemann Ls. Nittany Dol. Stonehenge Ls. Lorke Dol.			

\* Designates formations outcropping in Dauphin County.

Table 3.

## STRUCTURAL GEOLOGY

## INTRODUCTION

Problems inherent in resolving the structural geology of the Great Valley are typical of those in many old mountain belts - 1. lack of exposure, and 2. absence of topographic relief or drilled wells thus eliminating the third dimensions so vital in understanding the spatial configuration of the structures. Because of these problems it should be emphasized that the data and concepts presented in this section are an approximation of a truly complex situation.

The Cumberland and Lebanon Valley carbonates are characterized by the two distinct and disparate tectonic styles - the former a typically autochthonous style and the latter a typically allochthonous style.

Essentially the Cumberland Valley carbonates are part of the autochthonous South Mountain Anticlinorium. Rocks from the Catoclin greenstones through the Middle Ordovician carbonates are involved in related folding and faulting. The regional flow cleavage ( $S_1$ ) and fold pattern geometry are reflected through the entire sequence of rocks indicating that they were deformed as a single unit. All major faults are rectilinear high angle reverse faults. Individual folds and faults can be traced more than 30 miles, and further extension is limited only by lack of detailed mapping. Although the structural geology is complex it is extremely regular and maintains this regularity probably to Elkton, Virginia, south of which the Blue Ridge may be involved in considerable thrusting.

The allochthonous Lebanon Valley carbonates are essentially a recumbent tectonite sequence. Folds and faults there have irregular surface traces related to sub-horizontal transport. Major rock units disappear in an irregular manner against faults. Evidence of pervasive multiple deformation is common.

## STRUCTURAL GEOLOGY OF THE CUMBERLAND VALLEY AUTOCHTHON

General Structural Geology

Mountains of the Blue Ridge physiographic province are composed of a core of Precambrian Catoctin volcanics, rimmed by quartzite ridges of the Weverton, Harpers, and Antietam Formations. The Great Valley is floored by the Cambrian and Ordovician carbonates and by shales of the Martinsburg Formation. The physiographic provinces do not correspond with recognized major structural elements because the Cambrian and Ordovician limestone of the valley are intimately related in style of deformation to that characteristic of the Blue Ridge whereas deformation in the Martinsburg is of somewhat different type. An added measure of complexity is the varying response of these different rock types to a stress that apparently diminished from east to west. For purposes of structural consideration the writer follows the usage of Cloos (1951, p. 124) and divides the area into the South Mountain anticlinorium on the east and Massanutten synclinorium on the west.

Briefly the South Mountain anticlinorium includes rocks of the Catoctin greenstone, Chilhowee Group, and Cambrian and Ordovician carbonates that are folded into a southwest plunging anticlinorium dominated by a east dipping flow cleage (regional cleavage); whereas the Massanutten synclinorium includes shales of the Martinsburg Formation with some up faulted belts of Ordovician limestone folded into a north-east plunging synclinorium in which flow cleavage is absent. The boundary between the two divisions is selected, in Franklin County, at the Carbaugh-Marsh Creek fault which juxtaposes Cambro-Ordovician limestones against shale of the Martinsburg Formation (Figs. 2 and 3).

The northern limit of the South Mountain anticlinorium is essentially south of Carlisle. Quartzites of the Weverton, Harpers, and Antietam rim a narrow anticline which plunges to the northeast. The overlying Cambrian and Ordovician carbonates

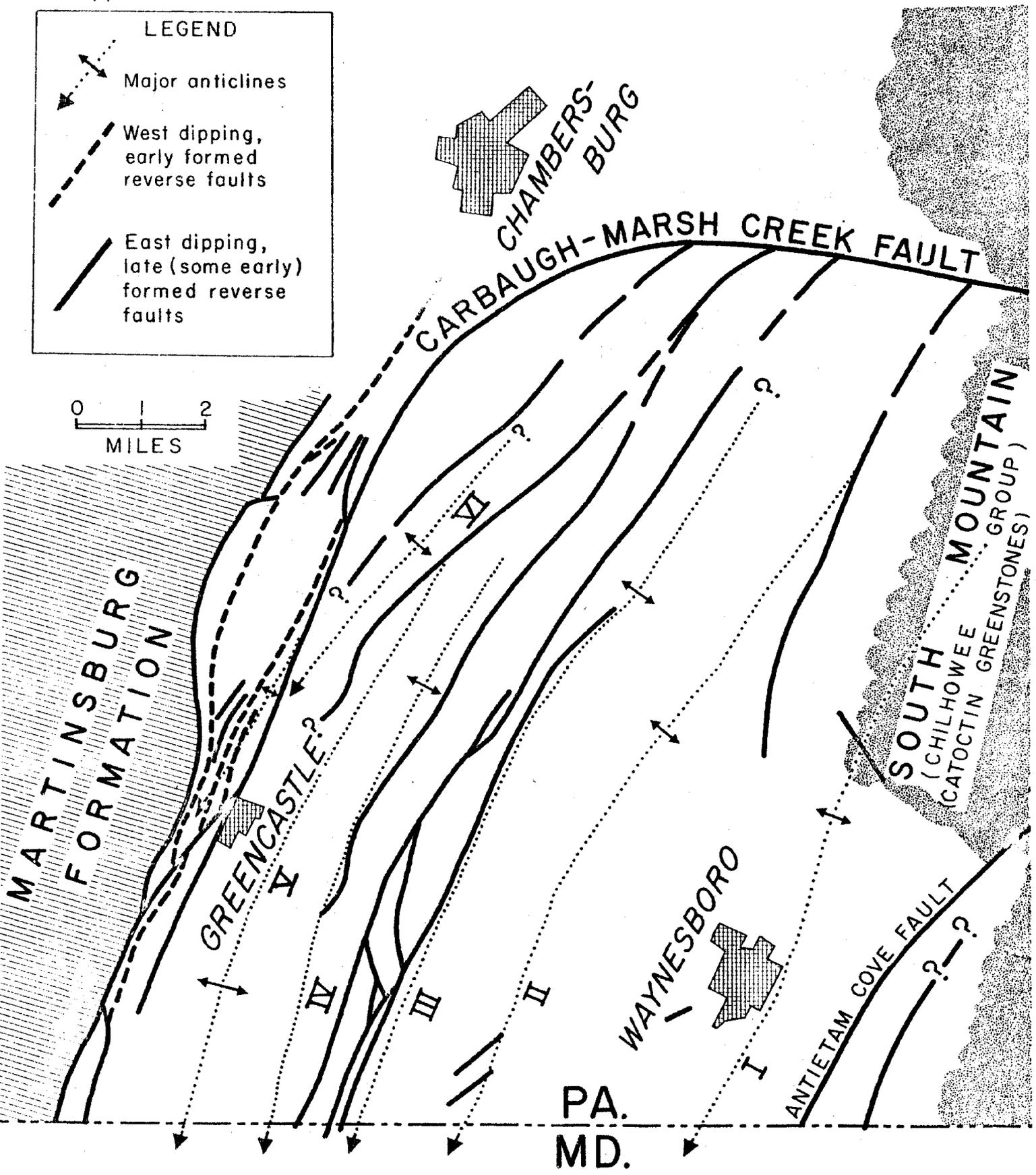
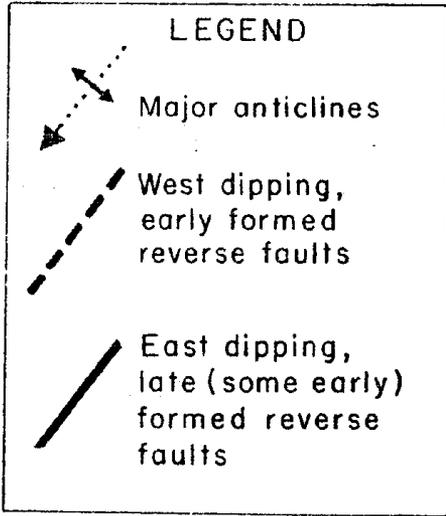


Figure 2. TECTONIC MAP OF SOUTHEASTERN FRANKLIN COUNTY

flanking the quartzites are cut off down plunge by the Yellow Breeches fault. The Triassic border fault, which forms the eastern limit of the anticlinorium, changes direction so that it transects more of the anticlinorium near Carlisle but less to the south. Tracing the anticlinorium southward up plunge, the oldest rock exposed are the Catoctin volcanics east of Shippensburg. A local structural culmination occurs here as the anticlinorium commences to reverse and plunge to the southwest and maintains this attitude into Maryland.

The following description of geometry and mode of deformation of the South Mountain anticlinorium is from excellent work of Cloos (1947, p. 845) based on oölite deformation in the Cumberland Valley of Pennsylvania and Maryland:

"The South Mountain fold is a large asymmetrical overturned anticline. Its axial plane dips to the southeast, and its crest is the western slope of South Mountain. Cleavage dips steeper in the upper than the lower limb thus forming a fan which opens to the northwest. All parts of this fold participate and reveal an identical deformation plan: fold axes are nearly horizontal, cleavage dips southeast, lineation is in the cleavage plane normal to the fold axes, also dipping east. All formations including the volcanics participate.

Intensity of deformation varies greatly within the fold depending on (1) physical properties of materials (2) location within the fold and (3) geographical location.

Approaching South Mountain from the west intensity grows gradually, is strongest in the lower limb, decreases toward the crest and upper limb. Abrupt changes as would be expected in large-scale thrusting were not observed, the deformation seems to have been absorbed within a much wider complex.

The fold is interpreted as a large "shear" fold as distinct from flexures. Deformation is thought to be due to laminar flow on subparallel planes. The presence of flow planes and the fact that oöids are extended at large angles to bedding show that stratigraphic thicknesses as now seen are not equivalent to depths of deposition. Calculations indicate that the latter amounted to less than one half of the present thickness."

The ultimate test of oölite deformation as an indicator of laminar flow (approximately in cleavage direction) would be to measure the thickness of a key bed about a single structure or across a large area. If thickness remained constant parallel

to the axial plane cleavage or regional cleavage (ab cleavage plane of Cloos) then this would demonstrate the shear mechanism of Cloos (1947). If, however, thickness remained constant normal to the bedding surface then a concentric or flexure (intrastratal slip) mechanism would prevail. Unfortunately, it has not been possible to locate such a key bed. From studies of the Beekmantown Group in eastern Maryland, Sando (1957, p. 12) concluded the laminar flow has not significantly modified stratigraphic thicknesses in that unit. Further south near Elkton, Virginia, King (1950, p. 52) considered thickening due to flowage. King concluded that thicknesses of Appalachian formations calculated in many geographically and structurally diverse sections fail to show the extreme variations to be expected from substantial effect of laminar flow deformation. The question of stratigraphic thickening of the limestone units will not be dealt with in this guidebook. However, the field trip participants are urged to observe for themselves the effects of deformation on bed thickness, as well as fabric and texture at stop 3, 4, and 5 where oölite deformation is 30-50 percent.

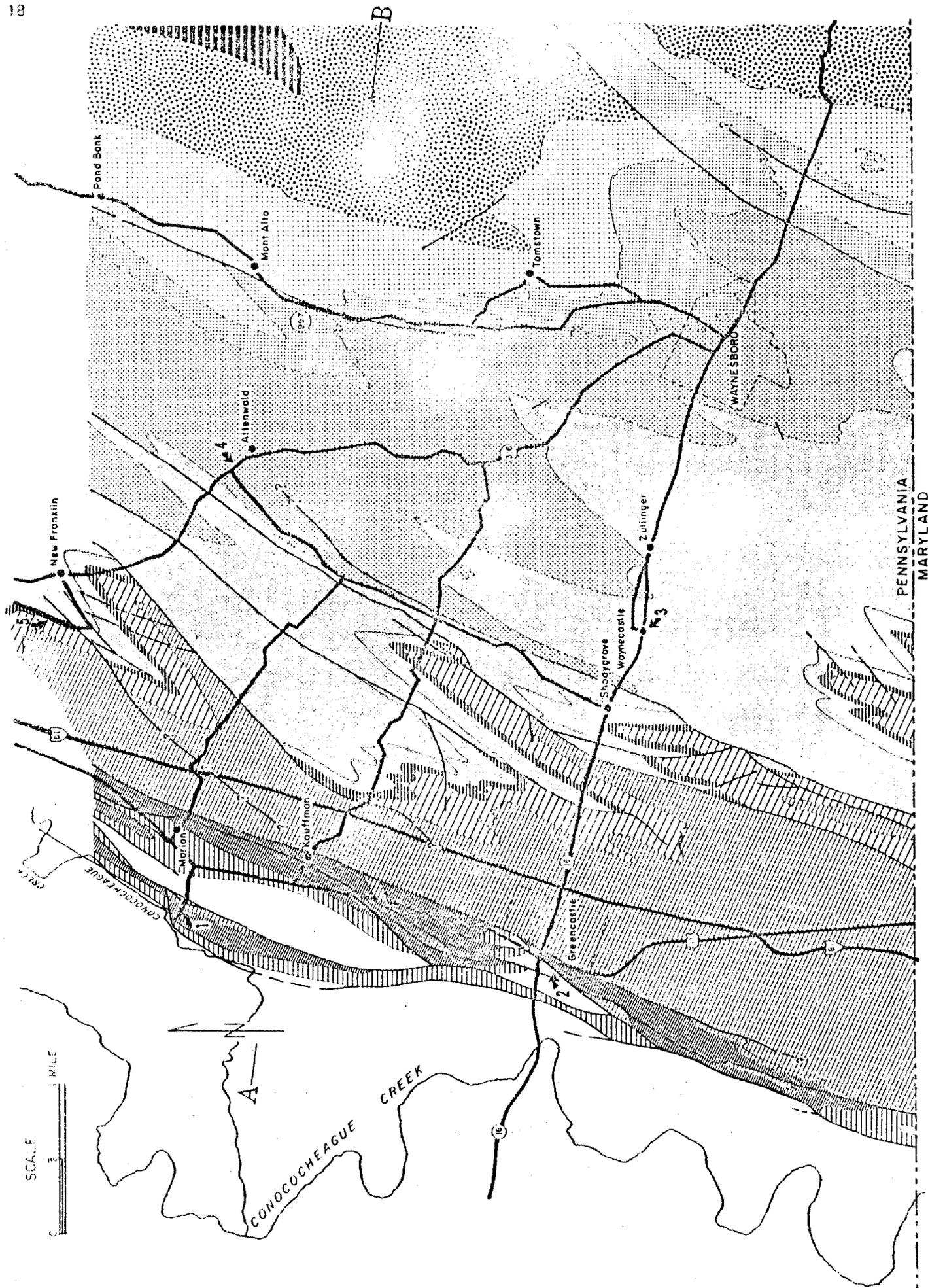
The term Massanutten synclinorium is actually more applicable in the area of Massanutten Mountain near Luray, Virginia, where the general structure is that of a syncline with a major reverse fault (North Mountain) on the west. In Franklin County three major reverse faults bring up Cambro-Ordovician limestones in the general belt of Martinsburg shale causing the synclinorium to be exceedingly complex here. At Shippensburg the synclinal structure apparently dies out and structure is that of a major complex homocline dipping west off South Mountain and including Cambrian, Ordovician, and Silurian sediments. The western limit of the Massanutten synclinorium is readily determined in the Shenandoah Valley of Virginia and West Virginia (Hack, Plate I) where the North Mountain fault thrusts Cambrian sediments over Ordovician-Silurian-Devonian sediments. It is less apparent in Franklin County because the fault splits into at least three faults bringing up the three limestone

belts in the Martinsburg shale terrane of the Great Valley (Fig. 1). A fourth fault, in the McConnellsburg area, also brings up Cambro-Ordovician limestone over Devonian shales. This may be the master fault splay of the North Mountain fault. Alternatively the fault carrying up the limestone belt that passes through Williamson may be the major splay from the North Mountain (Fig. 1) fault. Until additional detailed work is completed, it should be recognized that the single fault boundary of the Massanutten synclinorium in the Shenandoah Valley becomes a broad zone of faulting in Franklin County as a result of the northward splaying. As noted previously the eastern limit of the Massanutten synclinorium is well marked by the Carbaugh-Marsh Creek fault.

#### Local Structure

The field work accomplished to date demonstrates that the geology is considerably more complex than that mapped by Stose (1909). It shows much more reverse faulting than Cloos (1941) was able to map at a larger scale across the state line in Maryland, and confirms the structural patterns that Sando (1957) was able to map in his detailed study in Maryland.

A twofold structural division of the carbonates of the South Mountain anticlinorium is possible (Figures 2 and 3) based on different size of folds and their spacing as well as type of fault. Both are part of the same deformation plan although some of the Martinsburg is involved in the western zone and only carbonates are involved in the eastern zone. The eastern structural division includes most of the area of this report. Its western limit is the Carbaugh-Marsh Creek fault and its eastern limit is the limit of mapping. This area is dominated by 5 major, complex, southwest plunging anticlines and 7 major reverse, east dipping faults. In the southeastern corner the Antietam Cove fault emerges from the South Mountain volcanic core and causes a deviation from the deformational pattern of this structural division. The western structural division is a narrow zone about 2 miles wide near Kauffman



PENNSYLVANIA  
MARYLAND

SCALE  
1 MILE

CONOCOCHEAGUE CREEK

WAYNESBORO

Shadygrove  
Wynecastle

Zullinger

Greenocastle

Kauffman

Marion

Mont Alto

Tomstown

Allenwald

New Franklin

Pond Bank

957

61

A

B

LEGEND OF GEOLOGIC MAP

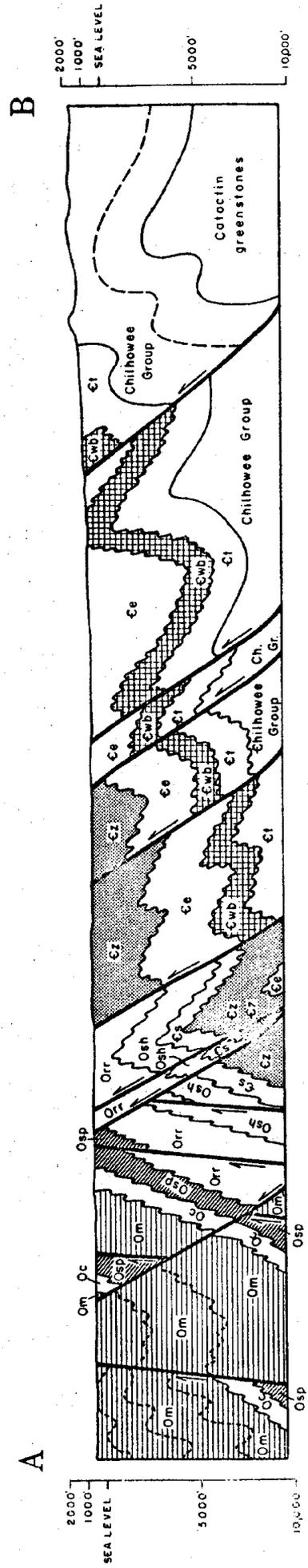
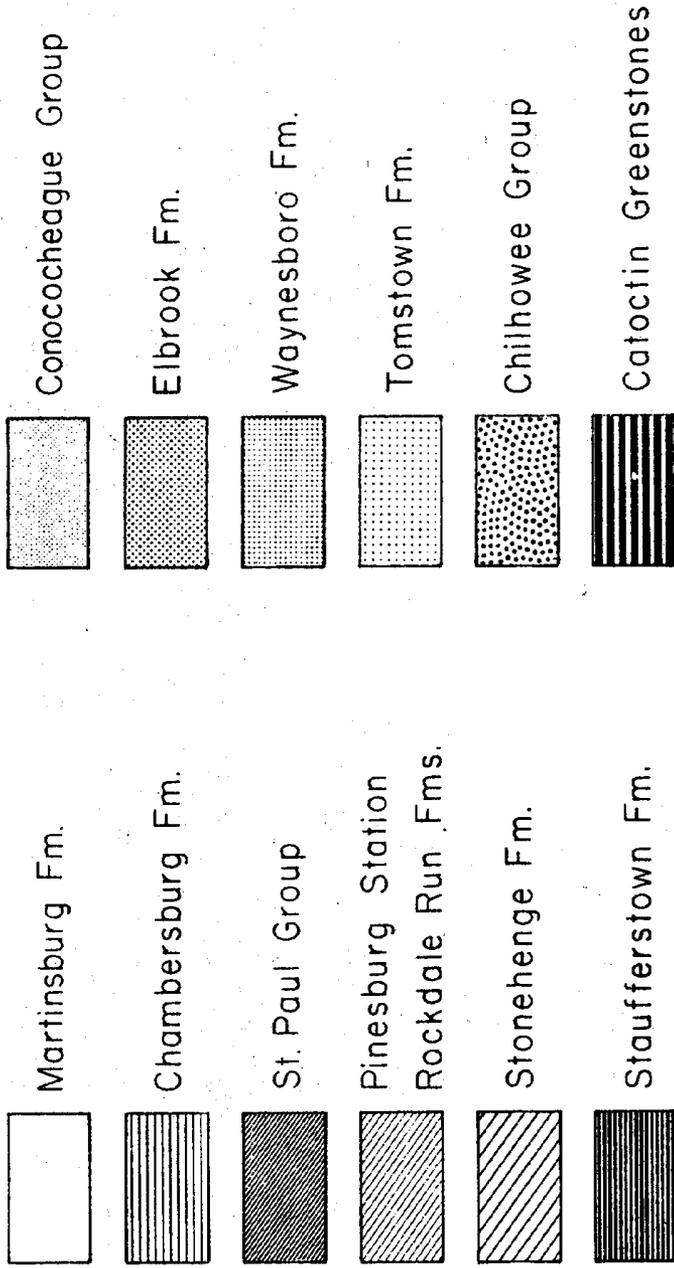


Figure 3. Geologic Map and Cross Section of Cumberland Valley, S.E. Franklin Co.

and 2,000 feet wide at the state line. It is limited on either side by faults related to the Carbaugh-Marsh Creek fault zone. This structural division is dominated by what are believed to be a series of closely spaced west dipping reverse faults cutting a major west facing anticlinal limb. Structural complexity increases north-east along strike of the zone.

Within the Massanutten synclinorium Martinsburg shales compose a separate, although not entirely distinct, structural entity from the limestones. There are insufficient outcrops and marker beds to decipher the structure, but in several large outcrops type and amount of deformation can be observed that is distinct from the deformation of the carbonates in the central and eastern structural divisions in the South Mountain anticlinorium. The form of the Martinsburg folds differ from the regular form of the carbonates. Flow or regional cleavage is absent, and a fracture cleavage related to flexure folding of strongly anisotropic beds is locally developed.

### Folds

The folds, although complex, are characterized by a remarkably consistent geometry. They are of the cylindrical, flexure slip type in the western half of the carbonate terrane but more related to flexure flow or passive slip type in the eastern half.

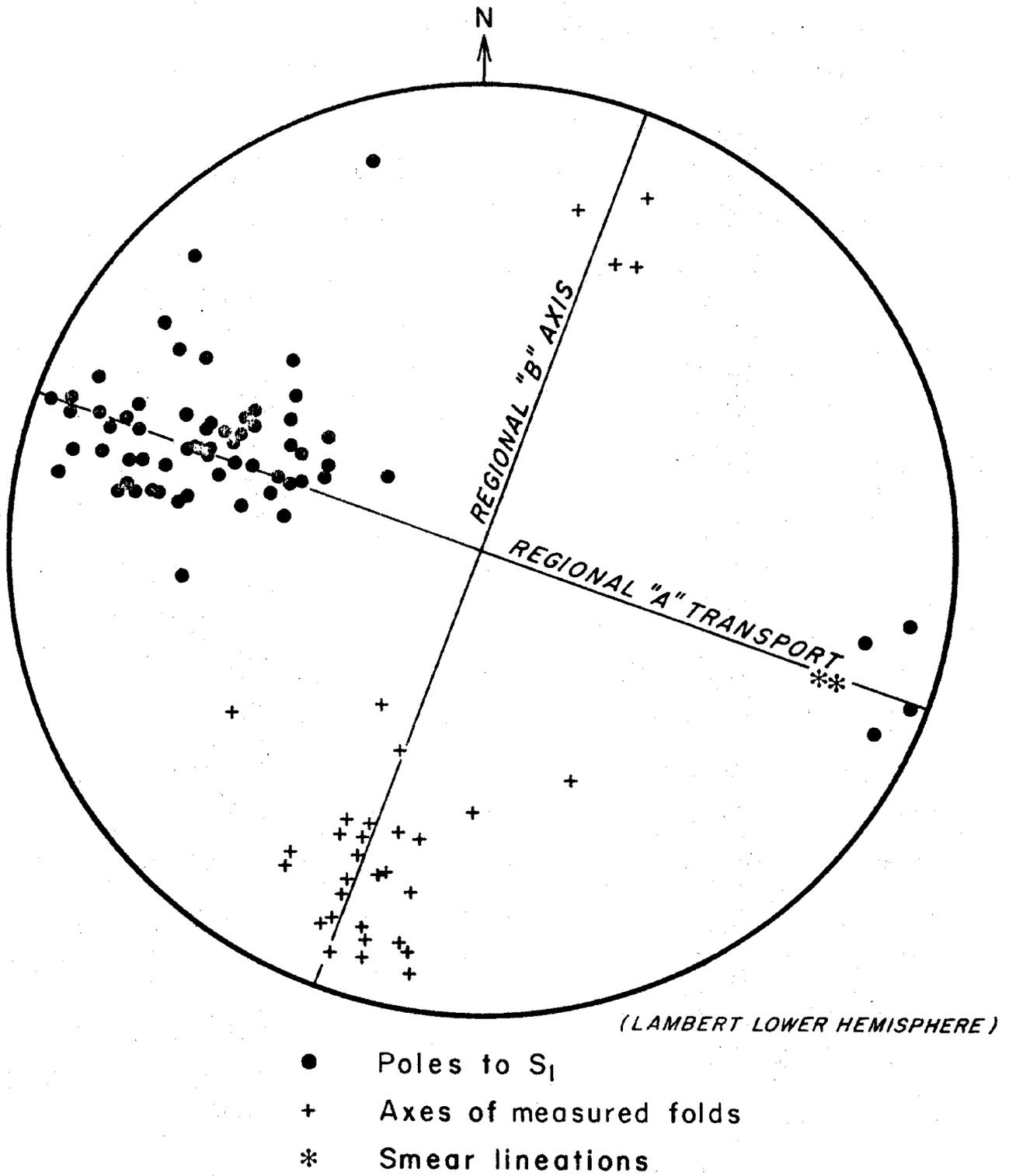
On a regional basis there are 6 major anticlines whose northern limit is the tear fault segment of the Carbaugh-Marsh Creek fault (Figure 2). The eastern most fold (VI) is cut off by the Carbaugh-Marsh Creek fault about two miles north of Greencastle but; the other folds continue into Maryland where, Sando (1957) has been able to map folds II, III, IV, and V as far as the Potomac River. Thus, these folds have a total mapped length of 27 miles and may continue for a considerable distance south of the Potomac River. Fold I does not appear as a major structure on Cloos' (1941) map of Washington County.

Major folds and associated subordinate folds all have the same geometric pattern (Figure 4); they plunge at average of  $25^{\circ}$  S $20^{\circ}$  W well into Maryland. Regional cleavage, or  $S_1$ , striking at N20E parallels the fold axis, and the few smear lineations present are normal to the fold axes and lie within the  $S_1$  planes. This relationship is simply a kinematically congruent fold.

Axial surfaces of the folds are vertical along the western edge of the carbonate terrane and gradually become east-dipping as the Blue Ridge is approached. Fold surfaces dip to the east at  $50^{\circ}$  in Elbrook Formation outcrops near Altenwald. They are, of course, part of the overturning of the South Mountain anticlinorium as noted by Cloos (1947). This pattern is so predominant that one can determine position on a fold from any one outcrop by determining the dip of the beds. Any beds that dip to the west, are vertical, or are overturned to the east at high angles must be on the west facing limb of an anticline. Any beds that dip east at less than  $50^{\circ}$ , or somewhat more steeply in the west where axial surfaces are steeper, are on the east facing limb of an anticline. This relation is generally true even close to the major faults.

Interstratal slip during flexure folding has formed most of the folds in units younger than Elbrook; certainly the brittle shattering of faulted limestones at Kauffman do not indicate the conditions necessary for shear folding. The quarries at New Franklin (Stop 5) expose a thick sequence of Stonehenge limestone in which almost every bedding surface is slickensided, showing interstratal slip congruent with fold kinematics. Elbrook exposures in the railroad cuts northwest of Altenwald (Stop 4) show the effects of shear folding and ductile faulting as both flowage and slip across bedding. Ductile faulting occurs without loss of cohesion. It would seem that close to the Blue Ridge, temperature and pressure conditions were such that a high mean ductility of the rocks was attained, and passive folding was operative. To determine the actual amount of deformation orthogonal thickness of

Figure 4. SYNOPTIC PETROFABRIC DATA  
EASTERN FRANKLIN COUNTY, PA.



a key bed should be measured around a fold. This would be a conclusive check on bulk rock deformation that Cloos (1947) determined only on the basis of deformed oölites. It is of interest to note that oölite deformation near Altenwald, where shear folding is obvious, is 52 percent, but it is only 30 percent at Waynecastle Dairy and the quarry at New Franklin where flexure folding appears dominant.

Thus the effect of passive folding diminishes gradually to the west from the Blue Ridge, and the impress of only moderate slip across layering would probably not be visible in field examination of a fold.

### Faults

The carbonate terrane of southeastern Franklin County is dominated by the Carbaugh-Marsh Creek fault, which is a tear fault in its east-west segment and a reverse fault elsewhere. On the west several faults splay from it forming a zone. On the east it overrides some smaller faults. The Antietam Cove fault in the southeast corner of the area is not well understood.

Only one major fault is exposed in the area, the others are interpretive and based on considerations of fault and fold mechanics. The quarry at Greencastle shows the St. Paul to be thrust over the Martinsburg (Stop 2) along a portion of the Carbaugh-Marsh Creek fault that strikes  $N45^{\circ}E$ , dips  $60^{\circ}$  east. The east dip is consistent with east dipping reverse faults exposed in the same belt of rocks to the south (Page, et al, 1964) in West Virginia. On this basis all faults east of the Carbaugh-Marsh Creek, with the exception of the Antietam Cove fault, are considered to be east dipping reverse faults. The main fault between the limestones and Martinsburg Formation north of Greencastle and close to Conococheague Creek is also considered to be an east dipping reverse fault splaying off the main Carbaugh-Marsh Creek fault about two miles southwest of Greencastle. Faults repeating slices of limestone between Greencastle and Marion are probably west dipping reverse faults.

The Carbaugh-Marsh Creek fault is a major feature of this area juxtaposing

Cambro-Ordovician limestone against the Martinsburg shale along its entire length where it is a reverse fault. Sando (1957) was able to trace this fault to the Potomac River, and it undoubtedly continues farther south, perhaps into Virginia. Apparent displacement is greatest near Williamsport, Maryland, where Sando (1957) mapped lower Stonehenge in a reverse fault over the Martinsburg--a stratigraphic displacement of at least one mile. In Pennsylvania, where this fault swings east and enters South Mountain, it is undoubtedly a high angle tear fault. Thus it has the form of a large high angle thrust block that has moved out over the Martinsburg shale. Units as old as the Catoclin greenstones are involved in the movement of this block.

#### Fault and Fold Mechanics

In order to consider those faults whose dip is not known, it is necessary to consider mechanical properties of deformed rocks and the domain in which this deformation takes place. Vertical stratification of the rocks in the area is such that they are naturally divisible into four major structural lithic units (Currie, et al, 1962, p. 670) based on the relative competencies of the rocks as observed in the field. The Chilhowee Group of quartzites is considered to be relatively competent. The carbonates and shaly carbonates of the Tomstown, Waynesboro, and especially the Elbrook formations are considered to be relatively incompetent. Carbonates of the Conococheague, Beekmantown, St. Paul, and Chambersburg units are considered as relatively competent. The Martinsburg Formation, composed largely of shale, is considered to be relatively incompetent. In terms of absolute mean ductility, for instance, the Tomstown-Elbrook sediments may be less ductile than the Conococheague-Chambersburg sediments, but the greater temperatures and pressures at which the former were deformed caused them to yield with apparently lesser competency.

Because the Conococheague - Chambersburg structural lithic unit, some 9000 feet

thick, is best exposed it can be considered in some detail. As the unit was folded, where radius of curvature approached the thickness of a stratum, progressive increase in curvature of strata toward apices of the folds was accommodated by flexure-slip thrust faults that were kinematically concordant with interstratal slip (Price, 1965, p. 78). Where there is marked anisotropy of the stratified sequence, especially where a relatively incompetent unit overlies a competent unit, as where the relatively incompetent Martinsburg overlies the carbonates, symmetrically opposed overthrusting compensates for the lack of room in the core of a concentric fold. Gwinn (1964, p. 892) shows many similar examples in western and central Pennsylvania. Here symmetrical east and west dipping faults on the limbs of a fold lead to a depressed axial zone (Figure 5). The faults between the Carbaugh-Marsh Creek fault zone (Figure 2) are believed then to be west dipping reverse faults of the type discussed above (Figure 5). These faults could also be explained by an east dipping normal fault generated early during folding; however, this does not appear to be realistic considering the compressional history of the area. Also normal faults would occur on the crest, rather than on the limb where these faults are located. The complimentary east dipping fault is now overridden by, or has become part of the Carbaugh-Marsh Creek fault (Figure 5, III).

Let us assume that in the upper part of a folded sequence, where pure concentricity is no longer possible, thrusts symmetrically opposed about the fold may develop. We must now examine what happens at lower position in the folded sequence where there is less anisotropy and the sequence is relatively competent. In this case lack of space due to the geometric impossibility of maintaining concentricity downward results in thrusting. It is known that in these cases the thrust will propagate itself through the asymmetric limb of the fold (DeSitter 1956, p 241). The faults that merge with the Carbaugh-Marsh Creek fault are located on the eastern limb of major synclines (Figure 3); hence, they are assumed to be east dipping reverse faults that have sheared up along the subvertical to overturned west limbs of anticlines (Figure 6).

# FOLD DEVELOPMENT IN GREAT VALLEY MIDDLE ORDOVICIAN CARBONATES

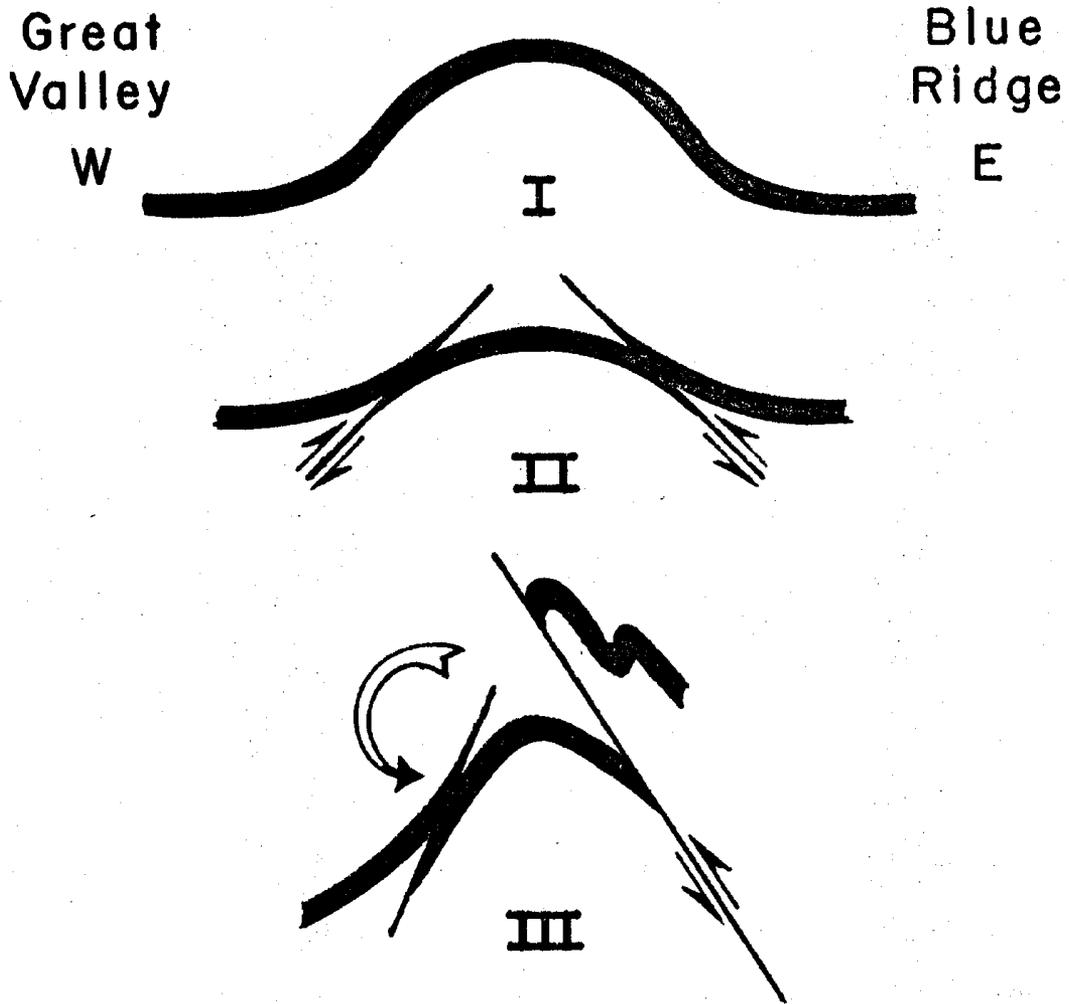


Figure 5.

# FOLD DEVELOPMENT IN LOWER ORDOVICIAN AND UPPER CAMBRIAN CARBONATES

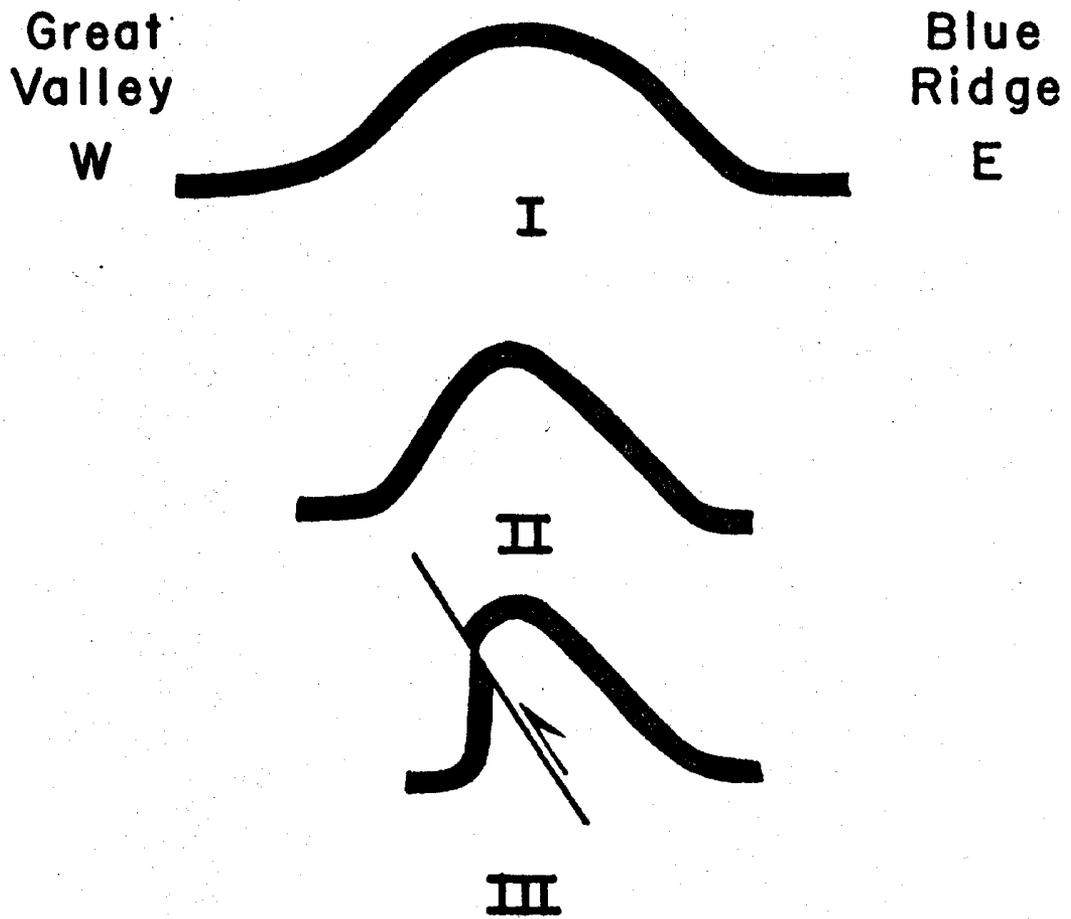


Figure 6.

Faults are notably absent in the area of the map which largely represents the relatively incompetent structural lithic unit of the Tomstown - Elbrook Formations. This probably results from yield by passive folding rather than flexure folding. These units could 'flow' into the cores of concentric folds developed in the overlying, relatively competent Conococheague-Chambersburg structural lithic unit. Hence, there was no problem of space to be resolved by faulting as there was no maintenance of geometric concentricity in these less competent units.

#### Deformation of the Martinsburg Formation

Deformation in the Martinsburg is not unlike that in Cambro-Ordovician sediments when it is considered that this flysch sequence is strongly anisotropic and undoubtedly was subjected to a smaller stress. However, it should be noted that there are actually few exposures of the Martinsburg that indicate this type of deformation. The most striking aspect within the Martinsburg is the complete dominance of interstratal slip and paucity of  $S_1$  that is so well developed in the limestones. Close to the limestone contact some  $S_1$ , harmonious with the  $S_1$  in the adjacent limestones is present, but farther west  $S_1$  is virtually absent. Strong fracture cleavage is developed, especially in the thick greywacke beds of the sandy portion of the Martinsburg.

Geometry of the Martinsburg folds is similar, but on a much reduced scale, to that in the limestones (i. e. asymmetric to the west and plunging to  $S20^{\circ}W$  at  $25^{\circ}$  close to the limestone outcrop belt. In the middle portion of the shale valley the folds have no plunge, and close to the up faulted belt of limestone that passes through Williamson all folds plunge to the northeast. This reversal of plunge, as compared with folds of the South Mountain antictinorium is one principal feature of the Massanutten synclinorium.

The Carbaugh-Marsh Creek and related faults that separate the limestone from the shale is not a boundary between two different tectonic units. The shales

adjacent to the limestone still retain some imprints of the South Mountain anticlinorium deformational plan. It is not inconceivable that a major fault passes through the shale valley juxtaposing southwest plunging structures on the east against northeast plunging structures on the west. Poor exposure prevents determination of the possibility. If no fault is present then the change in plunge across the valley probably becomes related to a larger problem -- arcuation of the Appalachians.

### Structural History

The structural history of this area emphasizes deformation processes in the Conococheague-Chambersburg structural lithic-unit. An evolutionary sequence in the tectonic history is postulated below.

- I. Gentle folding of the beds.
- II. With continued folding, there was symmetrically opposite thrusting toward the anticlinal axis in the upper part of the sequence where a relatively incompetent structural lithic unit overlies the carbonates.
- III. With continued folding and development of asymmetry, shearing (reverse faulting) through the steepened and west limb permitted tightening in the core of the fold.
- IV. Major block adjustment then took place.

This involved translation of the entire block bounded by the Carbaugh-Marsh Creek faulting including the Catoctin greenstone. This block moved westward a considerable distance; certainly more than the two miles indicated by immediate offset of the contact of the Catoctin greenstones across the fault. This is concluded because major structures in the Chilhowee cannot be matched across the fault, and it is possible that several widely spaced Chilhowee folds were overridden to bring this block to its present position.

Movement across the block diminished westward as some of the lateral translation was dissipated along the pre-existing east-dipping reverse faults concentrated between folds II-IV, increasing the original displacement across these faults. The folds were oversteepened or overturned even more to the west. The Carbaugh-Marsh Creek fault block then overrode the early symmetrically opposed west dipping thrusts between Chambersburg and Greencastle truncating most of them west of Greencastle. In places it may have followed along the east dipping fault developed in the symmetrically opposed thrusting (Figure 5 III). The west dipping faults locked during this event and no movement took place, but they were externally rotated and oversteepened, so that they are now probably near vertical or even overturned and dipping east. Movement along the Carbaugh-Marsh Creek fault induced a splay between Greencastle and Chambersburg so that there is a reverse fault between the Martinsburg shales and Ordovician limestones along the east branch of Conococheague Creek.

- V. If the Antietam Cove fault is related to the main movement of the Carbaugh-Marsh Creek fault block, then it probably formed in the late stage of this movement. If the fault dips east, then it is a normal fault produced by drag as the Carbaugh-Marsh Creek fault block moved west. If it dips west, then it is a reverse fault that served to 'pop-up' the terrane between Waynesboro and Greencastle.

#### Structural Problems

Some fundamental problems must still be resolved by future work. Among these are:

- I. Was there only one period of deformation? Analyses of fold kinematics (Figure 5) and absence of an  $S_2$  surface would indicate only a single deformation. In the Piedmont multiple deformations have been recognized

(Freedman et al 1964, and Lapham and McKague, 1964), and two periods of deformation have been recognized in the immediate Valley and Ridge (Pierce and Armstrong, 1966). In the Lebanon Valley allochthon multiple deformation is also recognized.

Several stages are recognized in the deformation of the Cumberland Valley autochthon. If these are secular rather than continuous stages, then folding and minor faulting might represent an early period of deformation and translation of the Carbaugh-Marsh Creek fault block might represent a later period of deformation. If there actually was multiple deformation in the Cumberland Valley, geometry of the fold pattern was nearly homoaxial in both instances.

- II. When did the deformation or possibly deformations occur?
- III. Do the detachment surfaces recognized by deep drilling in the Appalachian Mountain Section of the Valley and Ridge continue into the Tomstown-Elbrook relatively incompetent structural lithic-units where they have subsequently been folded?
- IV. Are the Blue Ridge Mountains autochthonous at depth?

## STRUCTURE OF THE LEBANON VALLEY ALLOCHTHON

Introduction

Nappe structure within the carbonates of the central Lebanon Valley was recognized by Gray (1959) and details are shown in 3 published 7½' quadrangles (Geyer, Gray, and others 1958, 1963). The relation of these structures to the relatively less complex folding in the Cumberland Valley, however, remained uncertain. Extension of the original Lebanon Valley mapping shows that the character of the central part extends westward with little significant change to the Yellow Breeches thrust. This thrust truncates the plunging nose of the South Mountain anticlinorium and terminates exposure of Cumberland Valley type lithology and structures.

General Structure

Upright beds are exceptional in exposures of the Lebanon Valley sequence and reflect relatively minor digitations or reversion by subsequent rotation. The entire sequence is regionally overturned - sometimes past simple recumbency. The whole valley thus effectively represents the under limb of an immense recumbent anticlinal fold, though it is possible that an upper limb never existed. Higher order satellitic folds of substantial size are rare, and smaller folds visible within a single crop are common only in the vicinity of thrust faults and in the oldest rocks. Thrust faults of all sizes, however, are common, usually lying nearly parallel with both the average bedding and the main flow cleavage where both are distinguishable. Minor fold axes and thrust lineations may at first appear erratic, but both are found to cluster in two groups roughly parallel and perpendicular to the regional strike. Smear lineations are abundant on bedding and cleavage surfaces but occupy only the strike normal position.

Figure 7, folded separately, shows a geologic map and cross sections of the carbonates in Dauphin County. The stratigraphic units are quite thick so that lithic distribution provides only a coarse indication of the type of structures observed;

but some sense of the structure is given by the structural symbols. The accompanying small scale tectonic map and sections are schematic but show the general relations across the Yellow Breeches thrust.

#### Crossfolding and Multiple Deformation

The existence of two sets of fold axes roughly parallel and perpendicular to the regional strike does not necessarily imply two stages of deformation, as they have all the characteristics of a syngenetic B1B' system such as has been associated with other far-traveled thrust masses. Certain structural details and overall tectono-stratigraphic relationships, however, suggest that multiple deformation as well as syngenetic cross-folding is represented.

Figure 8 is traced from a photograph of the abandoned Annville cut on the north side of the Bethlehem Steel Co. quarry at Steelton. This exposure is now partly covered and unsuitable for use on the present trip, but it nicely illustrates many features of one of the larger thrust zones within the Lebanon Valley carbonate sequence. At least 600 feet and probably more than 1000 feet of strata are absent between the adjacent Epler and Annville Formation beds, although the average dip of the thrust and of the bedding a short distance from the thrust zone do not differ appreciably. The deformation of some of the thrust surfaces apparent in this figure could be the result of sustained movement in a single phase, but it is consistent with two stages of deformation.

Variability of the flow cleavage attitude supplies more compelling evidence for a second deformational stage. While warping of the cleavage on the scale of a single exposure is not usual, cleavage often shows a degree of variability between exposures which is difficult to reconcile with warping in a late phase of the cleavage generating movement. Petrofabric data (to be discussed subsequently) convincingly show cleavage to be rotated about an axis inclined to the original fold axes; but this relationship is also suggested, if not demonstrable, by field relationships without

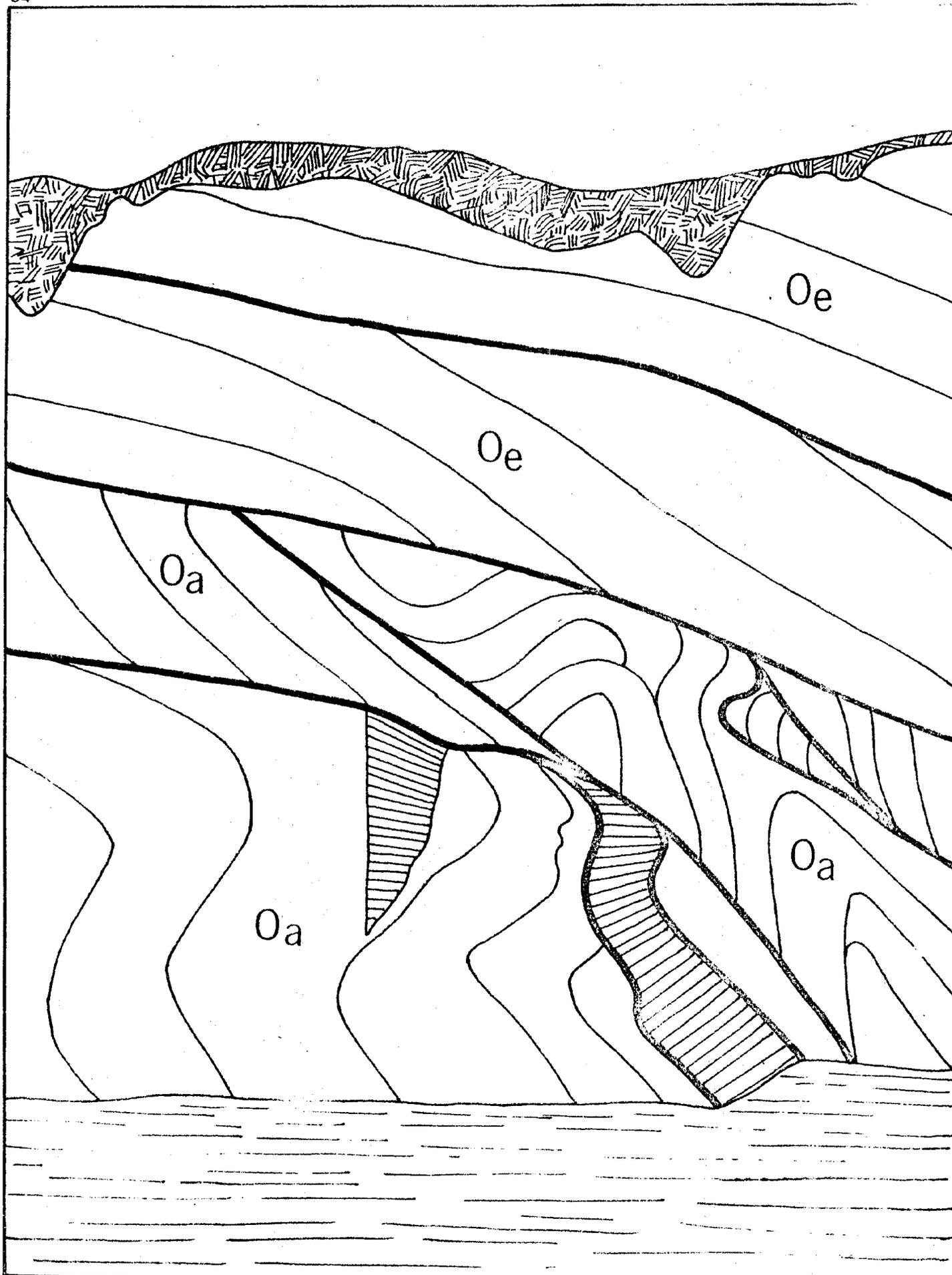


FIGURE 8. YELLOW BREECHES THRUST EXPOSED NEAR STOP 8.

this statistical sophistication.

A second cleavage, usually designated fracture cleavage in the field, is also recognized in some locations. This cleavage also suggests multiple deformation, but its attitude bears no obvious field relation to the cleavage to be expected from rotation in the direction implied by warping of flow cleavage. This fact might imply at least 3 deformational phases, but the subsequently discussed petrofabric analyses indicate 2 stages are sufficient. A definable penetrative surface generated by the event producing the principal rotation of flow cleavage has been recognized at only one place.

Large scale tectono-stratigraphic relationships also imply two deformational events. The fact that the Yellow Breeches thrust everywhere has the Martinsburg Formation in its sole without any inclusions of competent younger strata strongly implies that the initial inversion of the Lebanon Valley sequence was accomplished before the deposition of younger units, i. e. was a Taconic event. The Yellow Breeches thrust, however, truncates the South Mountain anticlinorium in such a manner that its emplacement would appear to have been subsequent not only to folding of South Mountain but also to substantial erosion. On the basis of structurally and stratigraphically plausible chronology for the Cumberland Valley and the adjacent ridges this would indicate emplacement not earlier than late Acadian and quite possibly Alleghenian. The implication is thus of two stages of thrusting widely separated in time.

#### Structural details of Yellow Breeches Thrust

Actual exposures of the Yellow Breeches thrust zone are rare owing to its position at the base of a shale escarpment. The best exposure is visited as Stop 8 of this trip. At this point and for several miles eastward it seems to be essentially similar to the thrust zone shown in Figure 8 but on a larger scale. At Stop 8 there is a parautochthonous tectonic slice of the Cumberland Valley sequence 100 + feet thick, the top of which is exposed at the station. This is followed by a truly allochthonous

slice of the Hershey Formation of comparable thickness above the master thrust, which, however, bears an obscure relationship to the overlying "Martinsburg" of the main thrust block. It is supposed that this slice was entrained in the thrust sole at some point well toward the breakoff of the thrust. At this point the Hershey Formation apparently extended somewhat southwest of its limit along the strike of the main block, where it is absent through most of Dauphin County.

Further to the east the thrust is apparently a single surface, as "Martinsburg" shales are exposed close to rocks of the St. Paul Group which are structurally continuous with the main Cumberland Valley sequence. The uppermost rocks are tectonized to the extent of development of conspicuous smear lamination and the development of a rather coarse subhorizontal parting surface, but this effect disappears within a fairly short distance from the thrust.

The considerable irregularity of the thrust front is an erosional effect which shows that the thrust is quite flat and locally even north dipping.

#### Petrofabrics

On the basis of the folding described above it may well be imagined that efforts to obtain a structural synthesis from the geometry of bedding proved a frustrating experience. While some quite extensive areas yielded simple maxima or orderly girdles, many areas as small as the data density would allow yielded chaotic patterns or apparent girdles giving rise to a meaningless scatter of virtual rotation axes.

Limiting analysis to elements produced by or younger than the first major deformation ( $D_1$ ), however, has proved much more rewarding. The stereograms of Figure 9 summarize deformational elements in the eastern half of the Dauphin County carbonate belt from Hummelstown eastward (essentially the area between Stops 10 and 13 on Fig. 1). Incomplete analysis of the western half shows little change. The patterns in these digrams are complex owing to cross-folding and multiple deformation, but all elements are entirely consistent and give a fairly complete geometry and movement plan of two

distinct deformations ( $D_1$  and  $D_2$ ). The notation used in discussing the structural elements is summarized in Table 4.

The central contours of plot A show poles of flow cleavage ( $S_1$ ). It is apparent that, though somewhat diffuse, to a first approximation, the cleavage poles define a major fraction of an upright girdle to which the solid great circle labeled  $A_{2c}$  is the visual estimate of best fit. The existence of the girdle implies rotation ( $D_2$ ) of  $S_1$  around an axis normal to it which is labeled  $B_{2c}$ .

Contours at the NE and SW margins of the net show the distribution of measured axes of small scale  $B_1$  folds. These do not form a simple maximum as would be anticipated from a single deformation but are clearly distributed around a major portion of a small circle. This conclusively demonstrates that  $B_1$  axes have been subsequently rotated about an inclined axis  $B_2$  which may be considered horizontal to a first approximation. The small circle of  $17^\circ$  radius fitted to  $B_1$  poles by this approximation implies a rotation axis  $B_2$  labeled  $B_{2b}$  on the diagram.  $B_{2b}$  is sensibly coincident with  $B_{2c}$  within the inherent limitations of the statistical method. Indeed the girdle implied by  $B_{2b}$  (dashed and labeled  $A_{2b}$  on the diagram) is hardly a worse fit for the  $S_1$  girdle than  $A_{2c}$  previously estimated. The two independent methods of deriving  $B_2$  leave no reasonable doubt of its objective reality even though only one occurrence ( $L_{1x2}$  of diagram B) of a mesoscopic field lineation corresponding to this axis is known.

Close inspection of the fit of the small circle about  $B_{2b}$  to the  $B_1$  poles reveals that improved fit could be obtained by fitting a circle of about  $15-16^\circ$  radius about an axis plunging less than  $5^\circ$  to the northeast. This refined approximation, however, contributes little additional information to structural analysis and hardly warrants the considerable effort required to rotate each of the hundreds of points contributing to the analysis. It is sufficient to note that the  $B_2$  axis, which will be treated as horizontal in subsequent discussion, probably plunges very slightly northeastward; and

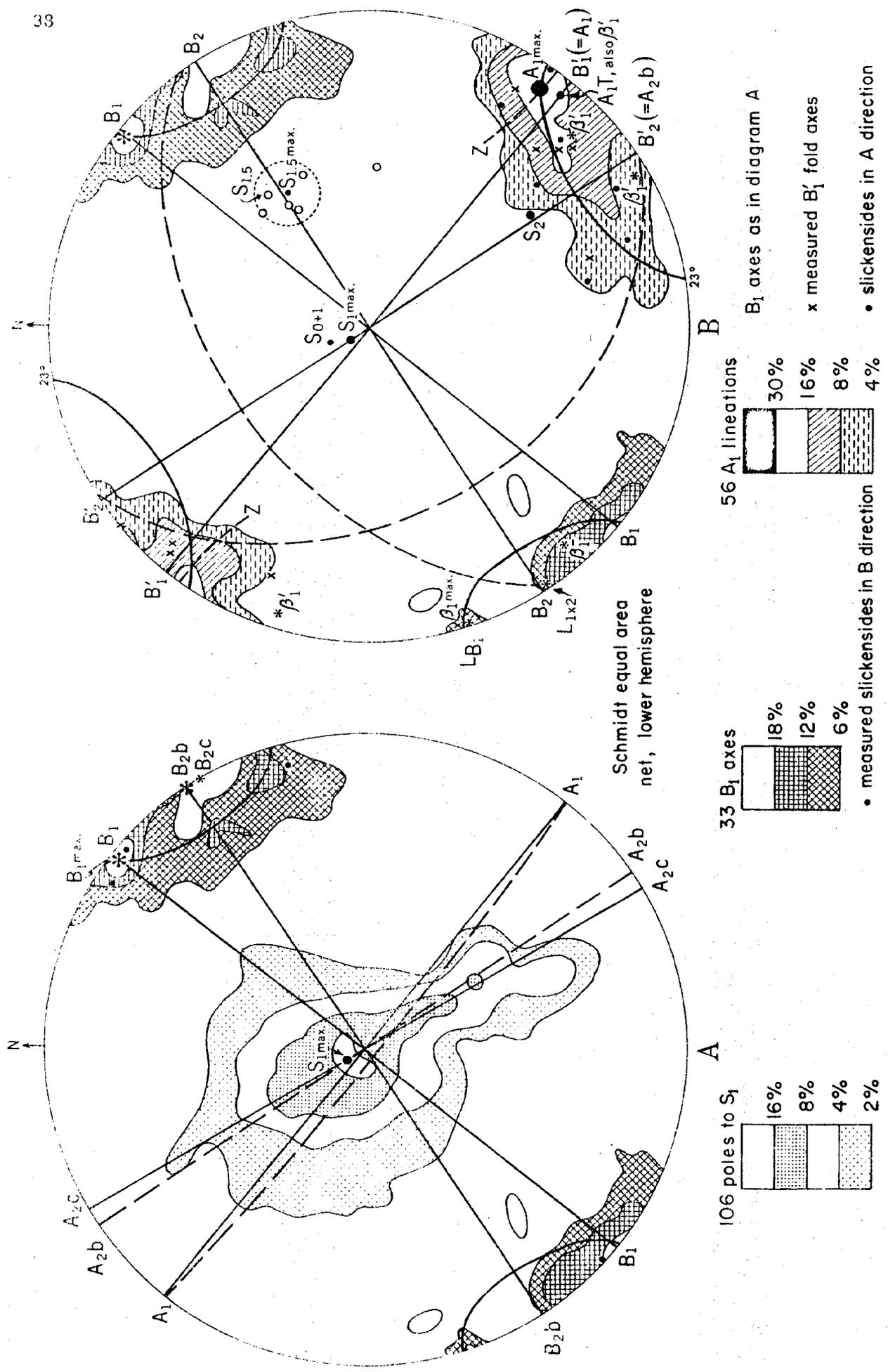


Figure 9. STEREOGRAMS OF EASTERN DAUPHIN CO. CARBONATES

Table 4

Notation of Fabric Elements

Basic Scheme of Notation

Visible fabric of deformed rocks is characterized by surfaces (S) and lineations (L) which define rotation (fold) axes (B) and transport axes (A). A subscript number designates the stage of deformation (D) with which a given element is associated. A primed element (as in  $B_1$ ) is related to syngenetic cross folding. A lineation defined by the intersection of S surfaces is indicated by the subscript appropriate to both surfaces, as in  $L_{1x2}$ , where the cross indicates the intersection. The rational combinations available in this scheme obviously far exceed those actually used, as shown below.

Notation in this Guidebook

$A_1$ Transport axis of 1st generation fold	$L_B$ Measured fold axes
$A_2$ Transport axis of 2nd generation fold	$L_{1x1.5}$ Lineation formed by intersection of $S_1$ and $S_{1.5}$
$A_{2b}$ Transport axis of 2nd generation fold derived from rotation of $L_{B1}^*$	$L_{1x2}$ Lineation formed by intersection of $S_1$ and $S_2$
$A_{2c}$ Transport axis of 2nd generation fold derived from rotation of $S_1^*$	$L_{1.5x2}$ Lineation formed by intersection of $S_{1.5}$ and $S_2$
$A_{lmax}$ Statistical maximum of measure $L_{A1}$ transport lineations	$S_0$ Fabric surface antedating $D_1$ (=bedding in sedimentary rocks)
$A_{1T}$ theoretical position of $A_1$ derived from geometry of $S_1$ and $B_1^*$	$S_1$ Fabric surface generated in $D_1$ (flow cleavage here)
$B_1$ 1st Generation fold axis	$S_2$ Fabric surface generated in $D_2$
$B_1'$ 1st Generation crossfold axis ( $=A_1$ )	$S_{1.5}$ Fabric surface shown by field relations to be between $D_1$ and $D_2$ in age <sup>t</sup>
$B_2$ 2nd Generation fold axis	$S_1'$ Fabric surface generated by $B_1'$ rotation
$B_2'$ 2nd Generation crossfold axis ( $=A_2$ )	$S_2'$ Fabric surface generated by $B_2'$ rotation
$B_{1B}$ Standard notation for geometry of syngenetic cross folds	$Z$ used to identify a small circle of rotation for convenience.
$\beta_1$ Statistical rotation axis defined by intersections of measured attitudes on a folded surface (first generation folding)	
$\beta_{lmax}$ Statistical maximum of $\beta_1$ intersections	
$\beta_{1-}$ Subordinate maximum of $\beta_1$ intersections	
$\beta_1'$ Subordinate maxima of $\beta_1$ intersections related to crossfold rotation	
$D_1$ 1st deformational event or all elements generated thereby collectively	
$D_2$ 2nd Deformational event or all elements generated thereby collectively	
$L_A$ Transport or smear lineations	

\*Designates notations which are not part of basic notation system used for convenience in discussing certain features of this fabric.

the inclination between  $B_1$  and  $B_2$  may be slightly less than  $17^\circ$  derived from the assumption of a horizontal  $B_2$ .

A similar refinement applied to fitting the  $S_1$  distribution is the observation that a considerably better fit than  $A_{2c}$  can be made by a small circle of relatively large radius about a plunging axis. The same general reasons as above apply for not pursuing this refinement. The significant fact that comes out of this relationship is that small circle rotation of  $S_1$  around  $B_2$  indicates that  $S_1$  was a passive element during  $D_2$ .

On the basis that the field evidence of  $D_2$  is mostly subtle and is consistent only with relatively minor rotation in most areas, it seems safe to assume the  $B_1$  maximum in the circle around  $B_{2b}$  corresponds to the original position of  $B_1$ . That is,  $B_1$  max represents that statistical position of  $B_1$  prior to  $D_2$ , and  $B_1$  was then generally plunging about  $3^\circ$ NNE.  $B_1$ max then defines the regional fold trend, the solid line  $B_1$  of the diagram, and the composition plane of  $B_1$  folding, the dashed great circle  $A_1' A_1$  of the diagram. Fanning of  $S_1$  caused by sustained movement during  $D_1$  would, of course, be in the  $A_1' A_1$  plane; and inspection of the diagram indicates that this may indeed be a significant cause of the lateral spread of the  $D_2$  girdle of  $S_1$ , though another cause ( $B_2'$  folding) is probably more important.

The small crosses within the contours of diagram 9B represent the measured axes of small scale folds steeply inclined to the regional strike. The dots indicate slickensiding and grooving on low angle faults. These points together with a considerable number of smear or transport lineations on bedding ( $S_0$ ) or flow cleavage ( $S_1$ ) were used to compile the contours shown.

In the absence of subsequent deformation, the contouring of  $A_1$  poles should show a simple maximum which corresponds to the statistical transport axis (A) of the fold system. This maximum ( $A_1$ max of diag. B) theoretically should lie in the composition plane ( $A_1-A_1$ ) at  $90^\circ$  from the cleavage maximum ( $S_1$ max of diag.) at the

position of point  $A_1T$  in diag. B. It may be seen, however, that  $A_1max$  and  $A_1T$  are about  $5^\circ$  apart. This discrepancy is sufficiently small that it might be entirely a statistical artifact, but slight real preferential rotation of  $A_1$  axes is possible for reasons related to the generation of  $S_{1.5}$ .

The fact that there exists a group of fold axes (crosses of diag. B) which show the same distribution as simple transport lineations strongly implies that both have a common origin. This situation can be theoretically and experimentally demonstrated to arise when a deformable body is pushed through a lateral restriction, which gives rise to the condition called restricted tectonic transport. Normal fold axes (B) perpendicular to the transport direction may be formed at the same time, which gives rise to the syngentic fabric  $R_1B'$  where  $B'$  represents folds in the transport direction.

In real geologic situations  $R_1B'$  geometry of bedding developed on a mesoscopic scale over substantial areas is uniquely associated with allochthonous rocks which, in all cases studied, appear to have been transported very substantial distances. The occurrence of this fabric thus appears to be diagnostic of major thrusting during the deformation generating this geometry.

The conditions of restricted tectonic transport imply derivative transport perpendicular to the main movement direction. In typical described cases the derivative transport is indicated only by the  $B'$  folds themselves which require lateral appression for their generation. In this case, however, we have evidence of minor thrusts displaced in the  $B_1$  direction, rather than in the usual direction of regional transport. In addition to the usual thrust slickensides distributed in the same manner as other  $A_1$  lineations shown on diag. B, the similar spots on diag. A are thrust slickensides showing transport along  $B_1$  and perpendicular to  $B_1'$ .

To this point in the discussion reference has been made only to  $A_1max$  without consideration of the actual distribution of  $A_1$  poles. It is obvious that the actual contours are not radially symmetric to  $A_1max$ , hence some rotation of the  $A_1$  axis is

implied. One such rotation whose real existence is the necessary consequence of actual rotation on  $B_2$  is rotation of  $A_1$  along small circles concentric to  $B_2$ . In particular this rotation would tend to spread the  $A_{1max}$  along the small circle of  $69^\circ$  radius which has been indicated by a dashed segment Z-Z in diagram B. About ( $\pm 20^\circ$ ) of such rotation is entirely consistent with the observed spread of  $A_1$  parallel to this small circle. However, it is obvious that the principal rotation of  $A_1$  has a different orientation. To a very close approximation the best fit for the main spread of  $A_1$  poles is a small circle of  $23^\circ$  radius around the  $A_{2b}$  axis of diagram A ( $B_2'$  axis of diag. B).  $A_{2b}$  is thus a B axis with respect to deformation of  $A_1 (=B_1')$  and accordingly becomes  $B_2'$  of a  $B_1B'$  fold system of  $D_2$ . Further evidence of  $B_2'$  rotation is afforded by the lateral spread of the  $S_1$  girdle, which is extensive and essentially symmetric to this axis.

The development of  $B_1B'$  geometry in  $D_2$  indicates that the later deformation was also characterized by large horizontal transport with a somewhat different direction than the earlier thrusting.

The remaining feature on this diagram which represents a structural element measured at several different localities are the six poles designated  $S_{1.5}$ . In the field this surface appears as a coarse or poorly defined cleavage generally appearing younger than  $S_1$ . While the number of readings is too small for statistically significant contouring, the available data clearly suggest that there is concentration of  $S_{1.5}$  poles ( $S_{1.5max}$ ) centered on a point very close to the  $B_2$  axis; and the single pole not falling within the 1 percent circle around  $S_{1max}$  (dotted on diagram) suggests possible rotation of  $S_{1.5}$ , probably around  $B_2$ . The statistical  $S_{1.5}$  plane defined by the pole  $S_{1max}$  is shown by a dashed great circle on diag. B which essentially includes the  $B_2'$  axis. This geometry suggests that  $S_{1.5}$  is cleavage generated by  $B_2'$  rotation and might properly be designated  $S_2'$ .

This simple geometric interpretation must be somewhat qualified, however. At one

station four  $S_1$  surfaces were recognized. The  $S_1$  flow cleavage is the dominant foliation of this exposure. The bedding ( $S_0$ ) which probably was initially close to  $S_1$ , has its original character much modified by shearing on  $S_1$  and is now geometrically inseparable. The attitude of this surface is shown on diag. B as the pole  $S_{0+1}$  and is perfectly normal for the region in that it lies close to the regional  $S_{1max}$ . Elsewhere in the same exposure, where four surfaces were not explicitly identified, 14 additional readings of  $S_{0+1}$  plot as a girdle with  $94^\circ$  spread, which indicates rotation around the axis labeled  $L_{B_1}$ , falls on the small circle of  $B_1$  rotation about  $B_2$  near the secondary maximum approximately opposite  $B_{1max}$ , indicating this exposure is in an area strongly affected by  $B_2$  rotation. A  $\beta$  plot of the  $S_{0+1}$  data shows two distinct areas of concentration at the 3 percent level. The major area has a clearly defined 33 percent maximum ( $\beta_{max}$  of diag. B) which is, as expected, statistically coincident with  $L_{B_1}$ . It also has a subordinate max ( $\beta -$  of diagram) which corresponds to a substantially less rotated position of  $B_1$ . The lesser discrete concentration has four approximately equal maxima ( $\beta'$  of diagram). These maxima have a clear relation to the contours of  $A_1$  lineations and show the effects of  $B_2'$  rotation on the local  $S_{0+1}$ .

Superposed on  $S_{0+1}$  is a coarse fracture cleavage whose pole is the labeled  $S_{1.5}$  pole of diag. B. The intersection of  $S_{0+1}$  and  $S_{1.5}$  generates a lineation ( $L_{1x1.5}$ ), measured values of which cluster around  $B_2'$  as to be expected if  $S_{1.5}$  is properly  $S_2'$ . At one point in this exposure it was recognized that both  $S_{1+0}$  and  $S_{1.5}$  bear second lineations. These lineations ( $S_{1x2}$  and  $S_{1.5x2}$  of diagram B) define a penetrative plane,  $S_2$ , which is otherwise so subtle that it would have been ignored. This plane is represented by a dashed great circle on diag. B, and the corresponding pole is marked  $S_2$ . It is apparent that this plane essentially includes the  $B_2$  axis; and it was presumably generated, therefore, by  $B_2$  rotation. Confirmation that this  $S_2$  actually corresponds to the regional symmetry plane of  $B_2$  rotation is found in the large antiformal syncline which includes the Stop 11 vicinity in its south limb.

This fold has an axial trend coincident with the regional  $B_2$  and a peculiar southeast facing asymmetry opposed to the usual northwest overturning in the valley. Calculations of the axial symmetry plane of this fold from the attitude of bedding in the limbs yields an attitude nearly coincident with  $S_2$  of the diagram.

Field relationships leave little doubt that  $S_1-S_{1.5}-S_2$  is a genetic temporal sequence, though no indication of a relative time interval is implied. The designation of  $S_{1.5}$  as  $S_2'$  has been avoided for this reason in part. This is not to say that  $S_{1.5}$  could not have been generated in  $D_2$ , but only that it was formed before  $D_2$  reached sufficient local intensity to form  $S_2$ , while  $S_{1.5}$  is more pervasive. This relationship does seem theoretically improbable, however, especially the other evidence of unusually active  $A'$  transport (transport in the  $B$  direction perpendicular to  $B'$ ) is the slickensiding associated with  $B_1$ .

An alternative explanation is that  $S_{1.5}$  was the result of sustained  $D_1$  movement after  $S_1$  had already been defined. This seems a more plausible sequence both with respect to the probable theoretical order of  $S$  and  $S'$  generation and the obvious difference in maximum intensity of  $D_1$  and  $D_2$ . If  $S_{1.5}$  is in fact  $S_1'$ , the attitude of  $S_{1.5max}$  suggesting a geometric relation to  $B_2'$  is anomalous. The anomaly has a rational explanation: as  $S_{1.5}$  is clearly antecedent to at least some part of  $B_2$  rotation, it will be rotated thereby. It is entirely possible that the  $16^\circ$  of net rotation of  $S_{1.5}$  about  $B_2$  required to bring  $S_{1.5max}$  from its theoretical position on the  $B_1$  trend on to the  $B_2$  trend actually happened; but the fact that  $S_{1.5max}$  falls at this particular point, rather than some other statistically more probable point closer to  $B_1$ , sounds a note of caution.

These alternatives seem to be the practical limit of analysis of  $S_{1.5}$  by the available data. It seems reasonably certain that it was generated by a  $B'$  rotation, probably in  $D_1$  by qualitative considerations, but possibly in an early phase of  $D_2$ .

Advanced students of macropetrofabrics may have noted a peculiar feature in the

preceding discussion of  $S_{1.5}$ . This is that the general theory of  $B_1B'$  folding does not provide for a unique  $S'$  maximum. The usual geometry of  $B'$  considered in isolation is orthorhombic (fan folding, as displayed in some Caledonian rocks, is an extreme example). The single  $S_{1.5}^{\max}$  indicates a monoclinic symmetry for  $B'$ . The essential difference is that the orthorhombic symmetry shows movement perpendicular to  $B'$  but no net transport, while the monoclinic symmetry of  $S_{1.5}^{\max}$  indicates net transport to the northeast. Considering the regional framework, however, this net transport is entirely expectable, and the  $S_{1.5}$  maximum is entirely consistent with  $B_1B'$  folding. As the Lebanon Valley nappe system never overrode the main South Mountain uplift (Fig. 1) but merely passed its plunging nose, the data of Fig. 9 are taken from a location which is close to the real western limit of the system. When the Yellow Breeches sheet was pushed (slid) past this lateral obstruction, northeastward net transport at the west edge of the sheet was a natural consequence. This does not imply net lateral transport throughout the entire sheet. I anticipate that diagrams comparable to Fig. 9 for the Lebanon-Cornwall (Stop 12) area would show patterns generally similar to Fig. 9 except that  $B'$  elements would show normal orthorhombic symmetry.

It was previously mentioned that the failure of the geometrically constructed  $A_1T$  axis to coincide perfectly with the statistical maximum,  $A_1^{\max}$ , of  $A_1$  lineations might be more than a statistical artifact. It may be mentioned at this point a few degrees net rotation of  $A_1$  lineations about  $B_2'$  would about halve the discrepancy. Net rotation of these axes would imply net transport perpendicular to  $B_2'$ . This effect is not large enough for positive statements, but it does suggest possible independent confirmation.

#### Synopsis of Tectonic History

At the depositional locus of the Lebanon Valley sequence, Paleozoic history starts with the initial subsidence of an already ancient crystalline terrane. A basal Lower

Cambrian quartzite marks this transgression. Typical miogeosynclinal conditions were soon established; and nearly 8000 feet of carbonates were deposited without substantial interruption, at least from Middle Cambrian to Lower Middle Ordovician.

While deposition was apparently continuous in this area through the Middle (?) Chazyan Annville limestone, the first evidences of tectonic instability appear at the beginning of Middle Ordovician time. This instability is not indicated by evidence internal to the Lebanon Valley sequence in rocks older than Trenton, except by the absence of Black River equivalents; but it is stratigraphically apparent on a larger regional scale. Regional facies and thickness changes in Chazyan and younger carbonates are obviously much more rapid and complex than in the underlying Canadian and older rocks; and local to subregional disconformities exist at differing horizons in various areas. These relations demonstrate a fairly abrupt change in the megatectonic framework of deposition, which culminates in the Taconic orogeny near the end of the Ordovician.

The first feature of active local tectonism appears as the conglomerate wedge of the lower Hershey Formation. This conglomerate, composed of Beekmantown (?) fragments obviously was locally derived from a steep declivity of considerable stratigraphic relief - presumably formed by surface faulting. This proposed fault may in fact be ancestral to the present fault at the eastern limit of Hershey exposure near Wernersville. Conglomerate in the Hershey slice of the Martinsburg area is presumably not derived from the same scarp, but is of related genesis.

Deposition of the shaly Hershey carbonates was followed by a widespread Taconic flysch. In the allochthonous "Martinsburg" Formation, which is apparently indigenous to the depositional locus the Lebanon Valley, wildflysch elements older than Trenton, but radically unlike other rocks described in this report, apparently "float" in the unit (Platt, M. S.). These features imply close approach to an active orogenic axis.

The complete absence of post-Martinsburg rocks in the allochthon strongly suggests

that initial overturning and thrusting were immediately sequential to flysch deposition. If this is a supracrustal phenomenon, it could be accomplished by break off high on the flank of the tectonic welt, followed by upturning and inversion of the broken end, followed by an increasingly large overturned segment sliding down over the parent unit. Smaller scale examples of this process in the Iranian salt hills provide a model for this hypothesis. If the gneisses of the Reading Prong were involved at this stage it is, of course, untenable. It seems likely that overturning by this supracrustal mechanism might be atectonic (not generating penetrative fabric). In this case the conspicuous cleavage related to the first recognizable deformation could be post-Taconic, but any other mechanism would imply loads and movements such that cleavage would be cogenetic with overturning, hence, presumably Taconic.

In any case, it is clear that the first recognizable deformation involved substantial northwestward transport of overturned strata with abundant thrusting developed. Lateral restriction during transport produced syngenetic cross-folds aligned in the main transport direction. The simplest synthesis of stratigraphic and structural data indicates that this represents Taconic orogeny.

If the first deformation is Taconic, a long period of quiescence followed, as the next recognizable event is probably no older than late Acadian. This event is characterized by renewed thrusting about  $17^{\circ}$  more northerly than the previous stage. Folds and associated syngenetic cross-folds present in the cleavage of the first stage were produced at this time. A minimum age of late Acadian is derived from the relation of the present allochthon to the plunging South Mountain axis.

Subsequent to the Yellow Breeches thrust emplacement in the second deformation, there were relatively small movements on steep thrusts in the Cumberland Valley, but the larger movements on these faults probably antedate the Yellow Breeches thrust. Minor steep faults may be related to this movement. Relatively late normal faults apparently related to development of the Triassic basin are the youngest feature

recognized, with possible exception of the "Triassic dikes" which may be Jurassic. Later Mesozoic and Cenozoic broad vertical movements undoubtedly affected this area, but such local evidence of these movements as may be found is largely in the domain of the geomorphologist.

## Road Log For Field Trips

October 7 and 8, 1966

## 31st Field Conference of Pennsylvania Geologists

Stops 1-5, on the first day, are located in southern Franklin County. The 15' quadrangles pertinent to this portion of the field trip are: Harrisburg, Carlisle, Newville, Fairfield, Chambersburg, and Shippensburg. The area is covered by the Baltimore and Harrisburg, 1:250,000 AMS topographic maps. Geology in various areas is covered by: U. S. G. S. Quadrangle Report GQ-28 which includes the Carlisle Quadrangle, U. S. G. S. Folio 170 which includes the Chambersburg Quadrangle, and U. S. G. S. Folio 225 which includes the Fairfield Quadrangle. Reports in preparation or in press by the Pennsylvania Geologic Survey concerning geology of the South Mountain area are A-129 and PR-169 and concerning the southern Cumberland Valley A-119 C and D

Stops 6-13, on the second day, are located in Dauphin and Lebanon Counties. Area visited is included in the Harrisburg, Hummelstown, New Cumberland, and Lebanon 15' quadrangles (Harrisburg East, Hummelstown, Lebanon, Palmyra, and Steelton 7½' quadrangles). These are included in the Harrisburg AMS 1:250,000 sheet. Geologic mapping is available for the Lebanon 7½' quad (Pa. G. S. A-167 C). The Palmyra quadrangle is in progress (Pa. G. S. A-157 D). Seven and one-half minute scale mapping of the Dauphin County Carbonates is included in Pa. G. S. Bul. G-44 (in press).

Reference starting and termination point for both trips is the Zero Highway Marker in back of the State Capitol Building on the west side of Commonwealth Avenue.

DescriptionMileage

- |     |  |
|-----|--|
| 0.0 | From Zero Highway Marker proceed south on Commonwealth Avenue.                                 |
| 0.1 | Turn right onto Walnut St. The Penn Harris Hotel is one block west on Walnut Street from here. |
| 0.5 | Left turn onto Front Street.   |

- 1.1 Approach to south Interstate 83 and U. S. 11.
- 1.4 Right turn onto South Bridge and Interstate 83.
- 1.6 On right Susquehanna Water Gap and left Triassic hills.
- 2.1 On right are St. Paul carbonates in railroad cut.
- 2.6 Keep straight on U. S. 11 south.
- 4.9 Keep straight on U. S. 11 south.
- 5.2 St. Paul limestones on right.
- 7.6 Good view of Blue Mt. to right.
- 9.2 Left turn onto Silver Springs Road to Mechanicsburg.
- 10.4 Beekmantown exposed on left.
- 10.5 Strategic ore stockpile on left, Mechanicsburg Naval Supply Depot.
- 11.6 Enter Mechanicsburg.
- 11.7 Turn right at light, jct. Rt. 114.
- 12.3 Straight at light leave Rt. 114 follow Rt. 641.
- 14.1 Cross Pennsylvania Turnpike, good view Blue Mt.
- 14.5 Turn right on Rt. 174.
- 15.3 Conococheague exposed in cut. First view of South Mt. ahead.
- 15.8 For 0.7 miles roadcuts of Cambrian limestone.
- 17.6 Roadcut with Elbrook limestones.
- 18.0 Crossing Appalachian Trail.
- 18.6 Cross Rt. 74.
- 19.0 Roadcut with Elbrook limestones.
- 20.0 Allenberry Playhouse.
- 20.6 Boiling Springs, left on Front St, four blocks. Triassic diabase dike passes through here.
- 21.0 Right on Fifth Street.

- 21.1 Rejoin Rt. 174, turn left. Note Antietam quartzite quarries visible on ridge ahead.
- 21.7 Elbrook limestone in roadcut.
- 22.5 Cross Yellow Breeches Creek.
- 24.9 Entering Mt. Holly Springs.
- 25.2 Left on Rt. 34.
- 25.6 Triassic brownstone library on left.
- 25.8 Half left, continue on Rt. 34.
- 25.9 Enter South Mountain, at this point, at the most northerly extension of the Blue Ridge Mountains.
- 26.1 Antietam quartzites on left.
- 26.5 Cross creek, quartzites of Mont Alto Member of Harpers Formation exposed.
- 26.6 Cross railroad.
- 26.8 Bear right on Rt. 34.
- 28.8 Bear right on blacktop, leave Rt. 34.
- 29.1 Cross railroad.
- 29.9 Entrance to Philadelphia Clay Co. Kaolinite at base of Tomstown is mined here for use in white cement.
- 33.6 Entrance to Pine Grove Furnace State Park.
- During the 1800's much iron was mined from numerous local limonite ore deposits in wash and residual clay at the foot of South Mountain. Manganese and phosphorus, in the form of wavellite, occasionally occur with the limonite. Furnaces constructed from limestone, used in the smelting of the ore are numerous, and this park maintains some of the better preserved furnaces.
- 33.7 Outcrop of quartz sericite schist in road bank.
- 33.8 Enter Laurel Lake Recreational Area.

- 34.2 Quartzite outcrop in roadbank.
- 34.7 Quartzite outcrop in roadbank.
- 35.7 Enter Fuller Lake Recreational Area.
- 36.0 Cross Appalachian Trail and iron furnace to left.
- 39.8 Enter Adams County.
- 41.6 Quartzite on left.
- 44.9 Leave Micheaux State Forest.
- 45.7 Re-enter Micheaux State Forest.
- 46.6 Cross creek that is intake to Chambersburg reservoir.
- 47.2 Chambersburg reservoir on left.
- 48.6 Enter Caledonia State Park.
- 48.8 Remains of old iron furnace on left.
- 49.8 Junction U. S. 30, turn right. The tear fault segment of the Carbaugh-Marsh Creek fault is in this vicinity. Leave South Mountain in short distance.
- 51.2 View across valley to Blue Mt. ahead. Now proceeding on limestone terrane.
- 52.1 Note displacement of South Mountain to the east looking left (south).
- 52.3 To left is Little Mt., an upfaulted block of Antietam quartzite.
- 53.6 Cross Rt. 997.
- 56.6 Conococheague outcrop on right.
- 57.0 Conococheague outcrop on right.
- 57.4 Beekmantown outcrop.
- 57.7 Upper Conococheague anticlinal axis exposed in roadcut.
- 58.0 Beekmantown outcrop on left.
- 58.4 Cross Interstate 81.
- 60.0 Enter square at Chambersburg and turn left on U. S. 11. This

town founded some 200 years ago was held for ransom and then burned by the Confederacy during their Civil War advance on Harrisburg. To counter the threat of the Army of the Potomac at Frederick, Maryland, Lee sent most of his troops to Gettysburg, through the gap in South Mountain where U. S. 30 passes. This led to the unique situation of the Confederacy attacking from the north and the Union attacking from the south.

- 61.1 Notice low ridge in middle distance left, composed of the Martinsburg shale.
- 61.2 St. Paul exposed on left.
- 61.4 Chambersburg exposed on left. Good view across valley here. Wooded more elevated areas is Martinsburg terrane.
- 62.1 Cut in Chambersburg cobbly limestones.
- 62.9 Cut in Chambersburg cobbly limestones.
- 63.6 Cut in Chambersburg cobbly limestones.  
Compressor station of Tennessee Eastern Gas.
- 63.8 Railroad cut with good exposure Chambersburg beds.
- 64.0 St. Paul exposed in field on right.
- 65.0 Cut in St. Paul limestones. View of Martinsburg on right.
- 65.9 From here to turn, intermittent exposures of Chambersburg limestone.
- 66.5 Turn left off Rt. 11 onto Kauffman Road.
- 66.6 Chambersburg-Martinsburg gradational contact poorly exposed in road bank on right.
- 67.0 Road junction, bear right and cross fault of Martinsburg against Beekmantown.

67.1 Stop 1. Section at Kauffman Farm:

This stop (see sketch map Figure 10) shows the basal Chambersburg Formation, complete St. Paul Group, and dolomite referred to the Pinesburg Station Dolomite of the Beekmantown Group. It shows the limestone to be faulted, in a brittle type of deformation, against the Martinsburg shale.

The eastern fault bringing Beekmantown against Martinsburg shale is believed to be a reverse fault that formed early in the folding history. It is presumed to have been west dipping (see discussion in text and Figure 8) and with continued stress it was externally rotated to what is now probably a vertical, or even overturned to the east, position. The fault on the west brings Chambersburg beds onto shales of the Martinsburg. It is believed to be an east dipping reverse fault that formed late in the deformational history of the area and is probably a splay off the main east dipping Carbaugh-Marsh Creek Fault. Note the shattering of the limestone in fault zones and lack of ductile faulting, also note the complete inversion of the horizontal beds at Conococheague Creek as the beds pass gradually from subvertical through overturned to locally recumbent here.

Dolomites at the base of the section are termed Pinesburg Station Dolomite. However, as they contain many thick limestone interbeds of St. Paul lithology, they do not meet the strict definition of Sando (1957) for this formation, and a different term might be more applicable.

The St. Paul Group displays several interesting lithologies including chemical grade micritic birdseye limestone (vaughanite) at the base and top of the group. The large Maclurites-bearing beds are spectacular but it is nearly impossible to break a specimen out of the rock. Interbedded algal limestones and laminated dolomites may represent cyclical shoaling of a lagoon in which the algal limestones formed, then dessication of the limestones (note what may be mud cracked limestone below the dolomite) and finally deposition of a primary penecontemporaneous dolomite perhaps

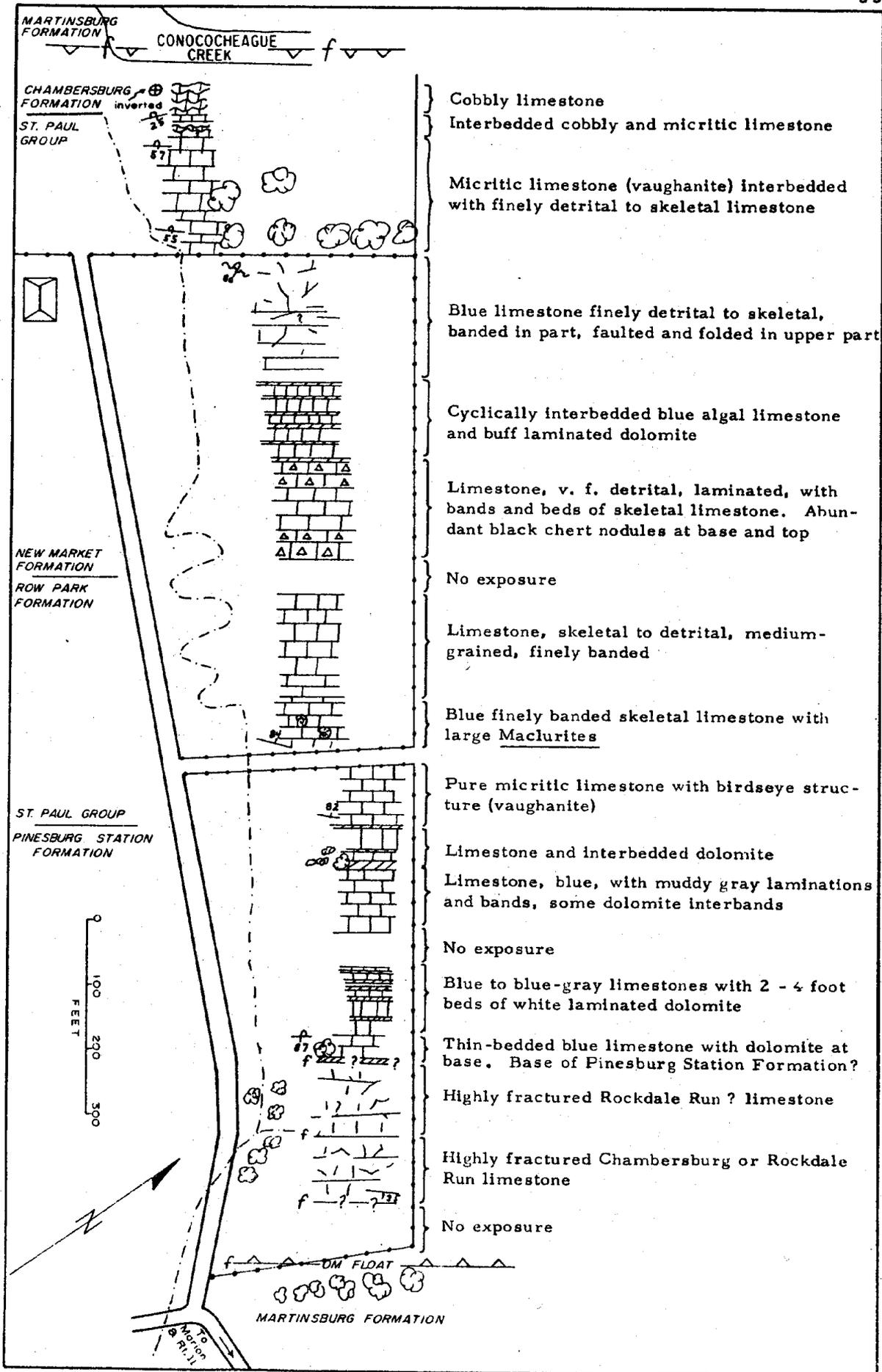


Figure 10. Sketch map of the geology at Stop 1

related to algal mats in a supratidal environment.

Micritic limestones of the St. Paul are interbedded with the cobbly limestones of the Chambersburg over an interval of at least 20 feet. The cobbly character of the Chambersburg is persistent over large distances in the Great Valley.

- 68.3 From Stop 1 retrace the route to the junction of U. S. 11 and turn right onto U. S. 11.
- 69.6 To here intermittent outcrop of Chambersburg.
- 70.0 St. Paul outcrop.
- 72.1 To here intermittent St. Paul outcrop.
- 72.3 Chambersburg outcrop in roadbank.
- 73.0 Martinsburg float in roadbank on right.
- 73.1 Cross Rt. 16.
- 73.3 Turn right onto gravel road and follow into quarry.
- 73.5 Stop 2 - Greencastle quarry.

This quarry contains the only exposed major fault in the area. In its beds of the middle part of the St. Paul are brought up over shales of the Martinsburg on the Carbaugh-Marsh Creek fault. About 1200 feet of limestone and an unknown amount of the Martinsburg shale are cut out by this reverse fault. The fault strikes  $N45^{\circ}E$  and dips  $60^{\circ}$  east, a slightly easterly deviation from the gross deformational plan, because the fault splays at Greencastle (Fig. 3.). The Carbaugh-Marsh Creek fault represents the last phase of deformation as it truncates earlier folds and faults.

Note the shattering of limestone above the fault and lack of flowage in the shales below the fault, all indications of brittle deformation. In the middle of the quarry floor regional cleavage can be seen to transect, at a considerable angle, some very fine grained graywacke interbeds of the Martinsburg.

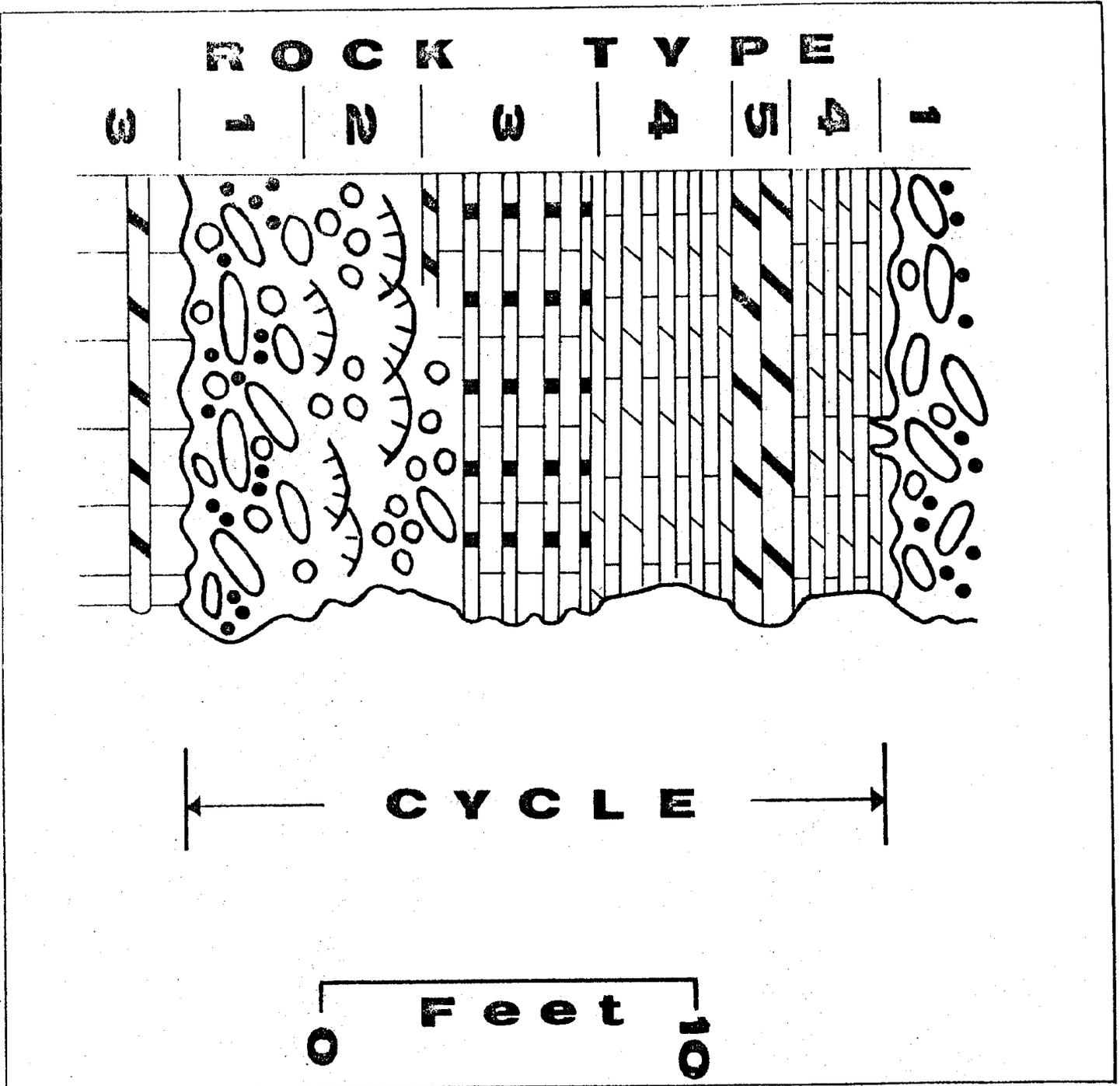
- 73.7 Return to U. S. 11 from quarry and turn left.

- 73.7 Turn right on Rt. 16 at intersection with U. S. 11.
- 73.8 Turn left on N. Jefferson St. in Greencastle.
- 74.1 Lunch Stop - Greencastle Park.
- 74.2 Proceed and turn right on N. Carlisle St.
- 74.3 Junction Rt. 16, turn left around monument and proceed east on Rt. 16. Note some of the antebellum-type mansions.
- 75.2 Cross Interstate 81.
- 75.4 Rockdale Run ledges in field on left.
- 75.7 Rockdale Run ledges in field on right.
- 76.1 Hill composed of Stonehenge limestone on left.
- 76.3 Cross fault here. Pure limestones of Shadygrove Formation exposed in roadbanks.
- 76.4 Re-enter Stonehenge outcrop area.
- 76.8 Pink stromatolitic limestones of basal Rockdale Run Formation in roadbank.
- 77.9 Zullinger Formation on right. Note increasing Blue Ridge elevation ahead and to south.
- 78.2 On left Zullinger Formation.
- 78.6 On left Zullinger Formation.
- 78.8 Cross Western Maryland Railroad.
- 78.9 Stop 3 - Waynecastle Dairy Section.  
Leave buses at feedmill.

This stop illustrates the lithology of the Zullinger Formation of the Conococheague Group as well as the degree of deformation in this region.

The Zullinger Formation is composed of a series of cyclically deposited carbonates (Fig. 11). The lithologic types are described in ascending order in their position within an ideal cycle, and assigned numbers.

FIGURE 11. TYPICAL WELL-DEVELOPED SEDIMENTARY CYCLE AND ROCK SEQUENCE IN THE ZULLINGER FORMATION, STOP 3.



Rock type 1, intraformational limestone conglomerate. In this rock type are included both edgewise and flatbedded conglomerates. This rock consists of pebbles of limestone, less frequently dolomite, discoidal in shape with rounded edges, usually  $\frac{1}{2}$  - 1 inch long and clearly derived from the underlying or adjacent beds. The clasts are set in a micrite matrix admixed with varied amounts of calcarenitic-oölitic components. This unit is frequently disconformable on the underlying unit.

Rock type 2, complex of calcarenitic, algal, oölitic limestones. The calcarenitic limestone grains may be of bioclastic or of inorganic origin. They seldom range above coarse-sand size and are set in a micrite matrix. The few coquinoïdal beds present are included here also.

The algal limestone is composed of stromatolites mostly of cryptozoon form, both cabbage head and sheet varieties.

Also included in this category are oölitic limestones. The oörites, which show both concentric and radial structure, are well sorted attaining a maximum size of 1-2 mm. Tectonic processes have deformed the oörites to some degree. They are set in a micrite cement.

The calcarenite, algal, and oölitic limestone are all intimately associated. Seldom is there a bed composed entirely of one lithologic type; there is usually an admixture or intercalation of the rock types within this category.

Rock type 3, interbanded limestone and dolomite. This rock type consists of limestone interbanded with dolomite. The limestone bands which comprise 60 - 70 percent of this rock type are usually  $\frac{1}{2}$  - 1 inch thick. Internally the bands may be finely laminated, structureless micritic, or, at times, finely clastic. The bands are wavy, imparting a ripple-marked aspect to some of the bands. The silty dolomite is in bands  $\frac{1}{4}$  inch thick and characteristically supports lichen growth. The contrast between the medium-gray limestone and the silty buff dolomite forms a distinctive banding. Occasionally there are intercalations up to 6 inches thick of rock types 1 and 2 within this sequence.

Rock type 4, Interlaminated limestone and dolomites. This rock type consists of limestone interlaminated with dolomite. The limestone and laminae which comprise usually about 60 percent of this rock type are 0.1 - 5 mm thick. The laminae are planar and parallel to bedding although gently undulose and cross-bedded laminae are also present. The limestone alternates with dolomite of similar thickness and fabric. The finely crystalline buff-colored dolomite is silty and weathers in relief relative to the medium-gray limestone laminae.

Rock type 5, dolomite. The thin dolomite beds weather characteristically to buff tones in contrast to most of the limestones which weather light to medium gray and are medium to light gray on fresh surfaces. The dolomite which is uniformly finely crystalline throughout and harder than adjacent limestones, is generally structureless with some internal laminations due to variations in crystal size.

Regional Analysis, Regionally a cyclic pattern has been observed elsewhere in surface exposures of the Conococheague Formation and its equivalents. In Central Pennsylvania near State College, Pelto (1942) and Krynine (1946) noted cyclicity of the dolomite beds comprising the Gatesburg Formation (Conococheague equivalent). The cycles, here because of their partly arenaceous nature, are probably the best developed and most distinctive in the state. At Snake Spring Valley, along the Pennsylvania Turnpike, Raymond Knowles (personal communication) has observed cycles similar to those recognized by Pelto. In the Lancaster area Stose (1930, p.33) remarked on the rhythmic occurrence of algal beds in the Conococheague and suggested seasonal growth as a control. The Richland and Millbach Formations of the Conococheague Group in Lebanon County are reported to be cyclical in character (Geyer, 1963). In easternmost Pennsylvania, in the Buckingham Valley area the Conococheague Formation according to Stose (in Bascom et al, 1931, p. 21) is marked by repetition of a tripartite limestone cycle. Thus, during the Upper Cambrian, carbonates accumulating in central and eastern Pennsylvania, a distance of at least 175 miles parallel to depositional strike, and 75 miles normal

to depositional strike were subjected to conditions leading to cyclical deposits.

Unfortunately the paucity of good exposures distance between outcrops, and lack of precise faunal markers for correlation cause difficulty in reconstructing the precise factors controlling the cyclicity of the Upper Cambrian carbonates. It appears that a single factor of regional extent controls this widespread repetition and the simplest mechanism is an oscillatory onlap-offlap relation. Whether this is due to rhythmic crustal movements or eustatic sea level change is unknown.

Rock types 1 and 2 undoubtedly were deposited in shallow water under conditions of high mechanical energy. Rock types 3, 4, and 5 could have been deposited either in progressively shallower water culminating in deposition of supratidal dolomites, or perhaps in deeper water in a restricted evaporitic environment that culminated in deposition of dolomites.

There are numerous places where part of a cycle develops or where the cycle develops but one or more of the rock types is absent. Because of the geologic factors controlling the rock sequence it is to be expected that development of the ideal cycle would be rare. Wave action which exerts much control upon the formation of the high mechanical-energy rock types 1 and 2 would be affected by any shift in strand line or by periods of variable storm intensity. Geochemical conditions, in large part, control the formation of low mechanical-energy-sediments rock types 3, 4, and 5. Changes in such factors as temperature, pressure, pH, ionic concentration etc. could affect the type and amount of carbonate being precipitated. Thus the dependence of the rock sequence in the cycle upon both mechanical energy and chemical conditions, partly independent factors, explains the paucity of perfectly complete cycles in the section.

Also note at this stop the internal deformation of the rock fabric. In many instances the most delicate laminations persist undeformed in this rock despite the presence of oölites that have been extended about 30 percent (Cloos, 1947).

Consider then the effects of shear vs. flexure folding here.

- 79.1 Turn around and proceed west on Rt. 16.
- 80.2 Turn right (north) in town of Shadygrove.
- 80.9 Conococheague limestone exposed on left. From here nearly to Rt. 316 abundant ledges of Zullinger limestones in the field and roadcuts. There are some good views across the valley along this portion of the trip.
- 86.4 Junction with Rt. 316. Turn left and proceed short distance to farm house and park.

Stop 4, Altenwald Railroad Cuts.

This stop in cuts of the Western Maryland Railroad, shows beds in the upper part of the Elbrook Formation. As at the previous stop, the beds are vertical, i.e. on the west facing limb of an anticline. However deformation here is more intense than at any stop in Franklin County, as passive flow is observed in the limestones and flexure slip is only present in some of the dolomites. In spite of the marked anisotropy here - interbedded limestones, silty dolomites, and limy siltstones, deformation has not been by interstratal slip but by slip across the beds. Both amplitude and wave length of the folds is on a much smaller scale than in carbonates to the west. There has been considerable passive flow of the limestone with thickening on fold crests and attenuation on limbs. Local flow of the limestone has been so intense that the form of the fold deviates considerably from ideal fold configuration in this area,  $S_1$  also deviates locally from the general  $S_1$  of this area -- phenomena which do not occur to the west.

Relatively competent beds such as dolomites and silty dolomites have, in places, maintained bed normal thickness within a fold. These beds frequently exhibit closely spaced fracture cleavage, the surfaces of which show development of "gouge" where there has been local movement along these surfaces.

This stop is in an area where Cloos (1947, pl. 9 and 12) has measured 50 percent elongation of oöids. Several large faults that the writer has mapped to the south probably pass close to this stop. Although deformation here is as intense as any observed in the Cumberland Valley limestones, it is not of the degree and complexity of deformation present in the Buffalo Springs Formation in the railroad cut at Cornwall (Stop 12).

- 86.6                    Continue northwest from farm house along Rt. 316.
- 87.6                    Cross contact of Elbrook and Conococheague limestones. Intermittent outcrop of Conococheague limestones to next turn.
- 90.5                    Turn left onto county road.
- 91.5                    Entrance to offices of Valley Quarries Co. Turn right and drive into quarry.

Stop 5, New Franklin Quarry.

This stop is in the Stonehenge Formation of the Beekmantown Group. As at several of the previous stops, the beds are subvertical which indicates that they are on the west facing limb of an anticline. Interstratal slip typical of flexure folding as well as the development of caves can be observed here.

Although the limestone lithology is fairly uniform, many of the bedding surfaces acted as surfaces of interstratal slip in the folding of these rocks. Bedding surfaces are pervasively slickensided and the general sense of slickenside movement on bedding and a single reverse fault (Fig. 12) indicates slip approximately in the ac direction. This is to be expected in a simple cylindrical flexure fold. However, a few of the slickensides indicate motion in a horizontal or subhorizontal sense demonstrating that more than simple folding of the sediments is involved. Subhorizontal transport probably reflects movement during translation of the block bounded by the Carbaugh-Marsh Creek fault. Many of the bedding slip planes have extensive calcite-slickensided surfaces with well developed steplike breaks. On the footwall the abrupt

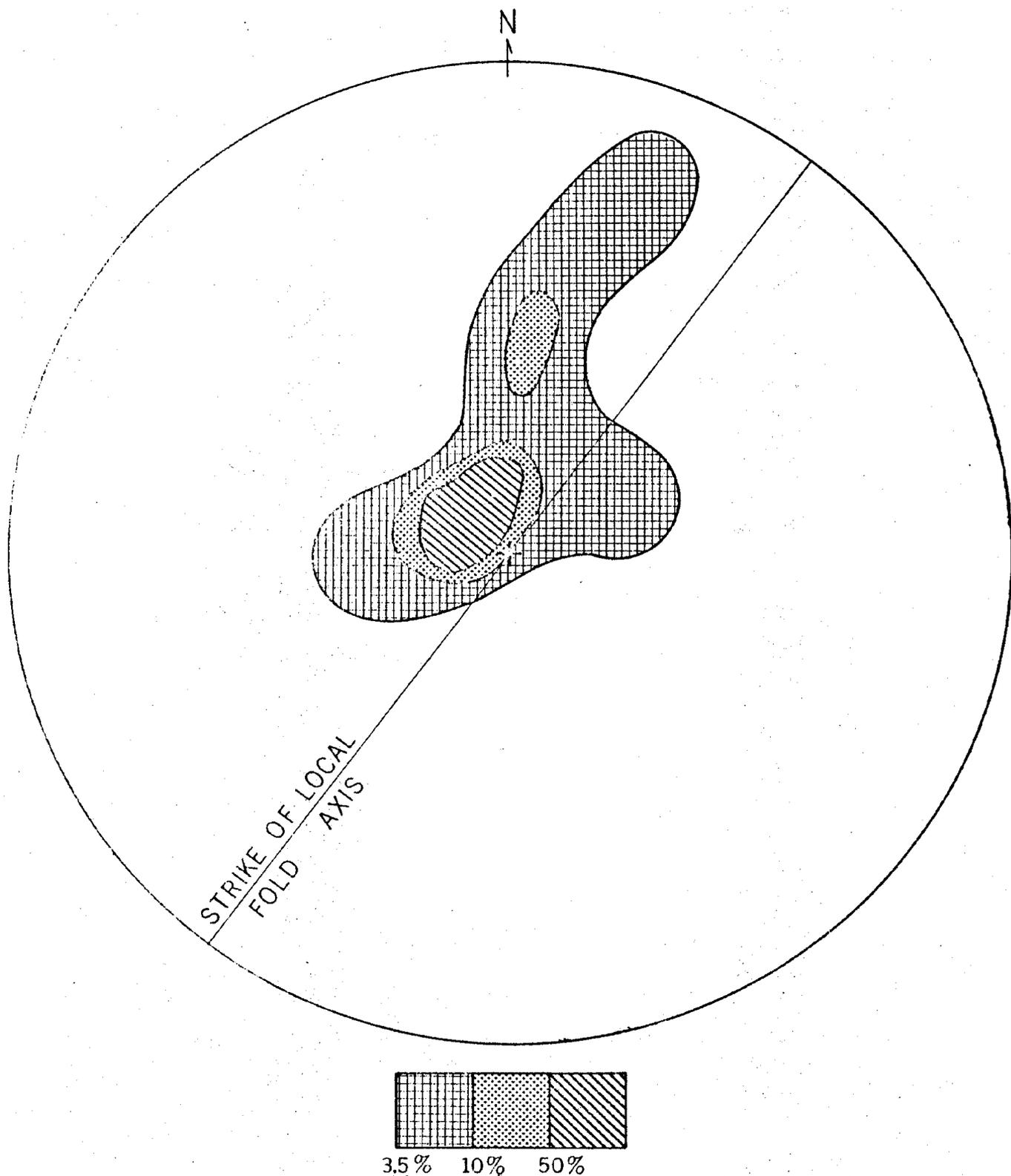


FIGURE 12. STERONEP PLOT OF SLICKENSIDES ON 12 BEDDING PLANES AND ONE REVERSE FAULT SURFACE, STOP 5. EQUAL AREA LOWER HEMISPHERE PROJECTION.

step usually faces down. Flexure-slip mechanics would indicate that the abrupt step faces the relative movement.

Several caves are exposed in cross section on the quarry face close to ground surface. Development of some of the caves appears to be controlled by the vertical bedding. Other, smaller, caves appear to be controlled in their development by cross fractures or joints.

- 91.6                Leave New Franklin Quarry, and turn left onto county road.
- 92.6                Turn left onto Rt. 316.
- 93.7                Turn right onto Interstate 81 north.
- 94.7                Cross U. S. 30.
- 96.9                Stonehenge Formation on left.
- 97.5                Note offset of South Mountain along Carbaugh-Marsh Creek fault.
- 101.6              Ridge to left probably the top of the Waynesboro Formation.
- 103.3              Cross Fayette St. exit.
- 103.6              Prominent hill on right probably Waynesboro Formation.
- 108.2              Observe end of cove in Tuscarora ridge to left.
- 116.2              Cross Rt. 233, Newville Exit.
- 116.7              Rest area on right.
- 123.9              Cross Plainfield exit.
- 131.5              Exit from Interstate 83 onto U. S. 11 to Harrisburg.
- 133.8              Cross Stony Ridge-a Triassic diabase dike.
- 134.6              To left ridges of Martinsburg faulted against Ordovician limestones that form the low valley.
- 136.0              St. Paul outcrop on left.
- 138.1              Intersection with Silver Springs Road where trip turned off to Mechanicsburg and Mt. Holly Springs in the morning.

The geology from here to Harrisburg is described at very first part of road log

Stay on Interstate 83 across South Bridge into Harrisburg.

- 146.0 Exit right, from Interstate 83 on 2nd Street and Rt. 322  
exit.
- 146.5 Left turn onto 2nd Street.
- 147.3 Right turn onto State Street.
- 147.4 Left turn onto 3rd Street.
- 147.5 Right turn onto North St.
- 147.6 Right turn onto Commonwealth Avenue.
- 147.7 End of trip at Zero Highway Marker in back of State Capitol  
Building.

ROAD LOG - 2nd DayMileage

- 0.0 Zero Milestone, Commonwealth Avenue, east of Capitol, head south on Commonwealth Avenue.
- 0.1 Stoplight, turn right on Walnut Street, take left lane 1 block.
- 0.15 Stoplight, turn left on 4th Street, continue past 2 lights to Mulberry Street bridge, follow bridge around to left.
- 0.5 Bear right on exit in middle of Mulberry Street bridge.
- 0.6 Stop, T intersection, turn right on Cameron Street.
- 1.1 Stoplight, turn left on Paxton Street. Cross Paxton thrust from shale to St. Paul limestone about 150 yards before light. St. Paul crops on right after turn.
- 2.3 Turn left on minor road just beyond Blake Cadillac-Olds, St. Paul exposure, locally steeply overturned, about 100 yd. east on north side of main road.
- 2.5 Stop 6, Hempt Brother #2 (Paxtang) Quarry.  
Park to left of quarry office.

This quarry is developed in the St. Paul Group within about 5 miles of the eastern limit of exposures of the Cumberland Valley sequence. While there are obvious differences between these rocks and the St. Paul section examined in Franklin County (Stop 1), the two are continuous along strike, and the north eastward increase of dolomite and decrease of high calcium limestone is a gradual and reasonable facies change. Tectono-stratigraphically the trend of facies change is significant because it is exactly opposite of that which would be required if it were to represent a gradation toward the exclusively high calcium limestone of the approximately contemporaneous Annville limestone of the Lebanon Valley sequence. The very substantial thickness and facies difference between those rocks and the Annville limestone,

which crops within a half mile of the easternmost St. Paul Group exposure, is an excellent example of the stratigraphic relationships which suggest substantial displacement of the allochthon normal to the strike of the depositional basin.

The syncline dominating the structure of this quarry is considered to be fairly representative of the tectonic style in the northeastern end of the Cumberland Valley and essentially similar to the style in Franklin County. The asymmetry of the structure is readily apparent though no overturning is visible in the quarry. However, exposures of the south limb of the syncline along the highway just to the south shows local overturning to about  $75^{\circ}$ . The change of form of this fold in about 200 yards across the quarry is quite conspicuous, and this axis has not been recognized a mile and a half westward at the Susquehanna River. The fold is thus relatively unpersistent. The overall structure of the easternmost exposed projection of the Cumberland Valley carbonate lithology and tectonic style into western Dauphin County is essentially a south dipping homocline. As such it is conceived to be the gentle limb of a major structure for which the fold exposed in the quarry is a satisfactory model.

Minor low angle thrusting may be observed high on the east wall of the quarry. It has not been established if this is simply the result of spatial adjustment within the core of the syncline or whether this is result of drag by the Yellow Breeches thrust which probably passed less than 200' above the top of the present exposure in this area.

- 2.6            Return to Paxton Street, turn right.
- 3.6            Stoplight (3rd), turn right on 13th Street.
- 3.8            Stoplight, turn left on Berryhill Street.
- 4.0            Stop 7, Harrisburg Cold Storage Warehouse.  
Turn left into parking lot east of plant.

The exposure on the east side of building shows Martinsburg shale at the north end and strongly cleaved shaly limestone of the Hershey Formation at the south end.

The Martinsburg here is essentially phyllitic and conspicuously different from that shown at Stop 2 in Franklin County. As at Stop 2, local effects from the shown faults in the immediate area are a factor contributing to the highly deformed character of this exposure; but the phyllitic aspect with bedding obscure to obliterated is extensively developed in the shale belt of Dauphin County. All or most of these phyllites with diverse associated lithologies exotic to normal Martinsburg terranes are believed to be allochthonous. Their emplacement is probably related to that of the allochthonous carbonates of the Lebanon Valley sequence.

The Hershey Formation is known only in the Lebanon Valley sequence in structurally simple situations. The exposure here is isolated from the main Lebanon Valley allochthone but its presence here is thought to be genetically related to the occurrence at Stop 8 where a thin slice appears in the main thrust zone. The appearance of Hershey here strongly supports the probability that shales of the Yellow Breeches plate are found north of the Cumberland Valley carbonates in this area.

Proceeding south along the railway spur fragments of pure carbonate probably derived from a Beekmantown Group terrane may be observed in matrix similar to the normal Hershey lithology. The characteristics and distribution of such conglomerate strongly suggests active surficial faulting during Hershey (lowest Trenton) time at the depositional locus of the Lebanon Valley sequence.

The Paxtang thrust, a steep thrust which is probably continuous with the Reading Banks thrust of Cumberland County, lies just south of the Hershey exposure under the mainline of the railway. This thrust brings normal Cumberland Valley sequence carbonates into contact with the Hershey Formation and elsewhere with the Martinsburg Formation. This fault is essentially comparable to the one at Stop 2. It is obvious from differences in deformation that a fault must also be present in the covered interval between the Hershey and Martinsburg exposures. It is structurally plausible that this might be a splay of the Paxtang thrust but an exposure on the

west side of the river indicates that this fault is probably substantially vertical. These relationships are sketched in fig. 13.

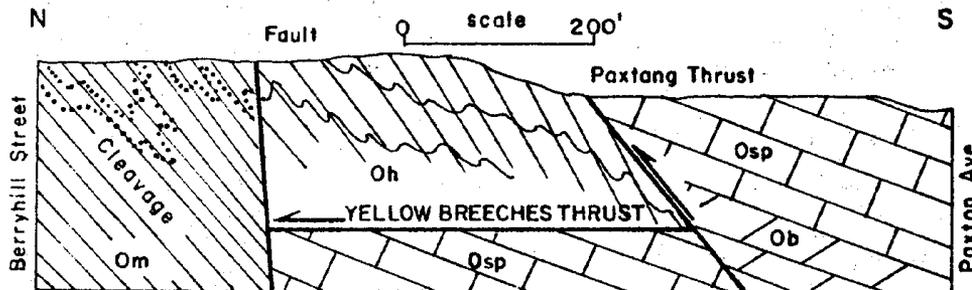


FIGURE 13.

- 4.0 Continue west on Berryhill Street about 200' to Cameron Street, STOP, turn left.
- 4.2 Cross trace of Paxtang thrust driving south on recent Susquehanna flood plane. Bluffs nearby to left drop somewhat passing from the shale "Harrisburg peneplane" to the limestone "Somerville peneplane." Use middle lane approaching stoplight ahead. Continue on Cameron Street.
- 4.3-4.9 Abandoned fluxstone quarries on bluff on left in St. Paul. Observe general south dip except locally at south end.
- 5.5 Bank on left begins exposure of "Martinsburg" soil overlying limestone which continues to Stop 8.
- 5.7 Stop 8, Cameron Street, South Harrisburg.  
Park south of Rozman Brother's Store on left.

The traverse just completed from Stop 7 represents the maximum width of the Cumberland Valley sequence carbonates in Dauphin County.

The critical exposure here is at the northeast corner of the Rozman Brother's Building at 1711 South Cameron Street (east side), as shown in Fig. 14.

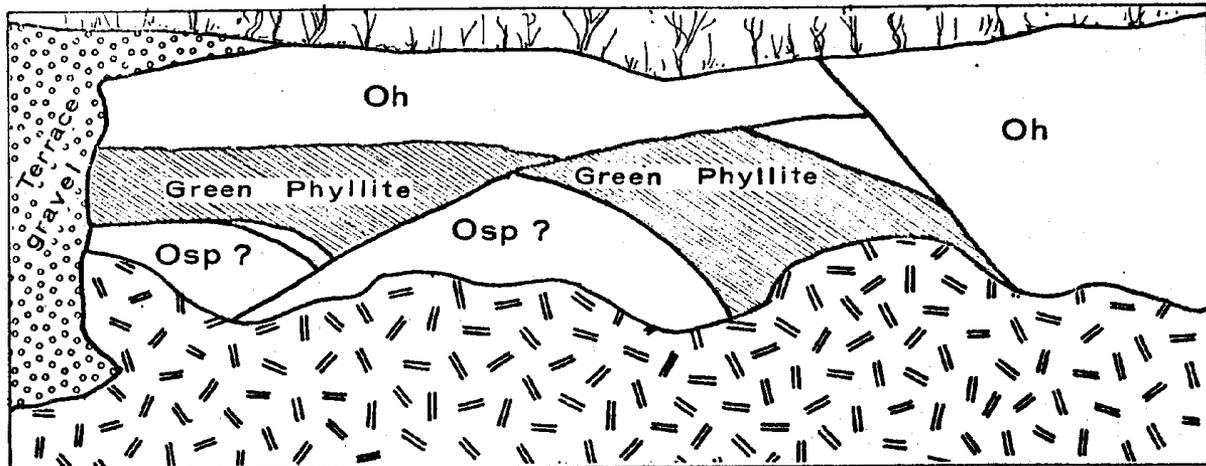


Figure 14.

The base of this exposure is gray limestone which seems certainly to be of Cumberland Valley affinities and has been questionably referred to the St. Paul Group.

This rock is, however, in a thrust slice in the sole of the Yellow Breeches plate, and has been dragged some uncertain distance, making it difficult to determine its exact stratigraphic relation to the less disturbed rocks.

The overlying green phyllite is a local phenomenon which is thought to be cataclastic and represents the locus of principal movement in the Yellow Breeches thrust zone.

The highly deformed Hershey Formation at the top of the exposure is also in an isolated slice whose structural relationship to the fairly orderly regionally inverted sequence of the allochthon is uncertain, but it has clear lithic affinity to the Lebanon Valley rocks. The Hershey slice is of no great thickness as a "Martinsburg" Formation soil extends to the top of the bank, and "Martinsburg" exposure may be found not far above to the east. The maximum thickness is probably about 200' as determined from well sample chips about 1 mile to the east. Neither the St. Paul slice nor the

Hershey slice are present in the fault zone more than about three miles east, and allochthonous "Martinsburg" directly overlies normal Cumberland Valley St. Paul at the eastern limit of the latter.

While the fault zone seems to have a distinct southerly dip at this exposure the fault can be seen to be approximately horizontal on a slightly larger scale by examination of the bank to the north and south. Though considerably broken by later minor faulting, scattered exposures of the thrust may be found at approximately the same elevation over more than 100 yards.

Return north on Cameron Street.

- 6.4 Beginning of quarries on right noted at mile 4.3.
- 6.7 Stoplight, turn right on Sycamore Street and ascend bluff, some crop on left.
- 6.8 Stoplight, turn left on 13th Street.
- 6.9 Turn right onto Interstate 33 north.
- 7.5 Beekmantown dolomite assigned to Pinesburg Station Formation exposed on left.
- 8.0 Brief view of Hempt Quarry (Stop 6) on right.
- 9.0 Good outcrop of pure limestone beds of St. Paul on both sides of road, exposures are remnants of old fluxstone quarries. At this point the scarp of the allochthonous "Martinsburg" to the south lies only about 500 feet from the highway, but in the next  $1\frac{1}{2}$  miles it swings about  $\frac{3}{4}$  mile south and then returns to the highway. This embayment in the thrust front clearly illustrates the essential flatness of the Yellow Breeches thrust.
- 9.7 Stoplight, continue east, get in right lane.
- 9.85 Stoplight, cross Eisenhower Blvd., continue east on U.S. 322, leave Interstate 83. Trace of Yellow Breeches thrust passes

- behind modern church visible well up slope to right.
- 10.1 Railway spur grade crossing.
- 10.5 The "Martinsburg" Formation swings up abruptly from the south almost to the road to form the west end of Chambers Hill. This prominent ridge, the northern scarp of which is well defined for the next  $3\frac{1}{2}$  miles eastward to the end of the Cumberland Valley sequence exposure, owes its unusual relief to vitreous quartzite locally developed in the "Martinsburg" Formation.
- 10.9 Cross minor tear fault which brings "Martinsburg" across the road for about 0.1 mile. View to north from crest of rise gives good impression of "Harrisburg peneplane" standing above the limestone valley which is here reduced to  $\frac{1}{2}$  mile width.
- 12.0 Blunt salient of Yellow Breeches thrust crosses road on crest of rise. Cross "Martinsburg" Formation for about 0.2 mile. A small shale outlier is found along the railway to the north.
- 12.2 Recross Yellow Breeches thrust. Small crop on right. Thrust continues approximately at base of escarpment to right beyond the cut.
- 12.8 Poor exposure of Yellow Breeches thrust above sheared St. Paul behind Osterlund Truck shop on right.
- 12.9 "Martinsburg" cut behind Texaco station on right. Yellow Breeches thrust swings just north of road for about 0.2 mile.
- 13.1 Recross Yellow Breeches thrust small St. Paul crop on right. Observe considerable rise in road ahead and box-like end to the valley.
- 13.7 Cross Breeches thrust, eastern limit of exposure of Cumberland Valley sequence carbonates. For the next mile east over the hill U.S. 322 crosses a relatively narrow neck of "Martinsburg" which

connects the main shale mass of the northern part of the Great Valley to the Steelton belt which includes Chambers Hill. Carbonates to the east of the shale are of the Lebanon Valley sequence.

- 13.75 Turn hard right onto Chambers Hill road, just before crest of hill.
- 14.0 Turn left on South 80th Street crossing "Martinsburg" of Yellow Breeches plate.
- 15.0 Dangerous curve to left, watch for stone trucks.
- 15.2 Stop 9, Fiddler's Elbow--Ebersole Quarry. Park in quarry yard.

On both sides of the covered bridge at Fiddler's Elbow about 2 miles southwest of Hummelstown on the right bank of Swatara Creek and in the quarry of George Ebersole & Sons there is a fairly complete though structurally complicated section of the Lebanon Valley sequence from the "Martinsburg" Formation on the west to the upper Beekmantown on the east. Dips range from about 14 to 32° SE and the entire carbonate sequence is overturned. It is probable that the "Martinsburg" Formation is also overturned as suggested by the superposition but internal evidence is ambiguous.

Starting to the west where the power line crosses the creek, the partly calcareous dark shales and silts of the "Martinsburg" Formation contiguous to the carbonates were assigned to the Hershey Formation by Prouty (1959) and included in his Hershey type section. This lithology, however, does not belong to the mappable Hershey Formation of the eastern Lebanon Valley, but is clearly related to exotic elements of the Dauphin County "Martinsburg" terrane which Platt (ms.) believes are clearly considerably older than type Martinsburg Formation. He proposes that these elements were redeposited by sliding into the flysch basin during Trenton time.

Cobble sized limestone fragments in a shaly matrix poorly exposed on the east side of North Union Street just below the Myerstown Formation may represent a true Hershey element. On the other hand the nearest Hershey conglomerate exposure along strike is over 25 miles away and the trend of westward thinning of mappable Hershey

is such that it is expectably absent here stratigraphically. A comparable exposure of supposed Hershey conglomerate at Steelton was shown by excavation to be a tectonic breccia of the Myerstown Formation caught in the "Martinsburg" by thrusting. It seems probable that the same situation applies here as differences in attitude between the Martinsburg and Myerstown strongly suggest thrusting at the base (stratigraphic top) of the Myerstown as is the case for all other formational contacts in this section.

The 56 feet of Myerstown Formation now rather poorly exposed south of the secondary crusher is the type section (Prouty, 1959) though it has been subsequently found to be incomplete owing to thrusting at the base and probable thrusting at the top. The thrust between the Myerstown Formation and the overlying (older) Annville limestone is well exposed south of the primary crusher. The succeeding 78 feet of Annville limestone is also less than a full stratigraphic thickness, and a thrust contact with the Ontelaunee Dolomite is exposed in the quarry. Cave development on and near this last thrust is exposed in the west wall of the quarry and is apparently related to water circulation along the thrust zone.

The most conspicuous structural feature here indicating a substantially different mode of deformation from that in the Cumberland Valley sequence is the general overturning and the numerous flat thrusts. Closer examination will show signs of distributed shear and cleavage approximately parallel to the bedding. This stop is fairly representative of the entire Lebanon Valley where upright carbonate beds are very exceptional.

Back to U.S. 322.

- 16.5 Stop, turn right on Chamber Hill Road.
- 16.7 Stop, rejoin U. S. 322 at mile 13.75.
- 16.9 "Martinsburg" shale crops on left at crest of hill. General view ahead, while descending hill, of the Lebanon Valley sequence

carbonate topography and the Triassic hills forming the southern margin of the Lebanon Valley.

- 17.7 Cross Swatara Creek. Thrust contact between Myerstown limestone and "Martinsburg" in or near west edge of creek, concealed. Thrust contact between Myerstown and Annville Formations exposed under east bridge abutments. Prominent cliff to right is Annville limestone Ontelaunee Dolomite thrust over Annville just above exposure. Thrusts here are apparently continuous with those at Stop 9.
- 17.8-18.0 Sporadic Ontelaunee exposure in road cut, cross into Epler Formation at about 18.0
- 18.3 Branch line railway grade crossing. Small sink hole to right opens downward.
- 18.5 Epler Formation crop on left.
- 18.9 Turn left on road to Middletown just before high school.
- 19.0 Strongly sheared Epler Formation crops on both sides of road. Turn right toward Indian Echo Cave (sign) 200 feet beyond.
- 19.4 Branch line railway grade crossing, railroad cut in Epler Formation visible to left.
- 19.5 Stop 10, Indian Echo Cave.  
Park at picnic area.

The cave and surrounding area are private property. Please respect owners rights and leave hammers and collecting equipment on buses. Damaging cave formations is unlawful. Samples of flowstone may be purchased at the cave office for thirty cents. Lunch will be served here either before or after geologic inspection depending on success in meeting the schedule. Shelter and restrooms available.

Owing to the relatively small size of some exposures to be examined passengers of each bus will please remain as a group which will be conducted to each point of

interest in rotation. All groups will proceed down the path and steps to the cave entrance. Points both up and down stream from the cave as well as the cave itself will be examined.

The rocks in this area are interbedded limestones and dolomites, in the upper part of the Epler Formation. Though there are naturally variations in detail, the lithology here is fairly representative of much of the thick Middle Cambrian to Lower Ordovician Carbonate Section of the Lebanon Valley. The greater part of the remainder is substantially more dolomitic like the Ontelaunee Formation at Stop 9. Purer limestones are somewhat less abundant. As the available time does not permit a complete stratigraphic synopsis, it is intended that this stop should give a sense of the "typical" carbonates of the Lebanon Valley sequence. The most conspicuous difference between these rocks and the rocks of the Cumberland Valley sequence previously examined is, perhaps, that recrystallization and internal flow have largely obliterated the primary textures and structures which could be observed in Franklin County.

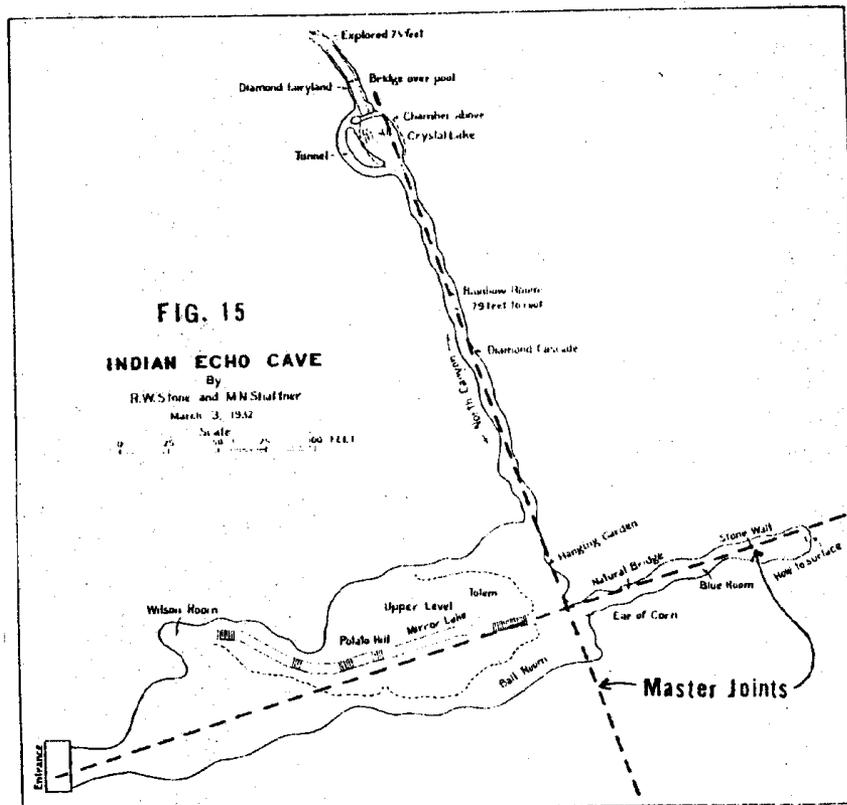
The tectonic style here is conspicuously different from that previously seen in the Cumberland Valley sequence. Attention here will be directed to minor thrusting parallel to the main bedding and the development of boudinage. Cumberland Valley sequence rocks examined which are most nearly correlative to this exposure are the Stonehenge limestone of Stop 5, but it will be readily apparent that deformation here is even more severe than in the much older rocks of Stop 4.

Boudins ranging from incipient to fully isolated are best observed in cross section in the cliff above Swatara Creek about 250 feet south of the cave entrance. Numerous other examples may also be observed throughout the area. Attention is particularly directed to above the cave entrance and the three dimensional exposure under the lowest flight of steps.

A minor thrust parallel to the underlying beds, but truncating some above, is

exposed about 125 feet north of the cave entrance.

About 100 yards north of the thrust Wildcat cave, a small opening, is approached by a narrow path. Limitations of access make this cave unsuitable for use by large groups, but the relation between fracturing and cavern development is well displayed.



The main cave particularly well illustrates the preeminence of fracturing in controlling solution effects. The two branches of the cave are developed along orthogonal master joints having no apparent displacement which are parallel to most of the joints in the area. The lesser features of the cave are also seen to be primarily controlled by jointing with bedding having only minor influence. To the extent that bedding does influence solution we find that this is still largely a fracture effect. The nominally less soluble dolomite beds are often more eroded than the limestones because the much more intense fracturing in this more brittle rock has left it more subject to attack. This effect is illustrated by the recessed

dolomite bed at floor level with a projecting limestone bed above found about 150 feet from the entrance on the route into the cave. Preferential development of smaller solution openings in dolomite beds because of their commonly fractured character is a common feature in the Lebanon Valley.

- 19.5 Continue around loop and retrace to U. S. 322.
- 19.7 Railway grade crossing.
- 20.0 Stop, T intersection, turn right.
- 20.2 Stop, turn right on U. S. 322.
- 20.3 Epler Formation outcrop on left, much disturbed by proximity to minor thrust.
- 21.4 Continue straight on U. S. 422 (slow down), U. S. 322 bears to right.
- 21.7 Turn right on Pa. 39 west.
- 22.0 Epler Formation crop on left, abandoned Epler quarry ahead on right. Boudinage of dolomite beds.
- 22.25 Cross Epler-Ontelaunee contact just before railway bridge.
- 22.3 Turn right just beyond bridge, Ontelaunee exposure on right in turn. Proceed east on W. Chocolate Avenue. Road runs approximately along strike of nearly vertical Ontelaunee Dolomite with the pure Annville limestone underlying a gentle shale to the north. The ridge which lies about 1,000 feet to the north is formed by "Martinsburg" shale. This shale occupies the core of an antiformal syncline in inverted strata, and is isolated from the main shale area.
- 23.5 Stop 11, Swatara Quarries.
- Buses park on right shoulder of road short of trailer park.
- Passengers cross road (with due care) to quarry overlook.

This is the western quarry of two abandoned Annville limestone quarries which form the Swatara district. Water depth in both pits is in excess of 100 feet and

they are currently used as reservoirs by the Hershey Chocolate Co. Numerous features of interest are found in the district but they are not conveniently accessible to large groups. The stop here is made expressly for pointing out the particularly prominent cross folding.

Cross folding plunging in the direction of tectonic transport is a common feature of the western Lebanon Valley. It is often difficult to recognize on the scale shown here, however, when it must be deduced from scattered smaller exposures. The cross folding is apparently syngenetic with the main transport phase of deformation and is the result of restricted tectonic transport. A well known phenomenon of theoretically related genesis is the development of complex folds with vertical axes in salt domes during emplacement. Cross folding of the type shown here is apparently not an unusual feature of large far-travelled thrust blocks. They have been most extensively studied in the Caledonides of Scotland and Norway. The students of Caledonian petrofabrics generally concur that this type of deformation is a positive indication of very substantial horizontal displacement of the affected rocks. The Caledonian occurrences described are all from rocks for which tens or even hundreds of kilometers displacement are inferred.

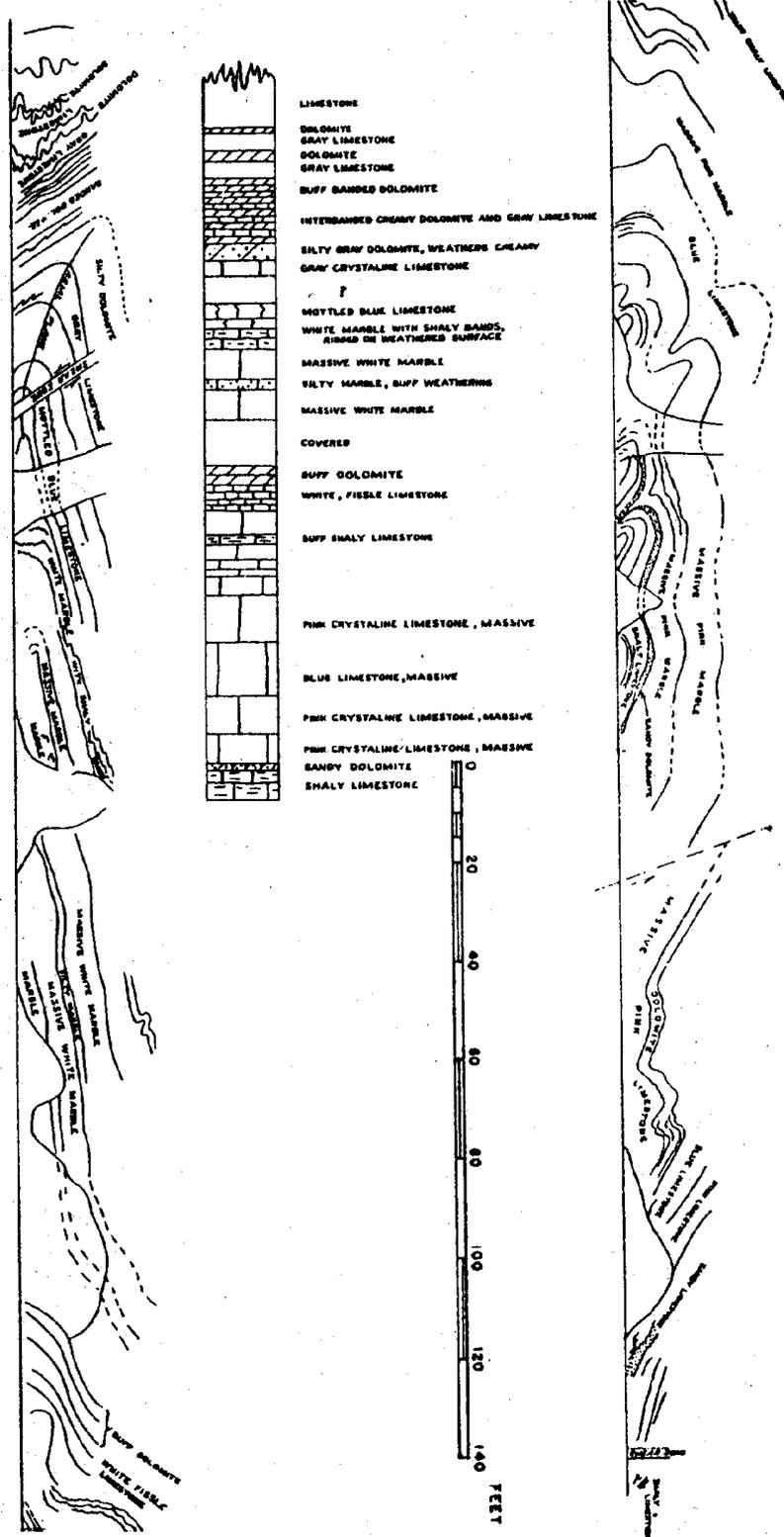
At the overlook you are standing on the upper pure dolomite member of the Ontelaunee Formation. Occasional beds of high calcium limestone, which are inseparable from the Annville limestone by appearance or insoluble residue, are interbedded with this member in this area. This is one of the bases for believing that the upper Ontelaunee is gradational to the middle (?) Chazyan Annville limestone and is probably of lower Chazyan age. The dolomite of the hanging wall extends down approximately to the water line. The underlying Annville limestone is here about 180 feet thick and has been entirely stripped from the Myerstown limestone footwall to reveal the crossfolded surface seen across the quarry.

- 24.0 Stop, T intersection, turn right on U. S. 422, proceed 1 block.
- 24.1 Turn left on Mill Street, Epler Formation crop (abandoned dimension stone quarry) behind gas station on left at corner. More crop on left in cut on Mill Street. Ontelaunee contact lies just north of U. S. 422.
- 24.4 Bear right at fork.
- 24.5 Stop, T intersection, turn left on Hockersville Road.
- 24.8 Stop, Turn left on Governor Road, U. S. 322.
- 25.4 Passing residences of Milton Hershey School, building at distance to left is Hershey Chocolate Plant.
- 25.8 Cross Epler-Stonehenge contact, exposure is almost always poor in this area.
- 27.0 Entering Lebanon County. The south Lebanon thrust, the largest flat thrust within the allochthon crosses the highway just to the east. This thrust is continuous about 30 miles along the valley, and probably extends eastward with offsets. The maximum stratigraphic cut out, however, is from this vicinity westward to its truncation by the Triassic border. In this interval the entire Upper Cambrian and probably parts of adjacent units are missing. From this point for 2.1 miles eastward detailed mapping is incomplete. Travel mostly on Buffalo Springs Formation.
- 29.1 Cross N-S fault onto Snitz Creek Formation.
- 30.2 Cross from Snitz Creek to Buffalo Springs Formation.
- 30.4 Re-enter Snitz Creek Formation. The Buffalo springs tongue just crossed probably represents the axis of a large cross fold.
- 31.1 Snitz Creek Formation crop on left.
- 32.0 Contact Snitz Creek-Schaefferstown Formation.

- 32.4 Enter Lebanon Quadrangle (Pa. Geol Survey Atlas 167C) cross Schaefferstown-Millbach contact.
- 33.2 Exposure of Millbach Formation on left near junction of Pa. 934.
- 33.4 Cross Millbach-Schaefferstown contact, good ledges in field ahead to left give fairly complete exposure from upper Schaefferstown to lower Richland.
- 34.5 Cross Schaefferstown-Snitz Creek contact, low ridge ahead is supported by sandy dolomites of Snitz Creek Formation.
- 34.8 Cross Snitz Creek-Buffalo Springs contact, fair exposure of units in this area.
- 35.3 Turn left on Pa. 419. Snitz Creek Formation crops on 322 just beyond turn, where it is brought up through the Buffalo Springs on a minor thrust.
- 36.0 Stop, cross Pa. 72.
- 36.7 Enter Cornwall.
- 36.9 Bear left at fork on Pa. 419.
- 37.3 Stop, turn left on Cornwall Pike (sign to Lebanon).
- 37.8 Buffalo Springs crop on left.
- 37.9 Turn right on Culvert Street.
- 38.2 Caution, narrow underpass with blind approaches, stop on far side.
- 38.25 Stop 12, Cornwall Railway.

Easiest ascent to the railway level without hazard of fouling electric lines is up the south abutment on the west side (opposite to parking) of the underpass. The underpass is located approximately on the Snitz Creek-Buffalo Springs contact. The cut in the Buffalo Springs Formation lies several hundred yards to the south. On route to the exposure numerous iron ore pellets produced at the Cornwall Mine concentrator may be found scattered in the track ballast. These pellets have

FIGURE 16.



occasionally been mistaken for meteorites when found individually by layman.

The Buffalo Springs Formation exposed here is now thought to be of Middle Cambrian age and correlative to the Elbrook Formation of the Cumberland Valley sequence.

This conclusion is based on study of comparative lithostratigraphy. Evidence for faunal confirmation of this conclusion has not been discovered in these highly deformed rocks. The general similarity between these rocks and those at Stop 4 is readily apparent. The principal difference is that shale beds which are common in the Elbrook Formation are only rarely observed in the Buffalo Springs Formation.

The mode of deformation, however, is radically different from that at Stop 4. This stop is basically intended to bring out this contrast in the deformation of correlative units in the allochthone and autochthone where the deformation in each approaches its maximum. The major structures of the east side of the cut are shown in Fig. 16. Starting at the north end we can see that we are in the digitated nose of recumbent antiformal structure which is probably in fact synclinal as the whole unit is generally inverted. Axial planes of minor folds and cleavage are here essentially horizontal. Passing southward into the structure the cleavage becomes warped to progressively steeper dips. It is obvious that bedding was essentially passive in this deformation in marked contrast to even the most severe deformation observed in the Cumberland Valley.

- 38.25                    Continue east on Culvert Road.
- 38.6                    T intersection, turn right on Whitman Road.
- 38.8                    T intersection, turn right on S. Lincoln Avenue.
- 39.0                    Ore pelletizing plant built in 1960 visible ahead on left.
- 39.2                    Stop, T intersection, turn right on Schaeffer Road.
- 40.0                    Railway grade crossing.
- 40.3                    Stop, T intersection, turn right on Pa. 419, railway grade

- crossing 50 feet beyond corner.
- 40.4 Intersection, rejoins outbound route at mile 37.3. Retrace to Campbell town via Pa. 419 and U. S. 322.
- 41.7 Stop, cross Pa. 72.
- 42.3 Stop, T intersection, turn right on U. S. 322.
- 50.0 Turn right on Palmyra Street in Campbelltown.
- 50.3 Bear left at fork onto Lingle Avenue. Cross south Lebanon thrust at about this point. A small thickness of Snitz Creek just south of the thrust represents the approximate western limit of exposed Upper Cambrian rocks in the Lebanon Valley. The thrust here overrides Lower Ordovician Stonehenge Formation.
- 50.9 Cross Stonehenge-Epler contact.
- 51.7 Epler Formation crops on left.
- 51.9 Stoplight, cross U. S. 422.
- 52.7 Cross Epler-Ontelaunee contact.
- 53.0 Stop 13, Palmyra Quarries, H. E. Millard.
- Buses park in large gravel area to right.

This is the type section of the Annville Formation (Prouty, 1959) and the quarries are representative of development in the main quarry district. High calcium lime for a variety of industrial uses is actively produced from the newer east quarry opened after roof falls forced abandonment of underground mining in the west quarry. Stone is trucked through a tunnel under the road and hoisted by belt from the underground workings after primary crushing. Though water flow in these quarries is not excessive, flows approaching 40,000 gpm forced abandonment of a quarry a half mile to the west.

A complete normal stratigraphic succession is apparently present here though there is evidence of considerable slippage on both contacts of the Annville limestone.

The full complement of 4 metabentonite beds may be found in the Myerstown Formation in the road cut north of the Quarries.

The bedding here dips approximately  $40^{\circ}$  SSE overturned which is about average for the main quarry belt. The large expanses of fairly uniformly dipping overturned strata shown here is characteristic of the Lebanon Valley and obviously quite different from the structures observed in the Cumberland Valley. A comparison is facilitated by recalling the structure at Stops 1 and 6 which expose strata correlative to the Annville. The great difference in facies aspect as compared with the lithology at Stops 1 and 6 is readily apparent as may be verified by comparing the following section with the column in Fig. 10. It should be noted that the lateral change of the St. Paul Group northeastward in the Cumberland Valley is such that the contrast in thickness and lithology between the Annville limestone and the closest St. Paul exposures is even more extreme.

Section Description

Thickness

Unit	Cumulative
ft. in.	ft. in.

Meyerstown Formation (not measured):

1. Limestone, very dark gray, fine-grained, slicken-sided carbonaceous partings, forms footwall of quarry. Thin greenish-gray shale (metabentonite?) beds, found along road to northwest about 100 to 150 feet.

Annville Formation (180.5 feet):

- |   |      |       |
|---|------|-------|
| 2. Limestone, medium-dark-gray, shaly, thinly laminated.  | 5.0  | 180.5 |
| 3. Limestone, medium-to medium-dark-gray, fine to nearly dense, weathers very light gray, granular. | 64.0 | 175.5 |
| 4. Limestone, very dark gray, carbonaceous, somewhat shaly.   | 1.2  | 111.5 |
| 5. Limestone, medium-to medium-dark-gray, calcilutite, weathers light gray, granular.               | 62.0 | 110.3 |

6.	Limestone, dark-gray, dense; partly covered.	11.0	48.3
7.	Limestone, medium-gray, quite pure, weathers very light gray, granular.	5.0	37.3
8.	Limestone, medium-dark-gray, calcilutite.	1.0	32.3
9.	Limestone, medium-light-gray, weathers light gray, granular.	4.0	31.3
10.	Limestone, medium-dark-gray, calcilutite.	7.0	27.3
11.	Limestone, medium-light-gray, very light-gray weathering.	6.0	20.3
12.	Limestone, nearly white, marbleoid, a few medium-gray laminae, weathers flour-like.	1.8	14.3
13.	Limestone, medium-dark-gray, fine-grained, 4" shaly bed near middle.	2.5	12.5
14.	Limestone, medium-light-gray, fine-grained thin-bedded. weathers somewhat shaly.	10.0	10

Beekmantown Group--Ontelaunee Formation (801 feet) Partial Section

15.	Dolomite, medium-dark-gray (N4) to dark gray, very finely megacrystalline, parting into 1-to 2-foot layers; black, soft, carbonaceous shale between massive dolomite beds in lower portion; numerous stylolitic partings.	27	
16.	Dolomite, partly concealed, medium-dark-gray, very finely megacrystalline, laminated, deeply weathered light gray; stylolitic partings; black, carbonaceous shale layers.	16	
53.0	Continue north on Lingle Avenue.		
53.2	Stop, bear left at intersection.		
53.5	Stop, bear left on Pa. 743.		
54.4	Turn right on Air Park Road, continue on Pa. 743.		
55.3	Straight on Air Park Road, leave Pa. 743.		
56.9	Continue straight, join Pa. 39.		
58.4	End Pa. 39, bear right on U. S. 322 west.		
60.6	Railway grade crossing.		
65.9	Railway grade crossing.		

- 66.2 Stoplight, continue straight, join Interstate 83, use center lane approaching light.
- 69.1 Turn right at exit 24, take 13th Street north.
- 70.0 Stoplight, turn left on Market St., 4th stoplight on 13th St.
- 70.5 Stoplight, turn right on 5th St., just beyond railway underpass, use right lane.
- 70.6 Turn left from right lane onto Walnut Street (5th St. traffic has right of way).
- 70.6+ Stoplight, turn right on Commonwealth Avenue.
- 70.8 Arrive at 0 mile stone, end of second day completes field conference, Glück Auf!

## REFERENCES CITED

- Bascom, F., Wherry, E. T., Stose, G. W., and Jonas, A. I. (1931), Geology and Mineral Resources of the Quakertown-Doylestown District, Pennsylvania and New Jersey, U. S. Geol. Survey Bull. 828.
- Cloos, E. (1941), Geologic Map of Washington County, Maryland, Md. Geol. Survey, E. Cloos compiler.
- \_\_\_\_\_ (1947), Oolite Deformation in the South Mountain Fold, Maryland and Southeast Pennsylvania, Geol. Soc. Amer. Bull., v. 58, p. 843-978.
- \_\_\_\_\_ (1951), The Physical Features of Washington County, Md. Dept. Geology, Mines, Water Res., 333 p.
- Currie, J. B., Patmode, H. W., and Trump, R. P. (1962), Development of Folds in Sedimentary Strata, Geol. Soc. Amer. Bull., v. 73, p. 655-674.
- DeSitter, L. U. (1956), Structural Geology, McGraw-Hill Book Co., 552 p.
- Geyer, A. R. and others (1958), Geology of the Lebanon Quadrangle, Pa. Geol. Survey, 4th ser., Atlas 167c.
- \_\_\_\_\_ (1963), Geology and Mineral Resources of the Womelsdorf Quadrangle, Pa. Geol. Survey, 4th ser., Atlas 177c.
- Gray, Carlyle (1959), Nappe Structure in Pennsylvania (abs.), Geol. Soc. Amer. Bull., v. 70, no. 12, p. 1611.
- \_\_\_\_\_ and others (1958), Geology of the Richland Quadrangle, Pa. Geol. Survey, 4th ser., Atlas 167d.
- Gwinn, V. E. (1964), Thin-Skinned Tectonics in the Plateau and Northwestern Valley and Ridge Provinces of the Central Appalachians, Geol. Soc. Amer. Bull., v. 75, p. 863-900.
- Hack, J. T. (1965), Geomorphology of the Shenandoah Valley, Virginia and West Virginia and the Origin of Residual Ore Deposits, U. S. Geol. Survey, Prof. Paper 484, 84 p.
- Jonas, A. I. and Stose, G. W. (1930), Geology and Mineral Resources of the Lancaster Quadrangle, Pa. Geol. Survey, 4th ser., Atlas 168, 106 p.
- King, P. B. (1950), Geology of the Elkton Area, Virginia, U. S. Geol. Survey, Prof. Paper 230, 82 p.
- Krynine, P. D. (1946), From the Cambrian to the Silurian, near State College and Tyrone, Guidebook 12th Annual Conference of Pennsylvania Geologists, 32 p.
- MacLachlan, D. B. (1966)(in press), Geology of the Carbonate Rocks of Dauphin County, Pa. Geol. Survey, 4th ser., Bull. G 44.
- Page, R. C., Burford, A. E., and Donaldson, A. C. (1964), Geology of the Martinsburg Quadrangle, W. Va. Geol. and Econ. Survey, Geol. Map GM 2.

- Pelto, C. R. (1942), Petrology of the Gatesburg Formation of Central Pennsylvania, M. Sc. Thesis, Pennsylvania State University, 60 p.
- Platt, L. B., in Carswell, L. D. and Hollowell, J. R., (MS), The Geology and Hydrology of the Martinsburg Shale in Dauphin County, Pennsylvania.
- Price, R. A. (1965), Flathead Map-Area, British Columbia and Alberta, Geol. Survey Canada, Memoir 336, 220 p.
- Prouty, C. E. (1959), The Annville, Myerstown, and Hershey Formations of Pennsylvania, Pa. Geol. Survey, 4th ser., Bull. G 31, 47 p.
- Sando, W. J. (1957), Beekmantown Group (Lower Ordovician) Maryland, Geol. Soc. Amer. Memoir 68, 161 p.
- Stose, G. Q. (1909), Description of the Mercersburg-Chambersburg District, Pennsylvania, U. S. Geol. Survey, Geol. Atlas of U. S. Folio 170, 19 p.