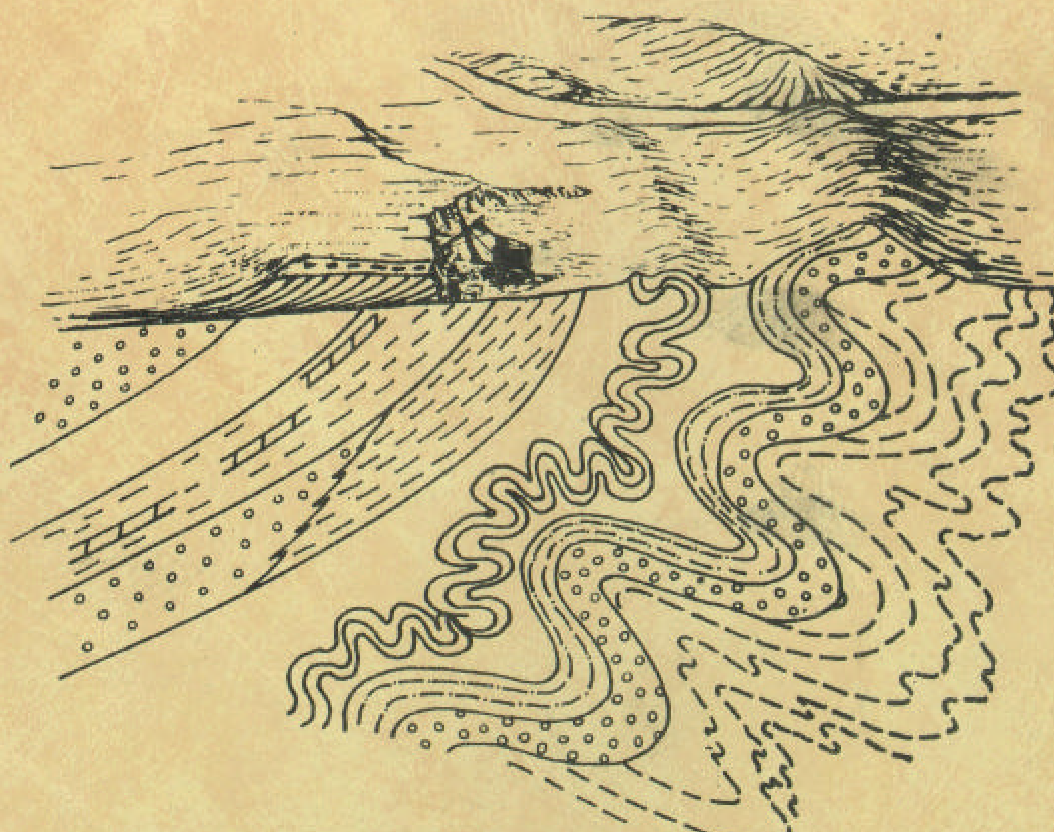
GUIDEBOOK

32nd Field Conference Of Pennsylvania Geologists

East Stroudsburg, Pa.

September 29 and 30, 1967



Hosts

United States Geological Survey

Pennsylvania Geological Survey

Guidebook for the

32nd Annual Field Conference of Pennsylvania Geologists

GEOLOGY IN THE REGION OF THE DELAWARE TO LEHIGH WATER GAPS

September 29 and 30, 1967

Hosts: U. S. Geological Survey

and Pennsylvania Geological Survey

By

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INTRODUCTION

This field conference will demonstrate the interrelationship of the stratigraphy, structure, geomorphology, glacial geology, and economic geology of Middle Ordovician through part of the Middle Devonian strata and overlying surficial deposits in the area between the Delaware and Lehigh Rivers in eastern Pennsylvania. Rocks north and south of this area were seen on two previous field trips. The 26th Field Conference of Pennsylvania Geologists, in 1961, dealt with the rocks in the Great Valley and Reading Prong to the south. The 28th Field Conference concerned the geology north and west of Stroudsburg, Pa., and included rocks generally younger than Lower Devonian.

Data for this field trip have been gathered by (1) nearly completed bedrock and surficial mapping of all or parts of eight 7½-minute quadrangles by J. B. Epstein, U. S. Geological Survey (Stroudsburg, East Stroudsburg, Portland, Saylorsburg, Wind Gap, Kunkletown, Palmerton, and Lehighton--the last five being done in cooperation with the Pennsylvania Geological Survey), and (2) stratigraphic studies of Upper Silurian and Lower Devonian rocks of northeastern Pennsylvania, New Jersey, and southeastern-most New York by Epstein and others (1967). In addition, we have benefited from discussions and exchange of data with several coworkers, including A. A. Drake, Jr., U. S. Geological Survey, and J. D. Glaeser, J. F. Wietrzychowski, and W. D. Sevon of the Pennsylvania Geological Survey. D. G. Parrillo and A. J. Depman of the U. S. Army Corps of Engineers have supplied the data concerning the engineering geology of the Tocks Island damsite which will be discussed at stop 2, second day. They have also made available cores from the damsite which will be seen at the lunch stop on the second day. D. W. Kohls supplied the road-log description of The

New Jersey Zinc Company operations at Palmerton. Much of the work is still incomplete, and some of the conclusions presented in this guidebook should be regarded as tentative.

We will examine the probable facies relationships and correlations between rocks in the eastern and western sections of the area and consider the environmental conditions under which these strata were deposited. The rock stratigraphic units have been grouped into four successive lithofacies, each of which displays a different style of deformation. Folds produced in these rocks are disharmonic, and it is believed that each rock sequence is set off from sequences above and below by a decollement, or zone of detachment. Movement was northwest into the Appalachian basin, primarily by gravitational sliding, aided by directed tectonic forces. The contact between the Shawangunk Conglomerate of Silurian age and Martinsburg Formation of Ordovician age, believed by most workers to be an angular unconformity, may also be one zone of detachment. The deformational effects of the Middle to Late Ordovician Taconic orogeny may not be as intense in this area as some geologists believe.

Erosion of the folded heterogeneous bedrock in this part of the Appalachians has produced linear ridges and valleys. This topography had a profound effect on the manner of retreat of the Pleistocene glaciers. We shall demonstrate that during the Wisconsin Glaciation a moraine-dammed proglacial lake existed in the area south of Stroudsburg, Pa. Other glacial features will be examined, including older, possibly Illinoian drift in the western part of the area. Knowledge of the underlying bedrock lithology and drift petrography aids in the interpretation of the direction of Pleistocene glacier movement. The evolution of the modern Delaware-Lehigh River drainage system is closely tied to bedrock structure.

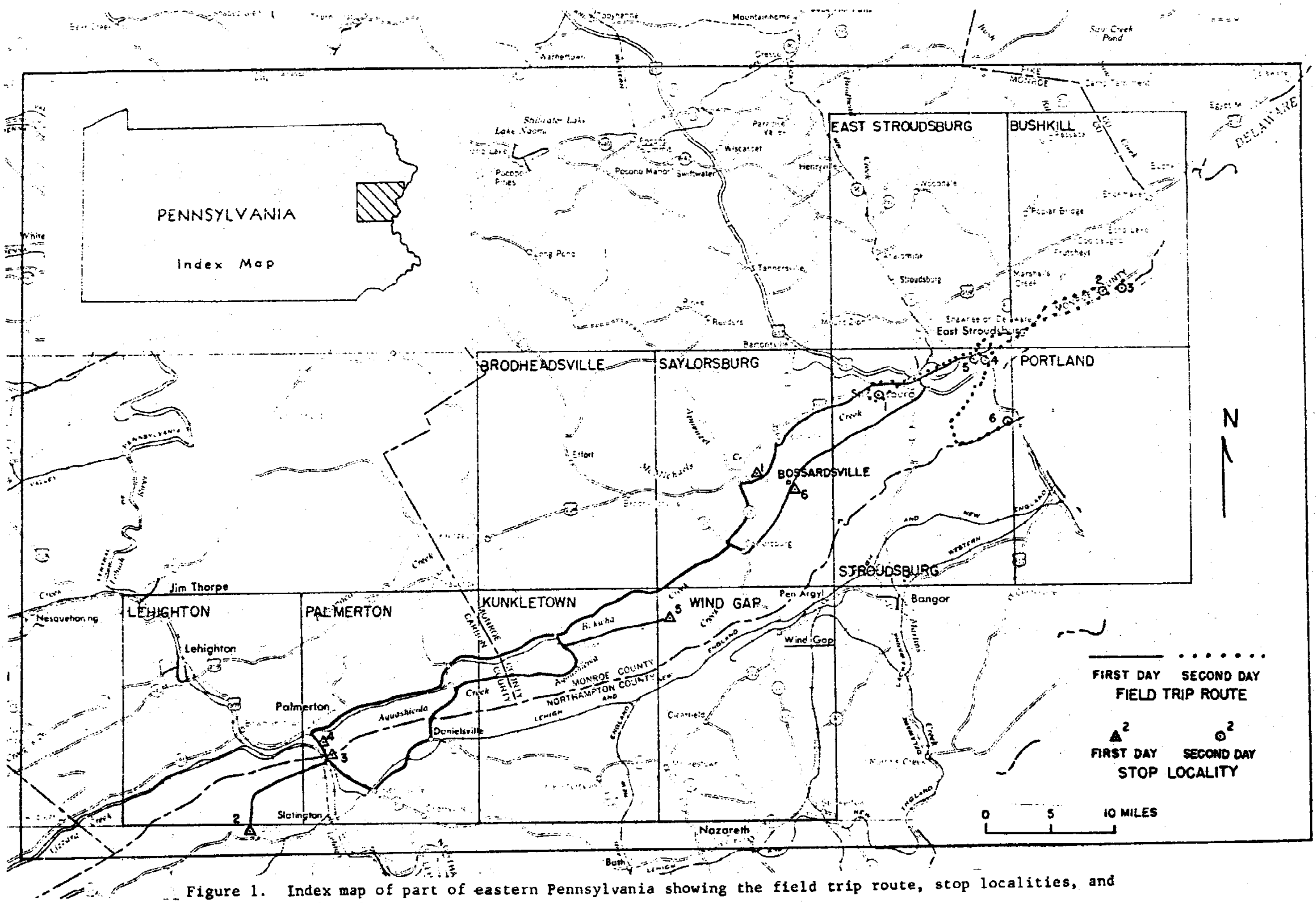


Figure 1. Index map of part of eastern Pennsylvania showing the field trip route, stop localities, and quadrangle coverage.

Detailed mapping has shown that the many wind and water gaps are structurally controlled, placing doubt upon the hypothesis of regional superposition. Finally, an intimate knowledge of all these facets of geology yields insight into the origin of the economic deposits of the area.

Figure 1 is an index map of the field-trip area showing trip routes and quadrangle coverage. A generalized geologic map of the field-trip area showing the limit of Wisconsin drift is presented as figure 2. Figure 3 is a physiographic diagram of the field-trip area showing stop locations and the position of the Wisconsin terminal moraine.

On the first day we will examine a delta deposited in proglacial Lake Sciota and then see representative exposures of the four lithotectonic units in the western part of the field-trip area. These stops will include a slate quarry in the Martinsburg Formation; the Martinsburg-Shawangunk contact and effects of the Taconic and Appalachian orogenies at Lehigh Gap; tightly folded Upper Silurian-Lower Devonian sedimentary rock saprolites near Kunkletown; and a structurally similar unweathered sequence of Upper Silurian rocks at Bossardsville. On the second day we will stay entirely in the Delaware Water Gap area and compare this eastern sequence with sequences seen on the first day. Stops will deal with sedimentary structures and interpretation of Wisconsin glacial deposits, biohermal and nonbiohermal facies of the Coeymans Formation, engineering geology of the Tocks Island damsite, cores from the Tocks Island damsite, stratigraphy and structure of Godfrey Ridge, and finally the origin of wind and water gaps from atop Kittatinny Mountain, and a discussion of the overall tectonics of the area.

EARLY HISTORY

The area between the Delaware and Lehigh Water Gaps seen on this

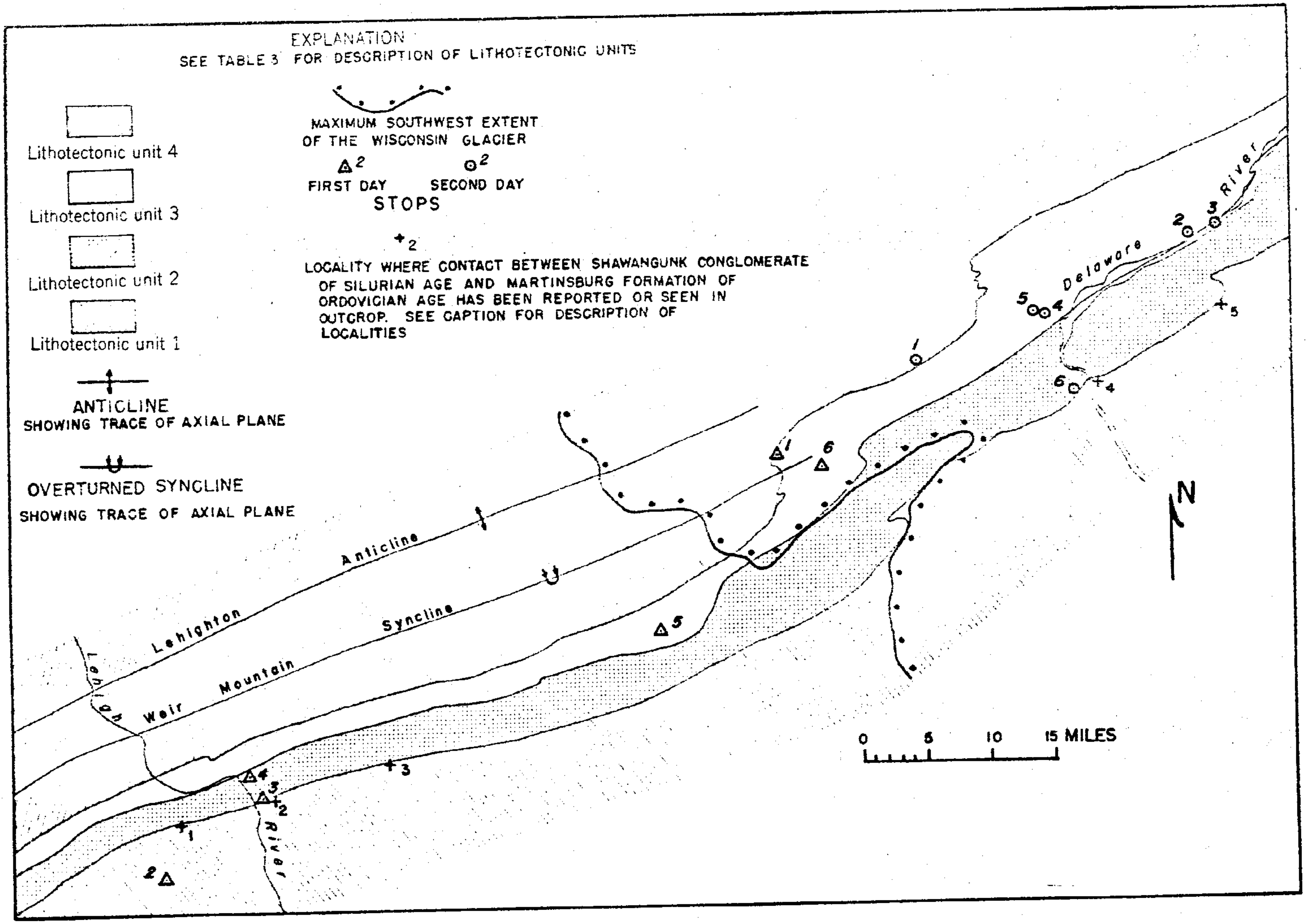


Figure 2. Generalized geologic map of the Delaware River-Lehigh River area, Pennsylvania-New Jersey. Modified from Gray and others, 1960. Martinsburg-Shawangunk contact localities: 1, Northeast extension of the Pennsylvania Turnpike tunnel; 2, Lehigh Gap; 3, Water tunnel for city of Bethlehem, at Little Gap; 4, Delaware Water Gap; 5, Yards Creek hydroelectric project near Blairstown, N. J.

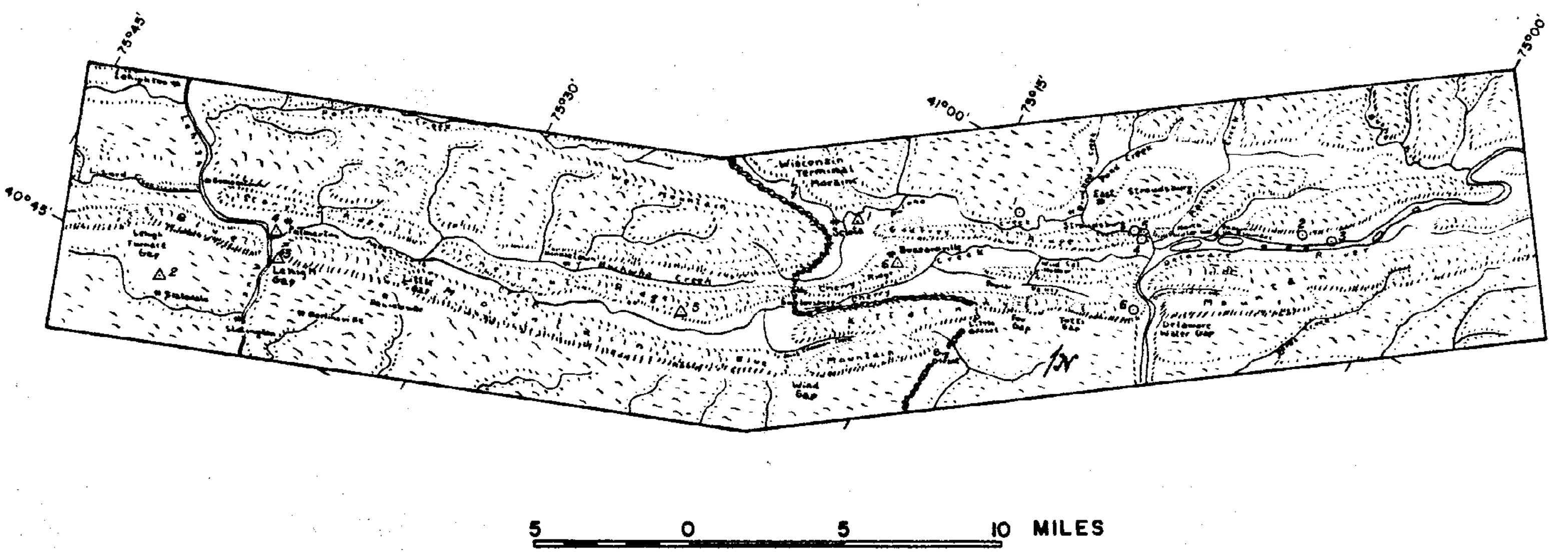


Figure 3. Physiographic diagram of field-trip area showing stop locations and position of Wisconsin terminal moraine.

field conference has had an interesting geologic history, the subject of this guidebook. The human history of the region is also of interest; some of the Indian lore and legend is given here, most of which is taken from Brodhead (1870), Miller and other (1939), Stokes (n.d.), and Woodward (1944).

The Lenni-Lenape Indians, better known as the Delawares, a branch of the Algonkians, occupied the Delaware River drainage basin from New York to Delaware. According to legend, their ancestors had great antiquity, having originated west of the "Mamoesi Sipi" (Mississippi). The Wolf clan of the Delawares occupied the area covered by this field conference and had their main village, Minisink, in New Jersey just north of Delaware Water Gap. The Wolf clan, and finally the entire Lenni-Lenape nation were brought into subjugation through war and stratagem by the Iroquois or Five-Nation Confederacy who occupied lands to the north, at about the time of arrival of William Penn in Pennsylvania. Penn began buying land from the Delawares in 1682. Most of the land south of the "Endless Mountains" (Blue and Kittatinny Mountains) (specifically the colony of "Penn's Woods,") was deeded to the white man by the warring Indians in the peace treaty of 1736.

The white man perpetrated all manner of trickery against the Indian. The crowning injustice came with the notorious "Walking Purchase" in 1737. In 1734, Thomas Penn claimed to have found a copy of a deed dated 1686 from the Delaware chiefs to his father, William Penn, giving title to certain lands north of Blue and Kittatinny Mountains, the area occupied by the Minsi tribe of the Wolf clan. The tract of land was outlined, in part, by the distance a man could walk in a day and a half. In 1737, the Delaware Indians, believing the walk would be an ordinary day and a half journey with pauses for rest and food, finally allowed the land to be measured. Penn, however, hired trained athletes and had them make preliminary trips to find the shortest and fastest routes. A reward was offered to the runner who covered the greatest distance. The "walk" began on September 19th near Wrightstown in Bucks County. By finish time, all runners had fallen exhausted except one who reached Broad Mountain in Carbon County, about 65 miles north of the starting point and about twice as far as the Indians thought a man could walk in the time alloted. According to the deed, all land east of the line of walk to the Delaware River would be assigned to Penn, but Penn drew the line in a northeasterly direction, thus acquiring an extra 25 miles of territory.

The Indians felt they were cheated and refused to vacate their lands. They were finally expelled by the Pennsylvania authorities with the help of the Six-Nation Indians. The Minsi tribe migrated to the western part of the state and then to Canada where their identity with the Lenni-Lenape nation was lost. It is not surprising that many of these Indians joined with the French against the English during the French and Indian War in 1754.

During the French and Indian War, Chief Teedyuscong led the Delawares in many bloody massacres against the white settlers. In 1756 he joined an alliance with the Shawnees, Nanticokes, and Mohicans, and the Governor of Pennsylvania declared war on the Indians. A chain of forts was built from the Delaware to the Susquehanna. Bounties were offered for Indian scalps. Many atrocities were committed on both sides. In 1756, Tom Quick, Sr., was killed and scapled by Indians near Milford, Pa. His son escaped and vowed vengeance. Near the end of his life, Tom Quick, Jr., regarded by his friends as a hero but outlawed by the government, claimed that he had killed 99 Indians and regretted that he did not make it an even hundred.

In 1762 peace was negotiated, Teedyuscong claiming that the reason he went to war was because the Delawares were cheated by the Walking Purchase.

However, he and many other Delawares were murdered by a war party of Six-Nation Indians in 1763. After 1770 the Lenni-Lenape journeyed to Ohio and then finally to Oklahoma where they settled permanently and lost their identity as the Lenni-Lenape nation.

The earliest geological investigation in the area occurred in the middle of the 17th century under Dutch auspices. The Dutch discovered a copper deposit in the Bloomsburg Red Beds on the north side of Kittatinny Mountain about 6 miles northeast of Delaware Water Gap village in Pahaquarry Township, N. J. They believed the Pahaquarry mine to be a New World Kupferschiefer and built a road ("The Old Mine Road") to Esopus (now Kingston), N. Y., a distance of more than 100 miles, to transport the ore. This was the longest and best road in the colonies at the time. Unfortunately, the mine was unprofitable, and attempts at working it have been unsuccessful to the present day. The Dutch were on friendly terms with the Lenni-Lenape Indians of the Minisink valley and their chief, Wissinoming. The chief had a daughter, the princess Winona. The head of the Dutch exploration group, Hendrich Van Allen, fell in love with the princess. They often climbed the mountains around Delaware Water Gap together. When the Dutch surrendered New Amsterdam (New York) to the English in 1664, Van Allen was ordered to abandon mining operations. His position was such that he could not take Winona with him to Holland as his wife. When he reported the news to Winona, she bade farewell and ran to the edge of a precipice. He made an attempt to stop her, and in doing so they both fell to their deaths. The part of the cliff overlooking Delaware River where this episode is supposed to have taken place is now known as "Lover's Leap" and is located along the Appalachian trail below stop 6 of the second day of this field trip.

TABLE 1. DESCRIPTION OF ROCK UNITS IN KITTATINNY MOUNTAIN AND GODFREY RIDGE, PA.

SYSTEM	SERIES	LITHO-TECTONIC UNIT	GROUP	FORMATION	MEMBER	DESCRIPTION	THICKNESS (feet)	LOCALITIES WHERE UNIT WILL BE SEEN ON FIELD TRIP AND ECONOMIC USE
DEVONIAN	Middle	4		Mahantango Formation		Medium-dark-gray siltstone and silty shale; contains Centerfield coral bed, a calcareous siltstone biostrome having abundant horn corals.	about 2,000	
DEVONIAN	Middle	4		Marcellus Shale		Dark-gray silty shale. Basal 200 feet consists of interbedded medium-dark-gray calcareous silty shale, silty shale and slightly calcareous shale. Sparsely fossiliferous. Upper contact gradational.	800	Quarried for fill.
DEVONIAN	Middle	3		Buttermilk Falls Ls. of Willard (1938)	Upper member	Medium-gray limestone and argillaceous limestone containing nodules and beds of dark-gray chert. Fossiliferous. Upper contact probably abrupt.	150	Quarried for road metal. Stop 5, 2nd day.
DEVONIAN	Middle	3		Buttermilk Falls Ls. of Willard (1938)	Middle member	Medium-gray calcareous argillite containing lenses of light-medium-gray limestone. Fossiliferous.	40	Quarried for road metal. Stop 5, 2nd day.
DEVONIAN	Middle	3		Buttermilk Falls Ls. of Willard (1938)	Lower member	Medium-dark-gray calcareous siltstone and argillite and argillaceous limestone containing beds, pods, and lenses of dark-gray chert. Fossiliferous; large crinoid columnals abundant in lower half.	80	Quarried for road metal. Stop 5, 2nd day.
DEVONIAN	Lower	3		Schoharie Formation		Medium- to medium-dark-gray massive argillaceous calcareous siltstone. Fossiliferous. Upper contact gradational.	100	Quarried for road metal. Stop 5, 2nd day.
DEVONIAN	Lower	3		Esopus Formation		Medium- to dark-gray silty shale and shaly to finely arenaceous siltstone. Poorly fossiliferous. Upper contact gradational.	180	Quarried for road metal. Stop 5, 1st day; stops 4 and 5, 2nd day.
DEVONIAN	Lower	3	Oriskany Gp.	Ridgeley Ss.		Medium- to light-gray fine- to coarse-grained calcareous sandstone and quartz-pebble conglomerate containing beds and lenses of siltstone and arenaceous fine-grained limestone and dark-gray chert. Fossiliferous. Upper contact abrupt.	40-50	Quarried for sand and road metal. Stop 5, 1st day; stop 4, 2nd day.
DEVONIAN	Lower	3	Oriskany Gp.	Shriver Chert		Medium-dark-gray siliceous calcareous shale and siltstone and beds, lenses, and pods of dark-gray chert. Fossiliferous. Upper contact abrupt.	50-60	Quarried for road metal. Stop 5, 1st day; stop 4, 2nd day.
DEVONIAN	Lower	3	Helderberg Group.	Port Ewen Shale		Lower 60 feet consist of medium-dark-gray poorly fossiliferous irregularly laminated calcareous shale and siltstone; upper 90 feet consist of medium-dark-gray fossiliferous irregularly bedded calcareous siltstone and shale. Upper contact gradational.	150	Stop 4, 2nd day.
DEVONIAN	Lower	3	Helderberg Group.	Minisink Ls.		Dark- to medium-gray fine-grained argillaceous fossiliferous limestone. Upper contact abrupt.	14	Stop 4, 2nd day.
DEVONIAN	Lower	3	Helderberg Group.	New Scotland Formation	Maskenozha Member	Dark-gray silty calcareous laminated fossiliferous shale containing beds and lenses of medium-gray fine-grained argillaceous fossiliferous limestone. Upper contact abrupt or gradational.	43-48	Stop 4, 2nd day.
DEVONIAN	Lower	3	Helderberg Group.	New Scotland Formation	Flatbrookville Member	Medium-dark-gray silty and calcareous fossiliferous shale containing beds and lenses of medium-gray fine-grained argillaceous very fossiliferous limestone and dark-gray chert. Upper contact gradational.	20-33	Stop 5, 1st day; stops 2 and 3, 2nd day.
DEVONIAN	Lower	3	Helderberg Group.	Coeymans Formation	Stormville Member	Lenses of medium-gray fine- to coarse-grained biogenic limestone, fine- to medium-grained arenaceous limestone, fine- to coarse-grained crossbedded calcareous limonitic sandstone and quartz-pebble conglomerate. Contains nodules and lenses of dark-gray chert. Fossiliferous. Upper contact abrupt	2-26	Stop 5, 1st day; stops 2, 3, and 4, 2nd day.
DEVONIAN	Lower	3	Helderberg Group.	Coeymans Formation	Shawnee Island Member	Nonbiohermal facies, medium-gray fine- to medium-grained argillaceous and arenaceous slightly limonitic irregularly bedded fossiliferous limestone. Upper 10-25 feet contain dark-gray chert lenses and nodules. Biohermal facies, medium-light-gray to light-pinkish-gray very coarse grained unbedded to crudely bedded biogenic limestone. Upper contact abrupt.	35-60	Stops 2, 3, and 4, 2nd day.
DEVONIAN	Lower	3	Helderberg Group.	Coeymans Formation	Peters Valley Member	Medium-gray arenaceous limestone to light-medium-gray fine- to coarse-grained pebbly calcareous sandstone. Crossbedded; fossiliferous. Upper contact gradational.	3-9	Stops 3 and 4, 2nd day.
DEVONIAN	Lower	3	Helderberg Group.	Coeymans Formation	Depue Limestone Member	Medium- to dark-gray fine- to medium-grained arenaceous and argillaceous, partially straticulate fossiliferous limestone. Upper contact abrupt or gradational.	13-17	Quarried for agricultural lime. Stop 3 and 4, 2nd day.

SILURIAN & DEVONIAN	Upper Silurian & Lower Devonian		Rondout Formation	Mashipacong Member	Medium-dark-gray to light-gray shale, calcareous shale, and very fine-grained to medium-grained argillaceous limestone. Mud cracks, cut-and-fill structure. Upper contact abrupt or gradational.	5-11	Stops 3 and 4, 2nd day
				Whiteport Dolomite Member	Dark- to medium-dark-gray laminated dolomite. Mud cracks. Upper contact abrupt or gradational.	5-9	Formerly quarried for agricultural lime. Stops 3 and 4, 2nd day.
				Duttonville Member	Dark- to medium-gray calcareous shale and argillaceous limestone. Mud-crack intervals and biostromal limestone beds. Upper contact abrupt.	12-17	Stops 3 and 4, 2nd day.
SILURIAN	Upper	2	Decker Formation	Wallpack Center Member	Lenses and beds of quartz-pebble conglomerate, calcareous sandstone and siltstone, and argillaceous and arenaceous fine- to coarse-grained limestone. Crossbedded, fossiliferous. Upper contact abrupt.	84	Stops 5 and 6, 1st day; stops 3 and 4, 2nd day.
			Bossardville Ls.		Lower 30-40 feet dark- to medium-gray, laminated, very fine-grained to fine-grained argillaceous limestone containing 2 intervals of deep mud cracks (as much as 5 feet deep) and the upper 60-70 feet dark-gray very fine-grained laminated limestone. Poorly fossiliferous. Upper contact gradational.	100	Quarried for bituminous concrete, road metal, and high calcium ls. Stop 6, 1st day; stops 3 and 4, 2nd day.
			Poxono Island Formation of White (1882)		Calcareous and dolomitic, light-olive-gray to green laminated fissile to nonfissile shale, olive-green dolomite, and minor sandstone and siltstone. Upper contact gradational.	about 700	Stop 6, 1st day; stop 3, 2nd day.
	Middle & Upper		Bloomsburg Red Beds		Red, green, and gray conglomeratic sandstone, sandstone, siltstone, and shale. Fifty percent sandstone, 45 percent shale and siltstone, and 5 percent conglomerate. Crossbedded; mud cracks; cut-and-fill structure. Fish scales in upper beds. Upper contact gradational.	about 1,500	Quarried for fill and road metal. Stop 4, 1st day; stops 3 and 6, 2nd day.
	Lower and Middle		Shawangunk Conglomerate	Upper quartzite-conglomerate member	Medium-gray to medium-dark-gray fine- to coarse-grained partly crossbedded, limonitic, pyritic, conglomeratic (quartz and argillite pebbles as much as 2 in. long) evenly to unevenly bedded quartzite containing about 2 percent dark-gray argillite. Upper contact gradational.	816	Stop 6, 2nd day.
				Middle quartzite-argillite member	Medium-light-gray to medium-dark-gray and light-olive-gray fine- to coarse-grained partly crossbedded limonitic pyritic evenly to unevenly bedded thin- to thick-bedded quartzite interbedded with thin- to very thick-bedded evenly to unevenly bedded medium-dark-gray to dark-gray argillite. Upper contact gradational.	273	Stop 4, 1st day.
				Lower quartzite-conglomerate member	Light-gray to medium-dark-gray and light-olive-gray medium- to coarse-grained partly crossbedded limonitic pyritic and feldspathic, unevenly to moderately evenly bedded thin- to thick-bedded quartzite, conglomeratic quartzite, and quartz-, chert-, and shale-pebble conglomerate (quartz pebbles as much as 2 in. long). About 7 percent dark-gray irregularly bedded locally mud-cracked argillite. Upper contact gradational.	300	Stop 3, 1st day.
ORDOVICIAN	Middle and Upper	1	Martinsburg Formation	Pen Argyl Member	Dark-gray to grayish-black, thick- to thin-bedded, evenly bedded claystone slate, rhythmically intercalated with beds of quartzose slate or subgraywacke and carbonaceous slate. Upper contact abrupt and unconformable.	3,000-6,000	Quarried for slate, lightweight aggregate, and fill. Stops 2 and 3, 1st day.
				Ramseyburg Member	Medium- to dark-gray claystone slate alternating with beds of light- to medium-gray, thin- to thick-bedded graywacke and graywacke siltstone. Graywacke composes about 20-30 percent of unit. Upper contact with Penn Argyl Member gradational.	about 2,800	Upper part quarried for slate in Bangor = Pen Argyl area.
				Bushkill Member	Dark- to medium-gray thin-bedded claystone slate containing thin interbeds of quartzose and graywacke siltstone and carbonaceous slate. Upper contact gradational.	about 4,000	Formerly quarried for slate.

TABLE 2. DESCRIPTION OF ROCK UNITS IN BLUE MOUNTAIN AND CHERRY, CHESTNUT, AND STONY RIDGES, PA.
(*Asterisk indicates information is similar to that of Table 1.)

SYSTEM	SERIES	LITHO-TECTONIC UNIT	FORMATION	MEMBER	DESCRIPTION	THICKNESS (feet)
DEVONIAN	Middle		Marcellus Shale		Dark-gray carbonaceous silty shale.	about 600
DEVONIAN	Middle	3	Buttermilk Falls Ls. of Willard (1938)		Deeply weathered cherty argillaceous limestone. Medium-gray argillaceous limestone and dark-gray chert where unweathered.	40-80
DEVONIAN	Middle	3	Palmerton Sandstone of Swartz (1939)		Weathered, very massive, partially conglomeratic, coarse- to very coarse-grained sandstone. A few siltstone and fine-grained sandstone beds near base. Molds of crinoid columnals and favositids. Medium-gray to medium-dark-gray where unweathered. Upper contact abrupt. Stop 5, 1st day.	0-about 110
DEVONIAN	Lower	3	Schoharie and Esopus Formations, undivided		Predominantly deeply weathered fossiliferous, partially cherty siltstone and fine-grained sandstone. Upper part, in fresh exposure, is dark-gray slightly calcareous siltstone. Upper contact abrupt.	48-about 100
DEVONIAN	Lower	3	Orisk. Gp.: Ridgeley Ss.		Beds and lenses of weathered crossbedded quartz-pebble conglomerate and conglomeratic sandstone, locally containing intervals of abundant brachiopod molds. Upper contact abrupt.	25-45
DEVONIAN	Lower	3	Orisk. Gp.: Shriver Chert		Beds and lenses of deeply weathered chert, sandstone and conglomerate. Brachiopod molds locally abundant. Upper contact abrupt.	25-45
DEVONIAN	Lower	3	Held. Gp.: New Scotland Formation		Deeply weathered fossiliferous chert and silty and sandy shale. Upper contact abrupt.	0(?)-55
DEVONIAN	Lower	3	Held. Gp.: Coeymans Formation	Stormville Member	Weathered very fine-grained to conglomeratic, partially fossiliferous crossbedded sandstone containing interbeds of arenaceous, probably calcareous, shale or siltstone. Upper contact abrupt.	0-45
SIL. & DEV.	U. Sil. & L. Dev.	3	Andreas Red Beds of Swartz & Swartz (1941)		Red, green, and gray partially pebbly sandstone, siltstone, and shale. Northeasternmost outcrop approximately 1.5 miles west of Bowmanstown, Pa. Overlain either by New Scotland Formation or Shriver Chert.	0-about 50
SILURIAN	Upper	3	Decker Formation		Lenses and beds of medium-gray and medium-light-gray shale and siltstone, dark-yellow-orange to greenish-gray very fine-grained to conglomeratic slightly calcareous fossiliferous sandstone, and medium-gray partly arenaceous fine- to coarse-grained fossiliferous limestone. Some beds of calcareous dolomite and dolomitic limestone. Upper part has red interbeds.	*
SILURIAN	Upper	3	Bossardville Limestone		*	*
SILURIAN	Upper	3	Poxono Island Fm. of White (1882)		*	about 300-400
SILURIAN	Middle & Upper	2	Bloomsburg Red Beds		Fining-upward sequences of sandstone, siltstone, and silty shale or shale. Mainly red, with fewer green and gray beds than in eastern area. Laminated to thick bedded; mud cracked locally. Upper contact probably gradational.	about 1,500
SILURIAN	Lower and Middle	2	Shawangunk Conglomerate	Quartzite-argillite member	Medium-gray to greenish-gray very fine to medium-grained thin- to thick-bedded quartzite containing a few intervals of dark-grayish-red-purple fine-grained partially silty quartzite. Grayish-orange to light-olive-gray shale, silty shale, and siltstone with some grayish-red-purple beds. Upper contact gradational.	about 1,225
SILURIAN	Lower and Middle	2	Shawangunk Conglomerate	Lower quartzite-conglomerate member	Medium-light-gray and greenish-gray, medium- to very coarse grained partially conglomeratic quartzite and very light gray to medium-light-gray and greenish-gray predominantly medium-grained quartzite. Upper contact gradational.	200-300
SILURIAN	Lower and Middle	2	Shawangunk Conglomerate	Conglomerate member	Greenish-gray to medium-gray medium- to thick-bedded quartz-, chert-, argillite-pebble conglomerate (quartz pebbles as much as 5 in. long). Medium-dark-gray medium- to very coarse-grained conglomeratic quartzite and a few beds of greenish-gray argillite. Upper contact gradational.	0-225
ORDOVICIAN	Middle & Upper	1	Martinsburg Formation	Pen Argyl Member	*	*
ORDOVICIAN	Middle & Upper	1	Martinsburg Formation	Ramseyburg Member	*	*
ORDOVICIAN	Middle & Upper	1	Martinsburg Formation	Bushkill Member	*	*

STRATIGRAPHY

The stratigraphic units with which this field trip is concerned are described in tables 1 and 2. Table 1 describes the units in the eastern part of the field-trip area; table 2 deals with the western part. Figures 4 and 5 show the lateral and vertical relationships of these rock units, from northeast to southwest, in the field-trip area.

Geographic and Tectonic Environments of Deposition

The Middle Ordovician through part of the Middle Devonian rocks with which this field trip is concerned compose virtually one complete flysch--molasse--carbonate-orthoquartzite shelf succession. This succession includes almost all the major sedimentary associations enumerated by Pettijohn (1957, p. 610): the graywacke, subgraywacke, evaporite, carbonate-orthoquartzite, and euxinic facies.

From Cambrian through Late Ordovician time, the Appalachian basin in the Delaware Water Gap-Lehigh Gap region gradually deepened and the influx of terrigenous materials gradually increased. The rock record indicates that the area slowly changed from a supratidal-shallow neritic shelf (Hardyston Quartzite, Leithsville Formation, Allentown Dolomite, and Beekmantown Group: primary dolomite, limestone, arkose, and orthoquartzite) to a deeper neritic-eugeosynclinal basin (fossiliferous calcarenite and calcilutite of the Jacksonburg Limestone to thick accumulations of rhythmically bedded graywacke and slate of the Martinsburg Formation). Jacksonburg time marked the onset of flysch-type sedimentation, which culminated in Martinsburg time with rhythmic graded sequences of graywacke turbidites and dark-gray slate. The Martinsburg sediments reflect Taconic orogenic activity, which reached its peak with the emergence of the area sometime in the Late Ordovician.

During Early and Middle Silurian time, sediment-laden streams crisscrossed the area, depositing coarse detritus in channelways (crossbedded conglomerate and quartzite with cut-and-fill structure of the Shawangunk Conglomerate) and finer grained materials (dark-gray locally mud-cracked argillites of the Shawangunk Conglomerate) as overbank deposits. Areas in close proximity to source rocks and to major channelways on the depositional plain received coarser detritus (basal conglomerate unit of the Shawangunk Conglomerate at Lehigh Gap, fig. 4). From Middle to Late Silurian time the mode of accumulation and character of the sediments gradually changed from rapid cut-and-fill deposition of predominantly coarse-grained nonmarine clastics (Shawangunk Conglomerate) to fining-upwards sequences of finer grained nonmarine clastics (Bloomsburg Red Beds), and finally to alternations of nonmarine fine-grained fluvial clastics and supra- to subtidal dolomites and limestones (Poxono Island Formation of White, 1882, and Bossardville Limestone). Thus, molasse sedimentation began in the Early Silurian and ended in the Late Silurian.

From Late Silurian through part of the Middle Devonian, in the Delaware Water Gap area, the rock units are of the marine shelf carbonate-orthoquartzite facies. Part of these units (Bossardville Limestone through the Port Ewen Shale, see table 1) record a steady deepening of the basin in this region, with only minor regressions. The area changed gradually from a supra- to subtidal restricted marine lagoon (Bossardville Limestone and part of the Poxono Island Formation of White, 1882; laminated limestone, dolomite, and dolomitic limestone containing mud-crack intervals, desiccation breccias, and leperditiid ostracodes) to a barrier-beach and (or) biostromal bank (Decker Formation: juxtaposed beds and lenses of quartzose detritus of variable grain size and biogenic limestone). Poxono Island-Bossardville-Decker conditions were true of both the Lehigh Gap and Delaware Water Gap

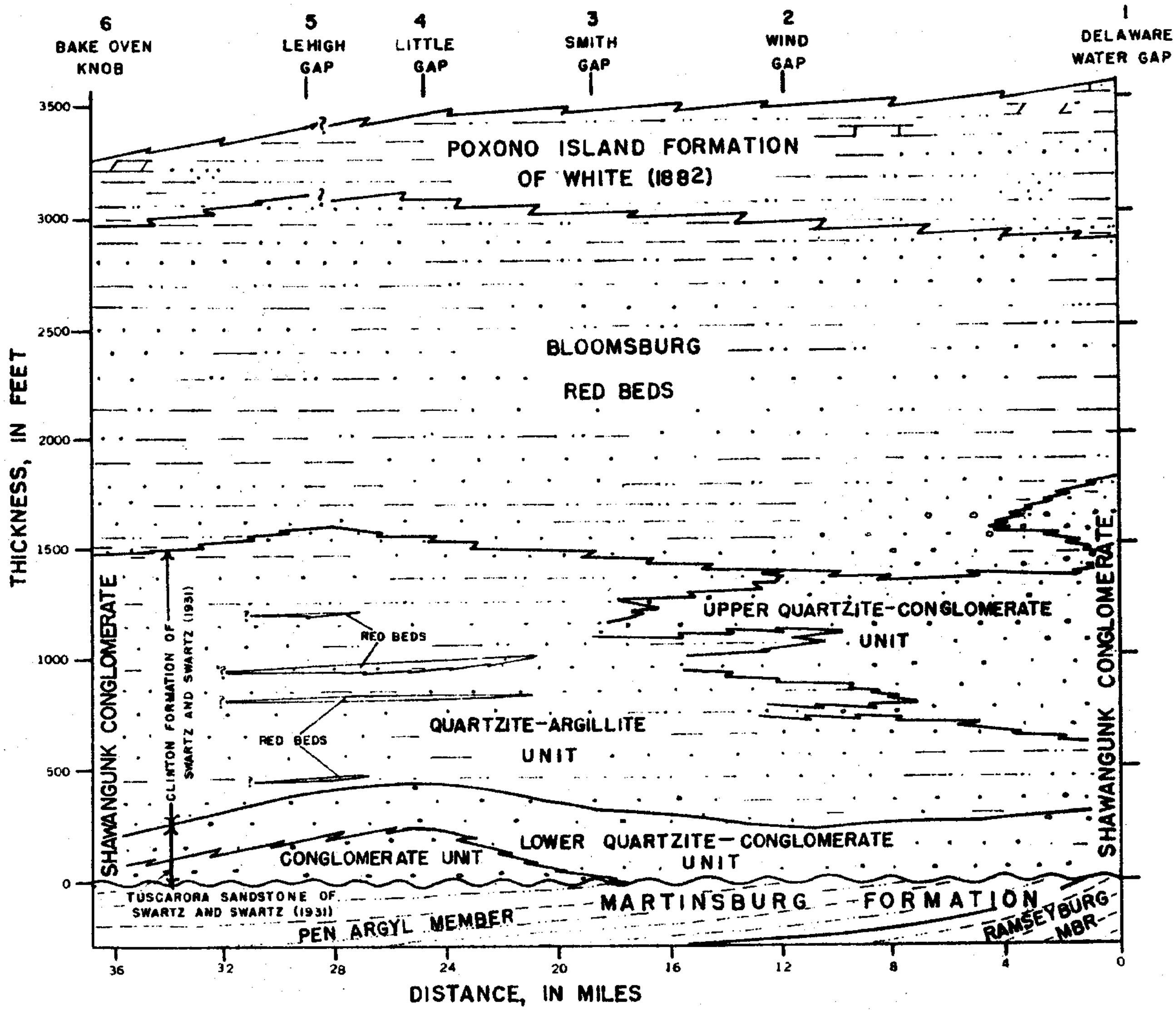


Figure 4. Stratigraphic section of the Shawangunk Conglomerate, Bloomsburg Red Beds, and Poxono Island Formation of White (1882) from Delaware Water Gap to Bake Oven Knob, Pa. (See fig. 5 for location of sections.)

areas. A restricted marine lagoon was re-established in Rondout time in the Delaware Water Gap area (laminated mud-cracked unfossiliferous dolomite and mud-cracked calcilutite with rare biostromal layers) whereas farther to the southwest near Lehigh Gap (see fig. 5), the area was emergent.

More normal marine shallow-shelf conditions prevailed in Coeymans time. From northeast to southwest (Wallpack Bend, Pa.-N.J., to Andreas, Pa., fig. 5) carbonate-orthoquartzite subfacies depositional zones crossed the present Coeymans outcrop belt. In Coeymans time, the area of Andreas, Pa., was probably emergent (Andreas Red Beds of Swartz and Swartz, 1941, a possible nonmarine clastic correlative of the Coeymans). The shoreline lay somewhere near Hazard, Pa., where sediment-bearing streams entered the basin and currents spread quartzose silt, sand, and pebbles out into the basin as well as along the shore as far northeast as the New York-New Jersey border (Epstein and others, 1967), as evidenced in the Stormville and Peters Valley Members of the Coeymans Formation (fig. 5). The following zones existed: 1) near Kunkletown, Pa., the barrier-beach zone (Stormville Member of the Coeymans Formation, fig. 5: lenses and beds of crossbedded quartzose sandstone and conglomerate); 2) near Minisink Hills, Pa., the barrier-beach-biostromal bank zone (Shawnee Island Member of the Coeymans Formation, fig. 5: argillaceous and arenaceous biogenic limestone), an area slightly more distant from shore and (or) clastic sediment influx; 3) near Tocks Island, N.J., the reef-inter-reef zone (biohermal and non-biohermal facies of the Shawnee Island Member, fig. 5: very coarse grained crudely bedded to unbedded biogenic limestone and argillaceous and arenaceous biogenic limestone), a high-energy marine enviroment where wave activity over the reefs swept clay- to sand-sized clastic and biogenic debris beyond the reefs or into inter-reef areas. These separate carbonate-orthoquartzite

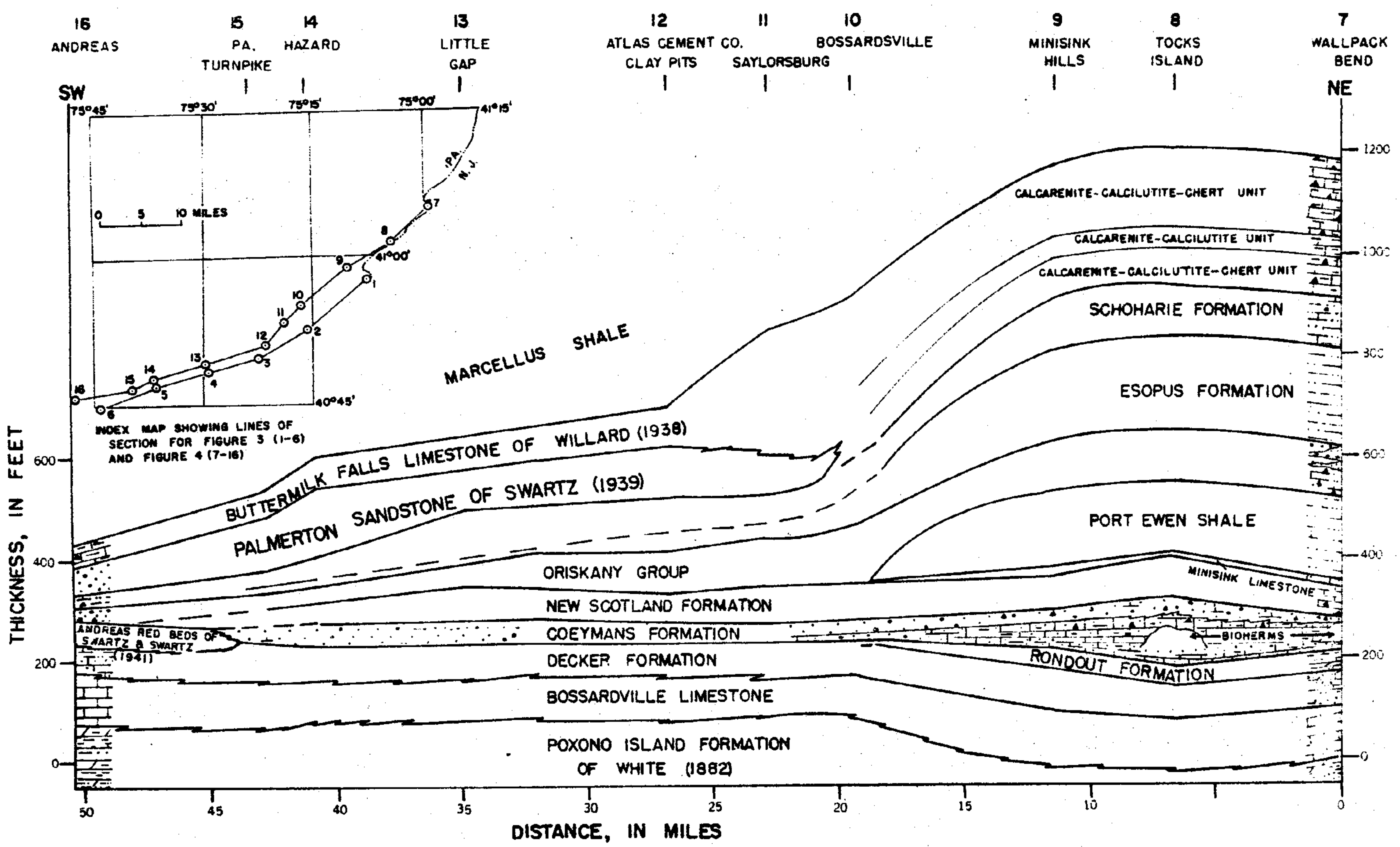


Figure 5 Stratigraphic section of the Poxono Island Formation of White (1882) through the Butterm: .x Falls Limestone of Willard (1938) from Wallpack Bend to Andreas, Pa.

subfacies merged into one barrier-beach facies from Lehigh Gap to the Pennsylvania-New Jersey border (fig. 5) in late Stormville time.

A deeper water neritic phase followed Stormville deposition. Rickard (1962) interprets the lithofacies of the New Scotland Formation and Port Ewen Shale as indicative of a deep-water neritic environment. From New Scotland through most of Port Ewen time, the basin slowly subsided (fossiliferous calcilutite containing beds and lenses of very fossiliferous limestone, both having an abundant benthonic fauna, and beds and lenses of chert, gradually give way to laminated calcisiltite with a less abundant fauna). In the Delaware Water Gap area, sediment influx exceeded basin deepening from late Port Ewen through Oriskany time. Deposition, however, was continuous, and a gradual transition from a deep- to shallow-water neritic shelf environment porceeded from Port Ewen to Oriskany time. To the southwest, beds of the Oriskany Group overlie successively older strata, so that at Kunkletown, Pa., the Oriskany overlies the New Scotland Formation, whereas farther to the southwest at Andreas, Pa., it overlies the Andreas Red Beds of Swartz and Swartz, 1941 (fig. 5). In late Oriskany time the strandline continuously shifted to and fro across the field-trip area (lenses and beds of quartzose sandstone and conglomerate, barrier-beach deposits, abruptly overlie and lense into beds of monospecific brachiopod hash, very shallow littoral deposits). The entire area was emergent following Oriskany time. Neritic shelf conditions were re-established in late Early Devonian time. From late Early Devonian through early Middle Devonian time, sediment influx and basin filling were more or less concomitant. Where clastic influx was high and (or) the area lay slightly more shoreward, coarser grained sediments characterize the record, e.g., the Palmerton Sandstone of Swartz, 1939, is a probable coarse-grained quartzose near-shore facies of part of the Buttermilk Falls Limestone of Willard, 1938, a highly fossiliferous deeper neritic calcilutite. Shallower waters lay to the southwest in early Middle Devonian time.

Marcellus through Mahantango time records the re-establishment of geosynclinal flysch sedimentation (carbonaceous shale with a depauperate fauna, Marcellus Shale, grades upward into rhythmically bedded fossiliferous graded siltstones, Mahantango Formation). The Middle and Upper Devonian formations, Marcellus Shale through the Catskill Formation, repeat, with minor variations, the Middle Ordovician through Upper Silurian flysch-molasse succession.

Structural geology

Field mapping in rocks of Ordovician to Devonian age in eastern Pennsylvania and northwesternmost New Jersey indicates that rocks of differing lithology and competency have different styles of deformation. Folding is thus disharmonic. Four rock sequences, lithotectonic units, have been recognized. Each sequence has been deformed semi-independently of rocks above and below and presumably is set off from these by decollements (detachments along a basal shearing plane or zone). Type and amplitude of folds are apparently controlled by lithic variations within each lithotectonic unit. The lithotectonic units, their lithologies, thicknesses, and styles of deformation are listed in table 3.

Three decollements, or zones of decollement in relatively incompetent rocks, are believed to separate the four lithotectonic units. The Martinsburg-Shawangunk contact is interpreted to be a zone of detachment between lithotectonic units 1 and 2 and will be seen at Lehigh Gap (stop 3, first day). Thin fault gouge and breccia and development of bedding-plane slickensides with microscarps or steps indicating northwest movement of the

Table 3 ---Lithotectonic units in the Delaware River Lehigh River area, Pennsylvania

Litho tectonic unit	Age of lithotectonic unit and stratigraphic sequence (see tables 1& 2)	Lithologic characteristics	Style of folding	Average size of folds
4	Upper and Middle Devonian Marcellus Shale and younger rocks	More than 10,000 feet of sandstone, conglomerate, siltstone, and shale	Nearly symmetric, concentric, predominantly flexural slip	Two major folds in the area (Weir Mountain syncline and Lehighton anticline--fig. 2); half-wavelengths of more than 5 miles; amplitudes diminish from 4,200 feet near Kunkletown to zero near Bossardsville
3	Middle Devonian to Upper Silurian Buttermilk Falls Limestone of Willard (1938) to upper part of Poxono Island Formation of White (1882)	700 to 1,500 feet of limestone, shale, siltstone, sandstone, and dolomite; heterogeneous stratigraphic units between 3 to 180 ft. thick.	Asymmetric, concentric and similar, flexural slip and flow, passive slip and flow. Cascade folds in the east and flaps (antiformal synclines and synformal anticlines) in the west	Wavelengths 1,000 to 1,500 feet; amplitudes about 250 feet in the east increasing to about 1,500 feet in the west
2	Upper to Lower Silurian Lower part of Poxono Island Formation of White (1882) to Shawangunk Conglomerate	3,100 feet of sandstone, siltstone, shale, and conglomerate; coarser toward base of sequence	Asymmetric, concentric; flexural slip with minor passive slip and flow. Extensive bedding slip and wedging in the Bloomsburg Red Beds. Folds tighter in western part of area with development of faulted-out cores of anticlines west of Lehigh River	Wavelengths about 1 mile; amplitudes 1,500-5,00 feet
1	Upper and Middle Ordovician Martinsburg Formation	About 12,000 feet of thick monotonous sequences of slate and graywacke	Asymmetric, similar nearly isoclinal, nearly recumbent in eastern section; mainly passive flow and slip, flexural slip near contact with Shawangunk Conglomerate. Folds probably superimposed on upright limb of large regional nappe	Wavelengths 1,000 to 3,000 feet; amplitudes 400 to 2,000 feet. Small-scale imbricate faults and major thrusts with possible displacements in miles south of field-trip area

overlying Shawangunk Conglomerate will be seen at this stop.

A thick detachment zone probably separates lithotectonic units 2 and 3. The change in style of deformation between the two units takes place in the Poxono Island Formation of White (1882), but considerable northwest movement is indicated by wedging and bedding slip in the Bloomsburg Red Beds. At stop 4, first day, it will be suggested that the net telescoping in the Bloomsburg may amount to many miles. Certainly the amount of shortening in lithotectonic unit 3 in the western part of the field-trip area amounts to several miles. Field evidence does not support an interpretation made by Wietrzychowski (1963) that the folds in lithotectonic unit 3 are related to the extension of the Sweet Arrow fault of Wood and Kehn (1961). The Sweet Arrow fault must terminate several miles west of the Lehigh River.

The movement between lithotectonic units 3 and 4 appears to have occurred within the Marcellus Shale. This incompetent formation is extensively faulted in the Lehigh Gap area (J. D. Glaeser, oral commun., 1967). In the Stroudsburg area, to the east, the possible zone of movement in the Marcellus Shale is not seen because of thick drift cover. Wedging and bedding slip observed in the Catskill Formation north of the field-trip area indicates that considerable movement may have taken place within lithotectonic unit 4. Examples of small-scale internal disharmony within all lithotectonic units are numerous.

Because the detachment zones generally dip to the northwest and may be rootless, northwest movement into the Appalachian basin may have been primarily by gravitational sliding, albeit aided by directed tectonic forces. Because cleavage in the Bloomsburg Red Beds is deformed at slippage planes and because the cleavage fans the folds, the sliding must have occurred after folding began and possibly was the result of the folding, i.e., the necessary slope for sliding was developed by folding. Upward shearing of these decollements, as described by Gwinn (1964) in decollements in central and western Pennsylvania, has not been observed in this area. Possibly these decollements are similar to or continuous with those described to the southwest by Gwinn.

The axial planes of the folds in lithotectonic unit 3 maintain a near-perpendicularity to the form surfaces of the underlying and overlying units. The folds, therefore, may have developed early in the deformational sequence and were later refolded. Certainly this should be a considered working hypothesis.

The intensity of deformation increases from east to west across the field-trip area: (1) In the east, the structure is generally monoclinal with numerous superimposed folds, many of which are overturned (fig. 6). In the west, many of the folds are recumbent and isoclinal, and continued tightening has produced faults in lithotectonic units 1 and 2 because of insufficient space in the cores of anticlines (fig. 7). 2) The Weir Mountain syncline increases in amplitude from zero near Bossardsville (figs. 2 and 6) to more than 4,200 feet west of Kunkletown. 3) Flow cleavage in the Marcellus Shale is recognizable in the Stroudsburg area, but farther west the cleavage is so well developed that the rock has been quarried for slate (Behre, 1933, p. 121). Other evidence may be cited. Most notable is the change in width of the Appalachian Mountain section of the Valley and Ridge province. In the east, this section is not more than 5 miles wide, but to the west it rapidly increases to about 40 miles west of the Lehigh River (see map of physiographic provinces of Pennsylvania provided in the front of this guidebook.

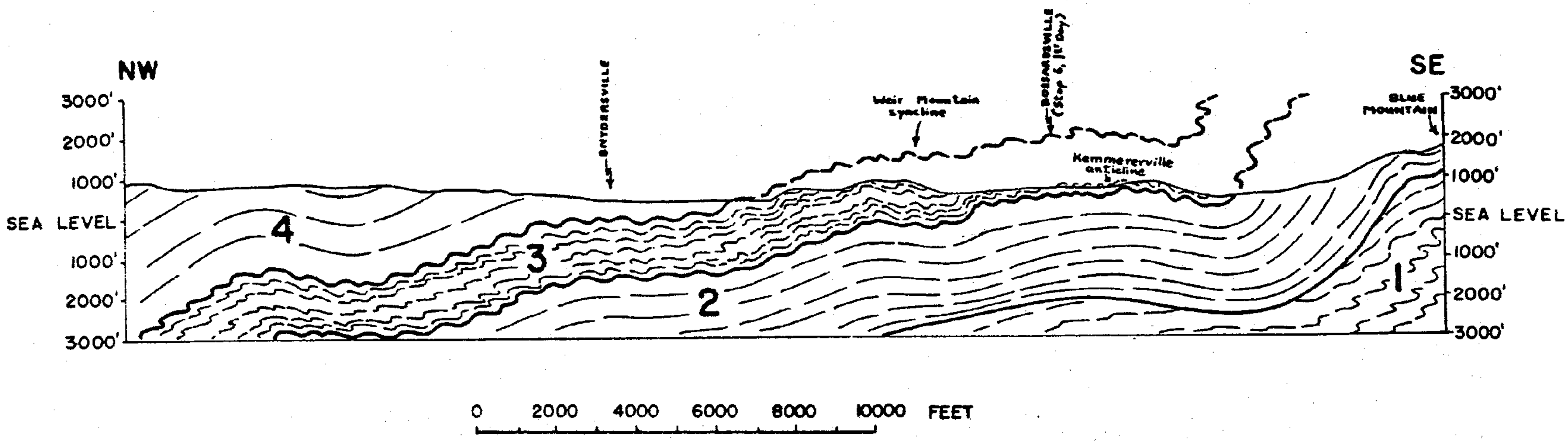


Figure 6. Geologic section through Bossardsville (Stop 6, first day), and Snydersville in the eastern part of the field-trip area, showing disharmonic folding in four lithotectonic units and the angular unconformity between the Martinsburg Formation of lithotectonic unit I and the Shawangunk Conglomerate of lithotectonic unit 2.

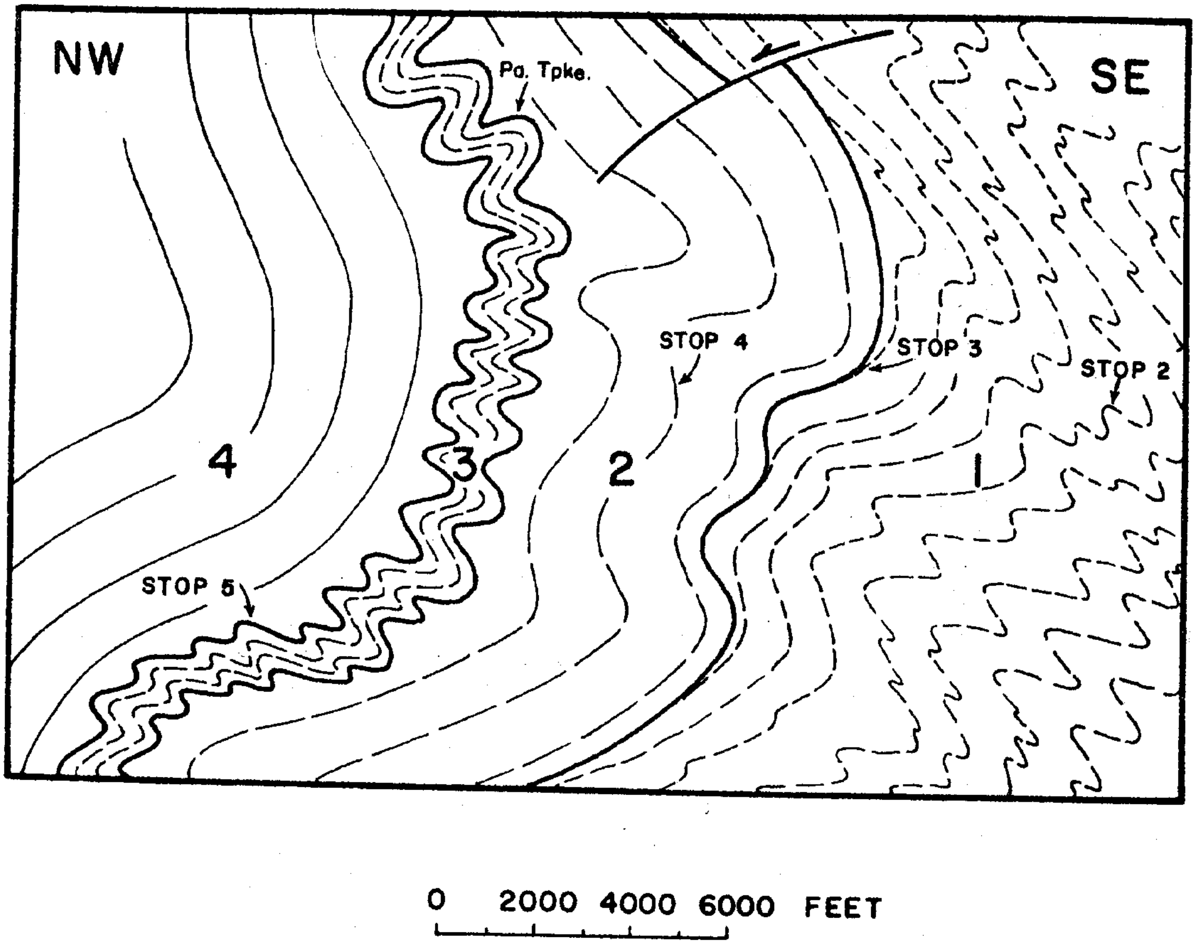


Figure 7. Reconstructed geologic section near Lehigh Gap in the western part of the field-trip area showing disharmonic folding in four lithotectonic units and the angular unconformity between the Martinsburg Formation of lithotectonic unit 1 and the Shawangunk Conglomerate of lithotectonic unit 2. Position of stops 2, 3, 4, and 5 of the first day projected to plane of section. Vertical scale same as horizonal.

Two mechanisms were operative in producing the folds: 1) flexural folding, in which bedding was active and movement was either by slip (flexural slip) or flow (flexural flow), and 2) passive folding, in which movement was along laminar-flow planes (passive flow) or slip planes (passive slip), and in which bedding was passive and merely indicates deformation in the direction of movement (see Donath and Parker, 1964). Flexural-slip folding in the field-trip area is characterized by extensive development of bedding-plane slickensides and by maintenance of constant orthogonal bedding thickness in all parts of the fold, whereas in flexural-flow folding, thickness perpendicular to bedding need not be constant. Passive folds are essentially similar in form, and constant axial plane thicknesses (the length between bedding planes measured along cleavage, for example) are generally maintained. If the planes of movement (the cleavage direction) are macroscopically discontinuous, the folding is by passive slip, but if the movement planes are so closely spaced as to be indistinguishable to the unaided eye, the folding is termed passive flow. In this day when the terminology of cleavages is so confused, it is tempting to call the first type of cleavage "slip cleavage" and the second type "flow cleavage," leaving fracture cleavage, along which there has been no apparent movement, as another end type of a continuous spectrum. Slaty cleavage thus becomes a descriptive term referring to the property, dependent upon the parallelism of platy minerals, whereby a rock can be split into very thin slabs of slate (Martinsburg Formation, stop 2, first day).

THE TACONIC OROGENY IN EASTERN PENNSYLVANIA

The contact between the Martinsburg Formation of Ordovician age and Shawangunk Conglomerate of Silurian age has attracted the attention of geologists ever since Rogers (1838) recognized that it was an unconformity and later proclaimed that the orogeny was the "...most momentous ... revolution" in North America (Rogers, 1858, p. 785). White (1882) described the contact as unconformable at Lehigh Gap, Pa., and Otisville, N.Y., but Chance (in White, 1882) and Lesley (1883) maintained that the angular relations were due to faulting. Later, Clark (1921) and Keith (1923), among others, maintained that the angular unconformity seen between Ordovician and Silurian rocks to the northeast is not to be seen in Pennsylvania.

Miller (1926) disagreed. He believed that an angular unconformity is present in Pennsylvania and based his conclusions on the following reasons: 1) the disconformable relations seen in exposures; 2) sericitized slate pebbles in the basal beds of the Shawangunk Conglomerate, apparently derived from the underlying Martinsburg; 3) omission of beds along strike; 4) the Martinsburg Formation is more highly metamorphosed than Devonian shales a few miles away; 5) structures in Ordovician and Cambrian rocks are more complex than those in Devonian and Silurian rocks; 6) the cleavage in the Martinsburg which was found during the Taconic orogeny is itself deformed into folds and was faulted by the later Appalachian orogeny.

Behre (1924, 1933) argued that the Taconic orogeny produced slaty cleavage, close overturned folds, and thrust faults and was more intense than later Appalachian deformation which merely distorted the slaty cleavage. Behre (1927, 1933) divided the Martinsburg into three members, a lower and upper slate separated by a sandstone unit. Stose (1930), however, maintained that the upper slate member of Behre is the lower repeated by folding; hence the Taconic orogeny must have been intense, for the Shawangunk Conglomerate rests on the lower member of the Martinsburg. Recent work by Drake and Epstein (1967) has re-established the threefold subdivision of the Martinsburg.

Willard and Cleaves (1939) showed that the angular unconformity extended as far southwest as Susquehanna Gap in Pennsylvania, where the Bald Eagle Conglomerate of Grabau (1909) rests conformably on top of the Martinsburg Formation. Willard (1938) earlier pictured the unconformity at Delaware Water Gap. His cross section through the gap is not in agreement with the information presented in this guidebook and will be discussed at stop 6 of the second day.

Hess (1955) believed that the Taconic orogeny was so intense that it was not the cause of folding of the sediments in the Appalachian geosyncline, but rather the cause of the geosyncline itself. Woodward (1957) maintained that the slate belt in the Martinsburg is the result of the superposition of three periods of folding, each having a different trend. However, there is no field evidence to support Woodward's views.

Recent work in the Delaware Valley by Drake and others (1960) led to the interpretation that the Taconic orogeny was more severe than the Appalachian orogeny in that area, but that far more complex structural terrane was present to the southwest, and that the slaty cleavage in the Martinsburg is Taconic in age. At the same time Arndt and Wood (1960) concluded that the Appalachian orogeny was by far the stronger. Wood and others (1963, p. 78) suggested that the discordant contact between the Martinsburg and Shawangunk might be largely the result of faulting. Maxwell (1962) concluded that the flow cleavage in the Martinsburg Formation in the Delaware Water Gap area was produced during the Taconic orogeny, but he maintained that the cleavage was the product of only slight stress on pelitic sediments with high pore-water pressures. The slate that was produced, therefore, is not a metamorphic rock, but rather a diagenetic rock. As a consequence, Maxwell concluded that the Taconic orogeny was minor. Fracture cleavage was produced in the Martinsburg and younger rocks during the later, more intense, Appalachian orogeny. Maxwell's ideas are stimulating, but the bulk of field evidence sheds doubt on many of his conclusions.

The recent interpretation that a large nappe underlies the Great Valley in easternmost Pennsylvania (Drake, and others, 1961, 1967; Drake 1967a, 1967b; Drake and Epstein, 1967; Davis and others 1967) with no structural counterpart in rocks younger than Ordovician, strongly suggests an intense Taconic orogeny. Nappes have been reported in other parts of the Great Valley (Stose, 1950; Gray, 1954).

Thus, the relative intensities of the Taconic and Appalachian orogenies in eastern Pennsylvania have not been resolved, and there has been disagreement whether the Ordovician was ever a period of mountain building in eastern Pennsylvania. On the basis of field evidence outlined below, it is concluded that 1) there is an angular unconformity between the Martinsburg Formation of Ordovician age and Shawangunk Conglomerate of Silurian age; 2) the slaty cleavage in the Martinsburg and younger rocks is Appalachian in age; 3) most of the folding seen in the field-trip area is Appalachian in age; and 4) the effects of the Appalachian orogeny in this small area were far more intense than the observed effects of the Taconic orogeny; however, if the Taconic nappe reported in the Great Valley was atectonitic (no tectonic fabric was developed), as the one reported by MacLachlan and Root (Field Conference of Pennsylvania Geologists, 1966, p. 47), then evidence for this nappe would not be present in the field-trip area and the Taconic orogeny may have been extremely intense.

The contact between the Martinsburg Formation and Shawangunk Conglomerate has been seen or reported at five localities in this area (fig. 2). On the basis of observations at these localities and from data gathered during mapping of 40 miles along the Martinsburg-Shawangunk contact, the following generalizations may be made:

1) Slaty cleavage penetrates all pelitic rocks of the Martinsburg Formation except within 100-200 feet of the contact with the Shawangunk Conglomerate where slaty cleavage disappears and bedding-plane slickensides become prominent.

2) A second (slip) cleavage cuts the earlier slaty cleavage in the Martinsburg in the southern part of the eastern section of the area. To the west, the slip cleavage appears higher in the Martinsburg, and in the Lehigh Gap area it is found in overlying formations.

3) No fragments of Martinsburg slate have been found in basal Shawangunk beds.

4) At all localities where the contact between the Shawangunk Conglomerate and Martinsburg Formation has been seen, there is a thin clay zone believed to be a fault gouge. At Lehigh Gap and along U. S. Interstate 84 about 4 miles east of Port Jervis, N. Y., there is a thin fault breccia at the contact. Steps on slickensided bedding surfaces indicate that the overridding beds in the Shawangunk moved to the northwest.

5) The attitudes of cleavage in the Martinsburg Formation within a few miles of the Shawangunk contact are very similar to attitudes of cleavage in overlying rocks, strongly suggesting that the Martinsburg cleavage was not deformed by the stresses that produced cleavage in the younger rocks and implying that all cleavages were formed during a single period of orogeny (fig. 8). Martinsburg cleavage, however, is folded into cleavage arches farther to the southeast, and a second (slip) cleavage is extensively developed, indicating that deformation increased in intensity in that direction.

6) In a few localities where they have been mapped, fold axes pass from the Shawangunk Conglomerate into the Martinsburg Formation without deflection, showing that the folds are post-Taconic in age. Cleavage in the Martinsburg is parallel to the axial planes of the folds, or fans the folds slightly, showing that the cleavage is also post-Taconic in age.

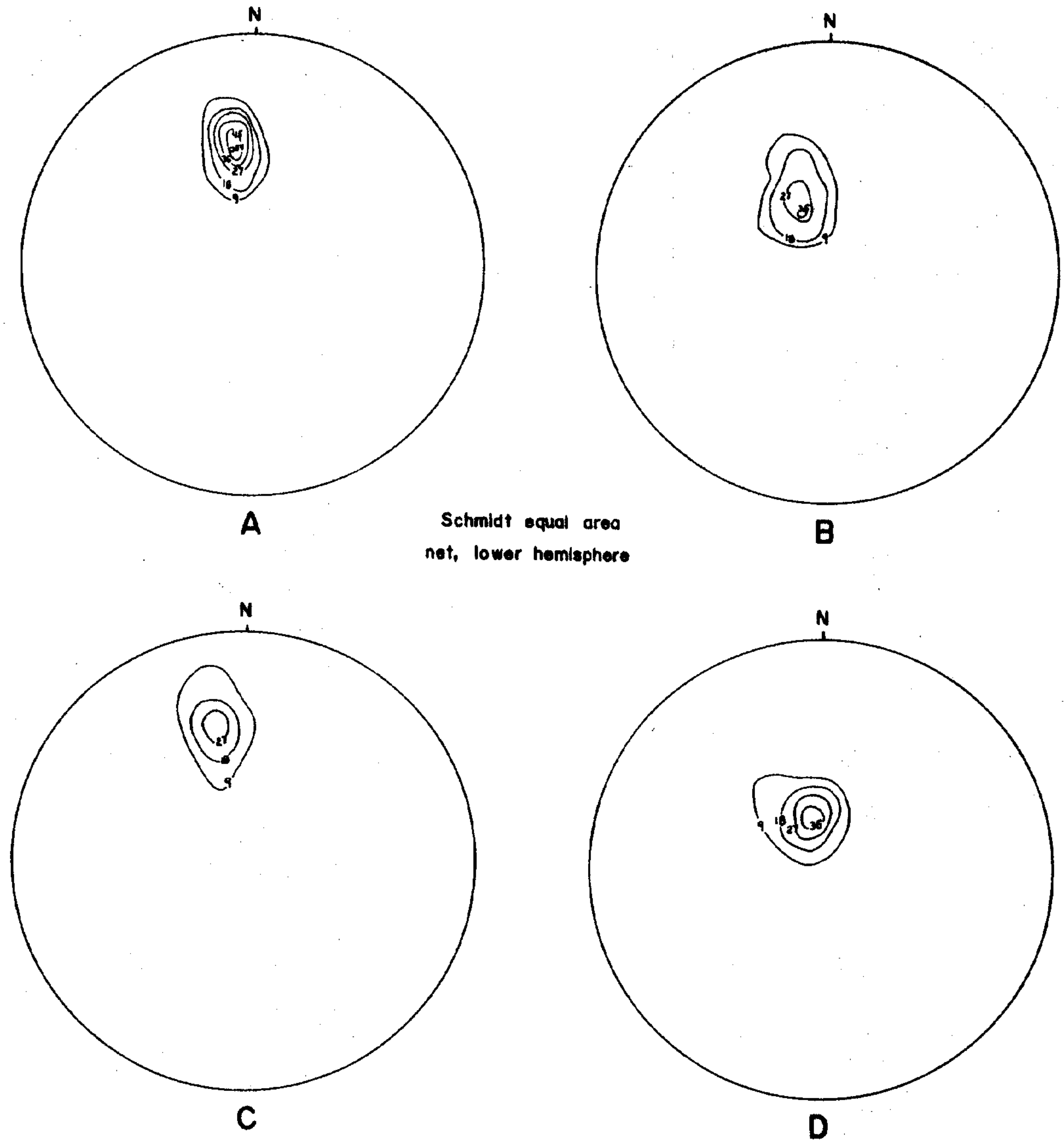


Figure 8. Stereographic projections of cleavage (S_2) in the Martinsburg Formation and Marcellus Shale and Mahantango Formation in the Palmerton and Stroudsburg quadrangles. Contour interval 9 percent per 1 percent area. See figure 1 for location of quadrangles.

A, Mahantango Formation, Palmerton quadrangle; 42 poles; maximum at N. 79° E., 42° SE.; data from W.D. Sevon, Pennsylvania Geological Survey.

B, Marcellus Shale and Mahantango Formation, Stroudsburg quadrangles; 28 poles; maximum at N. 66° E., 23° SE.

C, Martinsburg Formation, Palmerton quadrangle; 224 poles; maximum at N. 78° E., 50° SE.

D, Martinsburg Formation, Stroudsburg quadrangle; 90 poles; maximum at N. 75° E., 20° SE.

7) In the Delaware Water Gap area, moderately dipping southeast cleavage in the Martinsburg Formation flattens within 2,000 feet of the Shawangunk Conglomerate and then dips gently to the northwest as the contact is approached. Maxwell (1962) attributed this arching of the slaty cleavage to refolding during the Appalachian orogeny. This phenomenon is accompanied by the development of bedding-plane slickensides, and in view of what has been said concerning the disharmonic relations between lithotectonic units 1 and 2, it is suggested that the arching of the cleavage is due to drag as the Shawangunk moved over the Martinsburg on a decollement.

8) Quartz, chert, and quartzite pebbles in the basal beds of the Shawangunk, in places more than 5 inches long, indicate that the Martinsburg was breached at the time the basal part of the Shawangunk was deposited so that underlying stratigraphic units were exposed and supplying pebbles (possibly chert from the Beekmantown Group, quartzite from the Hardyston Quartzite, and vein quartz from Precambrian rocks). Thus an unconformity is indicated. The sharp lithologic break at the contact also indicates that rocks of inferred deep-water origin (Martinsburg Formation) are overlain by fluviatile-terrestrial deposits (Shawangunk Conglomerate).

9) There is an angular discordance at all localities where the Martinsburg-Shawangunk contact has been seen in outcrop or reported in tunnels. Figure 2 shows these localities, and they are described below:

1. Pennsylvania Turnpike Extension tunnel through Blue Mountain: Martinsburg is overturned and dips 35°SE.; the Shawangunk is also overturned but dips 45°SE.
2. Lehigh Gap: Martinsburg dips 46°NW.; Shawangunk dips 36°NW. (Seen at stop 3 of the first day.)
3. Water tunnel for the city of Bethlehem, Pa., at Little Gap,

from unpublished data by B. L. Miller, 1940: Martinsburg strikes N. 35° E. and dips 52° SE., overturned; the Shawangunk strikes N. 68° E. and dips 55° SE., overturned.

4. Delaware Water Gap: the contact was formerly exposed and reported by Beerbower (1956) to be unconformable by 3° in strike and 1° in dip. Mapping of graywacke beds in the Martinsburg in the gap area shows that the strike of the Martinsburg differs from that of the Shawangunk by about 15°, and the contact between the Pen Argyl and Ramseyburg Members of the Martinsburg Formation is unconformably overlain by the Shawangunk Conglomerate 2 miles west of Delaware Water Gap (see fig. 31).

5. Yards Creek hydroelectric pumped storage project near Blairstown, N. J.: the middle (Ramseyburg) member of the Martinsburg Formation is unconformably overlain by the Shawangunk Conglomerate. The cutting out of beds in the Martinsburg is discernible, but the angular relations are not readily measurable.

GEOMORPHOLOGY

The area of the field conference lies in the Appalachian Mountain and Great Valley sections of the Valley and Ridge physiographic province (see figure showing physiographic provinces of Pennsylvania, and fig. 3). The area has been extensively studied by geomorphologists who have concerned themselves with the classic problems of Appalachian drainage evolution, peneplanation, origin of wind and water gaps, etc. Discussion of one of these problems necessitates consideration of the others. However, on this field trip we shall limit our discussion to one topic, the origin of wind and water gaps.

It has been concluded that there is structural control of the gaps in the Stroudsburg area (Epstein, 1966; reprint provided in back of this field guidebook); that is, the gaps are located where folds die out over short distances, where folding is locally more intense, or where resistant rocks dip steeply and have a narrow width of outcrop. In addition to the gaps discussed in the included reprint, three gaps in Blue Mountain, in the western part of the field-trip area, also show structural control; Little Gap (on the limb of a recumbent, nearly isoclinal fold, fig. 9); Lehigh Gap (two folds die out abruptly to the west, stops 3 and 4, first day); and Lehigh Furance Gap (where a longitudinal fault emerges from the core of an antiform and has been rotated about a vertical axis during refolding; fig. 19, discussed at stop 4, first day).

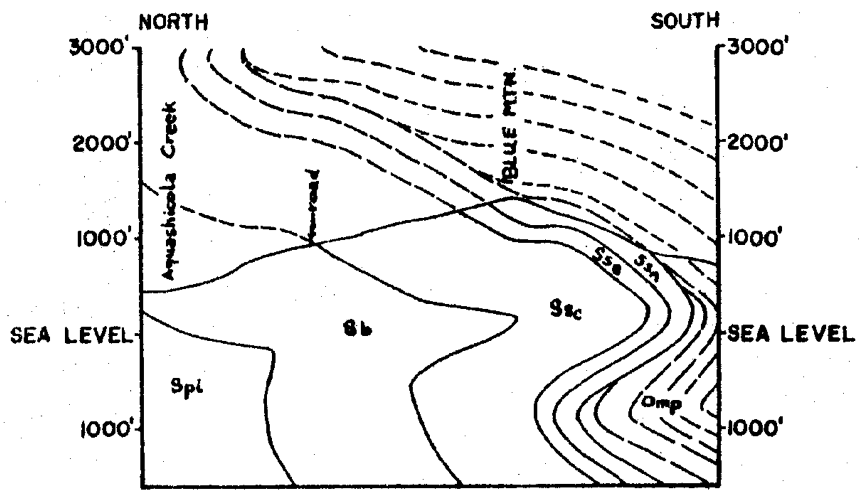


Figure 9. Geologic section through Blue Mountain, 2,000 feet east of Little Gap. Some data from unpublished cross section of water tunnel for city of Bethlehem, Pa., by B. L. Miller, 1940. Horizonal scale same as vertical. Spi, Poxono Island Formation of White (1882); Sb, Bloomsburg Red Beds; Ssc, quartzite-argillite unit of Shawangunk Conglomerate; Ssb, lower quartzite-conglomerate unit of Shawangunk Conglomerate; Ssa, conglomerate unit of Shawangunk Conglomerate; Omp, Pen Argyl Member of Martinsburg Formation.

Glacial Geology

There is evidence of at least two glaciations in the field-trip area. Deeply weathered till and outwash deposits, possibly Illinoian in age, occur beyond the limit of the fresher till and melt-water deposits of the Wisconsin drift sheet. The older (Illinoian?) drift will be seen at stop 2, first day.

Glacial sediments of Wisconsin age are composed of varying proportions of gravel, sand, silt, and clay. On the basis of texture, internal structure, bedding and sorting characteristics, and generally well-preserved landforms, the deposits are subdivided into till (ground, end, and terminal moraine) and stratified drift (deltaic, glacial lake-bottom, kame-terrace, and sublacustrine-end moraine deposits). The deposits and glacial history of the Stroudsburg quadrangle, in the eastern part of the field-trip area, have been described (Epstein, in press).

Wisconsin deglaciation occurred in successive phases of northeastward retreat across the area. Periods of stagnation are characterized by ice-contact deposits such as kames, whereas end moraines and ice-margin deltas are interpreted to reflect periods of normal retreat (i.e., the ice-margin was continuous with the retreating main ice mass). A conspicuous terminal moraine marks the limit of the Wisconsin Glaciation (figs. 2 and 3). Because the slope of the land just in front of the terminal moraine was eastward, toward the Delaware River, a basin formed in which lake sediments accumulated. These lake deposits now appear as a flat plain in the area west of Saylorsburg, in the valleys of Buckwha and Aquashicola Creeks (fig. 3). The pre-Wisconsin drainage divide in these valleys is about 5 miles west of Saylorsburg where the valleys are narrowest.

Melt waters from the northeastward-retreating ice were trapped between the ice front and the teriminal moraine, forming a lake, Lake Sciota (fig. 10). Numerous stratified deposits, including ice-margin deltas, varved lakebeds, and a sublacustrine end moraine, were laid down in the proglacial lake. At first, the outlet of the lake was in the terminal moraine at Saylorsburg, at an altitude of about 680 feet. The earliest deltas are graded to this level. Later, after the ice retreated up the Delaware Valley, a new outlet was formed as Delaware Water Gap was uncovered and the drift dam or stagnant ice plug in the gap was slowly removed. Lake level then dropped and succeeding deltas were graded to lower levels. The lake lowered to an altitude of about 350 feet, after which the gap was cleared and the lake drained.

The Wisconsin ice was locally more than 1,300 feet thick, as shown by glacial striae along the crest of Kittatinny Mountain (seen at stop 6, second day).

Ice in Cherry Valley, in the shadow of Kittatinny Mountain (fig. 10), remained stagnant for a long time, and lakebeds and kames were deposited there.

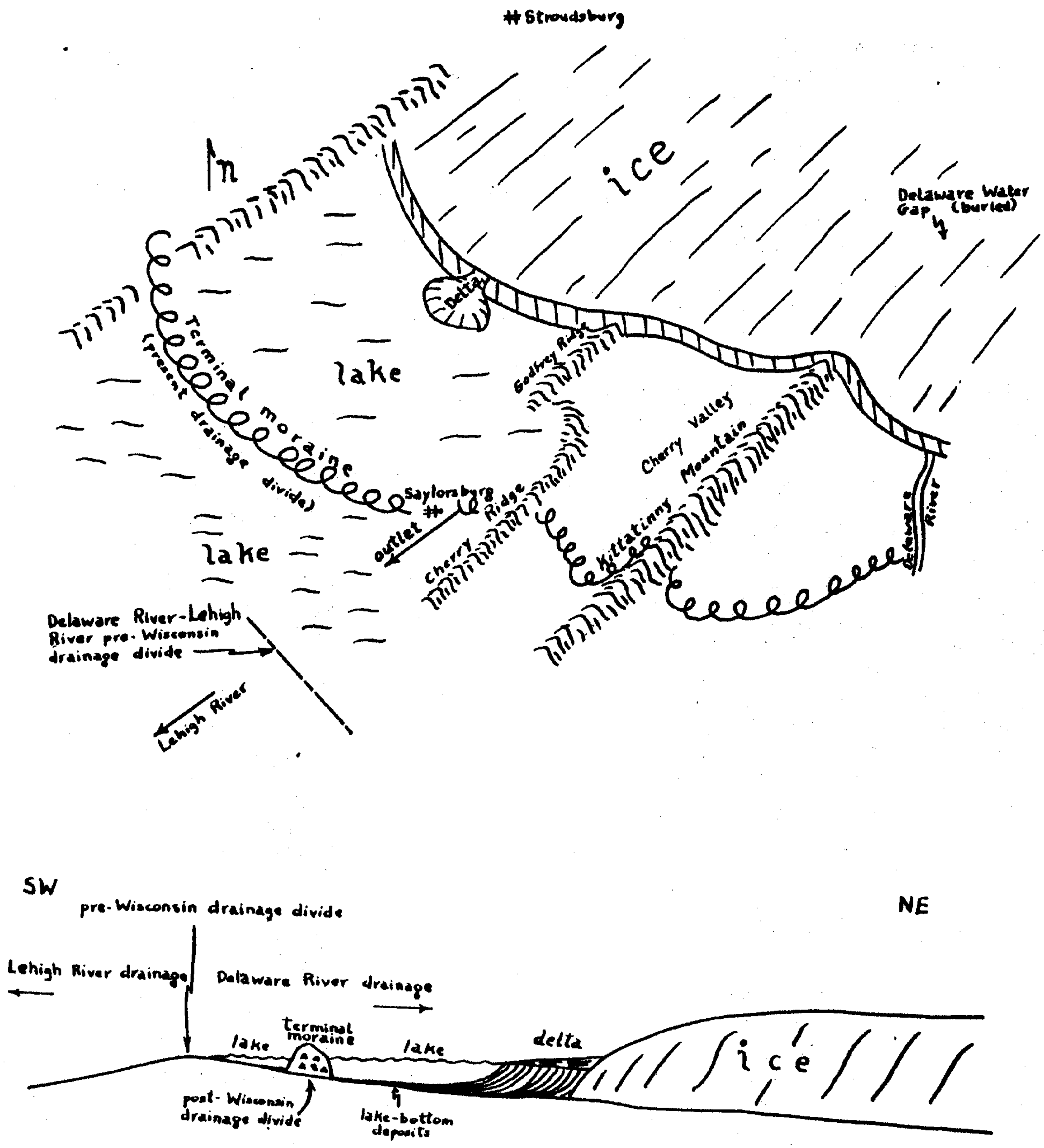


Figure 10. Diagrammatic sketch and section showing pre-Wisconsin drainage divide and position of Wisconsin glacier at the time of deposition of delta seen at stop 1, first day, in Lake Sciota. The terminal moraine marks the present Delaware River-Lehigh River drainage divide.

ROAD LOG --- FIRST DAY
Friday, September 29, 1967

Departure from the Holiday Inn Motel, East Stroudsburg at 8:00 A.M.
Field trip will follow route shown on figure 1.

<u>Mileage</u>

0.0 Leave Holiday Inn parking lot and proceed south on U. S. Rte. 209.

0.3 RIGHT turn onto U.S. Interstate 80. On right, roadcuts in the lower cherty limestone member of the Buttermilk Falls Limestone of Willard (1938). On left, Godfrey Ridge, underlain by Upper Silurian and Lower Devonian rocks.

0.9 Roadcut in Wisconsin ground moraine.

2.1 Cross Brodhead Creek.

2.3 Roadcut on left (south) exposes upper cherty limestone member of Buttermilk Falls Limestone on the northwest limb of an anticline. Road cut parallels axial trace of fold. Note variation in plunge of fold axis; folds in Godfrey Ridge are noncylindrical and nonplanar.

3.8 On left, sand and gravel in Wisconsin glacial delta deposit.

4.3 Bear RIGHT to U. S. Rte. 209S.

4.7 Coming out of cloverleaf, ridge ahead, lying at right angles to road, is an end moraine believed to have been deposited below lake level; it will be discussed at stop 1 of second day.

5.2 Road passes through sublacustrine end moraine and continues south onto glacial lake-bottom beds and other glacial fluviatile deposits.

6.5 On left, green house in birch grove sits on 1,000-foot-long ridge of stratified sand and gravel, an esker, that leads into an ice-marginal delta to the south.

Mileage

7.1 On left, sand and gravel pit exposes foreset beds of an ice-marginal delta. Proceeding south, we pass through a series of deltas whose topset plains are at an altitude of approximately 680 feet, indicating that the level of the proglacial lake, Lake Sciota, in which these deltas were deposited, was at approximately that altitude. The outlet for this lake was through the Wisconsin terminal moraine at Saylorsburg, 6.5 miles to the southwest.

8.2 Flat plain on left is underlain by varved lake-bottom beds which are locally capped with gravel.

8.5 Roadcut through Marcellus Shale.

9.0 The surrounding flat plain is underlain by varved glacial lake-bottom beds. Godfrey Ridge to left. Hills on right underlain by Marcellus Shale.

9.5 Leave interstate highway and bear RIGHT to Snydersville exit.

9.7 Stop sign, RIGHT turn.

9.9 Stop sign, LEFT turn.

10.1 Evergreen-capped ridge to right is an esker that leads into the ice-marginal delta of STOP 1.

10.5 Buttermilk Falls Limestone and Schoharie Formation exposed in roadcut to left.

11.1 Sand and gravel pit in an ice-marginal delta deposit.

STOP 1. GRAVEL PIT IN ICE-MARGINAL DELTA AND ESKER

20 MINUTES

The delta and esker at this locality are very well preserved (fig. 11). Note the flat top of the delta, the lobate foreset slope (as we pass south of it), and the typical nodular form of the esker to the northwest.

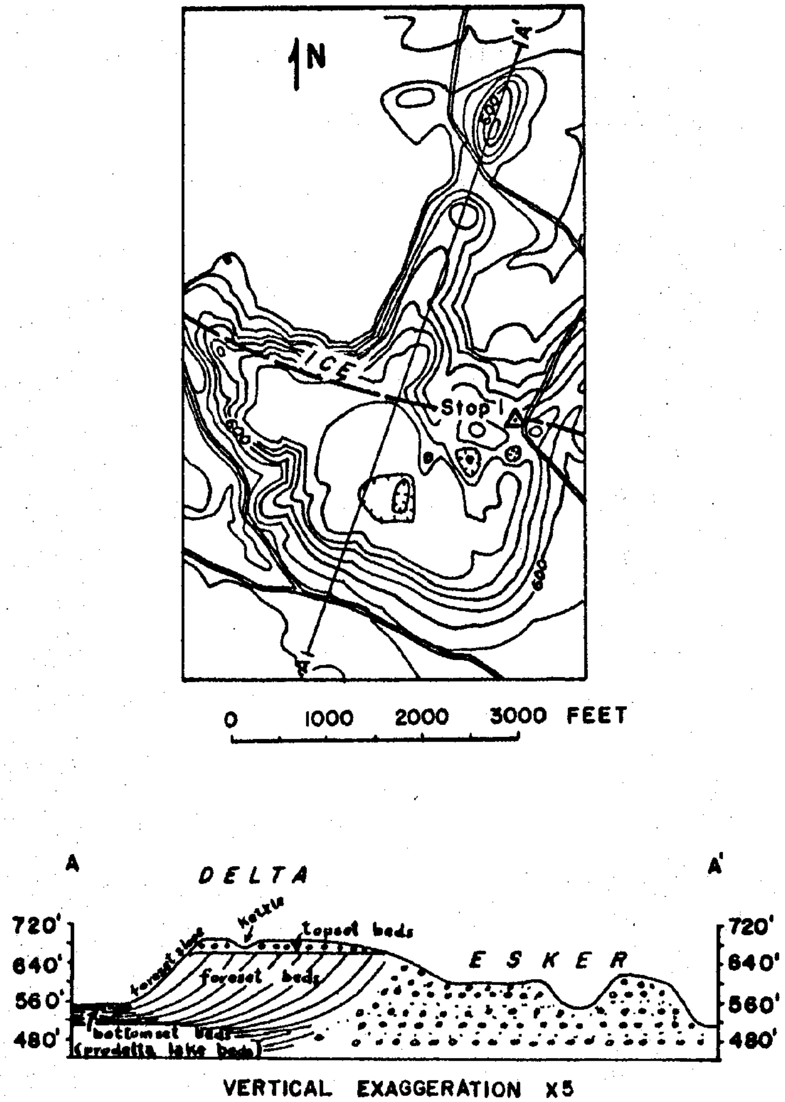


Figure 11. Topographic map and geologic section of esker and delta at stop 1, first day, showing inferred position of ice margin at time of deposition. The level of Lake Sciota in which the delta was deposited was near the topset-foreset interface. Topography from U. S. Geological Survey, Saylorsburg 7½-minute quadrangle, Pennsylvania.

Rhythmically laminated sand, silt, and clay were uncovered in the lakebeds to the south during construction of the underpass for U.S. Rte. 209 about 2,000 feet to the south. The topset and foreset beds are well displayed in the gravel pit. The esker was deposited subglacially or englacially. The hummocky proximal slope of the delta marks the position of the ice at the time of deposition (fig. 11). Kettle holes in the topset plain of the delta probably indicate areas where drift collapsed because of melting of buried ice masses.

The delta was deposited in glacial Lake Sciota, an ice-defended, moraine-dammed lake, during Wisconsin time. The outlet in the moraine was at Saylorsburg, 3 miles to the southwest (fig. 10). The level of the lake was at about 680 feet, the approximate altitude of the foreset-topset interface. The procession of ice-marginal deltas, passed enroute to this stop, were deposited as the ice margin moved northeast in normal retreat (i.e., the ice margin did not stagnate) and open water lay to the southwest. At its maximum extent, Lake Sciota was more than 8 miles long.

Note the fresh appearance of the sand and gravel that make up the topset and foreset beds of the delta. Compare this with the more distinctly weathered older drift, Illinoian (?), southwest and west of the terminal moraine and at stop 2.

Mileage

11.1 Continue on road towards Sciota.

11.3 Road curves around lobate foreset slope of delta. Lake-bottom beds in valley to left.

11.6 RIGHT turn towards Sciota.

12.4 Sciota. Stop sign at road junction. LEFT turn onto U.S. Rte. 209. Follow road to Saylorsburg.

12.5 Marcellus Shale in pit to right.

12.9 Glacial delta of stop 1 to left. Note the flat topset plain, the lobate foreset slope, and the valley underlain by lake-bottom beds in front of the delta. Blue Mountain in skyline; Cherry Ridge in middle ground. Note termination of Godfrey Ridge to left.

13.8 Route crosses Wisconsin terminal moraine. Note undulating topography and coarse texture of drift.

14.8 To left, Saylors Lake, a kettle lake.

15.1 Stop sign in Saylorsburg; LEFT turn onto Pa. Rte. 115.

15.2 RIGHT turn onto Kunkletown Road. At this point we are on terminal moraine near the outlet of glacial Lake Sciota, whose waters discharged via Buckwha Creek (Fig. 3) into Aquashicola Creek (at Little Gap, 12 miles to the west) and finally into the Lehigh River (5 miles farther west).

15.3 Outlet channel parallels road on left.

15.7 Wisconsin till in roadcut on right. Note undulatory topography on terminal moraine.

16.5 On right, shale pit in Marcellus Shale showing crudely stratified shale-chip gravel, possibly the result of periglacial solifluction, a congeliturbate.

17.1 Roadcuts in Marcellus Shale on right. For the next 10.7 miles, the road follows the outcrop belt of the Marcellus Shale and Mahantango Formation. On left, Chestnut Ridge, held up by the Ridgeley Sandstone and Palmerton Sandstone of Swartz (1939). Buckwha Creek valley narrows to the west as we approach the pre-Wisconsin Delaware River-Lehigh

River drainage divide.

19.1 Outcrop of Centerfield coral bed of the Mahantango Formation in creek on left, a calcareous siltstone biostrome.

19.8 Turkey farm on left.

20.6 Panoramic view. On left, Blue Mountain (underlain by Shawangunk Conglomerate and Bloomsburg Red Beds of Silurian age) and Chestnut Ridge (underlain by complexly folded uppermost Silurian to lower Middle Devonian rocks). Conical hill straight ahead is capped by a fine-grained sandstone in the Mahantango Formation (W. D. Sevon, oral commun.). Ridge on right is underlain by the Trimmers Rock Sandstone and lies on the northwest-dipping south limb of the Weir Mountain syncline.

21.4 On left, roadcut in Mahantango Formation.

21.8 Note the narrow valley of Buckwha Creek on left. This is the pre-Wisconsin drainage divide between the Lehigh and Delaware Rivers.

22.9 Roadcut in steeply-dipping uppermost Marcellus Shale on right.

23.0 Stop sign in Kunkletown; proceed straight ahead. Sandpits to left are in the Palmerton Sandstone of Swartz (1939) and Ridgeley Sandstone. SLOW!

24.2 Fork in road, keep LEFT toward Palmerton.

25.5 Note the widening of Buckwha Creek valley on left.

26.3 On right, uppermost Marcellus Shale or lowermost Mahantango Formation. Note well-developed slaty cleavage. These rocks have been quarried for slate at Aquashicola, 6 miles to the west.

27.0 Slate on right.

27.8 Little Gap. Continue straight ahead.

28.1 Roadcut through Stony Ridge. Exposed on right is an antiform and synform in Lower and Middle Devonian rocks (fig. 12). Sandpits in Palmerton Sandstone of Swartz (1939) and Ridgeley Sandstone on left. Buckwha Creek joins Aquashicola Creek at this point.

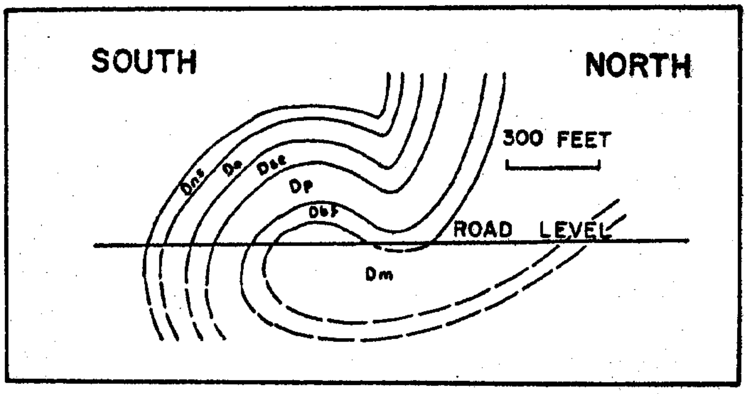


Figure 12. Diagrammmatic geologic section through Stony Ridge at Little Gap. Dns, New Scotland Formation; Do, Oriskany Group; Dse, Schoharie and Esopus Formations, undivided; Dp, Palmerton Sandstone of Swartz (1939); Dbf, Buttermilk Falls Limestone of Willard (1938); Dm, Marcellus Shale.

28.9 Broad valley on left is underlain by outwash deposits of Wisconsin age. More deeply weathered sand and gravel, believed to be remnants of a higher level Illinoian (?) outwash terrace, occur on right along road to Palmerton.

30.1 On left, Blue Mountain. Gray Shawangunk Conglomerate forms crest; Bloomsburg Red Beds below.

30.6 On left, large waste piles from the New Jersey Zinc Company smelting plant in Palmerton, rise more than 200 feet above valley floor.

31.7 On right, overturned beds of Palmerton Sandstone of Swartz (1939) in Stony Ridge dip steeply southeast.

32.0 On left, The New Jersey Zinc Company smelting plant.

The New Jersey Zinc Company
Palmerton, Pa. operation
by
Donald W. Kohls, Geologist, The New Jersey
Zinc Company

Proximity of the anthracite fields of Pennsylvania, the zinc deposits of New Jersey, and the large surrounding marketing area prompted the New Jersey Zinc Company, in the late 1890's, to select the area immediately north of the Lehigh Gap as a location admirably suited for the manufacture of zinc. As a consequence, the borough of Palmerton was founded, named for Stephen S. Palmer, then president of the Company, deriving its life blood from the world famous Franklin mine.

Until its depletion in 1954, Franklin was the major source of the ore smelted at Palmerton. The majority of ore now smelted is sphalerite, brought from the Company's mines at Friedensville, Pa.; Austinville and Ivanhoe, Va.; and Jefferson City and Flat Gap, Tenn. This supply is supplemented by purchased sulfide ore as well as oxide ore from the Company's mine at Sterling Hill, N. J.

The zinc is smelted by a pyrometallurgical process. Sphalerite is first roasted to free the zinc from the sulfur, producing impure zinc oxide and sulfuric acid. The impure zinc oxide is mixed with bituminous and anthracite coal, coked, and transferred to a vertical retort where metallic zinc is recovered. The zinc is further refined by fractional distillation to produce 99.99 percent pure zinc.

This zinc is used in die castings rather than in galvanizing, where high-purity zinc is not required.

In addition to metallic zinc, large quantities of zinc oxide are produced here. This pigment is used in paint, rubber, plastic, photoconductive paper, medicine, and a variety of other products.

Spiegeleisen, an iron alloy containing twenty percent manganese, is an important byproduct of smelting the Sterling Hill, N. J. ore. This material is used in steel manufacturing.

Cadmium, always found as a trace element in sphalerite where it substituted for zinc, is produced as a byproduct in the treatment of sulfide ores.

Mileage

32.5	Stop sign, Palmerton; proceed straight ahead. We will be traveling on a Wisconsin outwash terrace plain.
33.7	Railroad underpass. Road rises above Wisconsin outwash terrace at an altitude of 400 feet and onto an Illinoian (?) outwash terrace at an altitude of 445 feet.
34.2	Junction with Pa. Rte. 248E., bear LEFT.
34.6	Lehigh Gap straight ahead.
34.7	On left, Bloomsburg Red Beds (STOP 4).
35.0	On left, quartzite-argillite unit of Shawangunk Conglomerate.
35.5	Railroad underpass. On left, Shawangunk Conglomerate.
35.8	RIGHT turn onto Pa. Rte. 873S. and cross Lehigh River.
36.1	RIGHT turn at fork in road onto Mountain Road. Illinoian (?) drift on right.
36.4	On right, shale pit in Martinsburg Formation.
36.9	Blue Mountain on right. Road crosses sloping plain of Illinoian (?) drift (probably till mixed with colluvium from the mountain).
38.4	Pass over Pennsylvania Turnpike. On right, Shawangunk Conglomerate in Blue Mountain is steeply overturned to southeast.
39.4	LEFT turn.
40.2	On right, Penn Big Bed Slate Company quarry. STOP 2.

Stop 2. PENN BIG BED SLATE COMPANY QUARRY
I, ILLINOIAN (?) DRIFT AND CONGELITURBATE
II, STRUCTURE, STRATIGRAPHY, AND ECONOMIC GEOLOGY OF THE MARTINSBURG FORMATION

60 MINUTES

CAUTION: The quarry walls are steep-sided--do not get too close to the edge!

In the north end of the quarry the overburden consists of 14 feet of generally flat-lying tabular chips and fragments of slate as much as 6 inches long and ¼ inch thick. Pebbles and boulders from rocks north of the Martinsburg outcrop belt are scattered throughout this shale-chip gravel (fig. 13). The gravel is overlain by about 10 feet of horizontally stratified clay and pebbly

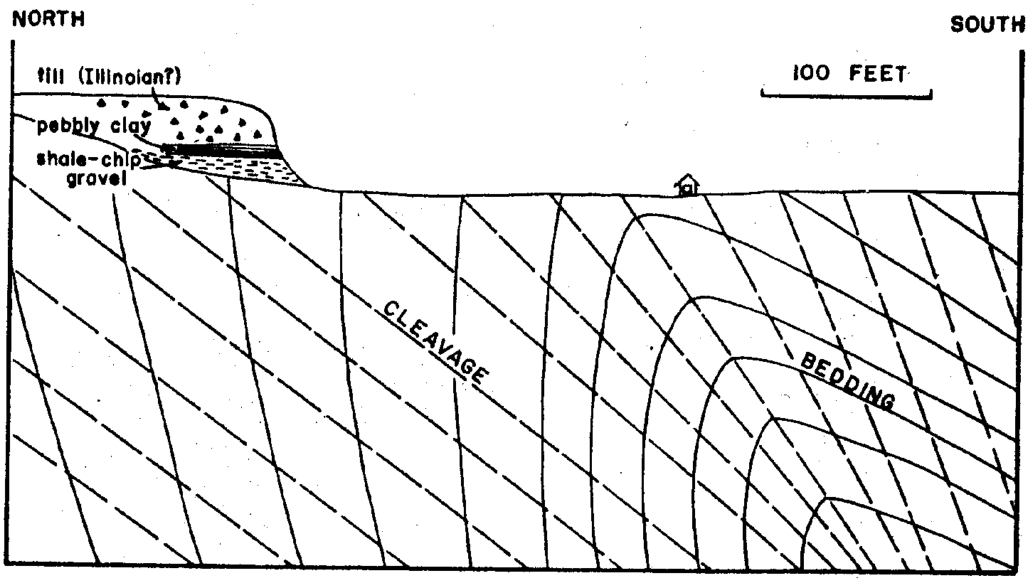


Figure 13. Diagrammatic geologic section of the Penn Big Bed Slate Company quarry, looking east, showing Illinoian (?) drift overlying the Pen Argyl Member of Martinsburg Formation. Vertical scale same as horizontal.

clay which grades up into nearly 20 feet of unsorted and unstratified yellowish- and grayish-orange bouldery clay till. The deep oxidation and leaching of the till shows that it is older than the fresher Wisconsin drift seen earlier. It is evidence of an earlier glaciation, tentatively assigned to the Illinoian Glaciation. The shale-chip gravel is interpreted to have been derived from bedrock hills a few hundred feet to the north and was probably emplaced by solifluction in a periglacial environment. It can be termed a congeliturbate. The scattered erratics in the gravel may have been brought in by streams, or more likely, because the larger boulders are angular and as much as 14 inches long, by the advancing Illinoian (?) glacier. The clay overlying the congeliturbate may be lacustrine sediments deposited in temporarily ponded areas as the ice advanced (note that the quarry area apparently occupies the site of a small buried valley). The overlying till was deposited by the south or southwest-advancing Illinoian (?) glacier as it overran the area.

This slate quarry is the only one active in the Lehigh Valley at present. There are hundreds of abandoned quarries in this area. The quarry is in the Pen Argyl Member (upper member) of the Martinsburg Formation. Behre (1927, 1933) divided the Martinsburg into three members, but Stose (1930) believed that the upper member was the lower member repeated by folding. Stratigraphic and structural evidence confirms Behre's interpretation. The Martinsburg was divided into three mappable members (Drake and Epstein, 1967) in almost the same way as Behre first defined them (see table 1).

The Martinsburg Formation is thick bedded in the quarry, typical of the Pen Argyl Member. One "big bed" seen near the top of the quarry is 12 feet thick (measured orthogonally) and is 21 feet thick along the "split" (cleavage). The rock is cyclically bedded with medium-gray slate grading up into grayish-black carbonaceous slate. Thinner beds of graywacke may form the base of some of the cycles, but they are not generally present. The graywacke contains primary convolutions and other penecontemporaneous sedimentary structures. Van Houten (1954) and McBride (1962) interpreted these structures as indicators of turbidity-current deposition.

The quarry is presently about 190 feet deep. An abandoned quarry about 300 feet along strike to the west, is about 300 feet deep but is filled with water to a depth of 200 feet. The slate taken from the quarry is used for roofing, blackboards, bulletin boards, floor tiles, structural slate, flagging, aquaria bottoms, sills and treads, and billiard table tops. About 50 percent of the rock removed ends up on the waste pile. Better quarrying procedures might cut this loss in half. The operation of this quarry, including the use of the wire saw, will be explained at the stop. Behre (1933) presents a complete discussion of slate-quarry operations.

The quarry is in an overturned anticline (figs. 7 and 13). The mechanism of deformation was predominantly by passive folding, although the many slickensided surfaces in the quarry indicate some flexural slip movement. Cleavage wrinkles these surfaces, indicating that bedding slippage preceded passive folding. The cleavage is generally a flow cleavage, but small-scale displacements on some bedding surfaces indicates that there has been some movement along the cleavage planes. The cleavage is an axial-plane cleavage and forms a fan with an angle of about 24°.

Mileage

40.2	Retrace route to Lehigh Gap.
41.1	Stop sign, RIGHT turn onto Mountain Road.
44.3	Intersect Pa. Rte. 873 and proceed across Lehigh River.
44.6	Stop sign, RIGHT turn onto Pa. Rte. 248E.
44.7	Fork in road, bear RIGHT on Pa. Rte. 45S.

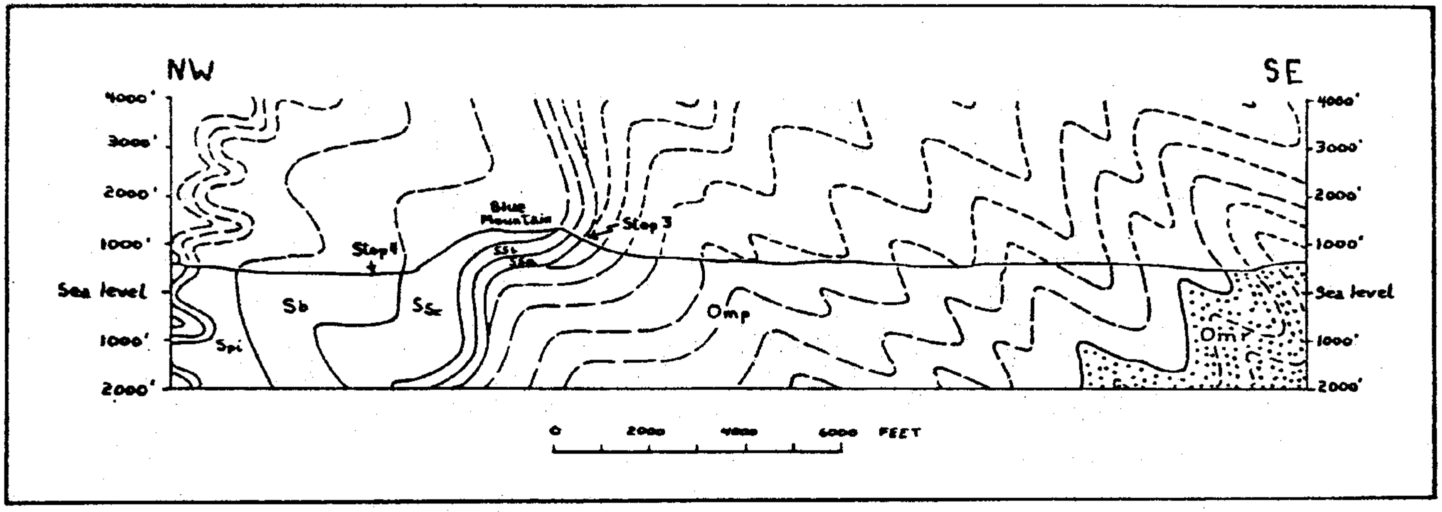


Figure 14. Geologic section 2,000 feet east of Lehigh Gap. Spi, Poxono Island Formation of White (1882); Sb, Bloomsburg Red Beds; Ssc, quartzite-argillite unit of Shawangunk Conglomerate; Ssb, lower quartzite-conglomerate unit of Shawangunk Conglomerate; Ssa, conglomerate unit of Shawangunk Conglomerate; Omp, Pen Argyl Member of Martinsburg Formation; Omr, Ramseyburg Member of Martinsburg Formation.

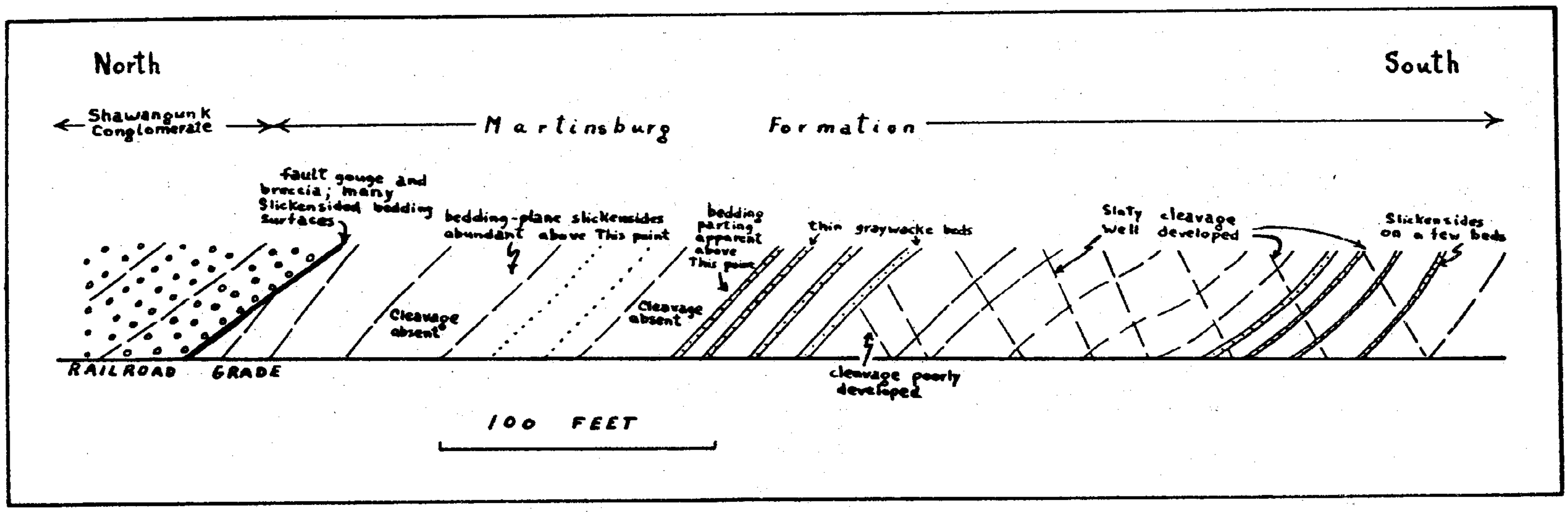


Figure 15. Diagrammatic geologic section through the Shawangunk-Martinsburg contact at Lehigh Gap.

44.8 RIGHT turn into parking area west of Atlantic gas station.

STOP 3. MARTINSBURG-SHAWANGUNK CONTACT ALONG ABANDONED RAILROAD GRADE IN LEHIGH GAP

90 MINUTES

The bedrock structure near the Lehigh River is shown in figure 14. A syncline and anticline occur in Blue Mountain at Lehigh Gap. These die out rapidly to the west. At this stop we will see the unconformable contact between the Martinsburg Formation and Shawangunk Conglomerate. Detailed structural relations are shown in figure 15. Slaty cleavage is well developed in the Martinsburg, 200 feet (stratigraphically) below the contact. The cleavage disappears 120 feet below the contact and bedding-plane slickensides become prominent. Steps on the slickensides indicate northward movement of the overlying beds. The upper-most 8 inches of the Martinsburg is heavily slickensided and contains fault gouge and breccia. Evidence, listed in the section on the Taconic orogeny in eastern Pennsylvania (p. 28-32), indicates that the cleavage in the Martinsburg was not produced during the Taconic orogeny and is an Appalachian feature. The Martinsburg-Shawangunk contact, which also separates lithotectonic units 1 and 2 (see section on structural geology and fig. 7), is interpreted as a decollement.

Quartz, chert, and quartzite pebbles in the basal conglomerate unit of the Shawangunk indicates that the Martinsburg was breached and underlying rocks were being eroded and supplying pebbles during early Shawangunk time. The sharp contact and angular relationship between the Shawangunk and Martinsburg, and the very different environments of deposition under which these two units accumulated, indicate an unconformable relationship. The contact is a folded and faulted unconformity.

Two cleavages (one a slip cleavage) occur in a 2 inch-thick argillite bed in the Shawangunk Conglomerate about 50 feet north of the contact

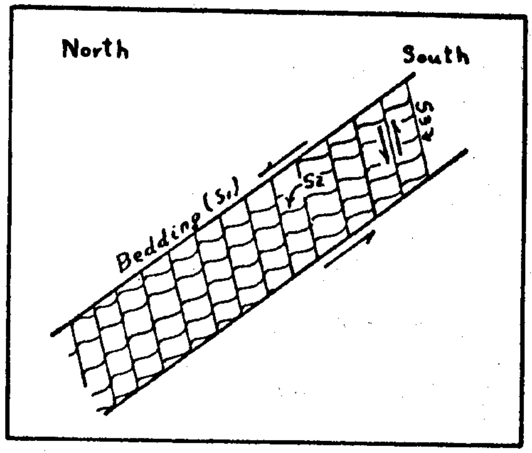


Figure 16. Diagrammatic sketch showing a 2-inch-thick argillite bed in conglomerate unit of Shawangunk Conglomerate. S_1, bedding; S_2, cleavage; S_3, slip cleavage. The first cleavage (S_2) may have formed in response to interbed shear with overriding beds moving to the north as indicated by bedding-plane slickensides.

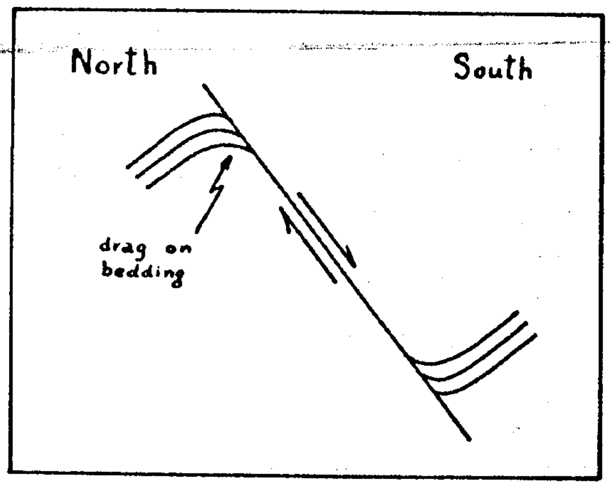


Figure 17. Diagrammatic sketch of normal fault in conglomerate unit of Shawangunk Conglomerate. Displacement about 10 feet.

(fig. 16). About 200 feet farther north is a small normal fault with a displacement of about 10 feet (fig. 17). The contact between the conglomerate unit and overlying lower quartzite-conglomerate unit may be seen about 250 feet north of the Shawangunk-Martinsburg contact. A few miles to the south, a partly dissected Illinoian (?) outwash terrace along the Lehigh River can be seen from this stop.

<u>Mileage</u>

44.8	LEFT turn onto Pa. Rte. 248W, heading toward Palmerton.
45.7	RIGHT turn onto service road.
45.8	Cross Aquashicola Creek, RIGHT turn. Quartzite-argillite unit of Shawangunk Conglomerate to left.
45.9	Shawangunk-Bloomsburg contact on left.
46.1	Mud cracks in Bloomsburg Red Beds on left.
46.4	Wisconsin valley train (outwash) to right.
46.5	RIGHT turn onto Lehigh Avenue, road follows Wisconsin valley train.
46.9	Travel 2 blocks, LEFT turn onto Fifth Street.
47.0	Travel one block, traffic light. LEFT turn onto Delaware Avenue.
47.1	Parallel park on right at First United Church of Christ. Lunch will be served inside.

LUNCH STOP

47.1	Continue west on Delaware Avenue.
47.4	LEFT turn onto Third Street (just past traffic light, and immediately before railroad underpass).
47.6	On left, Wisconsin outwash plain; on right Bloomsburg Red Beds.
47.9	Mud cracks in steeply-dipping Bloomsburg Red Beds to right.

48.3 RIGHT turn onto service road.

48.4 Park along soft shoulder of road. STOP 4.

STOP 4. I, ILLINOIAN (?) OUTWASH
II, BLOOMSBURG-SHAWANGUNK CONTACT, BEDDING SLIPPAGE, WEDGING, AND TELESCOPING IN THE BLOOMSBURG RED BEDS

60 MINUTES

In the small valley above the transitional contact between the Bloomsburg Red Beds and the quartzite-argillite unit of the Shawangunk Conglomerate is a deeply weathered deposit consisting of rounded pebbles and boulders in a clay to very fine sand matrix. Two miles to the south, along the Lehigh River, a similar but better exposed deposit is horizontally stratified. The terrace form, stratification, and rounded pebbles show that this is an alluvial deposit (an outwash terrace or valley train), possibly of Illinoian age. A pebble count indicates a north and northeast source area.

Note the fining-upward sequences (sandstone-siltstone-shale) in the Bloomsburg Red Beds. Poorly developed mud cracks occur near the base of the Bloomsburg.

The near-vertical beds at this stop are in the northwest limb of an overturned anticline (fig. 14). Many bedding planes are slickensided, and the steps indicate northwest movement of the overriding beds. Small-scale wedging corroborates this direction of movement (fig. 18). The net telescoping must have been considerable.

At this locality 900 feet of red beds are exposed. The Bloomsburg is estimated to be 1,500 feet thick. In the exposed section, 128 planes of bedding slippage were counted, so that the total number of such planes in the Bloomsburg may be 1,500/900 x 128, or 213. It is conservatively estimated that there has been about 4 feet of down-dip displacement along 100 feet of slippage surface. Therefore, for each 100 feet, in a northwest direction

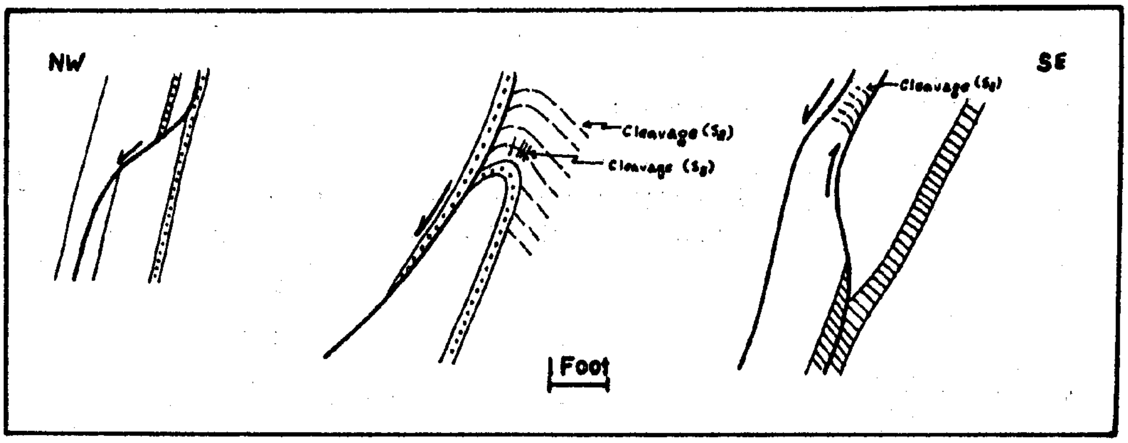


Figure 18. Diagrammatic sketch of wedges and bedding-plane slips in the Bloomsburg Red Beds at stop 4.

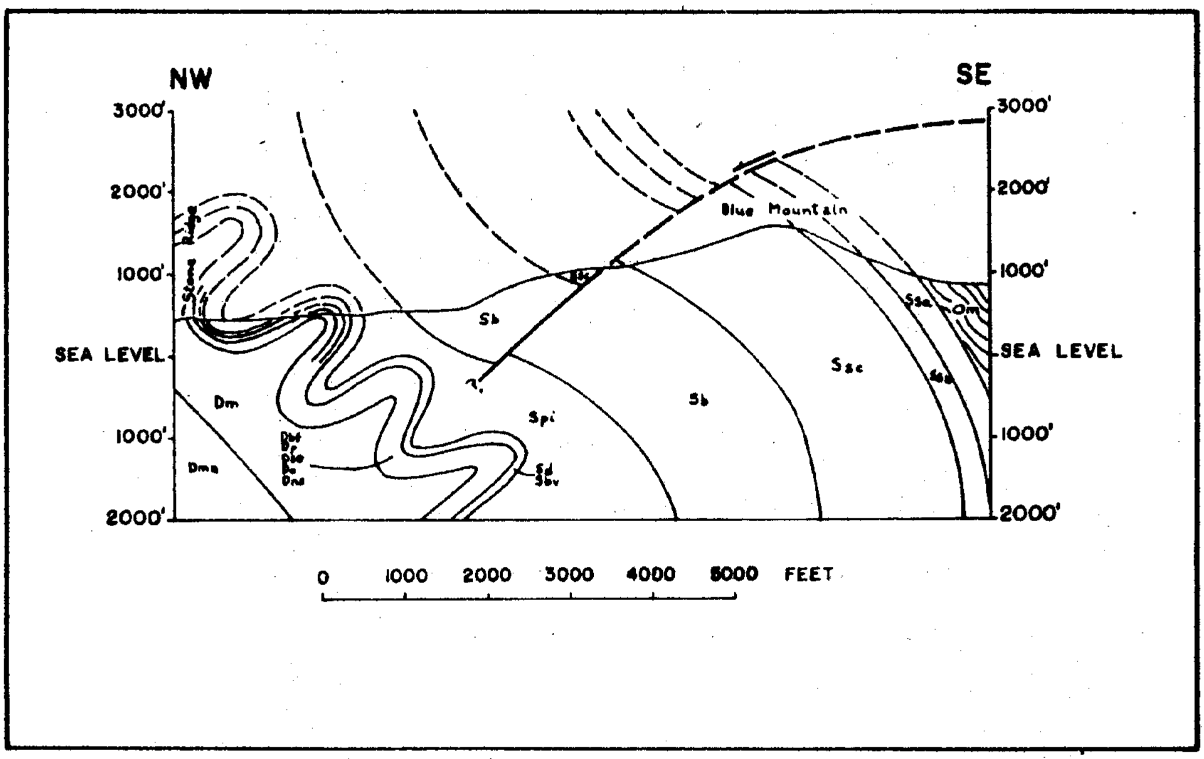


Figure 19. Geologic section through Blue Mountain, 1,500 feet west of the Pennsylvania Turnpike Extension tunnel. Dma, Mahantango Formation; Dm, Marcellus Shale; Dbf, Buttermilk Falls Limestone of Willard (1938); Dp, Palmerton Sandstone of Swartz (1939); Dse, Schoharie and Esopus Formations, undivided; Do, Oriskany Group; Dns, New Scotland Formation; Sd, Decker Formation; Sbv, Bossardville Limestone; Spi, Poxono Island Formation of White (1882); Sb, Bloomsburg Red Beds; Ssc, quartzite-argillite unit of Shawangunk Conglomerate; Ssb, lower quartzite-conglomerate unit of Shawangunk Conglomerate; Ssa, conglomerate unit of Shawangunk Conglomerate; Om, Martinsburg Formation.

parallel to bedding in the Bloomsburg, there could have been 213 x 4, or about 850 feet of displacement. Because northwest-dipping beds are at least 6,000 feet deep at this locality (fig. 14), the minimum estimated telescoping is 850 x 6,000/100, or 51,000 feet, or nearly 10 miles. The actual depth of northwest-dipping beds may be more than 10,000 feet, so that total telescoping could be more than 15 miles. If similar wedging and bedding slippage extends up into the Poxono Island Formation of White (1882), where the structural style between lithotectonic units 2 and 3 changes, then the amount of displacement could be even greater.

The estimated displacement parallel to bedding may not be unreasonable. Figure 7 shows that the rocks in lithotectonic unit 3 have been shortened 50 percent. In figure 7, lithotectonic unit 3 extends perpendicular to the strike for at least 3 miles. Shortening taken up by folding is at least 3 miles. The entire unit probably moved considerable distances while shortening within the unit took place.

The glide zones between all the lithotectonic units in the field trip area may extend to the northwest where they may shear upward, producing folds similar to those described by Gwinn (1964).

From the bend in the road, three sags can be seen in Blue Mountain above the Pennsylvania Turnpike Extension 2 miles to the west. The sags occur where a northwest-dipping fault emerges from the tightened core of an overturned anticline (figs. 7 and 19), showing that the intensity of deformation in lithotectonic unit 2 increases to the west. The antiforms and synforms shown in figure 19 were first described by Dyson (1956).

Mileage

48.4 Follow service road to stop sign.

48.7 Stop sign. LEFT turn onto Pa. Rte. 248

48.9 Bear LEFT on Pa. Rte. 248E and pass through Lehigh Gap.

50.6 Bear LEFT and follow Pa. Rte. 248E.

50.8 Illinoian (?) till in roadcuts to right and left.

52.6 Berlinsville, LEFT turn onto Pa. Rte. 946.

53.0 We are riding on the upper member (Pen Argyl Member) of the Martinsburg Formation. Hills to right (south) are supported by sandstones in the middle (Ramseyburg) member of the Martinsburg Formation.

55.7 Intersection in Danielsville. LEFT turn toward Little Gap. Ascend Blue Mountain at Little Gap and cross overturned, nearly recumbent rocks of the Shawangunk Conglomerate and Bloomsburg Red Beds (fig. 9).

56.5 On left, roadcuts in conglomerate unit of Shawangunk Conglomerate; quartz pebbles as much as 4 inches long; beds overturned steeply to southeast.

57.1 Blockfield to right in Little Gap.

57.3 On right, quartzite-argillite unit of Shawangunk Conglomerate overturned and dipping gently to southeast.

58.1 Nearly recumbent Bloomsburg Red Beds to right. Sand pits in Palmerton Sandstone of Swartz (1939) in Chestnut Ridge to north.

58.9 Base of mountain. Valley filled with Wisconsin outwash.

59.2 RIGHT turn toward Kunkletown.

60.0 Valley of Buckwha Creek to right, underlain by Wisconsin outwash. Valley narrows to the east approaching the pre-Wisconsin Lehigh River-Delaware River drainage divide.

63.0 On left, roadcut in Bloomsburg Red Beds.

63.3 Narrowest part of Aquashicola Creek Valley. Former Delaware River-Lehigh River drainage divide.

63.6 Cross Aquashicola Creek. Bloomsburg Red Beds on left. Note widening of valley as we proceed eastward.

64.4 LEFT turn, cross Aquashicola Creek.

64.6 Outcrop on left in Poxono Island Formation of White (1882)

65.3 RIGHT turn into quarries of Universal Atlas Cement Company, a subsidiary of U. S. Steel. Route follows ridgetop road.

68.1 Fork in road, bear LEFT and continue ascent of ridge.

69.2 Clay pit on left, follow blacktop road to right.

69.5 Cross claypit.

69.7 Buses park at red shed. STOP 5

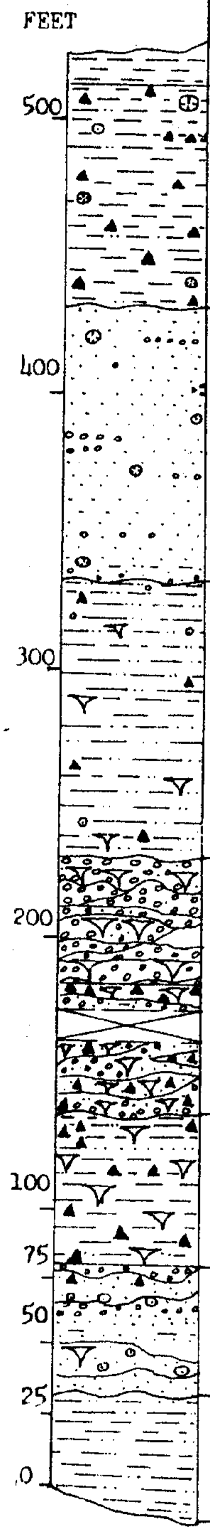
STOP 5. CLAY AND SAND PITS OF THE UNIVERSAL ATLAS CEMENT COMPANY STRATIGRAPHY AND STRUCTURE OF CHESTNUT RIDGE

90 MINUTES

Clay is currently being removed from deeply leached rocks (sedimentary rock saprolites) of the New Scotland Formation, Shriver Chert, and Buttermilk Falls Limestone of Willard (1938). The clay is shipped to the company's cement plant at Northampton, Pa., for use as whitener in cement. Sand is quarried from the Palmerton Sandstone of Swartz (1939) and Ridgeley Sandstone and is trucked to the crusher at Kunkletown a few miles to the west.

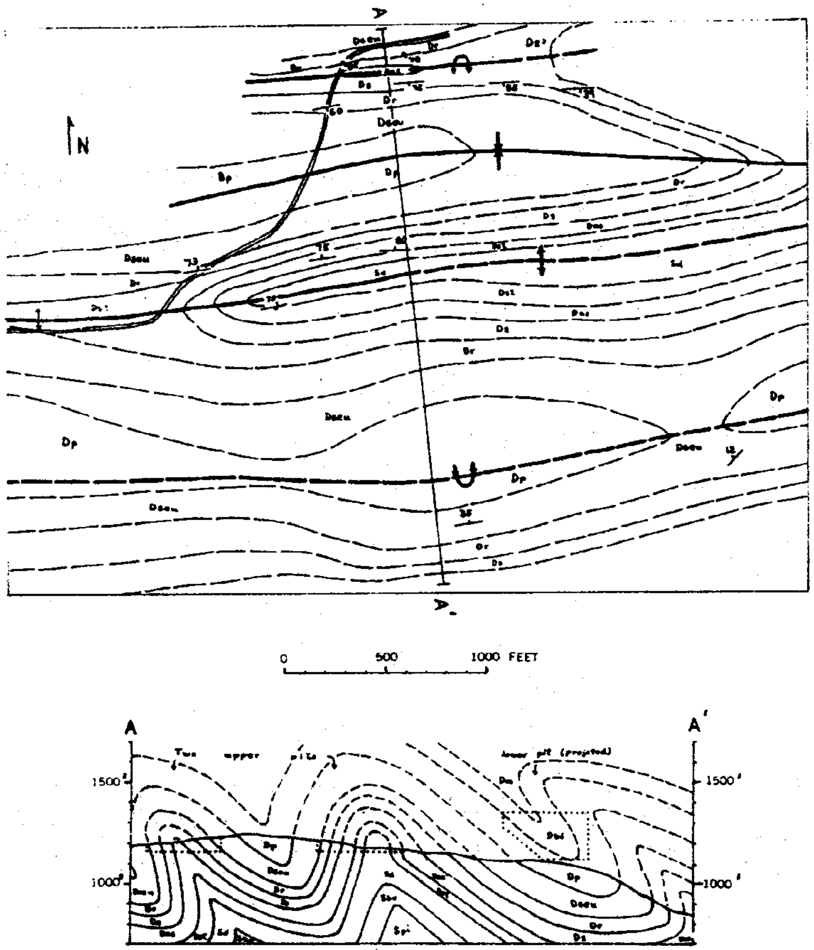
We will stop at the upper two pits in which rocks are exposed from the upper part of the Decker Formation to the lower part of the Schoharie and Esopus Formations (fig. 20). If time permits, we will visit the lower pit and see the Palmerton Sandstone, Buttermilk Falls Limestone and Marcellus Shale.

Four tight, nearly isoclinal folds with axial planes that dip steeply



Group	Unit	Description
	Union Springs Shale Member of the Marcellus Shale	Shale, grayish-black, fissile, carbonaceous.
	Buttermilk Falls Limestone of Willard (1938)	Clay, silty clay, and chert. Weathered; white and varicolored. Chert in pods and irregular beds. Hematitic near top. Fossiliferous. Thickness approximate.
	Palmerton Sandstone of Swartz (1939)	Sandstone and conglomeratic sandstone. Sandstone, very coarse to coarse-grained. Quartz pebbles as much as 3/4 inch long. Medium-dark-gray; weathers yellowish-orange. Scattered coral molds. Thickness approximate.
	Schoharie and Esopus Formations, undifferentiated	Siltstone and silty shale. Weathered; varicolored; minor chert; fossiliferous. Thickness approximate.
Oriskany Gp.	Ridgeley Sandstone	Quartz-pebble conglomerate. Pebbles rounded to well rounded; as much as 1 inch long. Crossbedded. Abundant lenses and beds of brachiopod shell hash.
Oriskany Gp.	Shriver Chert	Chert, conglomerate, sandstone, and minor clay. Weathered; very light gray to light-gray. Chert replaces quartz sand and pebbles. Spirifer arenosus(?) molds abundant.
	New Scotland Formation	Chert, clay, and silty and arenaceous clay. Weathered; white to light-gray, pale-yellowish-orange to light-brown. Lenses and thin beds of coarse-grained sandstone near top. Fossils, mainly brachiopods, abundant, especially in chert.
	Stormville Member of the Coeymans Formation	Sandstone and minor beds and lenses of conglomerate. Sandstone, very fine grained to coarse-grained. Conglomerate containing pebbles as much as 1 inch long. Weathered; very pale orange to dark-yellowish-orange; crossbedded in places; scattered molds of crinoid columnals and brachiopods.
	Decker Formation	Siltstone, sandstone, and shale. Weathered; pale-yellowish-orange to moderate-brown; limonitic and hematitic.

Figure 20. Columnar section showing stratigraphic units exposed in clay- and sandpits of the Universal Atlas Cement Company, stop 5.



EXPLANATION

Middle Devonian (DEVONIAN)

- Dm — Marcellus Shale
- Dbf — Buttermilk Falls Limestone of Willard (1938)
- Dp — Palmerton Sandstone of Swartz (1939)

Lower Devonian (DEVONIAN)

- Dse — Schoharie and Esopus Formations undivided
- Dr — Ridgeley Sandstone
- Ds — Shriver Chert
- Dns — New Scotland Formation
- Dcs — Stormville Member of Coeymans Formation

Upper Silurian (SILURIAN)

- Sd — Decker Formation
- Sbv — Bossardville Limestone
- Spi — Poxono Island Formation of White (1882)

Contact
Dashed where approximately located

Anticline
Showing trace of axial surface.
Dashed where approximately located.

Syncline
Showing trace of axial surface.
Dashed where approximately located.

Overturned syncline
Showing trace of axial surface and direction of dip of limbs. Dashed where approximately located.

Overturned anticline
Showing trace of axial surface and and direction of dip of limbs. Dashed where approximately located.

16 Inclined — 16 Overturned
Strike and dip of beds.

Figure 21. Geologic map and section of the Universal Atlas Cement Company clay and sandpits in Chestnut Ridge, approximately 4 miles north-northeast of Kunkletown, Pa.

to the southeast can be traced on the floors of the pits (fig. 21). The folds have wavelengths of about 1,000 feet and are believed to be superposed on an anticlinal crest or gently dipping limb of a larger fold in underlying lithotectonic unit 2 (fig. 7).

The lower pit is in an overturned syncline in the Palmerton Sandstone of Swartz (1939), Buttermilk Falls Limestone of Willard (1938), and Marcellus Shale (fig. 21). In places the upright north limb of the fold dips more steeply than the overturned south limb, so the fold is "tighter" than isoclinal. Note the massive Palmerton Sandstone and spheroidal weathering developed between joints in the southeast section of the pit. The Palmerton is similar to the Ridgeley Sandstone except that it lacks spiriferid molds but has rare favositid and crinoid columnal molds.

Cascade folds, similar to those developed in lithotectonic unit 3, but on a much smaller scale, can be seen in the normal southeast-dipping limb of the syncline in the Buttermilk Falls Limestone of Willard (1938) (fig. 22).

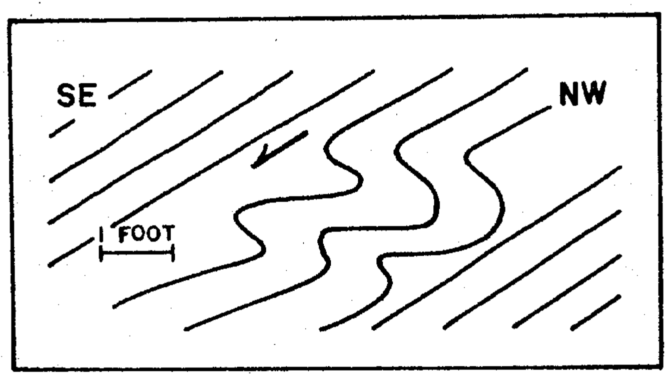


Figure 22. Diagrammatic sketch of small cascade folds in the Buttermilk Falls Limestone on the normal southeast-dipping limb of syncline, showing movement of overlying beds away from anticlinal crest.

Mileage

69.7 Retrace route to state road. If time permits make LEFT turn into lower pit at 71.3 miles.

74.3 RIGHT turn and descend ridge on north side and enter Kunkletown.

75.1 Stop sign, Kunkletown. RIGHT turn and proceed to Saylorsburg.

75.4 Bear RIGHT at fork in road.

77.9 Claypits of stop 5 to right on Chestnut Ridge.

82.7 Wisconsin terminal moraine.

83.2 Stop sign, Saylorsburg. RIGHT turn toward Wind Gap.

83.3 Outlet of glacial Lake Sciota in terminal moraine. Road ascends Cherry Ridge.

83.8 LEFT turn at crest of ridge towards Bossardsville.

83.9 Pass over interstate highway. Palmerton Sandstone holds up ridge to right.

84.1 Intersection with Pa. Rte. 115 and U. S. Rte. 209. Continue straight toward Bossardsville.

84.6 SLOW. Scenic view to left (see fig. 23).

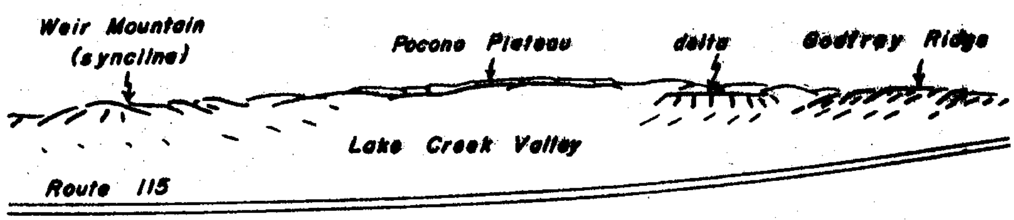


Figure 23. Sketch, from photograph, of view looking north from Cherry Ridge near Saylorsburg. Camelback Mountain in Pocono Plateau in distance. Flat-topped glacial delta of stop 1 in valley in middle ground; valley was site of glacial Lake Sciota. Weir Mountain syncline farther west. Termination of Godfrey Ridge to northeast in right middle ground.

87.2 RIGHT turn into Hamilton Stone Company quarry of Herbert R. Imbt, Inc. Proceed to upper level of quarry. STOP 6.

STOP 6. HAMILTON STONE COMPANY QUARRY
STRUCTURE AND STRATIGRAPHY OF THE DECKER FORMATION, BOSSARDVILLE LIMESTONE, AND POXONO ISLAND FORMATION OF WHITE (1882)

90 MINUTES

The stratigraphic units seen in the quarry are shown in figure 24. Figure 25 shows the nature of the folding. The rocks are part of lithotectonic unit 3 and illustrate cascade folds superimposed on the Kemmererville anticline in lithotectonic unit 2 (fig. 6). Compare the more upright axial planes of these folds with the ones seen farther west. Note also the lack of development of saprolite seen at stop 5. We are northwest of the Wisconsin terminal moraine.

From point A (fig. 25), rocks of the Trimmers Rock Sandstone and Catskill Formation in the southwest-plunging Weir Mountain syncline can be seen to the west, as well as Godfrey Ridge, the Pocono Plateau and the delta and lakebeds of stop 1 to the north, and the Bloomsburg Red Beds in an anticlinal ridge (the Kemmererville anticline) and glacial deposits in Cherry Valley to the east. The Decker Formation is well exposed at A.

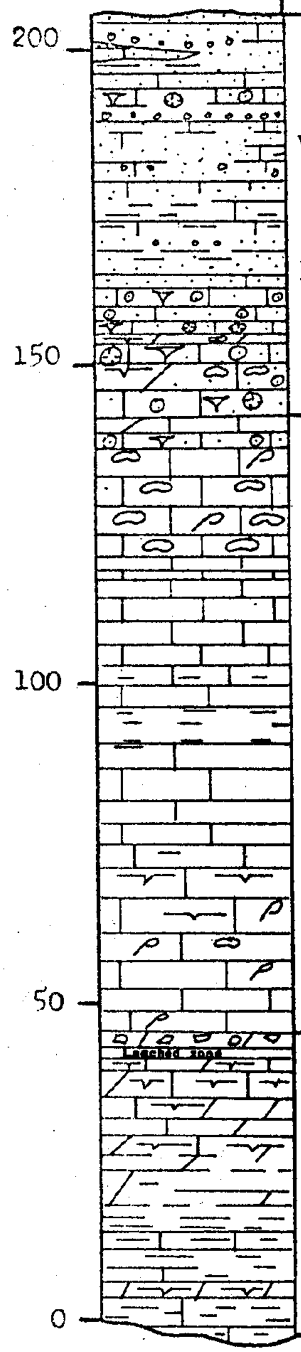
At B, mud cracks and desiccation breccias in the Poxono Island Formation and sedimentary structures and slip cleavage in the Bossardville Limestone will be examined. Here, small-scale satellitic folds occur in the Bossardville.

At C, the relations of drag folds, cleavage, and mud cracks in the Poxono Island Formation are seen (fig. 26).

Mileage

87.6 Buses meet group at lower level. Retrace route out of quarry.

87.9 Stop sign, RIGHT turn.



UNIT	DESCRIPTION
Wallpack Center Member of Decker Formation	Beds and lenses of medium-gray to medium-light-gray fine- to coarse-grained arenaceous limestone, medium-gray fine- to coarse-grained calcareous sandstone, siltstone, and conglomeratic sandstone; pebbles are white and pink quartz. Fossils in coarser grained limestone include brachiopods, rugose corals, and crinoid columnals; leperditiid ostracodes occur in basal beds in close proximity to mudcracked dolomite beds. Upper contact concealed.
Bossardville Limestone	Laminated dark-gray fine- to very fine grained pyritiferous limestone. Leperditiid ostracodes are rare at base, absent in middle beds, and abundant near top of unit. Upper contact is at top of uppermost laminated bed in section.
Poxono Island Formation of White (1882)	Medium-gray calcareous dolomite, medium-gray and mottled pinkish-gray-green to medium-greenish-gray to gray very fine grained dolomite, grayish-red limestone, and light-grayish-yellow-green shale and calcareous shale containing several mud crack intervals. Upper contact is at top of uppermost dolomite bed in section.

Figure 24. Stratigraphic column showing rocks exposed in Hamilton Stone Company quarry, stop 6.

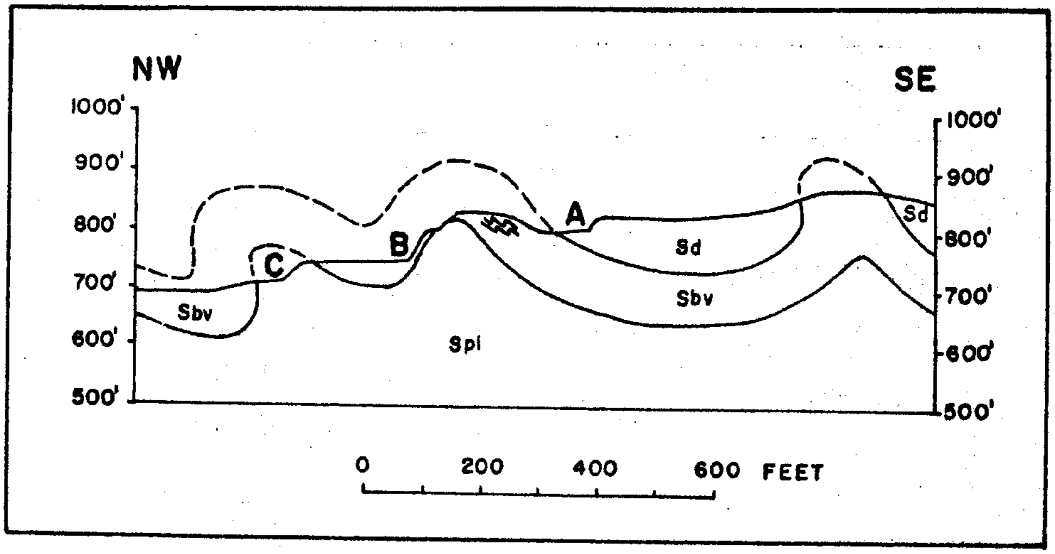


Figure 25. Geologic section of Hamilton Stone Company quarry. A, B, and C are localities described in text. Sd, Decker Formation; Sbv, Bossardville Limestone; Spi, Poxono Island Formation of White (1882).

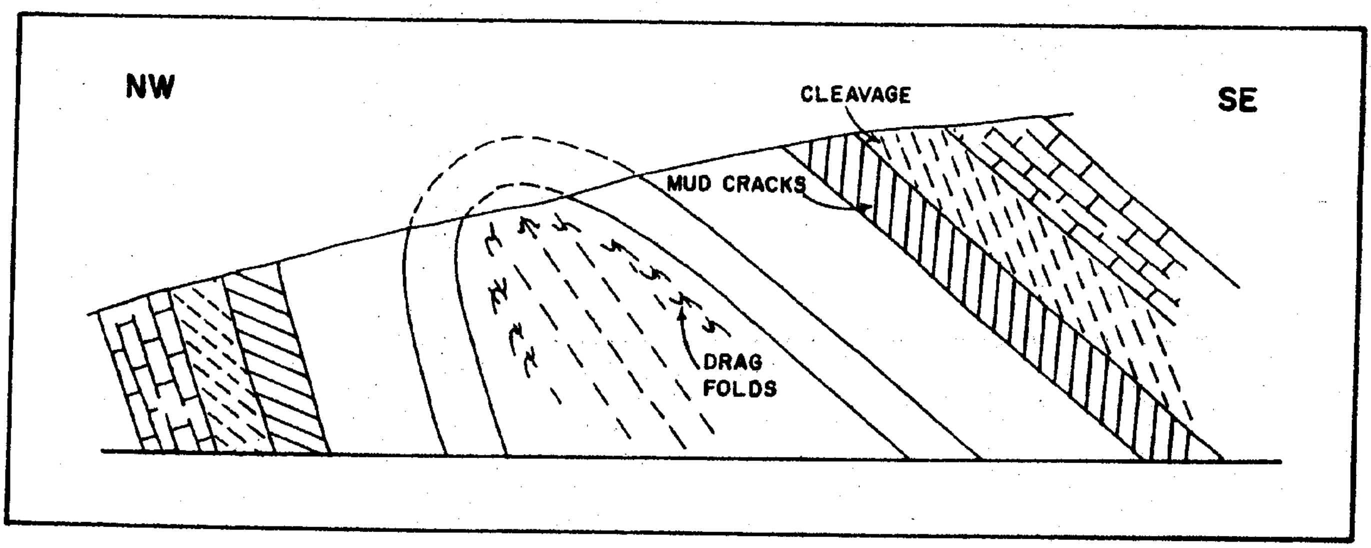


Figure 26. Diagrammatic sketch of overturned anticline in Poxono Island Formation of White (1882), showing structural relationships of cleavage, drag folds, and mud cracks at locality C (fig. 25). Length of exposure about 80 feet.

88.0 Bossardsville, bear RIGHT.

88.2 Abandoned quarries in Bossardville Limestone to right and left.

89.2 Cemetery at church in valley to right is underlain by small kame.

89.4 On right, flat bottom of Cherry Valley is underlain by glacial lake-bottom deposits.

89.6 On left, outcrop of Bossardville Limestone.

90.7 Village of Stormville, bear RIGHT at fork in road.

91.0 On left, mud cracks in the Whiteport Dolomite Member of the Rondout Formation.

91.2 Ridge across Cherry Valley to right is Kemmererville anticline which plunges to the southwest. The ridge rises in altitude to the northeast (straight ahead).

91.5 Kame on right.

92.5 Several kames in Cherry Valley to right.

93.3 Stop sign. LEFT turn onto Pa. Rte. 191. To right is Wildcat Hollow (a local name) cut through Kemmererville anticline and exposing Bloomsburg Red Beds. Flat Floor of Cherry Valley underlain by glacial lake-bottom clay, silt, and sand.

93.5 Fork in road, bear LEFT onto Pa. Rte. 191N. Roadcut on left in the Port Ewen Shale, Oriskany Group, and Esopus Formation. Road ascends Godfrey Ridge.

94.0 Sand and gravel in flat-topped glacial deposit at top of ridge is interpreted as a kame terrace. Roadcuts in Esopus Formation, Schoharie Formation, and Buttermilk Falls Limestone on right during descent of Godfrey Ridge.

94.1 Stop sign, LEFT turn onto U. S. Rte. 611 and follow signs to U. S. Interstate 80E.

94.8 LEFT turn onto U. S. Interstate 80E and follow highway to exit 52 and U. S. Rte. 209N to Holiday Inn.

END FIRST DAY

ROAD LOG --- SECOND DAY
Saturday, September 30, 1967

Departure from the Holiday Inn Motel, East Stroudsburg at 8:00 A.M.

Field trip will follow route shown on figure 1.

Mileage

0.0	Leave Holiday Inn parking lot and proceed south on U. S. Rte. 209.
0.3	RIGHT turn onto U. S. Interstate 80.
2.1	Cross Brodhead Creek.
3.4	RIGHT turn to Dreher Avenue exit, exit 49.
3.5	Cemetery to right on two Wisconsin delta terraces; mausoleum on higher level terrace.
3.6	LEFT turn onto Dreher Avenue.
3.8	Road rises onto Wisconsin delta terrace.
4.3	Follow Dreher Avenue which forks to right.
4.5	RIGHT turn onto Tanite Road.
4.9	RIGHT turn into sand and gravel pit. STOP 1.

STOP 1. WISCONSIN DELTA AND KAME DEPOSIT IN ABANDONED SAND AND GRAVEL PIT

45 MINUTES

The deposit in the lowest pit is interpreted as a kame and consists of more than 50 feet of cross-stratified lenticular beds of sandy pebble gravel with boulders as much as 3 feet long. Gravel composes 80 percent and sand 20 percent of the deposit. Pebble counts indicate a north to northeast source for the material.

Remnants of a delta are exposed in the higher pit. Sand, silt, and clay of the foreset and bottomset beds are exposed; the topsets have been eroded away. Load-cast involutions are exposed in a 4-foot-thick interval about 10 feet below the top of the exposure. They are aimless contortions of the sediments resulting from intrusion of clay, silt, and fine sand into overlying coarser beds. Spherical grayish-red clay balls as much as 3 inches in diameter are common. Small-scale soft-rock deformation features (faults) and ripple marks are abundant.

One thousand feet to the southwest is a 1,000-foot wide ridge, about 1.5 miles long, that rises more than 100 feet above the valley floor. It has a hummocky northeast slope with kettle holes, and presumably marks the position of a former ice front. It overlies lake-bottom clays; deltas in front and back are graded to altitudes above the top of the ridge. Clearly the feature was deposited below lake level, and it is interpreted as a sublacustrine end moraine.

<u>Mileage</u>

4.9 Return to Tanite Road and turn to RIGHT.

5.0 Sublacustrine end moraine on left. Road on a lower level Wisconsin delta terrace at an altitude of 490 feet. Tanite Road turns into Arlington Avenue.

5.2 LEFT turn onto Jane Street.

5.3 RIGHT turn onto U. S. Rte. 209.

5.6 RIGHT turn onto U. S. Interstate 80E and retrace route to Holiday Inn Motel.

6.0 Sand and gravel in delta terrace to right; town of Stroudsburg to left. Note uneven crest of Godfrey Ridge to right, reflecting complex folding of a heterogeneous sequence of sandstone, limestone, conglomerate, and shale.

7.7 Approximately 2000 feet to right is railroad cut in Buttermilk Falls Limestone and Schoharie Formation.

9.2 RIGHT turn at exit 52 onto U. S. Rte. 209N. Brodhead Creek on right cuts through an overturned syncline in the Buttermilk Falls Limestone directly beneath powerline. Wisconsin ground moraine exposed farther downstream.

9.8 Holiday Inn Motel, continue north on U. S. Rte. 209.

10.9 Roadcut on left in massive calcareous siltstone of the Schoharie Formation.

11.0 RIGHT turn onto county road heading to Shawnee on Delaware. Cross Marshall Creek. Buttermilk Falls to left. Type locality of the Buttermilk Falls Limestone of Willard (1938) (lower cherty limestone member exposed here).

11.1 Ridge of sand and gravel on right overlies Buttermilk Falls Limestone.

11.2 Anticline in Buttermilk Falls Limestone on left.

11.6 Roadcut in New Scotland Formation. Beds dip moderately to south.

11.7 LEFT turn at T in road.

12.0 Continuous roadcut on left exposes the New Scotland Coeymans, Rondout, and Decker Formations.

12.2 Fred Waring's Shawnee Inn on right.

12.4 Waterfalls on left provide excellent exposure of Bossardville Limestone and Decker Formation. Mud cracks in the Bossardville in creekbed are as much as 20 feet long.

12.5 LEFT turn at intersection in Shawnee on Delaware. On right, arenaceous silty limestone dipping very steeply to the northwest is Coeymans Formation.

12.7 RIGHT turn then quick LEFT turn 100 feet ahead. Esopus Formation on left. Road rises crossing Esopus Formation and Oriskany Group form ridge crest to right (south).

13.8 Esopus on left; well-developed southeast-dipping planar structure is cleavage, not bedding.

15.2 Powerline crosses road.

STOP 2. I, BIOHERMAL AND NONBIOHERMAL FACIES IN THE SHAWNEE ISLAND MEMBER OF THE COEYMANS FORMATION

150 MINUTES

A bioherm, in the Shawnee Island Member of the Coeymans Formation (fig. 5 and table 1), crops out on the southeast side of Wallpack Ridge opposite Tocks Island. It can be traced for at least 2,000 feet from an outcrop on the northwest side of the road at the foot of the ridge 1.95 miles northeast of Shawnee on Delaware, Pa., northeastward and uphill, beneath the powerline, and into the woods. It is at least 45 feet thick and has an irregular upper surface with relief as much as 20 feet within a horizontal distance of 200 feet.

We will view the bioherm along the cliff face under the powerline and then trace it northeastward along the hillside to where the bioherm passes laterally and vertically into the nonbiohermal facies of the Shawnee Island Member (fig. 27). At the powerline, beds strike N. 74°E. and dip 82°SE., overturned. A few hundred feet to the northeast, where biohermal and nonbiohermal facies grade into one another, beds strike N. 75°E. and dip 45°NW.

Nine biohermal structures in the Deansboro Member of the Coeymans Limestone have been described by Oliver (1960) and Rickard (1962) in Central New York. These reefs are identical in lithic character with the bioherms seen here. The New York bioherms have an average height

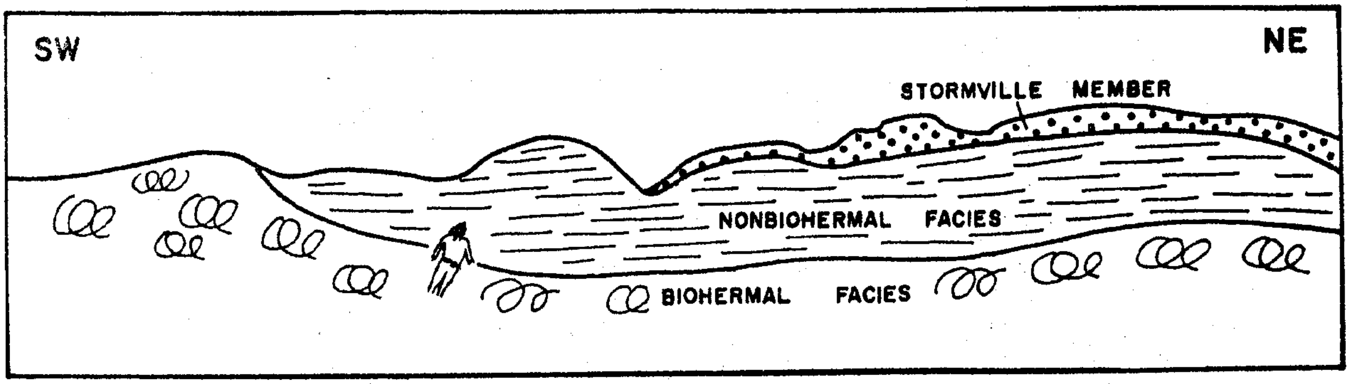


Figure 27. Sketch showing biohermal and nonbiohermal facies of the Shawnee Island Member of the Coeymans Formation overlain by the Stormville Member of the Coeymans Formation at stop 2, second day.

and diameter of 20 and 100 feet, respectively (Oliver, 1960, p. 60). Four bioherms have been recognized in the Coeymans Formation in the northeastern Pennsylvania-New Jersey area (Epstein and others, 1967) and have comparable dimensions of 40 and as much as 3,000 feet. Each is a separate body within the more typical argillaceous and arenaceous limestone of the Shawnee Island Member. The northeasternmost bioherm is near Montague, N.J., where it rests on biostromal layers of the Manlius Limestone. The southwesternmost bioherm occurs here and is the largest and best exposed. This bioherm and another at Wallpack Bend, Pa., grade down, within a 1- to 2-foot interval, into the Peters Valley Member of the Coeymans Formation. The Manlius biostromal beds and Peters Valley sandy limestone probably provided an advantageous substrata on the sea floor upon which the colonizing organisms of the bioherm could establish a firm hold.

II. ENGINEERING GEOLOGY OF TOCKS ISLAND DAM AND RESERVOIR

By
A.J. DEPMAN AND D.G. PARRILLO
Staff geologists, U.S. Army Corps of Engineers

The Tocks Island dam site will be located on the Delaware River

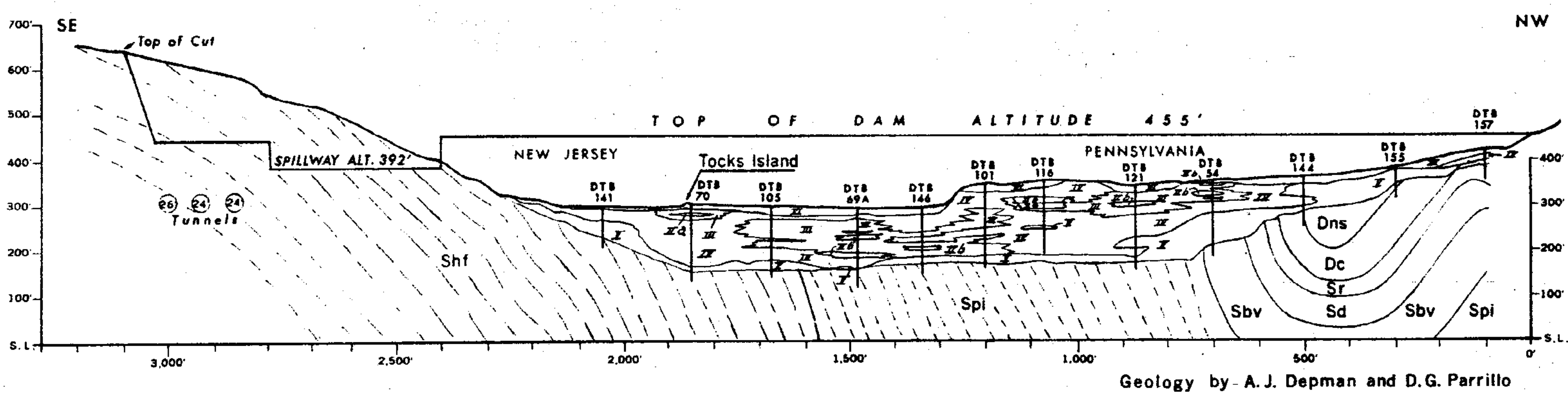


Figure 28. Geologic section at Tocks Island dam site. See text for explanation of letter symbols.

approximately two miles upstream from Shawnee on Delaware, Pa. The centerline will be about 100 feet downstream from the lower end of Tocks Island.

As proposed, the dam will be a combination earth and rockfill type with an impervious core and upstream impervious blanket.

Some pertinent statistics are:

Altitude at top of dam	455 ft.
Altitude of river bottom	295 ft.
Width at crest	30 ft.
Width at base	3260 ft.
Length of dam (excluding spillway)	2600 ft.
Spillway altitude	392 ft.
Spillway width	382 ft.
Outlet works	26 ft. diameter tunnel, 1835 ft. long
Power intake structure	2-24 ft. diameter tunnels, 1260 ft. long

Geology at the dam site

At the dam site the Delaware River flows in a broad U-shaped valley with a gentle gradient. The left abutment (New Jersey side) is formed by the western side of Kittatinny Mountain (crest elevation, 1500 feet). The High Falls Formation (of the New Jersey Geologic and Topographic Survey) is at or within 10 feet of the surface in most areas, with the exception of one area where a thick morainal ridge strikes east-west up the ridge. Outcrops on the New Jersey side indicate the bedrock surface plunges steeply below the river to depths of 135 feet (fig. 28) near where the High Falls (Bloomsburg Red Beds of the remainder of this report) grades into the overlying Poxono Island Formation. The bedrock surface rises gently beneath the river bottom, and on the Pennsylvania side the slope steepens and rocks of Devonian age crop out above an altitude of 450 feet.

The major structure in the valley is a broad southwest-plunging asymmetric syncline with a southeast-dipping axial plane. Minor undulations and cross folds are found within the larger structure. The east limb forms Kittatinny Mountain (in New Jersey); the west limb forms Wallpack Ridge (in Pennsylvania). The trough of the syncline is located under Wallpack Ridge.

A series of glacial deposits, as much as 250 feet thick, capped by a thin veneer of alluvium, overlie the bedrock surface beneath the river and most of the right abutment.

Stratigraphy

The following formations have been encountered within the dam foundation and structures:

		Thickness (in feet)
DEVONIAN		
Dns	New Scotland Formation	35
	Flatbrookville Member	
Ds	Coeymans Formation	89
	Stormville Member	20
	Shawnee Island Member	42
	Peters Valley Member	7
	Depue Limestone Member	20
SILURIAN		
Sr	Rondout Formation	34
	Mashipacong Member	12
	Whiteport Dolomite Member	7
	Duttonville Member	15
Sd	Decker Formation	55
Sbv	Bossardville Limestone	112
Spi	Poxono Island Formation	675
Shf	High Falls Formation	1100

Pleistocene geology

Deposits of Wisconsin age have been recognized at the dam site. Four recessional moraines have been identified in the Delaware Valley and there is evidence that a fifth occurred in the vicinity of Tocks Island. Borings show a hummocky belt of till (fig. 28, unit V) above bedrock and below ice-contact glaciofluvial and glaciolacustrine deposits (fig. 28, units I-IV). Low morainal ridges diagonally ascend both sides of the valley. As the ice edge melted back from the Tocks Island position, melting of the crevassed marginal zone left behind isolated ice blocks. Outwash was deposited around, between, and over these masses. Fine-grained sediments accumulated in local ponded areas. Some of these sediments show slump and collapse features indicating melting of buried ice masses after sediment deposition.

Leaching of limestone near the surface and precipitation from ground water at depth has cemented many ledges within the valley-train (outwash) material. Fluvial erosion has dissected the valley train to its present level. The stream course seems to have followed, for the most part, a series of longitudinal ice-block depressions in the valley train.

The glacial deposits encountered at the site include basal till, ablation till, fluvioglacial and glaciolacustrine deposits. A description of surficial deposits shown in figure 28 is presented below:

Alluvium		VI	Fine to coarse surface materials.
GLACIO-LACUSTRINE DEPOSITS		II a	Horizontal to gently dipping layers of fine sand, silt, and clay. Thickness of individual layers ranges from paper thin to several inches.
		II b	Same as IIa but bedding disturbed by slumping or sliding. Contains coarser material locally.
	GLACIO-FLUVIAL DEPOSITS	III	Silt, fine- to medium sand, and rare fine gravel. Includes material transitional from coarse outwash to type II, finer foreset beds, and local fine grained ice contact deposits.
		IV	Stratified fine to coarse sediments from silt to cobbles.
TILL		V	Heterogeneous mixture of fine to coarse material; unstratified.

Engineering aspects of the geology

The major problem in selecting the dam site was locating the best foundation within the glacial deposits. The gravel "highs" associated with the end moraine provided this locale. The permeability of the glacial deposits in the Pennsylvania bluff are believed to present no major problem since weathering has progressed to depths of ten feet, yielding a natural impervious blanket. In sections where this natural blanket has been breeched, it will be re-established during construction of the dam. Location of the spillway was governed by the type and condition of the rock in both abutments. The stability of rock slopes at the intake structures will be a major concern and design slopes will be determined on the basis of data obtained from a proposed test quarry in conjunction with detailed exploration and laboratory testing. Tunnels should present no special problems since they will penetrate the sandy part of the High Falls Formation. Springs issuing from surficial deposits and bedrock on the New Jersey side will be compensated for in the design of the dam.

All of the rock fill for the embankment will be obtained from excavation in the left abutment. Impervious core material is available from the uppermost weathered part of the outwash and from the till. Most of the unweathered outwash and alluvium will provide good pervious material. Concrete aggregate can be obtained from suitable parts of the High Falls within the excavation, the lower and upper Shawangunk, or from commercial sources in the area.

Mileage

15.2 Board buses and drive east.

15.8 RIGHT turn to Pardee's Beach Club.

16.0 Pavillion. STOP 3.

STOP 3. TOCKS ISLAND DAM SITE CORES: LUNCH

60 MINUTES

Cores show a continuous section from the New Scotland Formation through the Bloomsburg Red Beds. Cores are provided by the U. S. Army Corps of Engineers.

Mileage

16.0 Return to county road.

16.2 LEFT turn onto road to Shawnee on Delaware.

17.4 Coeymans bioherm on right. Road traverses hillocks and terraces of Wisconsin drift.

18.5 Outcrop of Decker Formation in creekbed on right.

19.5 Shawnee on Delaware, continue straight ahead.

20.3 Road intersection to right. Continue straight ahead.

20.4 Outcrop of New Scotland Formation on right.

20.6 Outcrop of New Scotland Formation on right.

21.3 Stop sign. Village of Minisink Hills.

21.4 LEFT turn toward Delaware Water Gap. Sand and Gravel in delta on left.

21.8 Cross Brodhead Creek. Flood plain of Delaware River. Delaware Water Gap to left.

22.0 Cross railroad tracks.

22.1 RIGHT turn onto U. S. Interstate 80W

22.7 Park on right shoulder of interstate highway where feed-on merges with main highway. STOP 4.

STOP 4. I, STRATIGRAPHY AND STRUCTURE OF GODFREY RIDGE
II, ORIGIN OF WATER GAPS

120 MINUTES

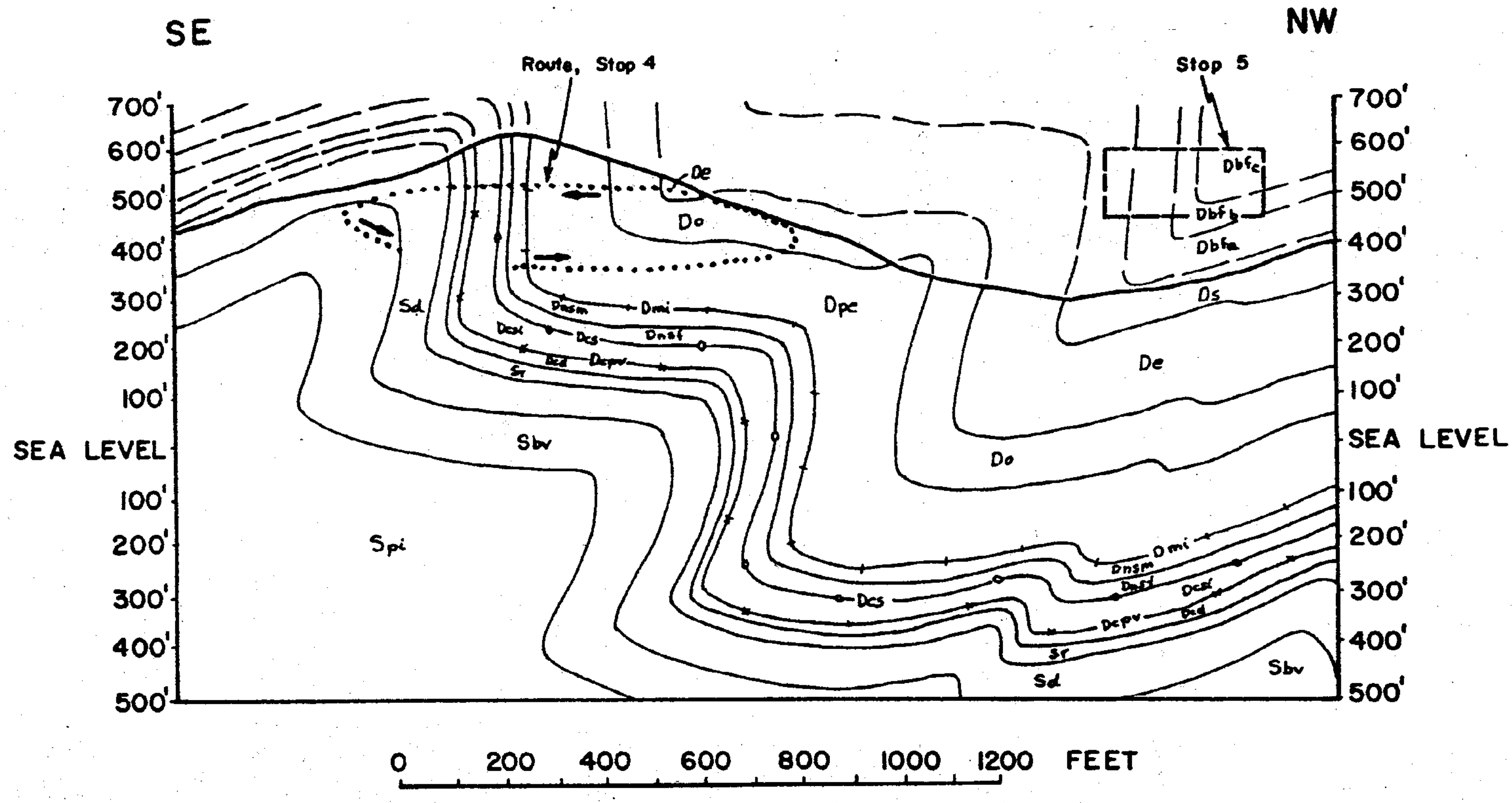


Figure 29. Geologic section through Godfrey Ridge at stop 4. Location of stop 5 projected to plane of section. De, Esopus Formation; Do, Oriskany Group; Dpe, Port Ewen Shale; Dmi, Minisink Limestone; Dnsm, Maskenozha Member of New Scotland Formation; Dnsf, Flatbrookville Member of New Scotland Formation; Dcs, Stormville Member of Coeymans Formation; Dcsi, Shawnee Island Member of Coeymans Formation; Dcpv, Peters Valley Member of Coeymans Formation; Dcd, Depue Limestone Member of Coeymans Formation; Sr, Rondout Formation; Sd, Decker Formation; Sbv, Bossardville Limestone; Spi, Poxono Island Formation of White (1882).

The route taken at this stop is shown in figure 29. This figure is similar to, but more detailed than, the cross section presented by Epstein (1966, fig. 5, C-C'; reprint provided at back of guidebook). Figure 5 of the reprint shows a geologic map of the area of stops 4 and 5, second day.

Rocks from the Bossardville Limestone up through the Esopus Formation are exposed in an overturned anticline and syncline at this stop. (See table 1 for the description of lithologic units.) The folds at this stop are similar in style to the cascade folds seen at Bossardville (stop 6, first day). We will walk up the construction benches on the west side of the highway and over the south side of the ridge to the Croasdale quarry where deep mud cracks in the Bossardville Limestone will be seen.

The flow cleavage in the Port Ewen Shale at this locality is unique in that it fans the fold and opens away from the synclinal trough (fig. 30).

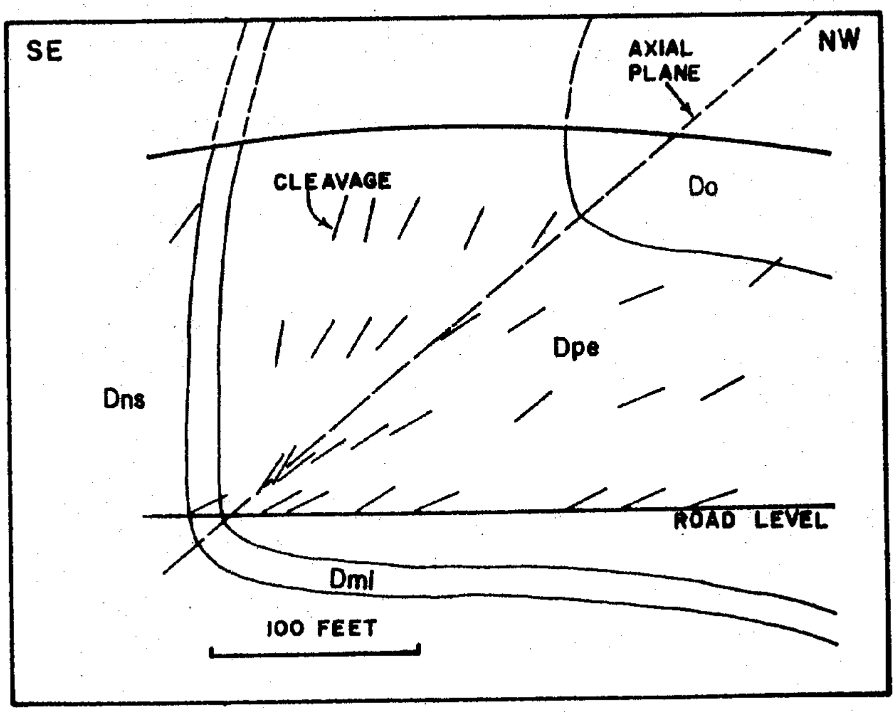


Figure 30. Diagrammatic geologic section showing fanning of cleavage in the Port Ewen Shale in Godfrey Ridge along U.S. Interstate 80, stop 4. Section is perpendicular to strike of beds. Vertical scale same as horizontal. Do, Oriskany Group; Dpe, Port Ewen Shale; Dns, New Scotland Formation; Dmi, Minisink Limestone.

Two delta terraces, at altitudes of 400 feet and 360 feet can be seen on the east side of the highway. These were deposited in glacial Lake Sciota after the Delaware Water Gap, 2 miles to the south, was uncovered and the lake began to drain.

Structural control for the locations of the two water gaps east of this locality (gap of Brodhead Creek and North Water Gap) will be discussed at the stop (see also reprint provided at back of guidebook, p. B83-B85, fig. 5).

Mileage

22.7 Continue west on U. S. Interstate 80.

22.9 Cross Brodhead Creek.

23.0 RIGHT turn onto U. S. Rte. 209 at exit 52.

23.4 RIGHT turn onto dirt road. Holiday Inn on left.

23.5 Bear LEFT at Y and continue under U. S. Interstate 80 into sand and gravel pit.

23.8 STOP 5.

STOP 5 I, WISCONSIN TILL AND LAKE BEDS
II, STRUCTURE AND STRATIGRAPHY OF THE BUTTERMILK FALLS LIMESTONE OF WILLARD (1938)

60 MINUTES

In the gravel pit at this stop, about 20 feet of rhythmically laminated sand, silt, and clay overlying more than 35 feet of till is exposed. The rhythmites are unique in that each cycle consists of clay grading up into silt and sand, with superjacent clay resting sharply on the sand. These rhythmites are believed to have been deposited in a ponded area in the valley of Brodhead Creek and may have been connected with glacial Lake Sciota through the valley.

In the abandoned quarry above the gravel pit, an overturned syncline (fig. 29) in the three units of the Buttermilk Falls Limestone is exposed. Note t bedding-plane slickensides, fanning of the cleavage, the thickening of beds and calcite fillings in the trough of the syncline on the southwest wall of the quarry, and the reverse folding in the trough of the syncline on the northeast wall of the quarry. The two lower units of the Buttermilk Falls Limestone of Willard (1938) yield abundant well-preserved silicified ostracodes when dissolved in dilute acetic acid. Large crinoid columnals, 1 inch in diameter, are seen in the lower unit at the extreme southwest end of the quarry where the Schoharie and Esopus Formations are also exposed.

Mileage

23.8	Retrace route to U. S. Rte. 209.
24.4	LEFT turn onto U.S. Rte 209S past Holiday Inn (this is not a paid commercial).
24.5	Bear LEFT onto U.S. Interstate 80E. Note that this is cloverleaf geology.
25.3	Cross Brodhead Creek.
25.7	Bear RIGHT at exit 53 and follow U.S. Rte. 611S to Delaware Water Gap.
25.9	Newly rebuilt Croasdale Manor on right.
26.5	Traffic light in Delaware Water Gap. LEFT turn.
26.6	One block, RIGHT turn onto Cherry Valley Road.
27.5	LEFT turn at golf course. Note undulating topography with kettle holes. Golf courses are partial to rolling glacial topography.
28.5	Road ascends Bloomsburg Red Beds on the northeast-dipping limb of the Kemmererville anticline.
29.0	Crest of Kemmererville anticline.
29.1	Bear LEFT at Y. Road descends along the gently dipping southeast

limb of the Kemmererville anticline in the Bloomsburg Red Beds.

29.4 Trough of Poplar Valley syncline. Note 10-foot long erratics of Buttermilk Falls Limestone of Willard (1938) in creek to right.

29.9 Ascend, we hope, steep dirt road to crest of Kittatinny Mountain. Cross Bloomsburg-Shawangunk contact.

30.1 Totts Gap. LEFT turn along ridge crest following Appalachian Trail. The road follows the Shawangunk Conglomerate which is overturned to the southeast or dips steeply to the northwest.

30.4 Good view of countryside to north.

32.2 Park at fire tower. Disembark and follow Appalachian Trail out to the edge of the mountain overlooking Delaware Water Gap and surrounding countryside. STOP 6.

STOP 6. TOP OF KITTATINNY MOUNTAIN OVERLOOKING DELAWARE WATER GAP

30 MINUTES

Walk along the Appalachian Trail to the Scenic overlook. At this stop we are on the upper quartzite-conglomerate unit of the Shawangunk Conglomerate. Compare the stratigraphy of the Shawangunk as seen on the northeast side of the gap in New Jersey (fig. 4 and table 1) with the section seen at Lehigh Gap yesterday.

The structure at Delaware Water Gap is described in the reprint provided at the back of this guidebook (p. B81-B82, figs. 2-4). Structural control for the location of the gaps described in the reprint places the hypothesis of regional superposition in doubt.

Note the satellitic folds in the Shawangunk Conglomerate across the Delaware River.

Mapping in the Delaware Water Gap area shows that the contact between the Pen Argyl and Ramseyburg Members of the Martinsburg Formation and the overlying Shawangunk is covered along the unconformity at the base of the Shawangunk two miles southwest of the gap (fig. 31). The regional strike between the Martinsburg Formation and Shawangunk Conglomerate differs by at least 15° in this area.

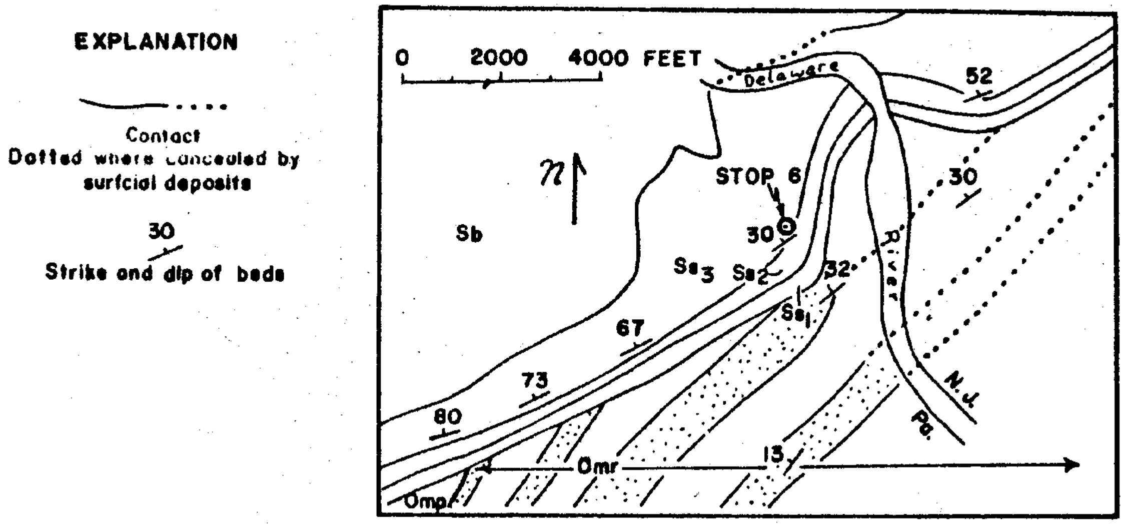


Figure 31. Geologic map of the Delaware Water Gap area showing the angular unconformity between the Martinsburg Formation of Ordovician age and the Shawangunk Conglomerate of Silurian age. Sb, Bloomsburg Red Beds; Ss_3, upper quartzite-conglomerate unit of the Shawangunk Conglomerate; Ss_2, quartzite-argillite unit of the Shawangunk Conglomerate; Ss_1, lower quartzite-conglomerate unit of the Shawangunk Conglomerate; Omp, Pen Argyl Member of Martinsburg Formation; Omr, Ramseyburg Member of Martinsburg Formation. Stippled areas are graywacke-bearing intervals in Omr. Surficial deposits not shown.

The very irregular contact between the Bloomsburg Red Beds and Shawangunk Conglomerate in Delaware Water Gap will be discussed.

Three erosion surfaces are seen to the east and south. These are believed to be peneplains by some geologists (the Schooley, Harrisburg, and Somerville peneplains) but are believed by others to represent a state of dynamic equilibrium in the erosion of rocks of varying resistances.

Note the glacial striae and roches moutonnees on joint surfaces of the Shawangunk, indicating that the Wisconsin glacier was thick enough to override Kittatinny Mountain at this point. The mountain is 1,300 feet high here. The striae trend about due south on top of the mountain, but in the valley to the north, the mountain partly deflected the glacier, and the striae trend southwest.

The top of the mountain just across the gap in New Jersey is named Mount Tammany, after the great Indian chief Tamanend. During the Revolutionary War a charitable and patriotic society was established in Philadelphia and New York in his honor. It soon passed out of existence, except in New York City where it became a powerful political machine (Tammany Hall).

Time permitting, we will end the field trip with a recapitulation of the geology between Delaware and Lehigh Water Gaps in eastern Pennsylvania.

Mileage

32.2 Retrace route back to Holiday Inn.

END OF SECOND DAY

ALTERNATE STOP 6

Mileage

23.8 Retrace route U.S. Rte. 209.

24.4 LEFT turn onto U. S. Rte 209S past Holiday Inn.

24.5 Bear LEFT onto U. S. Interstate 80E.

25.7 Bear RIGHT at exit 53 and follow U. S. Rte. 611S to Delaware Water Gap.

25.9 Newly rebuilt Croasdale Manor.

26.5 Traffic light in Delaware Water Gap. LEFT turn.

26.6 One block, RIGHT turn onto Cherry Valley Road.

26.8 RIGHT turn onto Mountain Road to Delaware Water Gap Vista.

27.0 Follow left fork of road. Road traverses red, green, and gray sandstone, siltstone, and shale of the Bloomsburg Red Beds. STOP 6, at Vista.

References cited

Arndt, H. H., and Wood, G. H., 1960, Late Paleozoic orogeny in eastern Pennsylvania consists of five progressive stages: U.S. Geol. Survey Prof. Paper 400-B, p. B182-B184.

Beerbower, J. R., 1956, The Ordovician-Silurian contact, Delaware Water Gap, New Jersey: Pennsylvania Acad. Sci. Proc., v. 30, p. 146-149.

Behre, C. H., Jr., 1924, Structures in the slates of northeastern Pennsylvania (abs.): Geol. Soc. America Bull. v. 35, p. 100-101.

_____1927, Slate in Northampton County, Pennsylvania: Pennsylvania Geol. Survey, 4th ser., Bull. M9, 308 p.

_____1933, Slate in Pennsylvania: Pennsylvania Geol. Survey, 4th ser., Bull. M16, 400 p.

Brodhead, L. W., 1870, The Delaware Water Gap; its scenery, its legends and early history: Philadelphia, 2d ed., 276 p.

Clark, T. H., 1921, A review of the evidence for the Taconic revolution: Boston Soc. Nat. History Proc., v. 36, no. 3, p. 135-163.

Davis, R.E., Drake, A. A., Jr., and Epstein, J. B., 1967, Geology of the Bangor quadrangle, Pennsylvania-New Jersey: U. S. Geol. Survey Geol. Quad. Map GQ-665 (in press).

Donath, F. A., and Parker, R. B., 1964, Folds and folding: Geol. Soc. America Bull., v. 75, p. 45-62.

Drake, A. A., Jr., 1967a, Geology of the Bloomsbury quadrangle, New Jersey: U. S. Geol. Survey Geol. Quad. Map GQ-595.

Drake, A. A., Jr., 1967B, Geology of the Easton quadrangle, New Jersey-Pennsylvania: U. S. Geol. Survey Geol. Quad. Map GQ-594.

Drake, A. A., Jr., Davis, R. E., and Alvord, D. C., 1960, Taconic and post-Taconic folds in eastern Pennsylvania and western New Jersey: U. S.

Geol. Survey Prof. Paper 400-B. 180-181.

Drake, A. A., Jr., and Epstein, J. B., 1967, The Martinsburg Formation (Middle and Upper Ordovician) in the Delaware Valley, Pennsylvania-New Jersey: U. S. Geol. Survey Bull. 1244-H, p. H1-H16.

Drake, A. A., Jr., McLaughlin, D. B., and Davis, R. E., 1961, Geology of the Frenchtown quadrangle, New Jersey-Pennsylvania: U. S. Geol. Survey Geol. Quad. Map GQ-133.

_____1967, Geologic map of the Riegelsville quadrangle, Pennsylvania-New Jersey: U. S. Geol. Survey Geol. Quad. Map GQ-593.

Dyson, J. L., 1956, Recumbent folding in the vicinity of Palmerton, Pennsylvania: Pennsylvania Acad. Sci. Proc., v. 30, p. 137-141.

Epstein, A. G., Epstein, J. B., Spink, W. J., and Jennings, D. S., 1967, Upper Silurian and Lower Devonian stratigraphy of northeastern Pennsylvania, New Jersey, and southeasternmost New York: U. S. Geol. Survey Bull. 1243, 74 p.

Epstein, J. B., 1966, Structural control of wind gaps and water gaps and of stream capture in the Stroudsburg area, Pennsylvania and New Jersey: U. S. Geol. Survey Prof. Paper 550-B,p. B80-B86.

_____(in press), Surficial geology of the Stroudsburg quadrangle, Pennsylvania-New Jersey: Pennsylvania Geol. Survey, Bull. G57.

Field Conference of Pennsylvania Geologists, 31st, Harrisburg, 1966, Comparative tectonics and stratigraphy of the Cumberland and Lebanon Valleys, by D. B. MacLachlan and S. I. Root: Harrisburg, Pa., Pennsylvania Geol. Survey, 90 p.

Grabau, A. W., 1909, Physical and faunal evolution of North America during Ordovicic, Siluric, and early Devonic time: Jour. Geology, v. 17, p. 209-252.

Gray, Carlyle, 1954, Recumbent folding in the Great Valley: Pennsylvania Acad. Sci., Proc. v. 28, p. 96-101.

Gray, Carlyle, and others, 1960, Geologic map of Pennsylvania: Pennsylvania Geol. Survey, 4th ser., scale 1:250,000.

Gwinn, V. E., 1964, Thin-skinned tectonics in the Plateau and northwestern Valley and Ridge provinces of the central Appalachians: Geol. Soc. America Bull., v. 75, p. 863-900.

Harrison, J. V., and Falcon, N. L., 1936, Gravity collapse structures and mountain ranges, as exemplified in south-western Iran: Geol. Soc. London Quart. Jour., v. 92, p. 91-102.

Hess, H. H., 1955, Serpentine, orogeny, and epeirogeny: Geol. Soc. America Spec. Paper 62, p. 391-408.

Johnson, M. E., 1950, Geologic map of New Jersey: New Jersey Dept. Conserv. and Econ. Devel., scale 1"250,000 (revised).

Keith, Arthur, 1923, Outlines of Appalachian structure: Geol. Soc. America Bull., v. 34, p. 309-380.

Lesley, J. P., 1883, The geology of Lehigh and Northampton Counties: Pennsylvania Geol. Survey, 2d, Rept. D-3, 283 p.

McBride, E. F., 1962, Flysch and associated beds on the Martinsburg Formation (Ordovician), central Appalachians: Jour. Sed. Petrology, v. 32, p. 39-91.

Maxwell, J. C., 1962, Origin of slaty and fracture cleavage in the Delaware Water Gap area, New Jersey and Pennsylvania, in Geol Soc. America, Petrologic studies: a volume in honor of A. F. Buddington: New York, p. 281-311.

Miller, B. L., 1926, Taconic folding in Pennsylvania: Geol. Soc. America Bull., v. 37, no. 3, p. 497-511.

Miller, B. L, Fraser, C. M., and Miller, R. L., 1939, Northampton County, Pennsylvania, geology and geography: Pennsylvania Geol. Survey, 4th ser., Bull. C48, 496 p.

Oliver, W. A., Jr., 1960, Rugose corals from reef limestones in the Lower Devonian of New York: Jour. Paleontology, v. 34, no. 1, p. 59-100.

Pettijohn, F. J., 1957, Sedimentary rocks: New York, Harper and Bros., 718 p.

Rickard, L. V., 1962, Late Cayugan (Upper Silurian) and Helderbergian (Lower Devonian) stratigraphy in New York: New York State Mus. Bull. 386, 157 p.

Rogers, H. D., 1838, Second annual report on the (1st) geological exploration of the State of Pennsylvania: Harrisburg, 93 p.

_____1858, The geology of Pennsylvania; a government survey: Philadelphia, 2 v.: 586 and 1046 p.

Stokes, A. F. (nd.), Indian history and legends of Pennsylvania's picturesque playground: Stroudsburg, Pa., A. B. Wyckoff, 22 p.

Stose, G. W., 1930, Unconformity at the base of the Silurian in southeastern Pennsylvania: Geol. Soc. America Bull., v. 41, p. 629-658.

_____1950, Evidence of the Taconic sequence in the vicinity of Lehigh River, Pennsylvania: Am. Jour. Sci., v. 248, p. 815-819.

Swartz, F. M., 1939, The Keyser Limestone and Helderberg Group, in The Devonian of Pennsylvania: Pennsylvania Geol. Survey, 4th ser., Bull. G19, p. 29-91.

Swartz, F. M., and Swartz, C. K., 1931, Early Silurian formations of southeastern Pennsylvania: Geol. Soc. America Bull., v. 42, p. 621-662.

_____1941, Early Devonian and Late Silurian formations of southeastern Pennsylvania: Geol. Soc. America Bull., v. 52, p. 1120-1192.

Van Houten, F. B., 1954, Sedimentary features of Martinsburg slate, northwestern New Jersey: Geol. Soc. America Bull., v. 65, p. 813-818.

White, I. C., 1882, The geology of Pike and Monroe Counties: Pennsylvania Geol. Survey, 2d, Rept. G6, 407 p.

Wietrzychowski, J. R., 1963, The Sweet Arrow fault in northeastern Pennsylvania, in Field Conference of Pennsylvania Geologist, 28th, Stroudsburg, 1963, Stratigraphy and structure of Upper and Middle Devonian rocks in northeastern Pennsylvania: Harrisburg, Pa., Pennsylvania Geol. Survey, p. 43-44.

Willard, Bradford, 1938, A Paleozoic section at Delaware Water Gap: Pennsylvania Geol. Survey, 4th ser., Bull. G11, 35 p.

Willard, Bradford, and Cleaves, A. B., 1939, Ordovician-Silurian relations in Pennsylvania: Geol. Soc. America Bull., v. 50, p. 1165-1198.

Wood, G. H., Jr., Arndt, H. H., and Hoskins, D. M., 1963, Structure and stratigraphy of the southern part of the Pennsylvania Anthracite region: Geol. Soc. America, Ann. mtg., New York City, 1963, Guidebook, Field Trip no. 4, 84 p.

Wood, G. H., Jr., and Kehn, T. M., 1961, Sweet Arrow fault, east-central Pennsylvania: Am. Assoc. Petroleum Geologists, Bull., v. 45, p. 256-263.

Woodward, H. P., 1944, Copper mines and mining in New Jersey: New Jersey Dept. Conserv. and Devel., Geol. Ser., Bull. 57, 156 p.

_____1957, Structural elements of northeastern Appalachians: Am. Assoc. Petroleum Geologists Bull., v. 41, p. 1429-1440.

STRUCTURAL CONTROL OF WIND GAPS AND WATER GAPS AND OF STREAM CAPTURE IN THE STROUDSBURG AREA, PENNSYLVANIA AND NEW JERSEY

By JACK B. EPSTEIN, Beltsville, Md.

Abstract.—Wind gaps and water gaps in the Stroudsburg area, in eastern Pennsylvania and northern New Jersey, are located where resistant rocks dip steeply and have a narrow width of outcrop, where folds die out over short distances, or where folding was more intense locally than nearby. All gaps trend about perpendicular to the strike of the ridges, and parallel to major cross-joint sets. These observations favor the hypothesis of structural control of the location of stream gaps, rather than that of regional superposition of the streams upon the resistant rocks. A second type of structural control, in which more resistant beds were exposed in Wind Gap than in Delaware Water Gap, may explain the capture of Wind Gap River by tributaries of the Delaware River.

WIND GAPS AND WATER GAPS

Numerous and extensive investigations of wind and water gaps in the Appalachians have contributed to the controversies regarding Appalachian geomorphic evolution. Many geologists believe that after the Appalachian orogeny the drainage divide between streams that flowed southeastward into the Atlantic and those that flowed toward the continental interior was located either in the crystalline highlands southeast of the present Great Valley or in the Valley and Ridge province. The divide has since shifted westward to its present position in the Appalachian Plateau. The location of the original divide, the means by which the divide migrated, and the process or processes by which the numerous wind and water gaps were formed are problems that need to be considered in any hypothesis which attempts to explain the drainage development of the Appalachians.

Johnson (1931) believed that the original drainage lines were obliterated during a Cretaceous marine transgression and that the present drainage pattern is mainly the result of superposition from a coastal-plain cover. The location of a gap was purely by chance and is not systematically related to any weakness in the ridge, although there may have been local adjustment to structure.

Meyerhoff and Olmstead (1936) believed that the present drainage descended from the pattern which had been established in Permian time and which had been controlled by structure and topography produced during the Appalachian orogeny. Hence gaps are found along transverse structures or in the northwest limbs of overturned folds.

Thompson (1949) argued that the original divide, which lay on crystalline rocks along the Blue Ridge-Reading Prong axis, was unstable because the southeastward-flowing streams had shorter courses than those that flowed northwestward. As a result, the divide shifted northwestward by normal stream erosion (headward piracy), and the gaps in Kittatinny and Blue Mountains are located at points of rock weakness.

Strahler (1945), who favored Johnson's hypothesis, stressed that the main test substantiating superposition was to show lack of coincidence of gaps and sites of structural weakness (specifically, transverse faults).

Structural characteristics and features other than transverse faults, however, may influence the resistance to erosion of hard-rock ridges. These include, among others: (1) changes in outcrop width, owing to changes of dip; (2) abrupt changes in strike, owing to dying out of folds; (3) local weakness of otherwise resistant rocks as a result of the overturning of beds and accompanying shearing; (4) closely spaced joints and strong folding resulting from intense local stress; (5) cross folds and attendant fracturing; (6) thinning of resistant units, which reflects the original processes of sedimentation; (7) thinning or elimination of resistant strata by strike faulting; and (8) change in facies.

Detailed structural data from gaps in the Stroudsburg area, presented by previous investigators, generally have been scanty. Detailed mapping of Blue and Kittatinny Mountains and of ridges to the north has shown that there is a correlation of gaps with one or more of the following conditions: (1) steep dips of beds and narrow outcrop widths of resistant units,

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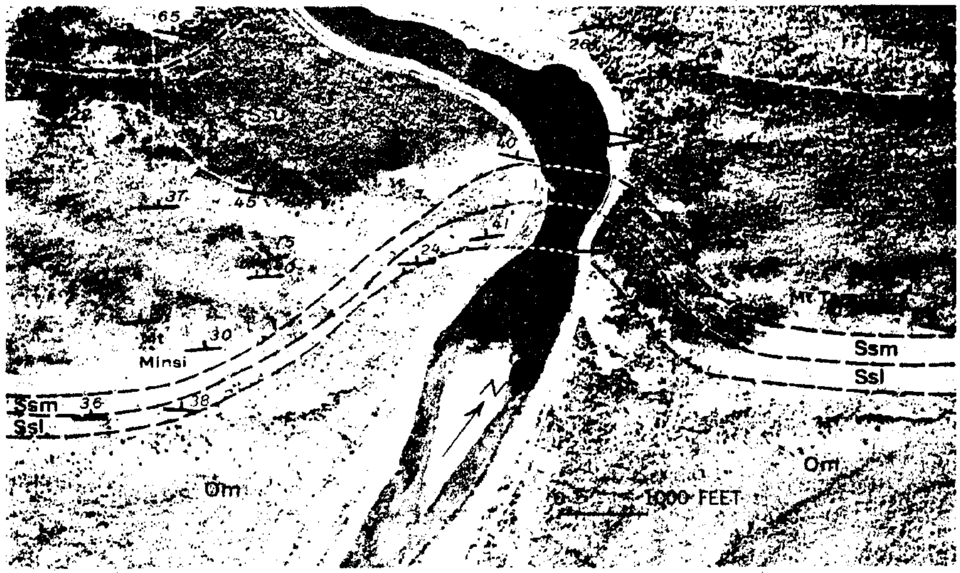


FIGURE 3.—Aerial photograph and geologic map of Delaware Water Gap. The Bloomsburg Redbeds, Sb, of Silurian age are underlain by three members of the Shawangunk Conglomerate: Ssu, upper conglomerate and quartzite member; Ssm, middle black argillite, quartzite, and conglomerate member; and Ssl, lower quartzite and conglomerate member. The Martinsburg Shale, Om, of Ordovician age underlies the Shawangunk.

Wind Gap.—Geologic Structures in Wind Gap duplicate those in the Delaware Water Gap area. Two major folds plunge out north of the gap. The Shawangunk Conglomerate is not repeated to the northwest because the Wind Gap anticline plunges to the southwest. There is a 15° difference in strike in beds in the ridge crest on either side of the gap, indicative of a flexure similar to that at Delaware Water Gap. In addition, several small folds in the Bloomsburg Redbeds are similar to those in the Bloomsburg at Delaware Water Gap. These folds were not included in figure 2*A* because outcrops are too few to permit tracing of their trends. Thinning of the outcrop width of the Shawangunk at the gap is evident on figure 2*A*. This is indicative of near-vertical dips which can be seen in cuts along the highway where it passes through the gap.

Gaps in Godfrey Ridge

Godfrey Ridge lies about 2½ miles north of Kittatinny Mountain and is supported by complexly folded Upper Silurian and Lower Devonian limestone, shale, sandstone, and conglomerate. Silty shale and sandstone of the Esopus Shale and Oriskany Formation support the higher parts of the ridge (fig. 5). Small folds are numerous and die out rapidly. Sags in the ridge crest are numerous, but it is difficult to relate structural features to them. The two largest gaps in Godfrey Ridge, the gap of Brodhead Creek and North Water Gap, are located about 2½ miles north-northwest of Delaware Water Gap.

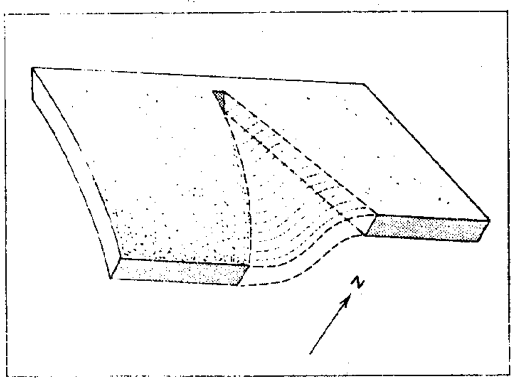


FIGURE 4.—Diagram showing reconstructed flexure at Delaware Water Gap. Dashed lines show form of bed before gap was cut. Presence of the flexure accounts for the topographic offset of the ridge and suggests extensive fracturing of the Shawangunk Conglomerate at the gap site in the flexure zone.

Gap of Brodhead Creek.—Brodhead Creek cuts through Godfrey Ridge at an altitude of about 300 feet. No rock crops out in the creek bottom, but bedrock is exposed in the creek bed about 1 mile upstream. Therefore, bedrock cannot be far below creek level in the gap. Folding at the gap is so complex that Willard (1938, p. 23) believed that the gap is the site of a north-south tear fault. Evidence of faulting could not be found, however. Rather, there are four overturned folds in the southwestern part of the ridge near Brod-

(2) dying out of folds within short distances, and (3) more intense folding locally than nearby. The parallelism of the gaps is controlled by prominent southeast-trending cross-joint sets present throughout the area. A plot of nearly four hundred joints shows a strong maximum with a strike of N. 14° W. and a dip about vertical.

Gaps in Blue and Kittatinny Mountains

Blue and Kittatinny Mountains, parts of a single ridge supported by the Shawangunk Conglomerate, are cut by several gaps: Delaware Water Gap, Totts Gap, Fox Gap, and Wind Gap. Figure 1 shows the locations of the gaps and other major physiographic features. Figure 2 shows the distribution of geologic formations and the structural geology of the area, and demonstrates the correlation of gap location with the three structural conditions mentioned above.

Delaware Water Gap.—Many early observers of Delaware Water Gap believed that it was the result of a violent cataclysm. Interesting excerpts of these early discussions are reported by Miller and others (1939, p. 139–142). Rogers (1858, v. 1, p. 283, v. 2, p. 896) noted that the ridge crest is offset 700 feet at the gap. He attributed the displacement to a transverse fault, as did Ashley (1935, p. 1406) and Willard (1938, p. 23). Chance (1882, p. 338), Johnson and others (1933, p. 26), Miller and others (1939, p. 144), and Strahler (1945, p. 58–59) believed that the ridge is offset by a slight flexure. Thompson (1949, p. 56, 59) found many small faults which he suggested might be offshoots of a major transverse fault, and attempted to show that the gap is structurally controlled.

During the present study no cross fault could be found at Delaware Water Gap. The Shawangunk Conglomerate consists of three units that match at river level and have contacts that are not displaced (fig. 3). The bedding dips 35° to 45° to the northwest on both sides of the stream at the bottom of the gap. At the top of the ridge on the New Jersey side, at Mt. Tammany, the dip is about 50°, whereas on the Pennsylvania side the dip decreases upward toward Mt. Minsi, being less than 25° at a place halfway up the mountain. Clearly, there is a small flexure at the gap; the beds on the New Jersey side dip more steeply than those in Pennsylvania, and the ridge crest in New Jersey lies about 700 feet northwest of the axis of the crest on the Pennsylvania side. The flexure can be seen by looking west from the New Jersey bank. Consideration of the structural geometry (fig. 4) reveals that there was an abrupt change in strike of the beds that formerly occupied the site of the gap. As a consequence the brittle Shawangunk must have been weakened by extensive fracturing in the flexure zone. Structural control is therefore thought to have determined location of the gap.

A series of folds in the Bloomsburg Redbeds along the course of Delaware River north of the gap dies out to the southwest, within a short distance (fig. 2). Probably the rocks are more highly sheared here, and resistance to erosion is less, than in the areas between gaps where similar folds were not observed.

Perhaps equally important in controlling the location of Delaware Water Gap is the fact that the outcrop width of the Shawangunk Conglomerate is narrower at the gap site than to the northeast where the formation

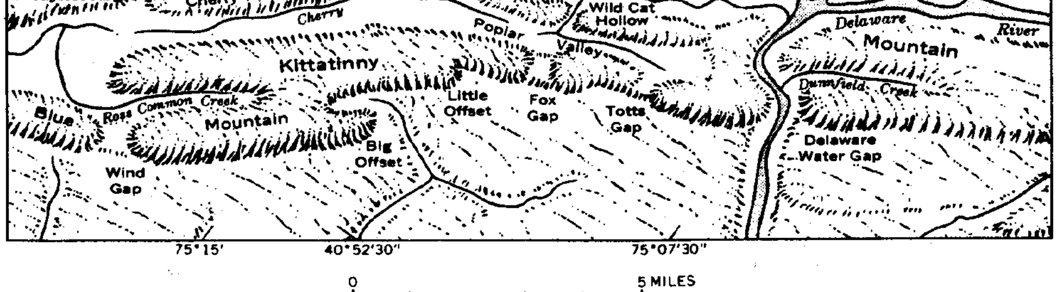


FIGURE 1.—Physiographic diagram of the Stroudsburg area, Pennsylvania and New Jersey.

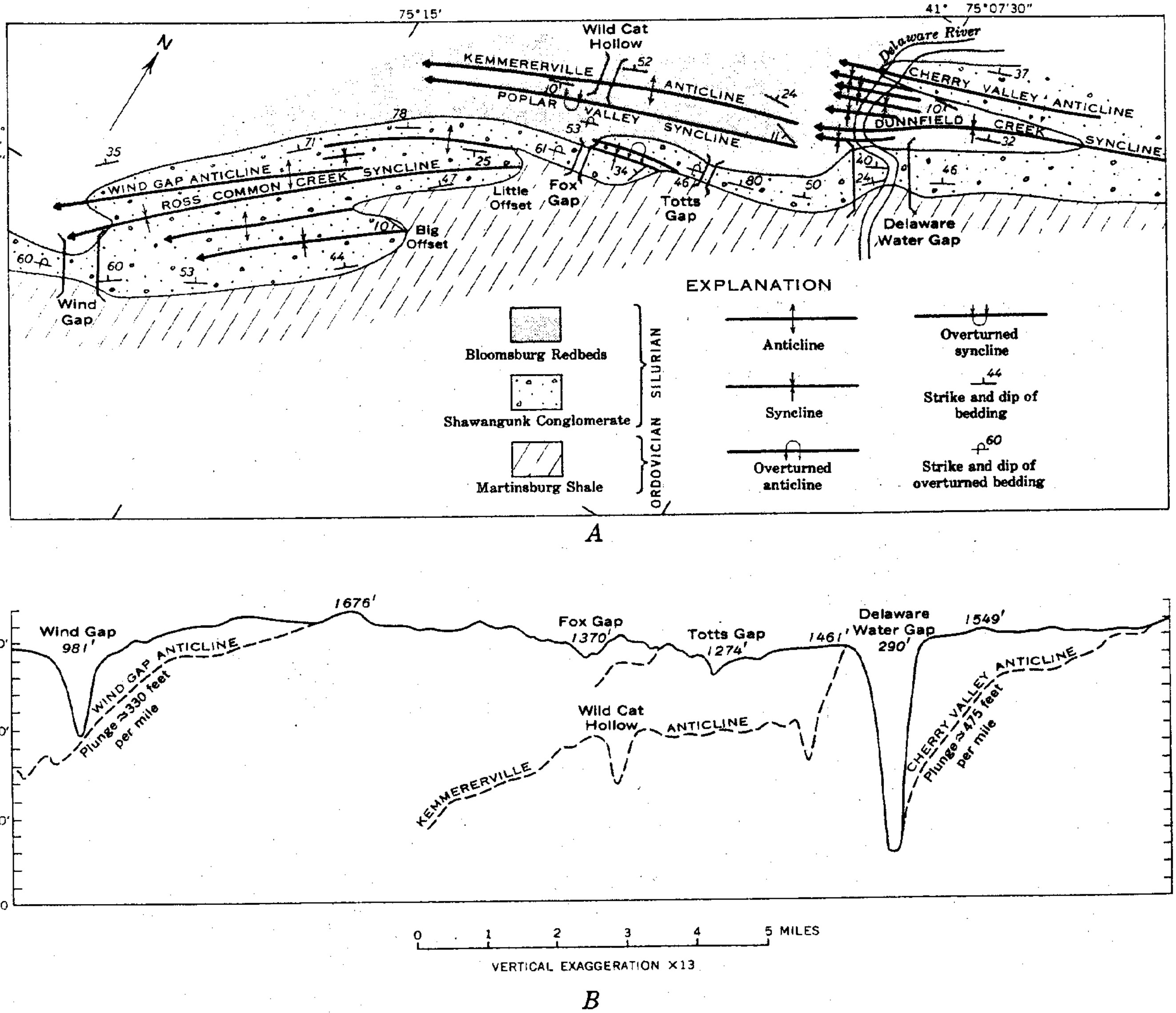


FIGURE 2.—*A*, Geologic map of the Stroudsburg area, Pennsylvania and New Jersey. *B*, projected longitudinal topographic profile, showing relation of geologic structure to location of gaps in Blue and Kittatinny Mountains (fig. 1). Profile viewed from the southeast. Dashed lines indicate topography behind main ridge and correspond approximately to crests of major anticlines. Several small folds north of Wind Gap, similar to those in Delaware Water Gap, are not shown; their extent is not well known because outcrops are poor. Topography from Wind Gap quadrangle, Pennsylvania–New Jersey (15 min.), and Portland quadrangle, New Jersey (7½ min.).

is repeated in the southwest-plunging Cherry Valley anticline. The river now flows on the Shawangunk where it crosses the anticline, but undoubtedly it flowed on the weaker Bloomsburg Redbeds earlier in its history before cutting down into the Shawangunk. This is an example of local superposition.

Totts Gap.—The beds at Totts Gap are more strongly overturned than elsewhere along the ridge crest in the area of study, and it seems likely that the rocks here were weakened more than in adjacent areas. Moreover, the Shawangunk Conglomerate has a narrow outcrop width at Totts Gap. Thompson (1949, p. 58) observed that between Totts Gap and Delaware Water Gap the ridge crest is lower where joints are more closely spaced than elsewhere, and that at Totts Gap, the lowest point along this stretch, the joints are most closely spaced. Whether this reflects greater stress, or whether it is due to chance exposure of different beds in the Shawangunk that possess different structural characteristics, is difficult to determine.

Fox Gap.—Fox Gap is located where two southwest-plunging folds die out over a short distance, much as they do at Delaware Water Gap. Also, the beds are strongly overturned, and the outcrop width is narrow.

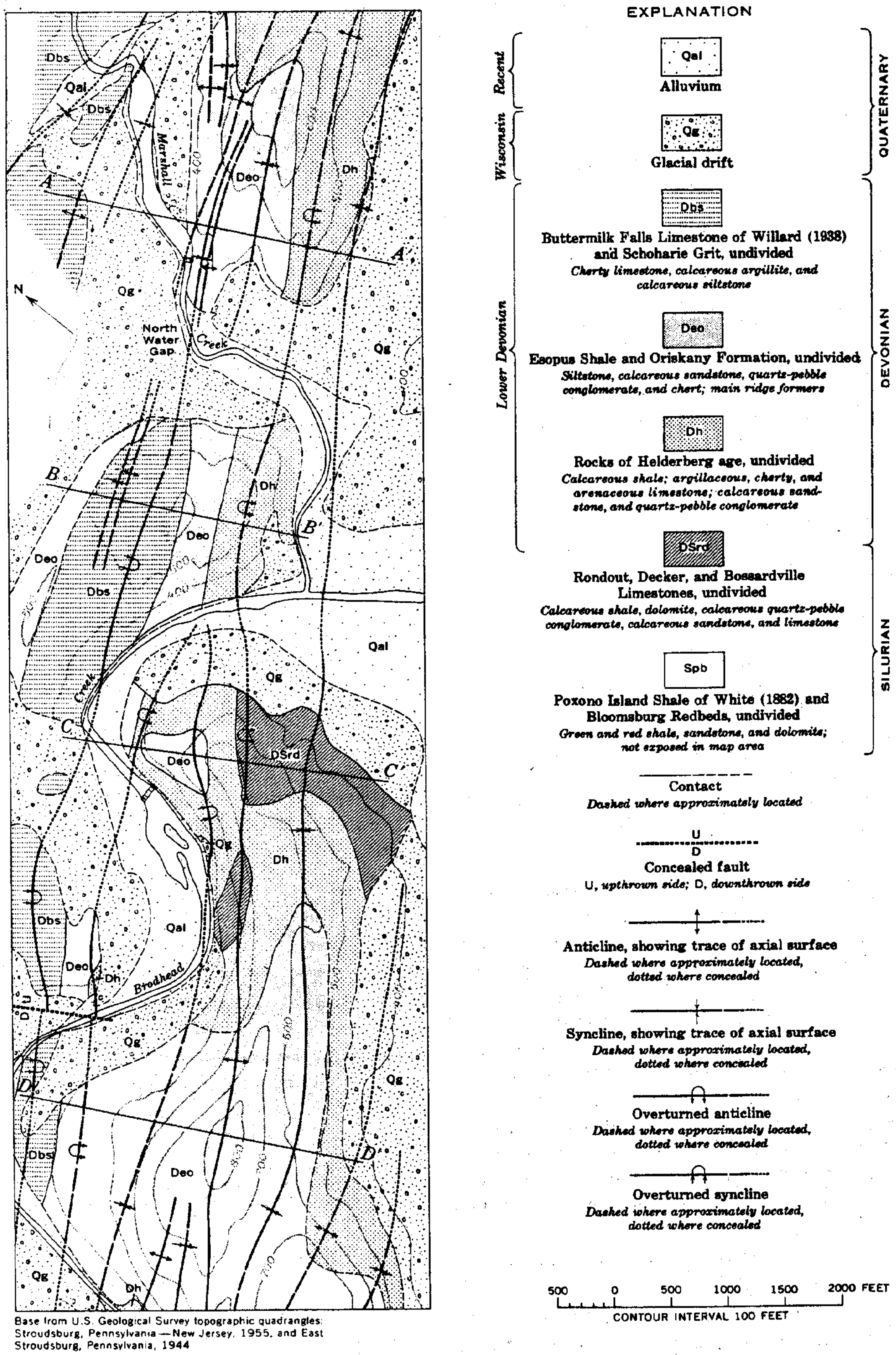
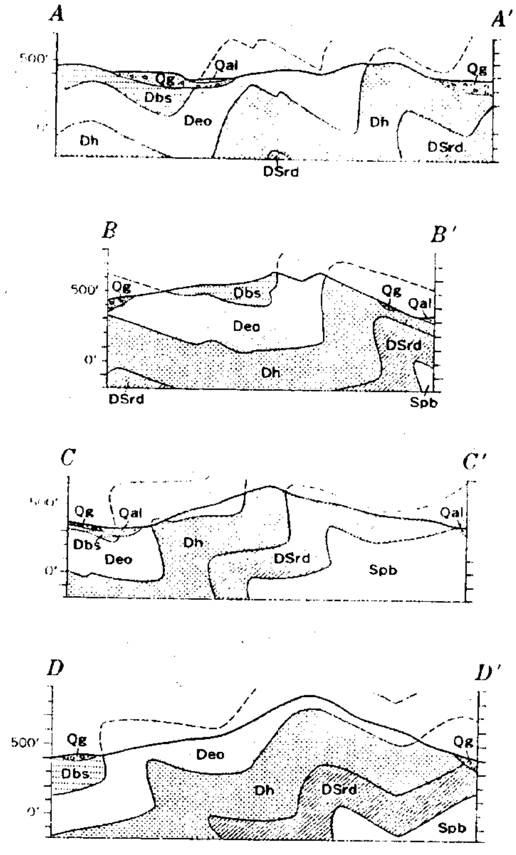


FIGURE 5.—Geologic map and sections of the area near North Water Gap and the gap of Brodhead Creek. Geology by J. B. Epstein, assisted by A. G. Epstein, 1962–63.



LINES OF SECTIONS ARE SHOWN ON FACING PAGE

head Creek, two of which die out and are absent in the northeastern part. The abrupt dying out of folds is well illustrated by sections *B–B′* and *C–C′* in figure 5. Change in strike of the beds that formerly occupied the site of the gap is inferred, as it is at Delaware Water Gap.

North Water Gap.—North Water Gap is located where Marshall Creek cuts through Godfrey Ridge, about half a mile northeast of the gap of Brodhead Creek. It is almost as deep as the latter, but no bedrock is exposed in the creek floor. Glacial debris which may be of great thickness [1] is found along the course of the creek in the gap. Clearly, North Water Gap was much deeper in preglacial times.

The structure at North Water Gap is similar to the structure at the gap of Brodhead Creek. Two folds trending toward the gap from the northeast die out within the valley and do not reappear in the ridge to the southwest (compare sections *A–A′* and *B–B′* in fig. 5). The two gaps are therefore located at sites where folds plunge out abruptly, and implication of structural control is clear. Moreover, because of near-vertical dips, the Oriskany and Esopus, which together make up the main ridge support, have a narrow outcrop width.

[1] Bedrock was penetrated at a depth of 296 feet in a water well near the west bank of the Delaware River at an altitude of about 300 feet and approximately 2,000 feet southeast of the mouth of the gap, as reported by a local resident.

STREAM CAPTURE

Structural relations in the Stroudsburg area are believed to have controlled not only the locations but also the history of the gaps. For example, Wind Gap was cut by a stream that was later captured north of Blue Mountain by tributaries of either the Lehigh River to the west or of the Delaware River to the east (Wright, 1896; Ver Steeg, 1930; Willard, 1939; Mackin, 1941). Mackin showed that the drainage changes in the Wind Gap area were exceedingly complex and implied that evidence of the original captor of the Wind Gap River may be gone. Nevertheless it seems likely on the basis of structural considerations that the tributaries of the Delaware were more agressive than those of the Lehigh, and that one captured the headwaters of Wind Gap River. Why was Wind Gap River, rather than the Delaware River tributary, beheaded? Mackin speculated that the present Delaware may have captured a stream which flowed through Culvers Gap in Kittatinny Mountain, 23 miles to the northeast, and greatly increased its own advantage at that time by this addition to its volume. Study of figure 2*B* suggests an alternative explanation.

The Wind Gap River was captured just after it had cut down to an altitude of about 980 feet, the present altitude of the floor of the gap. At that level the stream had reached the resistant Shawangunk Conglomerate in the Wind Gap anticline at about 980 feet, just northwest of the present gap, and its downcutting was retarded. The Delaware River, if it was at a similar altitude at that time, as seems likely, was still cutting down through weaker Bloomsburg Redbeds in the Cherry Valley anticline where the top of the Shawangunk is several hundred feet lower. The lower altitude of the top of the Shawangunk at Delaware Water Gap is explained by the difference in plunge of the folds: the Cherry Valley anticline plunges about 475 feet per mile while the Wind Gap anticline plunges about 330 feet per mile. Later, after the Delaware had captured the headwaters of Wind Gap River and cut through the Bloomsburg, it was superimposed on the Shawangunk in the Cherry Valley anticline and slipped down the plunge of the fold in a curving course. The curve was accentuated when it migrated downstream and reached the steeply dipping Shawangunk quartzites and conglomerates just west of the gap.

SUMMARY

Each of six major gaps in the Stroudsburg area is located in an area possessing some combination of the following structural features: (1) dying out of folds over a short distance, and associated abrupt changes in strike of bedding; (2) steep dip and narrow width of outcrop of resistant strata; and (3) folding that was more intense locally than in the surrounding rocks. None of these structural features is present along the ridges where there are no gaps. The presence of the gaps in the Stroudsburg area, at places where structural control seemingly was effective, does not favor the concept of regional superposition. Rather, it favors those hypotheses which maintain that gaps are located in zones of structural weakness where erosion was most effective during the course of stream competition along the ancestral drainage divide. Comparison of the structural settings of Wind Gap and Delaware Water Gap suggests that differences in the underlying rocks are an important factor in the development of gaps. The presence of resistant beds at a markedly higher altitude at Wind Gap favored the abandoning of Wind Gap as a result of stream piracy. At Delaware Water Gap, on the other hand, the resistant beds are several hundred feet lower. The Delaware River continued cutting down through the overlying softer rocks after Wind Gap had been abandoned by its stream.

REFERENCES

Ashley, G. H., 1935, Studies in Appalachian Mountain sculpture: Geol. Soc. America Bull., v. 46, p. 1395–1436.

Chance, H. M., 1882, Special survey of the Delaware Water Gap, *in* White, I. C., The Geology of Pike and Monroe Counties: Pennsylvania Geol. Survey, 2d ser., Rept. G6, 407 p.

Johnson, D. W., 1931, Stream sculpture on the Atlantic slope, a study in the evolution of Appalachian rivers: New York, Columbia Univ. Press, 142 p.

Johnson, D. W., Bascom, Florence, and Sharp, H. S., 1933, Geomorphology of the central Appalachians: Internat. Geol. Cong., 16th, United States, 1932, Guidebook 7, Excursion A–7, 50 p.

Mackin, J. H., 1941, Drainage changes near Wind Gap, Pennsylvania—a study in map interpretation: Jour. Geomorphology, v. 4, p. 24–52.

Meyerhoff, H. A., and Olmstead, E. W., 1936, The origins of Appalachian drainage: Am. Jour. Sci., 5th ser., v. 32, p. 21–42.

Miller, B. L., Fraser, D. M., and Miller, R. L., 1939, Northampton County, Pennsylvania, geology and geography: Pennsylvania Geol. Survey, 4th ser., Bull. C48, 496 p.

Rogers, H. D., 1858, The geology of Pennsylvania, a government survey: Philadelphia, v. 1, 586 p.; v. 2, 1045 p.

Strahler, A. N., 1945, Hypothesis of stream development in the folded Appalachians of Pennsylvania: Geol. Soc. America Bull., v. 56, p. 45–88.

Thompson, H. D., 1949, Drainage evolution in the Appalachians of Pennsylvania: New York Acad. Sci. Annals, v. 52, art. 2, p. 31–62.

Ver Steeg, Karl, 1930, Wind gaps and water gaps of the northern Appalachians: New York Acad. Sci. Annals, v. 32, p. 87–220.

White, I. C., 1882, The geology of Pike and Monroe Counties: Pennsylvania Geol. Survey (2d), Rept. G6, 407 p.

Willard, Bradford, 1938, A Paleozoic section at Delaware Water Gap: Pennsylvania Geol. Survey, 4th ser., Bull. G11, 35 p.

——— 1939, Stratigraphy and structure of the Kittatinny (Blue) Mountain gaps, *in* Miller, B. L., Fraser, D. M., and Miller, R. L., Northampton County, Pennsylvania, geology and geography: Pennsylvania Geol. Survey, 4th ser., Bull. C48, p. 145–158.

Wright, F. B., 1896, The origin of the Wind Gap: Am. Geologist, v. 18, p. 120–123.