GEOLOGY OF THE RIDGE AND VALLEY PROVINCE, NORTHWESTERN NEW JERSEY AND EASTERN PENNSYLVANIA

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INTRODUCTION

The rocks seen in this segment of the field trip range in age from Middle Ordovician to Middle Devonian and constitute a deep basin-continental-shallow shelf succession. Within this succession, three lithotectonic units, or sequences of rock that were deformed semi-independently of each other, have somewhat different structural characteristics. Both the Alleghenian and Taconic orogenies have left their imprint on the rocks. Wind and water gaps are structurally controlled, thus placing doubt upon the hypothesis of regional superposition. Wisconsinan deposits and erosion effects are common. We will examine these geologic features as well as some of the economic deposits in the area.

Figure 1 is an index map of the field-trip area, showing the trip route and quadrangle coverage. Figure 2 is a generalized geologic map.

STRATIGRAPHY AND ENVIRONMENTS OF DEPOSITION

The stratigraphic units seen on this trip are more than 15,000 feet (4,570m) thick. Their general characteristics are described in Table 1. More detail is given by Epstein and Epstein (1967, 1969, 1972; Epstein, 1973; and Epstein and others, 1967).

A thick sequence of rhythmically bedded shale (now slate) and graywacke was deposited during Middle and Late Ordovician basin deepening, forming the Martinsburg Formation which averages about 11,000 feet (3,350m) in thickness. The Martinsburg is divided into three members in this area--a middle graywacke-rich member (Ramseyburg) separating two distinct slate-dominated members (Bushkill and Pen Argyl). Taconic deformation and continental convergence peaked in the Late Ordovician when this area emerged. Uplands to the southeast shed nearly 3,000 feet (915 m) of braided stream deposits (Minsi and Tammany Members of the Shawangunk Formation), transitional continental-shallow marine sediments (Lizard Creek Member of the Shawangunk Formation), and meandering stream deposits (Bloomsburg Red Beds).

A general transgressive-shelf sequence followed characterized mainly by tidal sediments and barrier bars (Poxono Island, Bossardville, Decker, Rondout), succeeded by generally subtidal and bar deposits (Helderburg and Oriskany Groups), and then by deeper subtidal deposits (Esopus, Schoharie, and Buttermilk Falls), finally giving way to another deep-water to shoaling sequence (Marcellus Shale through the Catskill Formation). Rocks of the Marcellus through Catskill will not be seen on this trip.

This vertical stratigraphic sequence is complicated a bit because most Upper Silurian and Lower Devonian units are much thinner or are absent toward a paleo-positive area a few tens of miles southwest of the field-trip area. Thus, the Palmerton Sandstone of Swartz (1939) for example, is a probable shallow-marine sand body correlative with parts of the Schoharie and the Buttermilk Falls. The Palmerton crops out near Bossardsville at Stop 3.

STRUCTURAL GEOLOGY

The rocks in the field-trip area are disharmonically folded. Four lithotectonic units have been mapped in eastern Pennsylvania (Epstein and Epstein, 1969), three of which will be seen (fig. 3). The folds in each unit differ, and there is evidence that the units are separated by detachment zones or décollements. The lithologic variations and descriptions of folds are given in Table 2. Rocks overlying lithotectonic unit 3 are more than 10,000 feet (3,050 m) thick and are in large folds that have wavelengths of several miles (e.g., Weir Mountain syncline and Lehighton anticline, fig. 2). We will compare the characteristics of each of the lithotectonic units at Stops 2-4.

Two mechanisms produced 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

TABLE 1. GENERALIZED DESCRIPTION OF MIDDLE ORDOVICIAN TO MIDDLE DEVONIAN ROCKS IN THE DELAWARE WATER GAP AREA.

System	Series	Lithotectonic Unit	Group	Group, Formation, or Member	Average Thickness in Feet (m)	Description
DEVONIAN	Middle	3		Buttermilk Falls	270(82)	Medium-gray cherty limestone, argillaceous limestone, and calcareous argillite. Three members, from base upward: Foxtown, McMichaels, and Stroudsburg.
	Lower			Schoharie Formation	100(30m)	Medium-to-medium dark gray massive calcareous fossiliferous (including Taonurus) siltstone.
				Esopus Formation	180(55)	Medium-to-dark gray silty shale and siltstone containing Taonurus. Well developed cleavage
			Oriskany Group	Ridgely Sandstone and Shriver Chert	85(26)	Light-to-medium gray fine-to-coarse-grained conglomeratic fossiliferous sandstone grading down into medium-dark-gray siliceous calcareous and and cherty shale and siltstone.
			Helderburg Group	Port Ewen Shale	150(46)	Medium-dark-gray fossiliferous calcareous shale and siltstone that has well-developed cleavage.
				Minisink Limestone	15(5m)	Dark-to-medium-gray argillaceous limestone.
				New Scotland Formation	75(23)	Medium-to-dark gray cherty fossiliferous shale and limestone. Two members, from base upwards: Flatbrookville, Maskenozha.
				Coeymans Formation	55-110 (17-34)	Medium to dark-gray argillaceous arenaceous cherty fossiliferous partly biohermal limestone and light-medium to medium gray calcareous fossiliferous pebbly crossbedded sandstone and quartz pebble conglomerate. Four members, from base upwards: Depue Limestone, Peters Valley, Shawnee Island, Stormville.

	Upper Sil and Lower Devonian		Rondout Formation		30(9)	Light-to-dark-gray calcareous argillaceous fossiliferous mud-cracked limestone and medium dark-gray mud-cracked dolomite. Three members, from base upwards: Duttonville, Whiteport Dolomite, Mashipacong.
	Upper		Decker Formation		85(26m)	Calcareous quartz-pebble conglomerate, sandstone, and siltstone, argillaceous and arenaceous fossiliferous limestone and dolomite. Wallpack Center Member.
	Upper		Bossardville Limestone		100(30)	Medium-to dark-gray poorly fossiliferous mud cracked argillaceous laminated limestone.
	Upper		Poxono Island Formation		700±(213)	Light olive gray-to-green calcareous dolomitic shale, dolomite, sandstone, and siltstone.
SILURIAN	Middle and Upper		Bloomsburg Red Beds		1,500±(1457)	Red, green, and gray sandstone, siltstone, and shale partly in fining-upward sequences.
SILURIAN	Lower and Middle	2	Shawangunk Formation	Tammany Member	815(248)	Medium-to-medium-dark-gray fine to coarse-grained conglomeratic (quartz and argillite pebbles as much as 2 in. long) crossbedded and planar-bedded quartzite and minor argillite.
SILURIAN	Lower and Middle	2	Shawangunk Formation	Lizard Creek Member	275(84)	Medium-light-gray to medium-dark-gray and light-olive gray rippled and flaser-bedded sandstone containing burrows and trails, interbedded with medium-dark-gray to dark-gray burrowed siltstone and shale with rare fossils (euryptrids, Dipleurozoa, and Lingula).
SILURIAN ?	Lower and Middle ?	2	Shawangunk Formation	Minsi Member	300(91)	Light-gray to medium-dark-gray and light-olive-gray crossbedded and planar-bedded quartzite, conglomeratic quartzite, and quartz, chert, and shale-pebble conglomerate (pebbles as much as 2 in. long) and minor locally mud-cracked argillite.
ORDOVICIAN	Middle and Upper	1	Martinsburg Formation	Pen Argyl	3,000 - 6,000 (915-1820)	Dark-gray to grayish-black thick-to-thin bedded, evenly bedded claystone slate, rhythmically interbedded with quartzose slate or graywacke and carbonaceous slate.
ORDOVICIAN	Middle and Upper	1	Martinsburg Formation	Ramseyburg Member	2,800± (850)	Medium-to-dark gray claystone slate alternating with light-to-medium-gray thin-to-thick bedded graywacke and graywacke siltstone which makes up about 20-30 percent of the member.
ORDOVICIAN	Middle and Upper	1	Martinsburg Formation	Bushkill Member	4,000+ (1220)	Dark-to-medium gray thin-bedded claystone slate containing thin beds of quartzose siltstone and graywacke siltstone and carbonaceous slate.

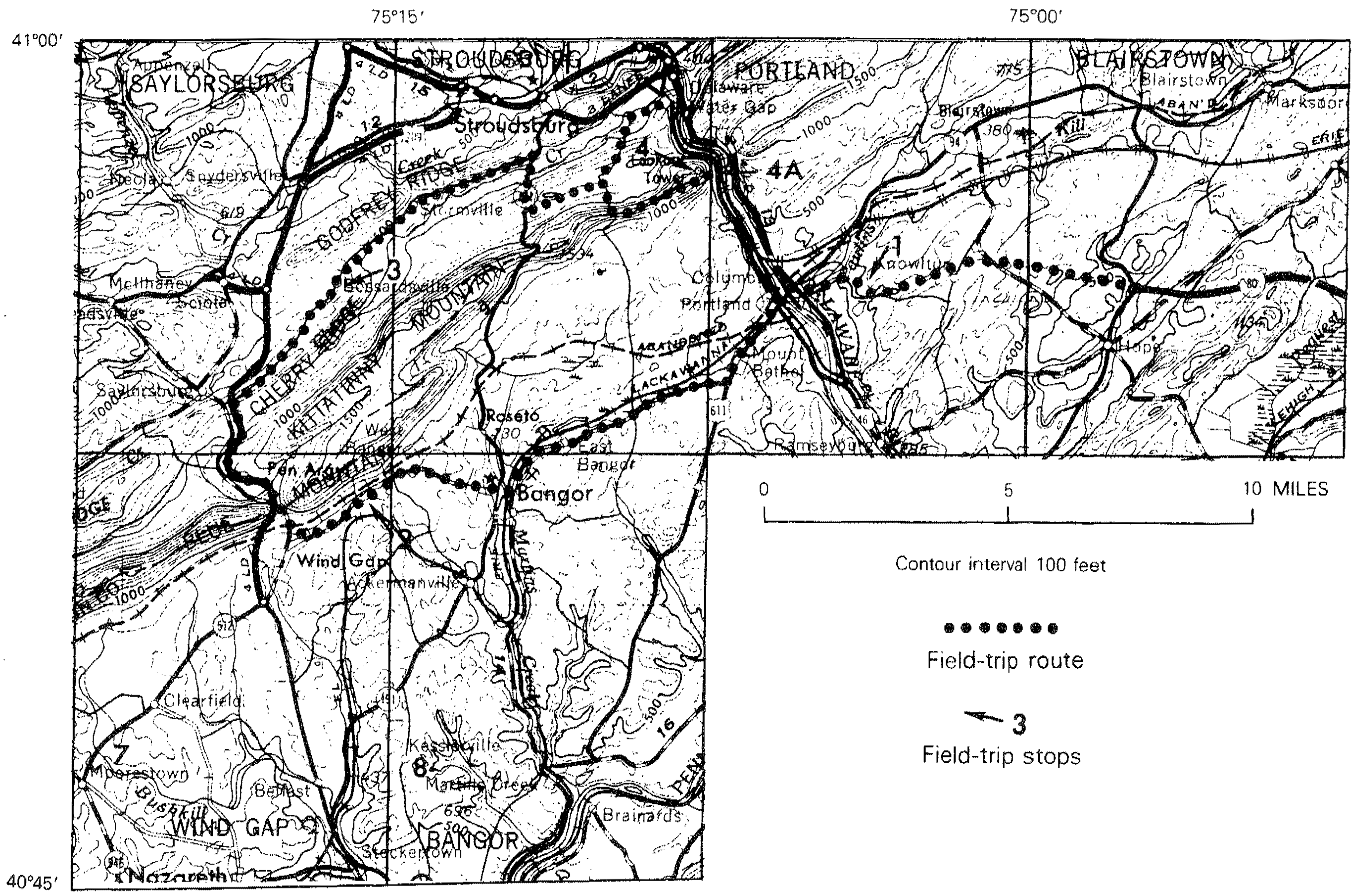


Figure 1

Index map of parts of northwestern New Jersey and eastern Pennsylvania showing the field-trip route, stops, and 7-1/2-minute-quadrangle coverage.

slip), and in which bedding was passive and merely documented deformation in the movement direction (see Donath and Parker, 1964). Flexural slip is indicated by bedding-plane slickensides and nearly 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 similar and axial-plane thickness is generally constant (i.e., distance between beds measured along cleavage). Passive slip is defined where movement along cleavage is mascroscopically discontinuous (and the cleavage may be termed "slip" cleavage). The two types of cleavage are gradational. "Slaty" cleavage in this area is a descriptive term referring to the property whereby a rock can be split into very thin slabs; this property is dependent upon the laminar character of the rock produced by very thin alternating zones of aligned platy minerals (cleavage folia) and less well oriented quartz-rich interfolial areas. A second-generation slip cleavage is common in many rocks in all lithotectonic units.

For many years there has been controversy regarding the relative intensities of Taconic and Appalachian (Alleghenian) deformation in eastern Pennsylvania. There has also been disagreement on the age and genesis of slaty cleavage, particularly in the Martinsburg Formation (see Epstein and Epstein, 1969, p. 163-170, for a summary). There is still considerable discussion of these topics, and my conclusions are that the dominant cleavage in all rocks in the field-trip area, and most of the structural features we will see are Alleghenian in age. Vestiges of Taconic cleavage may be present in some areas. Taconic orogenesis and deformation is indicated by the coarse detritus in the Shawangunk Formation shed from Taconic highlands to the southeast, by the profound angular unconformity between the Martinsburg and the overlying Shawangunk, and by large regional nappes that have been mapped in the Great Valley to the south (Drake and Lyttle, this volume).

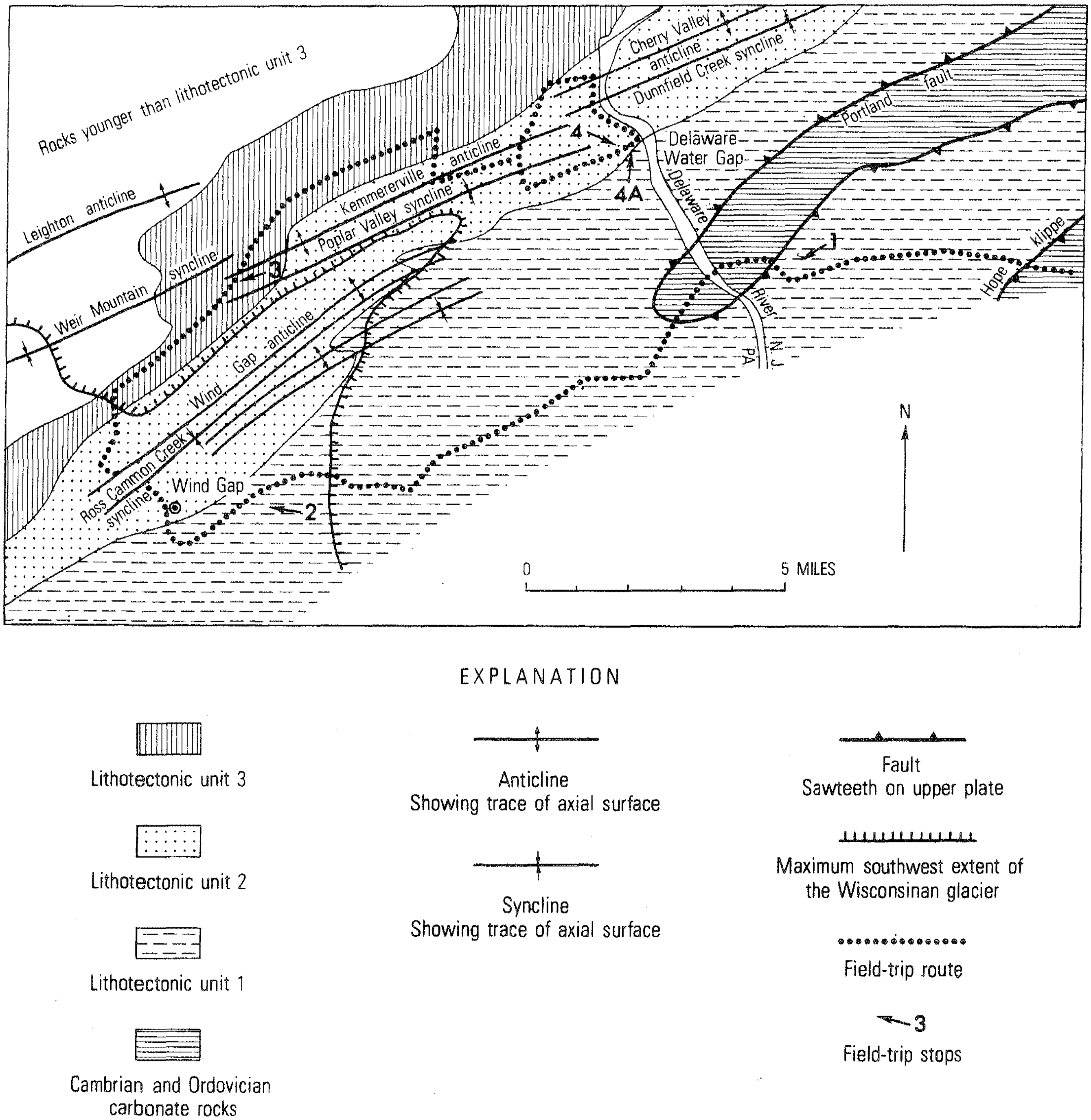


Figure 2.

Generalized geologic map of tahe Ridge and Valley province, Northwestern New Jersey and eastern Pennsylvania.

Table 2. Lithotectonic Units in the Ridge and Valley Province of Northwestern New Jersey and Eastern Pennsylvania

Litho-tectonic Unit	Age of Lithotectonic Unit and Stratigraphic Sequence (See Table 1)	Lithologic Characteristics	Style of Folding	Average Size of Folds
3	Middle Devonian to Late Silurian Buttermilk Falls Limestone to Poxono Island Formation	1,875 feet (570m) of limestone, shale, siltstone, sandstone, and dolomite; heterogeneous stratigraphic units between 3 and 180 feet (1 and 55 m) thick.	Asymmetric, concentric, and similar, flexural slip and flow.	Wavelengths 1,000 - 1,500 (305 to 455 m); amplitude about 250 feet (75 m).
2	Late to Early Silurian Bloomsburg Red Beds to Shawangunk Formation	2,900 feet (880m) 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.	Wavelengths about 1 mile (1.6 Km); amplitudes 1500 - 5000 feet (455 to 1525 m).
1	Late and Middle Ordovician Martinsburg Formation	About 11,000 feet (3,350 m) of thick sequences of slate and graywacke.	Asymmetric, similar, nearly isoclinal and recumbent; mainly passive flow and slip; flexural slip near contact with Shawangunk Formation. Folds Superimposed on upright limb of regional nappe.	Wavelengths 1,000 to 3,000 feet (305 - 915 m); amplitudes 400 - 2,000 feet (120 - 610 m). Small-scale imbricate faults and major thrusts that have possible displacements in miles south of field-trip area.

GEOMORPHOLOGY

Eastern Pennsylvania and northwestern New Jersey, in the Ridge and Valley and Great Valley physiographic provinces, have long been a classic area for the study of Appalachian geomorphology. Because several major wind and water gaps are here, the origin of the gaps is of particular interest to this field conference. I conclude that the gaps are structurally controlled, adding fuel to the controversies regarding the hypotheses of superposition and drainage evolution. This subject is discussed at Stop 4.

GLACIAL GEOLOGY

No stops in glacial deposits are planned, but evidence for Wisconsinan and older glaciation is seen everywhere--in the varied stratified deposits and till, in the numerous landforms on the deposits, and in the common glacial striae, grooves, and erratics. Many of these features will be seen at all stops. Discussions of the glacial geology in the area are given by Epstein (1969), Epstein and Epstein (1969), Crowl (1972), Connally and Epstein (1973), Crowl and Stuckenrath (1977), and Connally and others (1979).

ROAD LOG

Mileage

0.0 Overpass; U.S. Interstate 80 and N.J. 521 (Blairstown-Hope Road).

0.3 Gently dipping Allentown Dolomite in the Hope klippe (see Drake and Lyttle, this volume).

1.3 Dolomite and cherty dolomite in the Allentown (?) Dolomite.

1.9 Small anticline in the Allentown (?) Dolomite.

2.0 Graywacke and slate in the Ramseyburg Member of the Martinsburg Formation. We have just crossed a major fault separating the Middle and Upper Ordovician Martinsburg from Cambrian carbonate rocks in the Hope klippe.

4.4 Kittatinny Mountain to the right (north) held up by quartzites in the Silurian Shawangunk Formation. The mountain is offset to the northeast by a syncline-anticline couplet near the site of the Yards Creek Pumped Storage Project north of Blairstown, N.J.

5.8 Bear right to scenic overlook

6.3 STOP 1. DISCUSSION OF TRIP AND LUNCH.

See Fig. 4 for stop description. After leaving Stop 1, we will travel down the Paulins Kill Valley, across the Delaware River, travel to the southwest to Pen Argyl, Pa., and stop at a slate quarry in the upper (Pen Argyl) member of the Martinsburg Formation. After crossing Blue Mountain at Wind Gap, we will visit a quarry at Bossardsville, Pa., in Silurian rocks. We will than attempt to drive to the top of Kittatinny Mountain to a vantage point overlooking Delaware Water Gap and examine the Shawangunk Formation and Bloomsburg Red Beds. After passing through the gap we will return to Newark, N.J.

Return to Interstate 80.

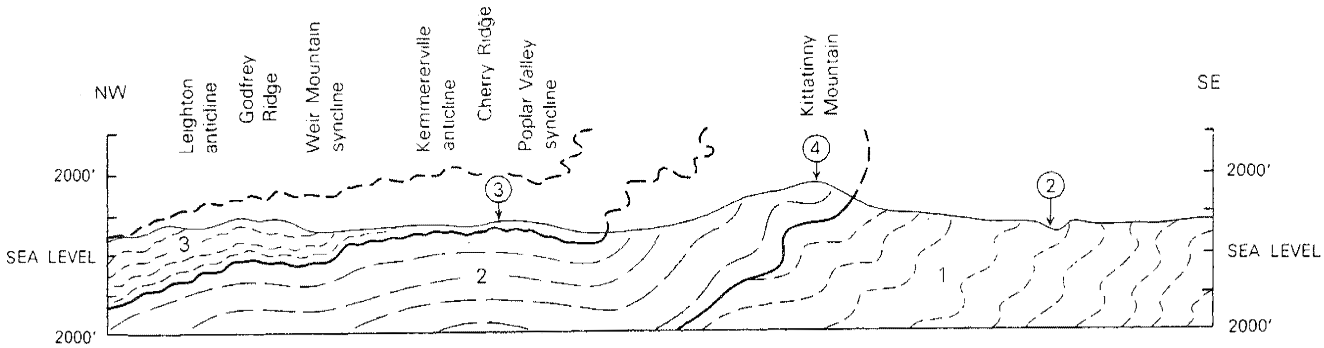


Figure 3

Composite cross section in the field-trip area showing disharmonic folding in the three lithotectonic units, 1, 2, 3, the Taconic unconformity between units 1 and 2, and the locations of stops 2, 3, and 4. Zones of detachment are believed to separate the lithotectonic units: the Blue Mountain decollement between units 1 and 2; Godfrey Ridge decollement between units 2 and 3; and Weir Mountain decollement between unit 3 and younger rocks.

6.6 Turn right on Interstate 80 heading west.

7.4 Laminated slates of the Bushkill Member of the Martinsburg Formation. Note the typical fine bedding in this member. You will not see similar laminations in slate of its Pen Argyl Member. This is one of the characteristics distinguishing the two predominantly slate-bearing members of the tripartite Martinsburg Formation.

7.7 Paulins Kill to right.

8.0 Junction with U.S. 46 and N.J. 94. Turn right following U.S. 46 east towards Columbia and Portland.

8.2 Junction of U.S. 46 and N.J. 94. Bear left on U.S. 46.

8.3 Southeast-dipping dolomite of the Epler Formation. We have crossed the Portland fault which separates the Epler from the Bushkill Member of the Martinsburg Formation.

8.5 Intersection of U.S. 80E and U.S. 46E. Bear left on U.S. 46.

8.6 Bear right on U.S. 611S heading towards Portland, Pa.

8.9 Crossing Delaware River. View of Delaware Water Gap to right (north). Tuscarora Power Plant smokestacks to left.

9.2 Toll Booth. Continue straight ahead on U.S. 611S. We will be driving on the Richenbach Dolomite of the Beekmantown Group for about 0.5 mile (0.8 km) and then on Wisconsinan kame deposits and till.

10.3 View of Kittatinny Mountain to right.

10.5 Mt. Bethel Post Office on left.

11.2 Turn right on Pa. 512S. The lowlands to the right are mostly underlain by Wisconsinan sand and gravel and some till.

13.3 Five Points. Glacial deposits are as much as 178 feet (54 m) thick in this area.

14.9 Follow Pa. 512 to right towards Bangor.

15.1 Crest of hill underlain by graywacke and slates of the Ramseyburg Member of the Martinsburg Formation. Note slate dumps ahead.

15.7 Slate dumps of the abandoned Capitol Slate quarry on right. Note the much thicker beds than in the Bushkill Member of the Martinsburg seen at mileage 7.4. We are in a slate "run" in the upper part of its Ramseyburg Member. Graywackes are found higher in the sequence and the contact with its overlying Pen Argyl Member is placed where graywacke beds become less dominant.

15.9 Flooded New Bangor and Columbia Bangor quarries on left, with nearly recumbent folds.

16.2 The Bangor Excelsior quarry on the left has been filled in, partly with fly ash. It was at least 140 (43 m) feet deep.

16.35 Pennsylvania Historical and Museum Commission sign on right: "Slate Industry—Robert M. Jones of Wales, who came here in 1848 as an immigrant, began the slate quarrying industry. The region became a major world center for slate. From here came slate roofs and old-time school slates and pencils."

To the right of the sign are the remains of an old kiln that used to fire the slate for lightweight aggregate (see Epstein, 1974a, for a discussion of the slate industry and potential uses for waste slate).

16.5 The Old Bangor slate quarry is over the dumps to the left. The nearly flat Old Bangor syncline is exposed in the quarry and can be traced for several miles in the area. The quarry also lends its name to the "Old Bangor run", a series of beds that include important commercial slate beds.

16.9 Railroad crossing, Town of Bangor. Follow Pa. 512S to right.

17.0 Follow Pa. 512 to left toward Pen Argyl.

18.0 Crest of Wisconsinan terminal moraine. Poor exposures of till may be seen in cuts to the right.

18.5 Contact between the Wisconsinan till to east and Illinoian(?) till to west. Note slate dumps from quarry in the Pen Argyl Member of the Martinsburg Formation straight ahead.

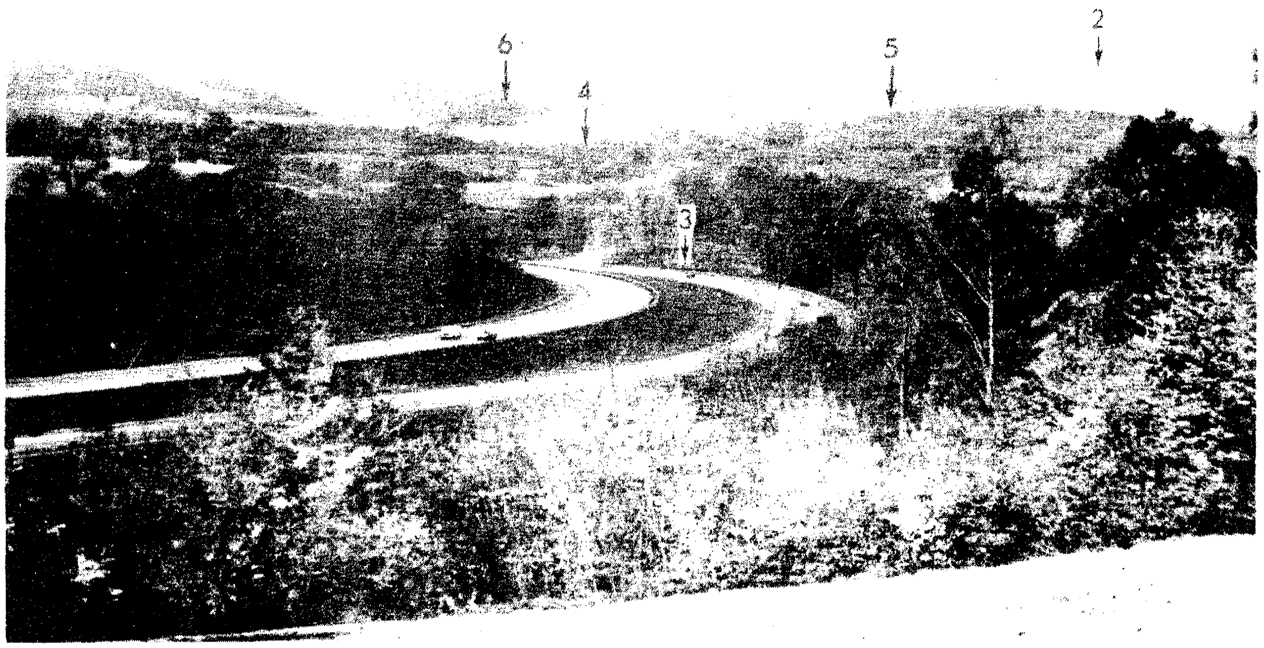


Figure 4

View northwest from Stop 1. Major small ridge (1) is Kittatinny Mountain underlain by resistant quartzite and lesser siltsone and shale of the Shawangunk Formation. The Shawangunk generally dips moderately to the northwest, such as at Delaware Water Gap (2), but is overturned to the southeast in places. The dark laminated slates exposed along Interstate 80 below (3) are in the lower (Bushkill) member of the Martinsburg Formation. Paulins Kill Valley (4) is underlain by carbonate rocks of the Allentown Dolomite, Beekmantown Group, and Jacksonburg Limestone that are in a window and are separated from the Martinsburg by the Portland Fault. The hills in the middleground beyond the Paulins Kill (5) are underlain by the Bushkill and Ramseyburg Members of the Martinsburg Formation. The upper (Pen Argyl) Member of the Martinsburg first appears across the Delaware River in Pennsylvania, coming out from under the Taconic unconformity with the overlying Shawangunk Formation (6) (also see Fig. 10).

19.8 Stop at traffic light. Do not turn right towards Wind Gap. Continue straight on East Main Street which merges into West Main Street.

20.3 Turn left into unnamed street just before two gasoline pumps and one block after (east of) Broad Street. Follow black top and gravel road to Stop 2.

20.5 **STOP 2.** STEPHANS JACKSON SLATE QUARRY; STRUCTURE AND STRATIGRAPHY OF THE MARTINSBURG FORMATION; SLATY CLEAVAGE; QUARRYING OPERATION.
DANGER—STEEP QUARRY WALLS, DO NOT BE TOO BOLD!

The Stephans Jackson Slate Quarry is one of only a few that remain active in the slate belt of Pennsylvania which extends for about 45 miles (72 km) west of the Delaware River. The belt is dotted with more than 400 abandoned slate quarries and prospects. The quarry is currently about 350 feet (110 m) deep. Quarrying and milling methods have changed little for the last 50 years, and are still much the same as described by Behre (1933). The slate is used for roofing, blackboards, flagging, aquaria bottoms, sills and treads, and billiard-table tops. Immediately southwest over the dumps is the abandoned Parsons quarry, which reportedly was more than 900 feet (274 m) deep, the deepest slate quarry in the United States.

The Stephans Jackson Slate Quarry is in an overturned syncline whose axial plane dips gently to the southeast (fig. 5). A bedding-slip fault forms much of the northwest wall of the quarry. Slaty cleavage and bedding in the overiding block are dragged into the fault and a slip cleavage that shows antithetic movement to the fault, has developed in the drag fold (see inset, fig. 5). In general, slaty cleavage

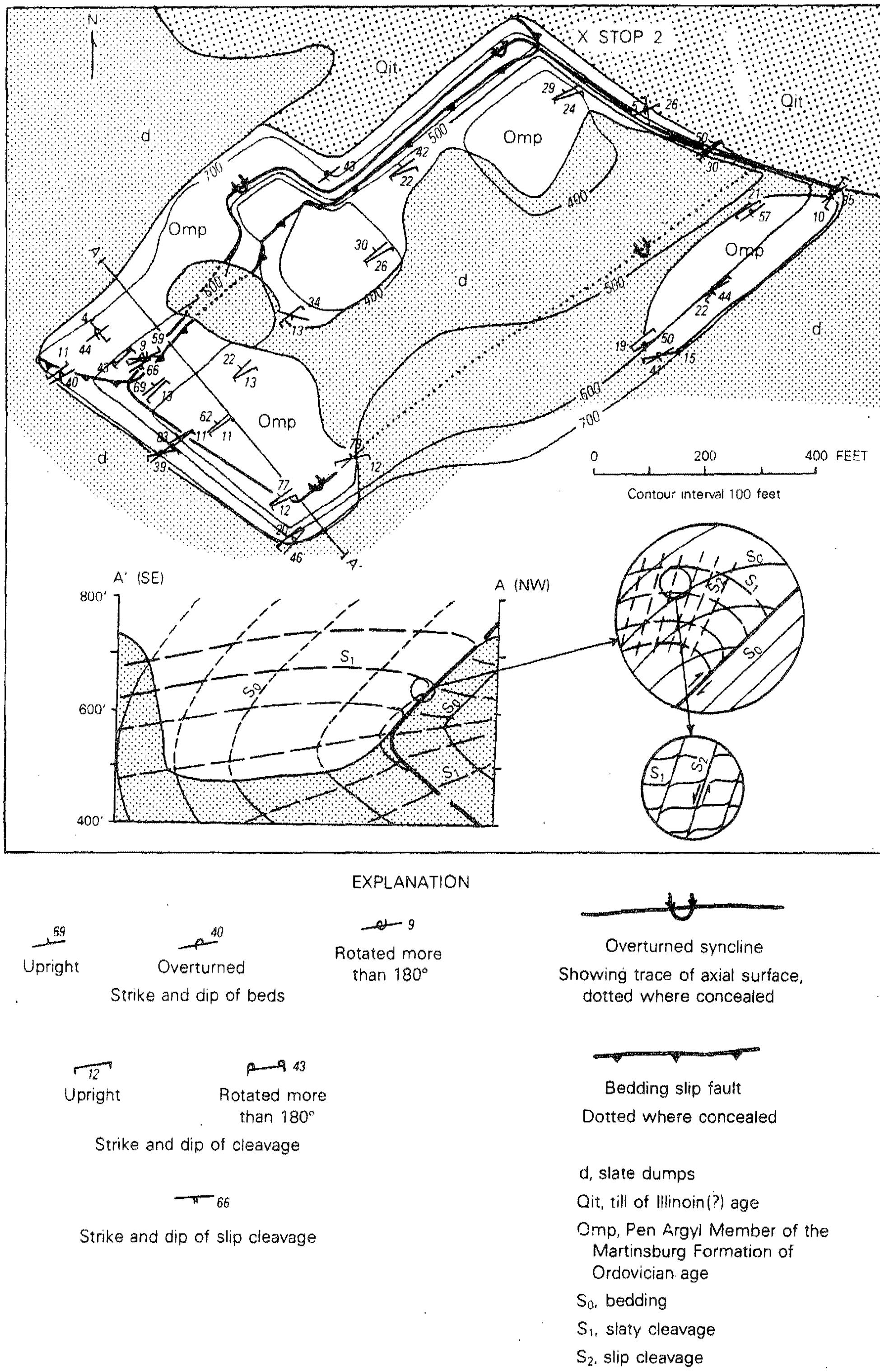


Figure 5.

Geologic map and section of the Stephans Jackson Slate Quarry. Section is drawn looking to the southwest, as seen from Stop 2.

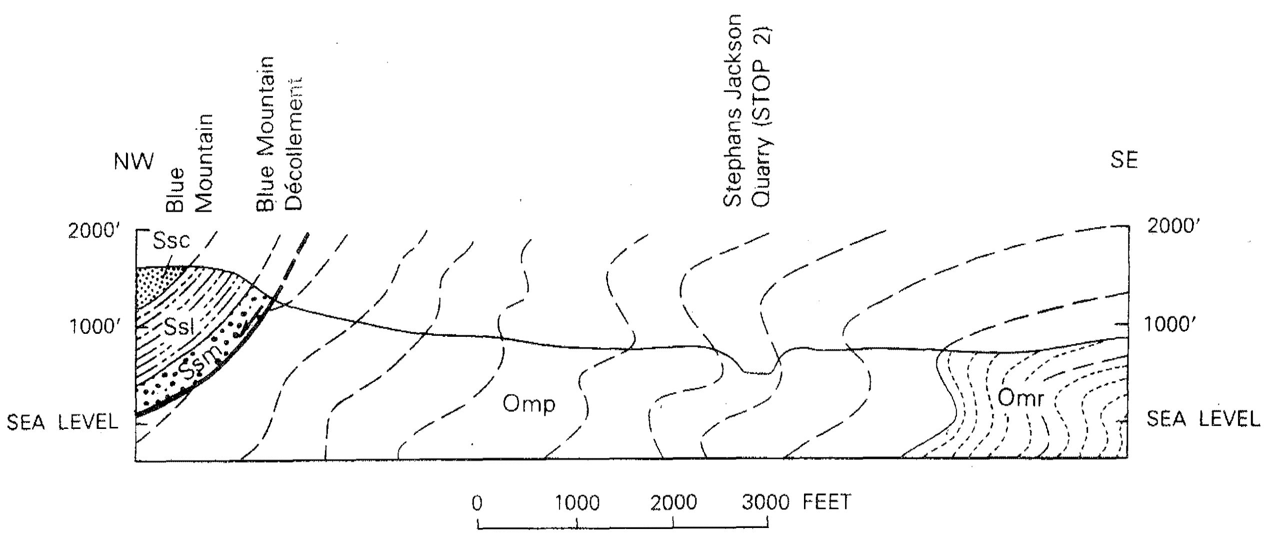


Figure 6.

Cross section showing the regional structural position of the Pen Argyl Member of the Martinsburg Formation (Omp) in the Stephans Jackson Quarry (Stop 2). Omr, Ramseyburg Member of the Martinsburg Formation; Ssm, Ssl, and Sst, Minsi, Lizard Creek, and Tammany Members of the Shawangunk Formation, respectively. Note that the Pen Argyl Member overlies the Ramseyburg Member and cannot be the lowest (Bushkill) member repeated by folding. This is evidence for three members in the Martinsburg, not two.

forms a gentle arch and fans the fold by about 14°. The fault is marked by a gouge or "spar zone" that is as much as 2 feet thick and filled with quartz and calcite.

The fault zone is a marked zone of weakness in the rock. In 1948, the northeast section of the quarry was being worked when a large mass of rock slipped down into the quarry along the zone, killing two workers below. That part of the quarry was abandoned, and the presently active section was started. Note the pins that were bent by the sliding mass in the northern corner.

The sequence of deformation was complex. Bedding-plane slickensides that are offset by cleavage indicate that initial flexural-slip folding was followed by passive folding (fig. 46, Epstein and Epstein, 1969). As the folds continued to tighten, failure was again along bedding, producing the bedding-slip fault, warping of slaty cleavage, and formation of crenulation cleavage parallel to the axial plane of the cleavage fold. Movement along the bedding-slip fault was up to the northwest, as indicated by the drag, but steps on one of two slickensided surfaces in the fault zone indicate an opposite sense of movement, perhaps due to earlier flexural slip.

The origin of slaty cleavage in the Martinsburg Formation, as well as in rocks above and below, has been a focus of considerable attention during the last two decades. Did it form by tectonic dewatering or did it form under conditions of low-grade metamorphism? Mapped relationships and petrologic considerations led me to conclude that it formed as a product of metamorphism (Epstein, 1974b) by a combination of the following processes: mechanical rotation of detrital grains parallel to the cleavage, corrosion of quartz by pressure solution and migration of silica, intrusion and flow of pelitic material, grain diminution by granulation, and by recrystallization and neocrystallization.

The Stephans Jackson Slate Quarry is in the Pen Argyl Member (upper) of the Martinsburg Formation and is about 1500 feet (457 m) above the contact with its Ramseyburg Member (middle) (fig. 6). The Pen Argyl is typically thick bedded, containing some beds of gray slate more than 10 feet (3 m) thick. The member is cyclically bedded, each cycle consisting of medium-gray slate grading up into grayish-black carbonaceous slate. Graywacke may form the base of some of the cycles.

For more than 70 years there has been controversy regarding the number of members in the Martinsburg (see Drake and Epstein, 1967). On the basis of the very characteristic difference in bedding thickness between the lower (Bushkill) and upper (Pen Argyl) members, and as proved by detailed mapping (fig. 6), I have mapped three members in this area, nearly in the same manner as Behre (1933). The Pen Argyl cannot be the Bushkill repeated by folding as earlier suggested by Stose (1930), for example. Recently, Stephens and others (1979) argued for a two-fold division based on fossil collections in the Schoharie Ridge area, about 35 miles (56 km) to the southwest. This bipartite interpretation, however, is presently clouded by structural complications that may be present in that area (Epstein and others, 1972; Lyttle, 1979).

Return to West Main Street.

20.7 Turn left on West Main Street.

20.9 Stop sign. Turn right on E Street and continue to top of hill.

21.1 Stop sign. Turn left on Pa. 512. We will be riding on gentle slopes underlain by colluvium and Illinoian(?) till which cover the Pen Argyl Member of the Martinsburg. Quartzites in the Shawangunk Formation are seen in cliffs in Blue Mountain to the right.

22.75 Junction with Alpha Road. Turn right at Arco station.

23.2 Stop sign. Junction with North Broadway in town of Wind Gap. Turn right.

23.5 Exposures of the lower (Minsi) member of the Shawangunk Formation in woods on left. The low col straight ahead is Wind Gap, underlain by nearly vertical quarzites and veneered with weathered colluvium.

23.6 Appalachian Trail. Bear right on Pa. 33 towards Stroudsburg.

24.4 Red shale, siltstone, and sandstone of the Bloomsburg Red Beds. For about 1.5 miles (2.4 km) along Pa. 33, the Bloomsburg is thrown into many small folds that are superimposed on the Ross Common Creek syncline and Wind Gap anticline. Note the well-developed cleavage in the Bloomsburg.

25.4 Chestnut Ridge to the left, underlain by complexly folded rocks of Late Silurian and Early Devonian age.

25.8 Bloomsburg Red Beds to right. Cherry Ridge straight ahead held up by sandstones in the Ridgeley and Palmerton Sandstones.

26.2 Wisconsinan till in road cut to right.

26.7 Cut through Cherry Ridge in South-dipping overturned Esopus and Schoharie Formations and Palmerton Sandstones.

26.9 Turn right off Pa. 33.

27.0 Stop sign at Cherry Valley Road. Turn left towards Bossardsville.

27.1 Many abandoned clay pits in deeply weathered Buttermilk Falls Limestone are in woods to right. These are in saprolites as much as 250 feet (76 m) deep. The clay is used as whitener in cement.

27.5 Panoramic view to left (see fig. 7).

27.8 Junction with road to Snydersville; continue straight.

29.7 Hill to right underlain by Decker Formation and Bossardville Limestone.

30.1 Village of Bossardsville. Turn right into Hamilton Stone Company quarry. Drive to upper working level of quarry.

30.8 **STOP 3.** HAMILTON STONE COMPANY QUARRY. STRATIGRAPHY AND STRUCTURE OF UPPER SILURIAN ROCKS IN CHERRY RIDGE.

Three Upper Silurian units are well exposed in the quarry in a series of upright to tight and slightly overturned folds (fig. 8). The units are, from top to bottom:

Wallpack Center Member of the Decker Formation: Medium-bedded and lenticular medium-gray to medium-light-gray, fine-to coarse-grained, quartzose limestone, medium-gray, fine-to coarse-grained calcareous sandstone, siltstone, and conglomeratic sandstone, containing brachiopods, rugose and colonial corals, bryozoans, and crinoid columnals. Leperditiid ostracodės are abundant near basal mud-cracked dolomite. Upper contact concealed. About 70 feet (21 m) exposed. Forms cap rock. Useful for crushed stone.

Bossardville Limestone: Graded laminated to very thin-bedded, dark-gray, fine-to very fine grained pyritic argillaceous mud-cracked limestone with scour-and-fill at base of graded units and leperditiid ostracodes. Uppermost beds very finely laminated limestone and smaller amounts of dolomite. About 95 feet (29 m) thick. Quarry rock useful for crushed stone.

Poxono Island Formation: Interbedded and interlaminated 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; contains several mud-crack intervals. Uppermost dolomite contains color contortions. About 40 feet (12 m) exposed.

These rocks are interpreted to have been deposited in a complex and generally transgressive tidal-flat barrier-bar

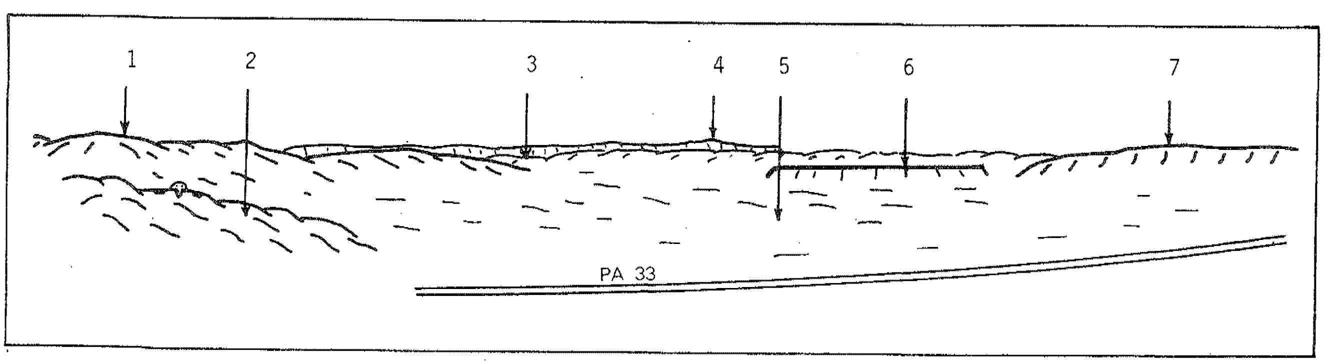
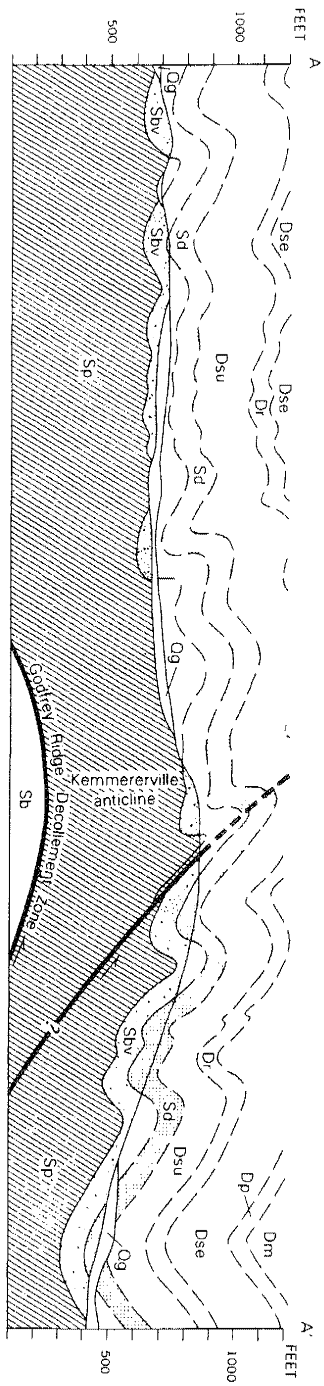


Figure 7.

Sketch of view looking north from Cherry Ridge at mileage 27.5. 1, Weir Mountain, held up by rocks in the Marcellus Shale, Mahantango Formation, and Trimmers Rock Formation. 2, Wisconsinan terminal moraine. 3, Trimmers Rock Formation in the northwest limb of the Lehighton anticline. 4, Camelback Mountain in the Pocono Plateau underlain by sandstones in the Catskill Formation. 5, Lake Creek valley underlain by varved lake beds, site of glacial Lake Sciota. 6, Flat-topped glacial delta which was deposited in Lake Sciota. 7, Southwest termination of Godfrey Ridge, underlain by complexly folded Lower and Middle Devonian rocks.



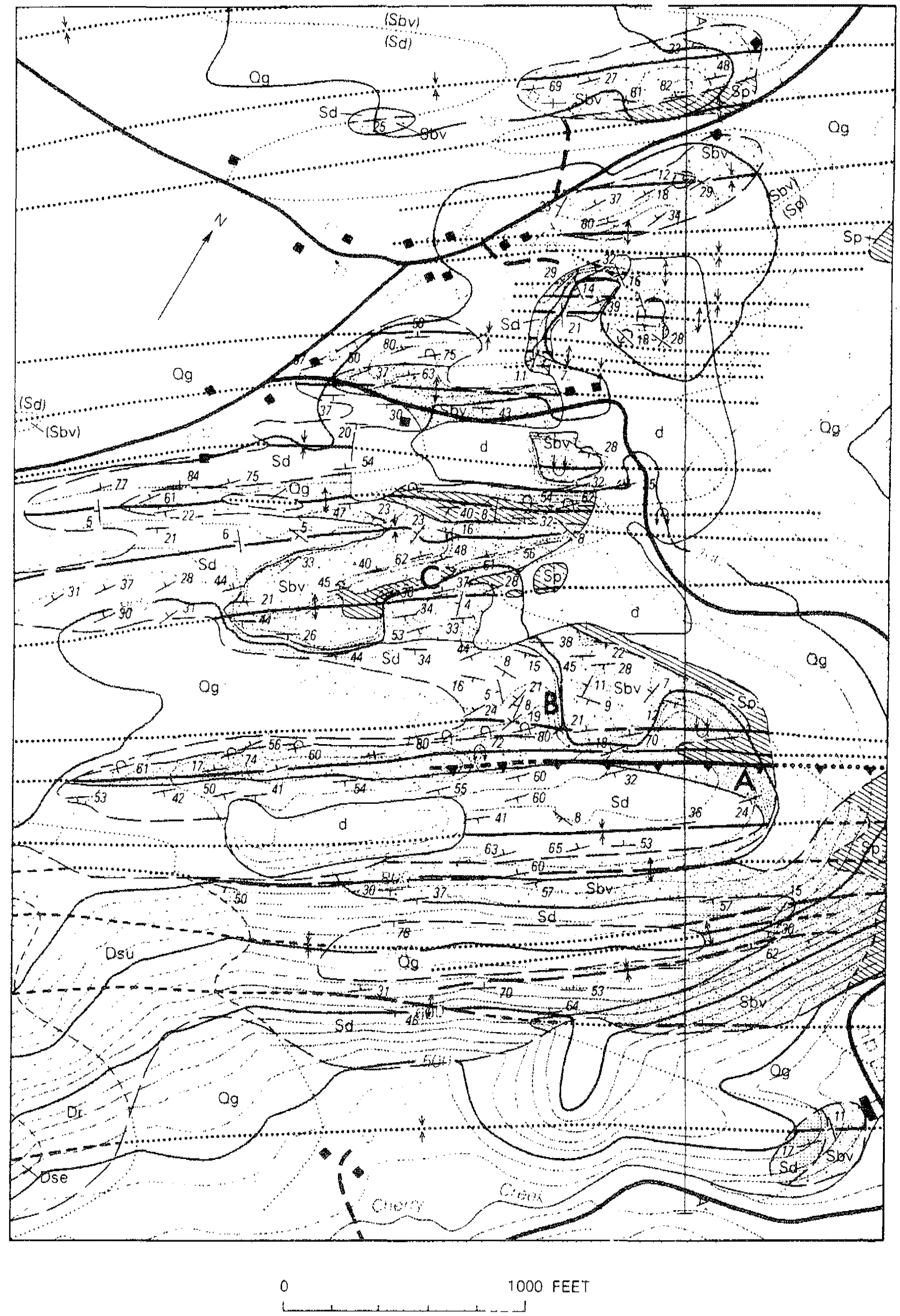


Figure 8.

Geologic map and section of the quarry area at Bossardsville, Pa. Letters represent localities discussed in text. The Poxono Island Formation, Bossardville Limestone, and Decker Formation are the only units shown with a pattern.

EXPLANATION

d
Dump

Pleistocene

Qg
Wisconsinan glacial deposit
Till in the quarry area; stratified drift in Cherry Valley

DEVONIAN

Middle Devonian

Dm
Marcellus Shale
Shown in section only

Dp
Palmerton Sandstone
Shown in section only

Lower Devonian

Dse
Schoharie and Esopus Formations, undivided

Oriskany Group

Dr
Ridgeley Sandstone

Helderburg Group

Dsu
Shriver Chert of the Oriskany Group and Helderburg Group, undivided

SILURIAN

Upper Silurian

Sd
Decker Formation

Sbv
Bossardville Limestone

Sp
Poxono Island Formation

Middle and Upper Silurian

Sb
Bloomsburg Red Beds

Contact
Long dashed where approximately located. Short dashed where inferred. Dotted where concealed

FOLDS

Anticline

Syncline

Overturned anticline

Overturned syncline
Showing trace of axial surface. Long dashed where approximately located. Short dashed where inferred. Dotted where concealed

27 Inclined
80 Overturned
Strike and dip of beds

Thrust fault
Sawteeth on upper plate. Dashed where inferred

U D
High-angle fault
U, upthrown side. D, downthrown side

shallow subtidal environment on the basis of lithology, sedimentary structures, texture, bedding characteristics, fossils, and lateral facies (see Epstein and others, 1967, and Epstein and Epstein, 1969, p. 192-196).

The structure in the quarry area is dominated by about 25 folds whose axial planes strike N. 50°-60°E. and whose axes plunge about 5°SW. These folds are disharmonic on the Kemmererville anticline in the Bloomsburg Red Beds in the underlying lithotectonic unit. The Poxono Island Formation is believed to be separated from the Bloomsburg by a decollement (see cross section, fig. 8). The anticlinal ridge underlain by the Bloomsburg rises as we travel to the northeast after leaving the quarry.

Folding was initiated by flexural slip followed by passive folding and development of cleavage. This is indicated by cleavage that wrinkles bedding-plane slickensides. In a few places, such as in the 10 foot-(3 m) wide fault zone in the east corner of the quarry, a slip cleavage cuts the earlier cleavage.

The stratigraphic units behaved differently during deformation. The more pelitic rocks failed passively, with development of prominent cleavage, whereas the more competent carbonate rocks and sandstones in the Decker and the Bossardville were concentrically folded and in places formed fold mullions. This small-scale folding is somewhat disharmonic and folds in the Poxono Island are generally tighter than in overlying rocks. This disharmonic folding is similar to the structure on a regional scale.

Places that we may visit in the quarry depend on the whims of the shovel, but we will probably go to three localities shown in figure 8: (A) A very tight anticline in the Poxono Island Formation and a fault that cuts out about 50 feet (15 m) of the Bossardville Limestone are conspicuous in outcrop here (fig. 9). As we look to the west from a high point we can see the Trimmers Rock and Catskill Formations in the southwest-plunging Weir Mountain syncline. To the north, the Pocono Plateau, Godfrey Ridge, and glacial lake deposits are seen. A well-developed ice-contact delta and esker marks a recessional position of the Wisconsinan glacier and the northeastern ice-defended boundary of glacial Lake Sciota. (B) Fold mullions and many sedimentary features are present in the Decker Formation in this overturned syncline. (C) Well-developed mudcracks, edgewise conglomerate, and other structures suggestive of supratidal deposition are of interest in the Poxono Island Formation. Cleavage that warps bedding slickensides is common in the Bossardville.

Return to Cherry Valley Road.

31.5 Stop sign. Turn right on Cherry Valley Road.

31.8 Abandoned quarries in the Bossardville Limestone to right and left.

32.0 View to right of Cherry Valley; Godfrey Ridge on left; rounded ridge in the middleground is underlain by the Bloomsburg Red Beds in the southwest-plunging Kemmererville anticline; northwest-dipping quartzites in the Shawangunk Formation hold up Kittatinny Mountain on the skyline.

32.35 Poxono Island Formation exposed in creek to right.

32.4 Near-vertical Bossardville Limestone on left.

32.9 Flat floor of Cherry Valley on right partly underlain by glacial lake clays, silts, and sands. Kittatinny Mountain forms skyline to right.

33.2 Near-vertical Bossardville Limestone on left.

34.2 Village of Stormville, type locality of the Stormville Member of the Coeymans Formation. Continue right on Cherry Valley Road towards Delaware Water Gap at fork in road.

34.6 Very well developed columnar mudcracks in the Whiteport Dolomite Member of the Rondout Formation on left.

34.8 Low hill ahead is a kame containing Wisconsinan sand and gravel.

35.0 Coeymans Formation on left in slump block.

35.2 Ridgeley Sandstone, which caps Godfrey Ridge, in float on left.

35.9 The Bloomsburg Red Beds in Kemmererville anticline to right rises up-plunge.

36.9 Junction with Pa. 191. Turn right towards Bangor. Good exposures of the Stormville Member of the Coeymans Formation in steep slope beyond farm house on right. If we cannot drive to the top of Kittatinny Mountain to Stop 4, we will turn *left* here and proceed to Stop 4a. See route to Stop 4a later in the road log.

37.1 Cross Cherry Creek.

37.6 Entering Wildcat Hollow. Exposures of northwest-dipping red and green clastic rocks of the Bloomsburg Red Beds in the northwest limb of the Kemmererville anticline.

38.0 Crest of Kemmererville anticline. South of here the rocks dip gently southeast.

38.15 Turn left on Poplar Valley Road.

39.7 Crest of Kemmererville anticline.

40.0 Stop sign. Junction with Totts Gap Road. Turn right and descend southeast limb of Kemmererville anticline.

40.3 Trough of Poplar Valley Syncline. Note ten foot long (3 m) long glacial erratics of Buttermilk Falls Limestone in creek to right.

40.8 Contact between the Shawangunk Formation and Bloomsburg Red Beds. Ascend (we hope) steep dirt road to crest of Kittatinny Mountain.

41.0 Crest of Kittatinny Mountain. Proceed east (to left) along dirt road to Stop 4. The quartzites of the Shawangunk Formation here are overturned to the southeast, dipping about 50°. As we proceed eastward, the rocks become vertical and then dip moderately northwest at Delaware Water Gap.

41.1 Microwave Tower of AT&T on right.

41.3 Good view of Kemmererville anticline, Godfrey Ridge, and

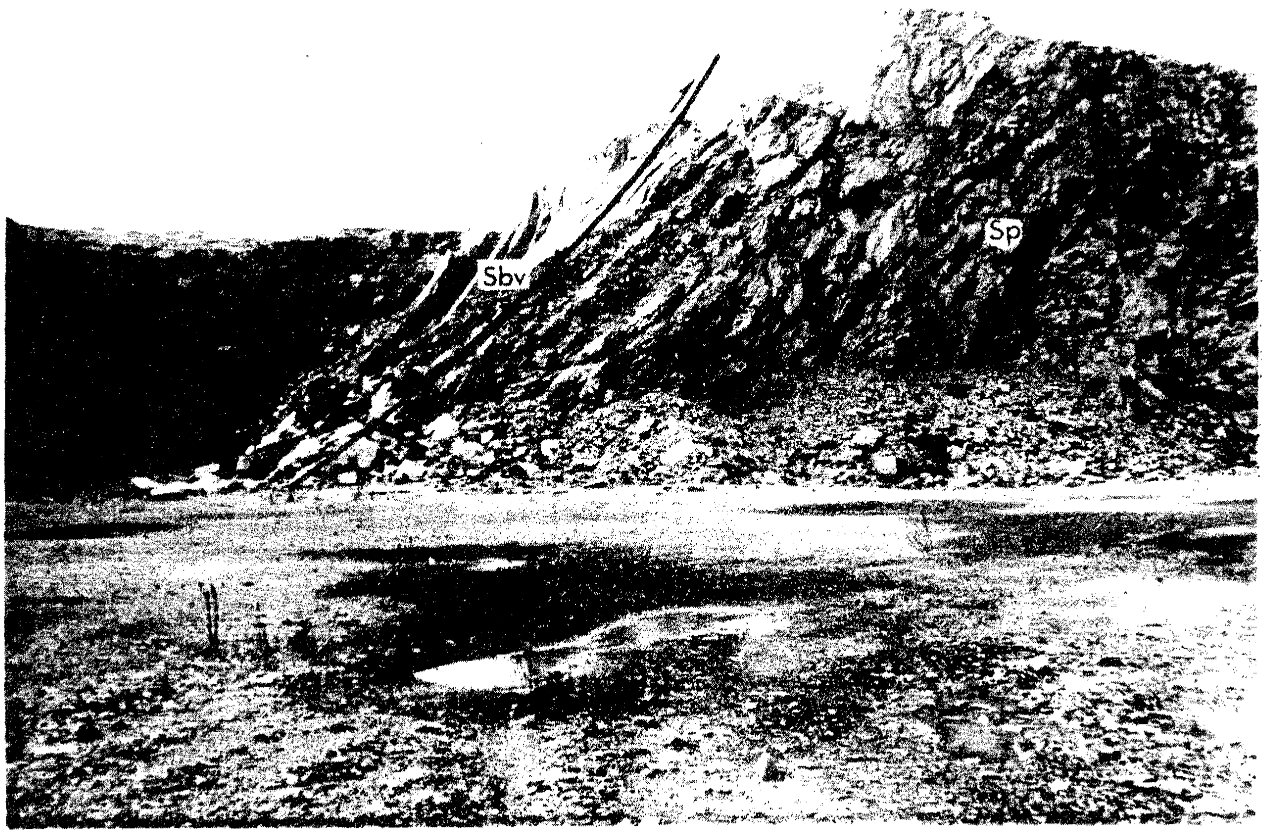


Figure 9.

Fault cutting out about 50 feet (15 m) of the Bossardville Limestone (Sbv) and traced of tight fold in the Poxono Island Formation (Sp), quarry of Herbert R. Imbt, Inc., Bossardsville, Pa., locality A in fig. 8.

the Pocono Mountains to the north (left).

41.35 National Park Service gate.

43.1 **STOP 4.** DELAWARE WATER GAP OVERLOOK. STRATIGRAPHY AND STRUCTURE OF THE SHAWANGUNK FORMATION: ORIGIN OF WIND AND WATER GAPS; NATURE OF THE ORDOVICIAN-SILURIAN CONTACT; SUMMARY OF TRIP.

Park at end of road. Disembark and follow Appalachian Trail to edge of Delaware Water Gap.

The three members of the Shawangunk Formation, basically two conglomeratic quartzite units separated by a sequence of argillites and quartzites, and the lower part of the Bloomsburg Red Beds, are well exposed in the gap. The Minsi and Tammany Members of the Shawangunk are interpreted to have been deposited by braided streams flowing off highlands uplifted during the Taconic orogeny, whereas the Lizard Creek Member of the Shawangunk represents a complex transitional continental-marine environment (Epstein and Epstein, 1967, 1969, 1972). Fining-upward sequences in the Bloomsburg are indicative of meandering streams. The contact between the Shawangunk and the Bloomsburg, based on an upward change from gray to red rocks, is extremely irregular, particularly near the village of Delaware Water Gap, 1.5 miles (2.4 km) to the northwest (see fig. 10 and Epstein, 1973).

The Shawangunk in the gap dips moderately to the northwest (figs. 10 and 11) and contains many small satellitic folds. The beds reverse their dip in the Dunnfield Creek syncline, and do so again in the Cherry Valley anticline. We will see the northwest limb of the Cherry Valley anticline at the toll booth on Interstate 80 in the village of Delaware Water Gap. Many small undulations, wedges, and bedding slips in the Bloomsburg are superimposed on the larger Dunnfield Creek syncline. Movement of these structures suggests sliding to the northwest.

The regional strike between the Martinsburg and the Shawangunk in this area differs by about 15°, and the Ramseyburg-Pen Argyl contact in the Martinsburg is buried beneath the Shawangunk 1.2 miles (2 km) southwest of the gap. The difference in structural trends is very apparent in the field, on aerial photographs, and high-altitude imagery. This regional Taconic unconformity is well documented. On the basis of several lines of reasoning, however, I believe the cleavage in the Martinsburg at the gap to be Alleghenian in age. Note that the cleavage in the

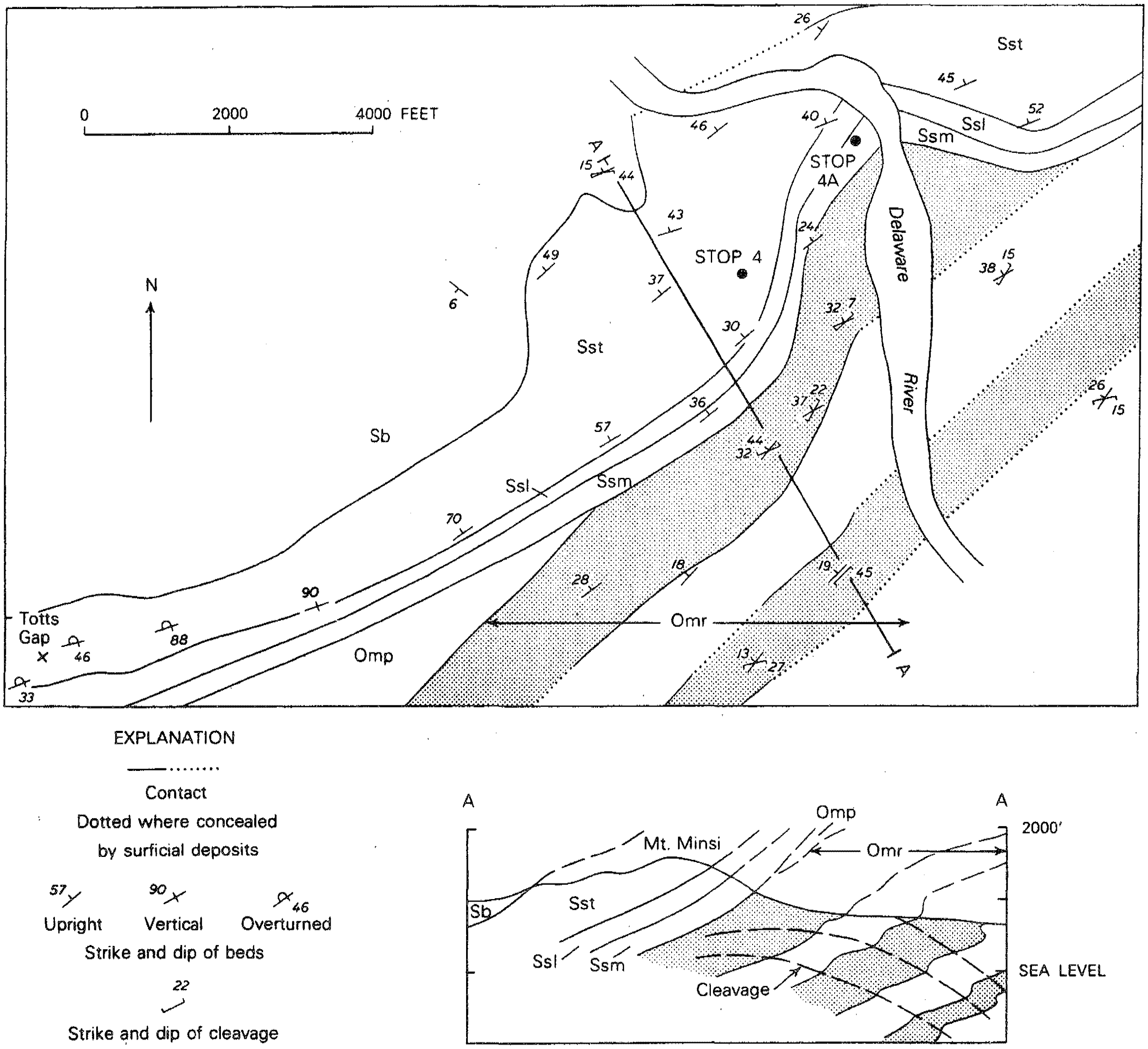


Figure 10.

Generalized geologic map and section at Delaware Water Gap showing the angular unconformity between the Martinsburg and Shawangunk Formations (also believed to be a zone of movement, the Blue Mountain Decollement) and the "arching" of cleavage in the Martinsburg. The cleavage is generally steeper in the graywacke beds than shown. Sb, Bloomsburg Red Beds; Sst, Ssl, and Ssm, Tammany, Lizard Creek, and Minsi Members of the Shawangunk Formation; Omp and Omr, Pen Argyl and Ramseyburg Members of the Martinsburg Formation. Stippled areas are grayacke-bearing intervals in Omr. Surficial deposits not shown. Positions of Stops 4 and 4A are shown.

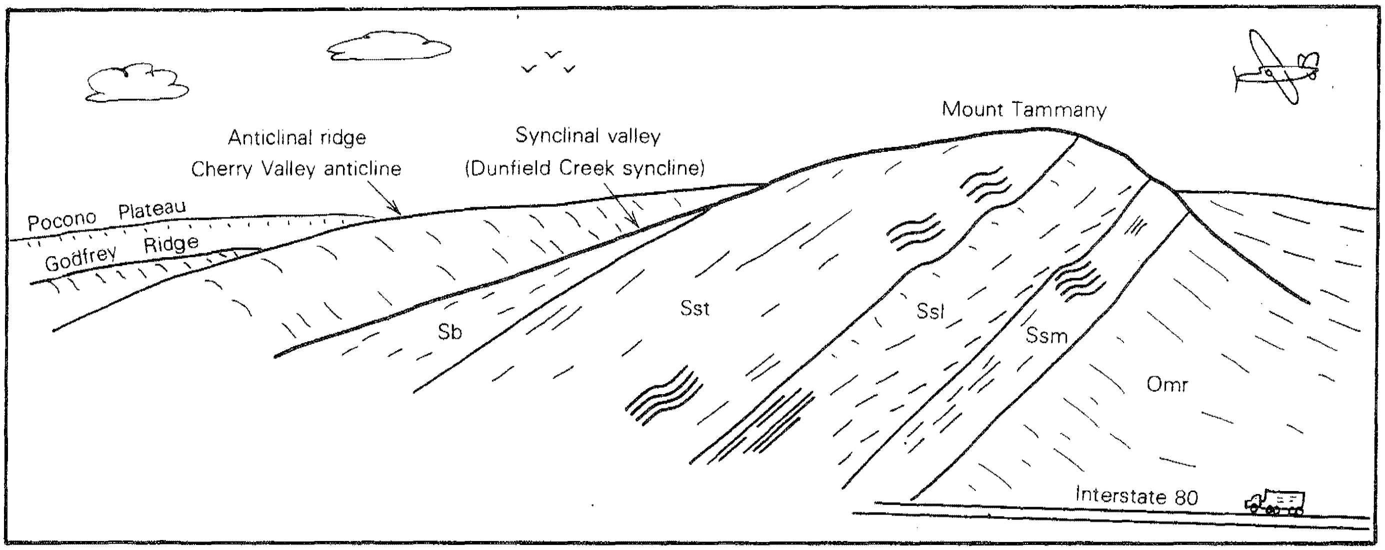


Figure 11.

Sketch from photograph looking northeastward into New Jersey from Stop 4 showing the geology at Delaware Water Gap. A few satellitic folds in the Shawangunk Formation are indicated. Relief between the Delaware River and Mt. Tammany is 1260 feet (384 m). Sb, Bloomsburg Red Beds; Sst, Ssl, and Ssm, Tammany, Lizard Creek, and Minsi Members of the Shawangunk Formation; Omr, Ramseyburg Member of the Martinsburg Formation, which is talus covered in the area of the sketch.

Martinsburg arches, whereas bedding maintains its general northwest dip (fig. 10), indicating that the arching was not caused by external rotation during post-Taconic deformation. Rather, I believe that the arching is due to a pressure-shallow mechanism whereby cleavage in pelitic rocks adjacent to more competent rocks fans away from the axis of a syncline (see Epstein and Epstein, 1969, p. 166-167). The upper limb of the syncline in the Shawangunk is eroded away, of course, but it can be seen down-plunge to the southwest where the beds are overturned, such as at Totts Gap.

Glacial striae and roches moutonnees are common on top of Kittatinny Mountain. They trend about due south, but the Wisconsinan glacier was deflected more to the southwest on the slopes and in the valleys, following the trend of the topography.

For many years there have been numerous discussions on the origin of wind and water gaps and how that origin relates to Appalachian geomorphic development. Basically, two contrasting viewpoints have been presented. One favors coincidental location of the gaps due to superposition from a coastal-plain cover (e.g., Johnson, 1931). The other argues for northwestward headward erosion from the original drainage divide to the southeast along lines or points of structural weakness. The test of superposition, according to Strahler (1945), was to show lack of structural control for the location of the gaps.

For 40 miles (64 km) along Kittatinny and Blue Mountains and the ridges to the north, I have mapped the geology at 12 major gaps in Pennsylvania and New Jersey. The gaps are located where one or more of the following geologic conditions exist: (1) folds die out within short distances, (2) beds dip steeply and resistant units have narrow outcrop widths, and (3) there is more intense local folding or shearing than nearby (see Epstein, 1966).

At Delaware Water Gap the crest of Kittatinny Mountain in Pennsylvania is offset 800 feet (245 m) to the southeast from the trend of the crest in New Jersey. However, a transverse fault is not present through the gap (as has been suggested by several workers), because the contacts of the three members within the Shawangunk are not displaced at river level (fig. 10). The offset of the ridge crest is due to downward flexing of the rocks on the Pennsylvania side whereas the rocks maintain a constant dip on the New Jersey side (fig. 12). The flexure can be seen by looking west from the New Jersey bank. The abrupt change in strike at the gap site must have resulted in extensive fracturing in the brittle Shawangunk. Structural control is therefore thought to have determined the location of the gap. Also, the Bloomsburg Red Beds just north of the gap are involved in about 15 folds that die out rapidly to the southwest, including the large Dunnfield Creek syncline and Cherry Valley anticline. This structural situation is present at other large gaps, such as Wind Gap and Lehigh Gap. The rocks were probably more highly sheared here, and resistance to erosion was less than in the areas between gaps where similar folds were not observed.

Thus, data supporting structural control for location of the gaps does not favor the concept of regional superposition. Rather, it favors those hypotheses that 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.

Time permitting, we will sumarize the themes of this trip: structural comparisons of the several lithotectonic units, ages of deformation, regional stratigraphic framework, history of sedimentation, and Quaternary history. Return to bus on Totts Gap Road. Proceed west.

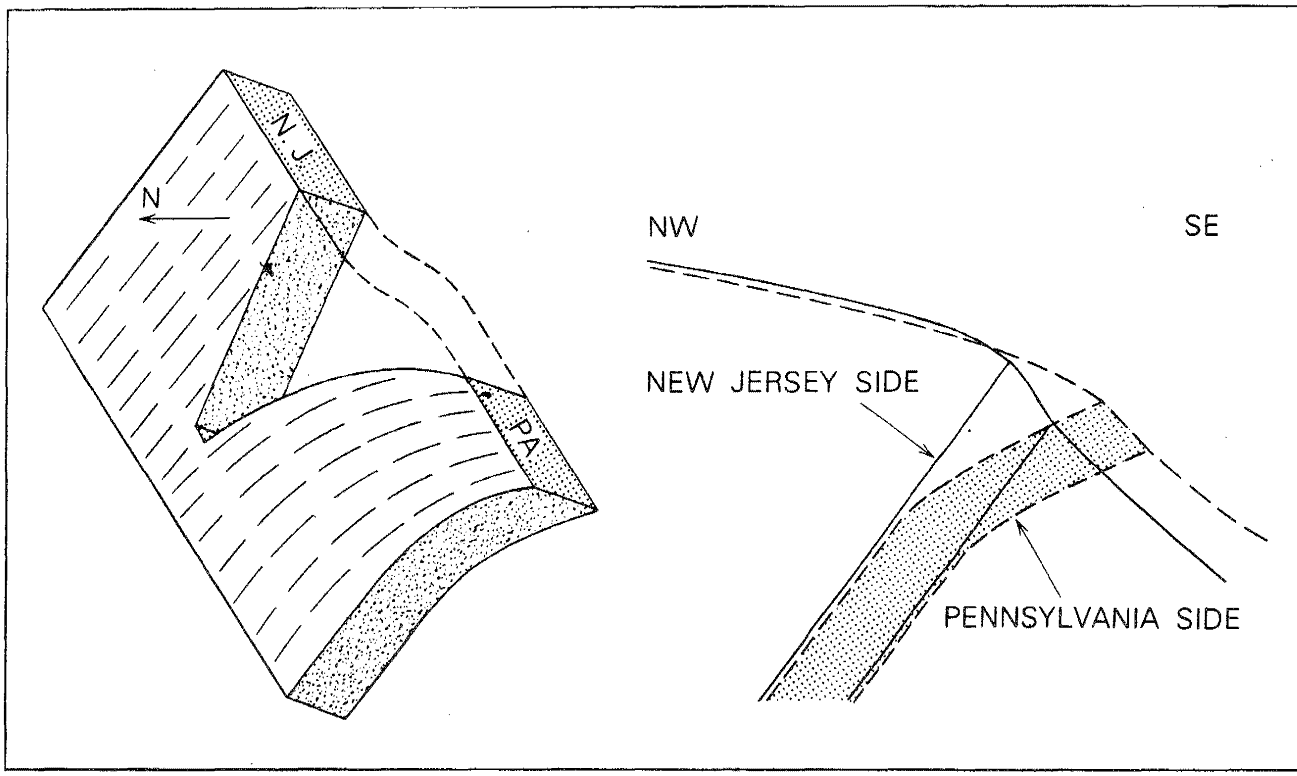


Figure 12.

Cross section and reconstructed flexure at Delaware Water Gap showing topographic offset of Kittatinny Mountain due to downwarping of the Shawangunk Formation in Pennsylvania, suggesting extensive fracturing at the gap site.

45.2 Turn right at Totts Gap and proceed down mountain.

46.2 Turn right at intersection of Totts Gap Road and Poplar Valley Road.

46.3 Crest of Kemmererville anticline. Descend northwest limb of anticline. A thin layer of till caps bedrock in most of this area.

47.4 Stratified Wisconsinan sand and gravel in kames underlying golf course on left. Godfrey Ridge, underlain by complexly folded Upper Silurian and Lower Devonian rocks, forms the ridge beyond Cherry Valley.

47.8 Intersection with Cherry Valley Road. Turn right.

48.7 Village of Delaware Water Gap. Intersection with U.S. 611. Continue straight ahead.

49.0 Stop sign. Continue straight to Interstate 80E.

49.1 Stop sign. Enter Interstate 80. Proceed to toll booth. Exposures are northwest-dipping rocks in the Shawangunk Formation on the northwest limb of the Cherry Valley anticline.

49.3 Exposures of Shawangunk Formation on right dip to south on the southeast limb of the Cherry Valley anticline.

49.6 Crossing Delaware River.

49.8 Undulations in the Bloomsburg Red Beds on left are superimposed on the northwest limb of the Dunnfield Creek syncline. Many wedges and bedding-plane slips are exposed in these rocks. Note the well-developed cleavage.

50.2 Water-worn and glacially striated Bloomsburg on left.

50.5 Kame terrace on left.

50.6 Contact between Shawangunk Formation and Bloomsburg Red Beds covered on left.

50.8 Massive conglomeratic quartzites of the upper (Tammany) member of the Shawangunk Formation on left.

50.9 Interbedded quartzite, siltstone, and shale in the middle (Lizard Creek) member of the Shawangunk Formation on left.

51.0 Quartzites of the lower (Minsi) member of the Shawangunk Formation on left. Note to the right that the Shawangunk dips about 45° at river level and is warped tô lesser dips halfway up the mountain (fig. 12). Note gabions retaining the colluvium on left. The contact of the Martinsburg and Shawangunk is buried here but was discussed by Beerbower (1956).

Continue south and then east on Interstate 80 back to Newark.

In case we do not go to Stop 4, follow this road log to alternate Stop 4, picking up at mileage 36.9.

36.9 Turn left on Pa. 191 North.

37.1 Bear left at "Y" heading towards Stroudsburg.

37.2 Steeply dipping Port Ewen Shale of the Helderburg Group, Shriver Chert and Ridgeley Sandstone of the Oriskany Group, and Esopus Formation on left. Note well-developed cleavage in the Esopus.

37.6 Crest of Godfrey Ridge supported by siliceous siltstones in the Esopus Formation. The road descends through several folds in the Esopus and Schoharie Formations and Buttermilk Falls Limestone.

38.1 Stop sign. Turn right on U.S. 611 S. Slightly overturned Buttermilk Falls Limestone on right.

38.3 Overturned Schoharie Formation on right. The road ascends through several folds.

38.9 Crest of Godfrey Ridge, underlain by the Esopus Formation seen on left with well-developed cleavage. View to right of Cherry Valley, the Kemmererville anticline underlain by the Bloomsburg Red Beds in the middleground, and Kittatinny Mountain, underlain by Shawangunk quartzites, in the skyline.

39.0 Esopus Formation on left.

39.1 Ridgeley Sandstone on left underlain by Shriver Chert.

39.2 Port Ewen Shale on left. The road descends through various Wisconsinan deposits.

40.5 Bear right on U.S. 611 S. in the village of Delaware Water Gap.

40.9 Traffic light. Continue south on U.S. 611.

41.3 Northwest-dipping gray sandstone and siltstone in the Shawangunk Formation on right.

41.5 Crest of Cherry Valley anticline. Note the lateral gradation of red, green, and gray beds at this contact between the Shawangunk Formation and Bloomsburg Red Beds.

41.7 Resort Point Overlook on left. Note the undulations in the Bloomsburg across the river which are superimposed on the northwest limb of the Dunnfield Creek syncline. Cleavage is well developed and wedges and bedding slips are common.

42.0 Note "Indian Head" in cliffs of the Shawangunk on the left side of the gap.

42.6 Shawangunk-Bloomsburg contact on right.

43.2 Turn right into Point-of-Gap Overlook and park in parking lot.

ALTERNATE STOP 4. See Stop 4 for discussion.

Leave parking lot and continue south on U.S. 611.

43.5 Cold Air Cave on right. Cave is formed by a large slab of quartzite float resting on smaller stones. Cold air stored in the colluvium flows down through the rocks and into the cave. It was used for storage of soft drinks more than 50 years ago (Stone, 1932).

43.7 Outcrop of the middle (Ramseyburg) member of the Martinsburg Formation on right. Beds dip 32°NW and cleavage dips 7°NW.

44.3 Very coarse kame-terrace deposits on right. These deposits flank both sides of Delaware Valley for more than 1 mile downstream.

45.4 Two quarries hidden in narrow valleys on right are in the lower (Bushkill) member of the Martinsburg Formation.

46.9 Traffic light in town of Portland. Continue straight ahead.

46.95 Intersection with U.S. 611 S. Continue straight under bridge.

47.1 Turn right to toll bridge. Cross Delaware River and follow Interstate 80 back to Newark.

End of trip.

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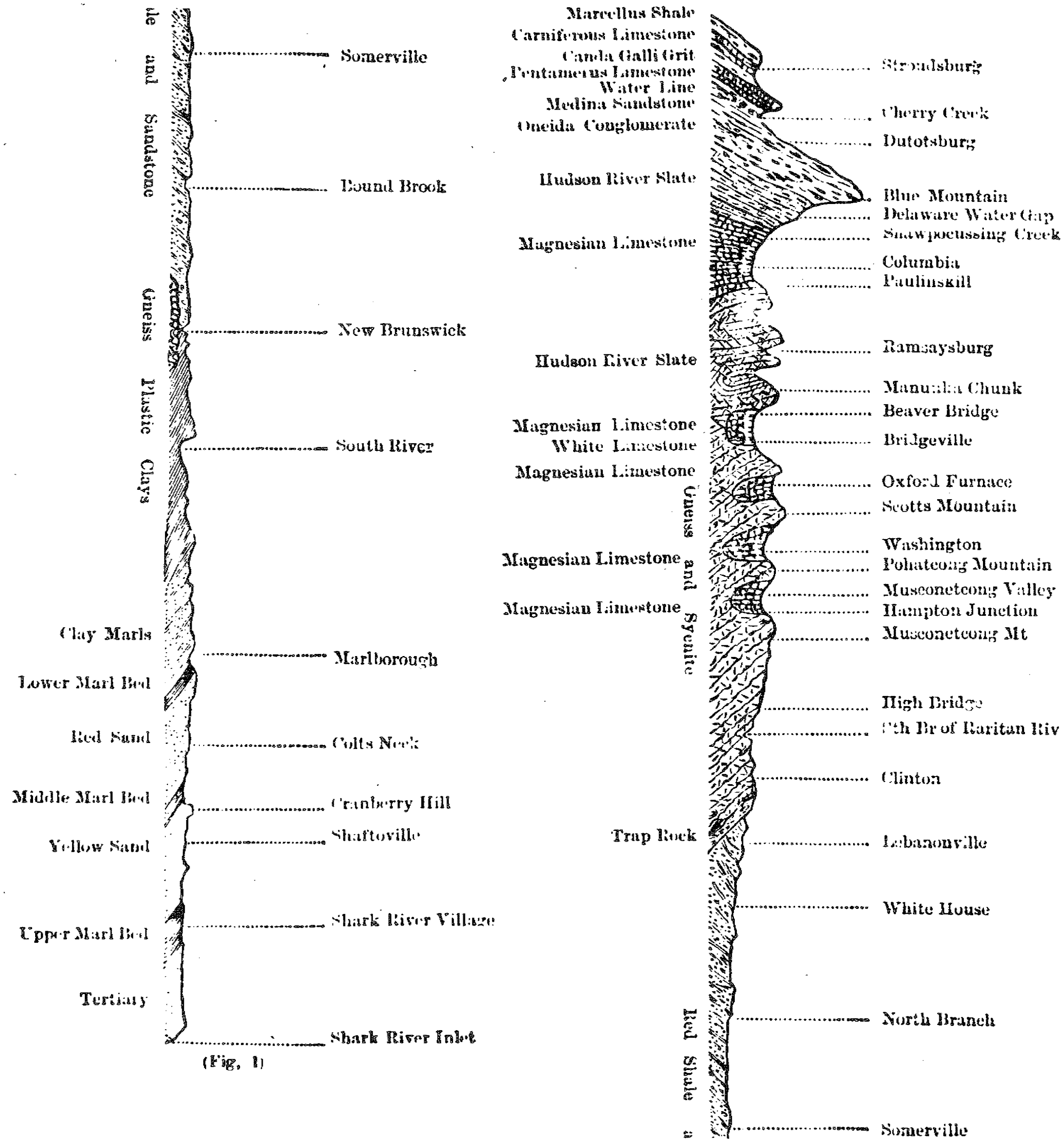

(Fig. 1)

Cross Section from the Delaware Water Gap to the Shark River Inlet by G.H. Cook, State Atlas of New Jersey, 1872.