Geology of the New Tripoli Quadrangle, Lehigh, Berks, Schuylkill, and Carbon Counties, Pennsylvania

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Prepared in cooperation with the
Pennsylvania Department of Environmental Resources,
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By JACK B. EPSTEIN and PETER T. LYTTLE

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Structure and stratigraphy of a complexly deformed
Paleozoic sequence in the central Appalachians of Pennsylvania

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Geology of the New Tripoli Quadrangle, Lehigh, Berks, Schuylkill, and Carbon Counties, Pennsylvania

By Jack B. Epstein *and* Peter T. Lyttle

Abstract

Sedimentary rocks exceeding 29,000 ft (8,800 m) in thickness form the stratigraphic sequence exposed in the New Tripoli quadrangle, Pennsylvania. Lying in the Great Valley and the Valley and Ridge province of the central Appalachians, these rocks range in age from Early Ordovician to Late Devonian and are overlain by Quaternary surficial deposits, including alluvium, colluvium, talus, and pre-Illinoian glacial deposits.

The sequence has been divided into six lithotectonic units; each has a distinct stratigraphy and structural style and is bounded by faults or décollements. Lithotectonic unit 1 (Windsor Township Formation of Early and Middle Ordovician age) consists of more than 4,600 ft (1,400 m) of shale, mudstone, and graywacke and minor conglomerate, limestone, and chert. The rocks are in northwest-verging folds having wavelengths as great as 1,200 ft (370 m). This unit is part of the lower thrust sheet of the Hamburg klippe. It is separated from lithotectonic unit 2 by the Weisenberg Church and Kistler Valley faults.

Lithotectonic unit 2 (Shochary Ridge sequence of Middle and Late Ordovician age) makes up a large-amplitude regional syncline containing more than 8,000 ft (2,500 m) of graywacke, shale, siltstone, and minor conglomerate. The unit is bounded on the north by the Eckville fault and on the east by the Game Preserve fault.

Lithotectonic unit 3 (Martinsburg Formation of Middle and Late Ordovician age) consists of more than 7,000 ft (2,000 m) of tightly folded slate, siltstone, and graywacke. The unit is separated from overlying rocks by an unconformity and the Blue Mountain décollement.

Lithotectonic unit 4 (Tuscarora Sandstone through Bloomsburg Red Beds of Middle and Late Silurian age) contains about 3,150 ft (960 m) of quartzite and other clastic rocks that hold up Blue Mountain, part of a ridge that extends throughout the length of the Appalachians of the Eastern United States. These rocks are tightly folded and faulted and are interpreted to form a duplex, whose floor thrust lies just below the Tuscarora Sandstone in the Martinsburg Formation and whose roof thrust lies within the Bloomsburg Red Beds. The Stony Ridge décollement separates lithotectonic units 4 and 5.

Lithotectonic unit 5 (Bloomsburg Red Beds through Marcellus Shale of Late Silurian to Middle Devonian age) consists of 700 ft (200 m) of a wide variety of sedimentary rocks forming 20 mappable units. Complex folds have wavelengths averaging 1,000 ft (300 m). The unit is separated from lithotectonic unit 6 to the north by the Weir Mountain décollement and the Sweet Arrow fault.

Lithotectonic unit 6 (Mahantango Formation through Catskill Formation of Middle and Late Devonian age) forms a large upright regional syncline in more than 5,800 ft (1,800 m) of siltstone, sandstone, and shale.

The Ordovician-Silurian boundary is marked by the Taconic angular discordance, a regional unconformity that is exposed for more than 200 mi (320 km) from central Pennsylvania through the New Tripoli quadrangle and into New Jersey and New York. Most structures in the quadrangle, including the regional cleavage in the Martinsburg Formation and younger rocks, formed during Alleghanian deformation. Taconic deformation in the Martinsburg (lithotectonic unit 3) was limited to gentle folding, whereas extensive Taconic folding and faulting are recorded in lithotectonic units 1 and 2. The Shochary syncline (unit 2) is anomalous in that there are virtually no satellitic folds on its limbs. Although it may have formed during the Taconic orogeny, it seems likely that it was tightened and cleaved during Alleghanian time.

Detailed mapping shows that the middle (Ramseyburg) member of the Martinsburg Formation pinches out westward and grades into and is replaced by the upper (Pen Argyl) member. This conclusion, a review of paleontologic data in the area, and mapping of the structures confirm that the Martinsburg is composed of three members in the eastern half of the quadrangle, as well as in all Pennsylvania to the east, and disagree with some previous interpretations of a two-member division within the Martinsburg.

INTRODUCTION

The New Tripoli quadrangle occupies an area of 56 mi^2 (145 km^2) within the Great Valley and the Valley and

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Table 1. Lithotectonic units in the New Tripoli quadrangle, Pennsylvania

Litho-tectonic unit	Age and stratigraphic sequence	Lithologic characteristics	Structural characteristics
6	Late and Middle Devonian Catskill through Mahantango Formations	>5,800 ft (1,800 m) of siltstone, sandstone, shale, and minor conglomerate	Nearly symmetrical, upright Weir Mountain syncline with half wavelength about 2 mi (3 km) and amplitude about 4,500 ft (1,400 m)
	Weir Mountain décollement and Sweet Arrow fault		
5	Middle Devonian to Late Silurian Marcellus Shale through Bloomsburg Red Beds	About 700 ft (200 m) of shale, limestone, sandstone, siltstone, dolomite, and conglomerate in thin, heterogeneous units	Asymmetric, northwest-verging, open to tight, upright and overturned, concentric and similar folds with wavelengths averaging about 1,000 ft (300 m) and amplitudes of 100–1,000 ft (30–300 m)
	Stony Ridge décollement and roof thrust		
4	Late to Early Silurian Bloomsburg Red Beds through Tuscarora Sandstone	3,150 ft (960 m) of quartzite, shale, siltstone, and conglomerate	Asymmetric and generally overturned northwest-verging folds with wavelengths averaging about 2,000 ft (600 m) and amplitudes about 900 ft (270 m), cut by a series of northwest-dipping thrusts believed to be ramps in a duplex bounded by floor and roof thrusts
	Blue Mountain décollement, floor thrust, Taconic unconformity		
3	Late and Middle Ordovician Martinsburg Formation	>7,000 ft (2,000 m) of slate, siltstone, and graywacke	Asymmetric, northwest-verging, generally overturned similar folds with wavelengths averaging 1,200 ft (370 m) and amplitudes averaging about 600 ft (180 m), with well-developed axial-plane cleavage
		Game Preserve and Eckville faults	
2	Late and Middle Ordovician Shochary Sandstone New Tripoli Formation	8,100 ft (2,500 m) of graywacke, siltstone, shale, and minor conglomerate. Beds coarsen and thicken upward	Regional asymmetric, northwest-verging syncline of very large amplitude and half wavelength greater than 10,000 ft (3,000 m). Smaller scale folds extremely rare. Cleavage always present but not as well developed as in lithotectonic unit 3
	Weisenberg Church and Kistler Valley faults		
1	Middle and Early Ordovician Windsor Township Formation	>4,600 ft (1,400 m) of shale, mudstone, graywacke, minor conglomerate, limestone, and chert. Bedding thickness quite variable, but generally thin to medium	Northwest-verging asymmetric and similar folds; wavelengths ranging from outcrop scale to 1,200 ft (370 m). Amplitudes range to as much as 600 ft (180 m). Slaty cleavage sporadically and variably developed

Ridge province of east-central Pennsylvania. Blue Mountain, a long, narrow ridge trending N. 65° E. and reaching altitudes of more than 1,500 ft (460 m), forms the boundary between these physiographic provinces and is the dominant topographic feature in the northern half of the quadrangle (pl. 1). Shochary Ridge, trending N. 75° E. and reaching altitudes of 1,000 ft (300 m), dominates the southern half. These two ridges converge westward and intersect at Hawk Mountain in the adjoining New Ringgold quadrangle.

A wide variety of sedimentary rocks, aggregating more than 29,000 ft (8,800 m) in thickness, is exposed in the quadrangle. These rocks are divided into six lithotectonic units that have different rock types, composite stratigraphic thickness, and age, as well as dissimilar structural styles (table 1, fig. 1). Faults of differing attitude, magnitude, and age separate these lithotectonic units. Detachments separate some of the units, which have deformed semi-independently of each other. One of these detachments, the Blue Mountain décollement, lies several hundred feet (about 100 m) below the Taconic unconformity in the New Tripoli quadrangle.

The Taconic unconformity represents a hiatus of more than 10 m.y. and separates Silurian sandstones and conglomerates from Upper Ordovician shales and graywackes. The divergence in dip at the unconformity is less than 15° in the New Tripoli quadrangle and throughout eastern Pennsylvania, northern New Jersey, and southern New York where the unconformity is exposed for more than

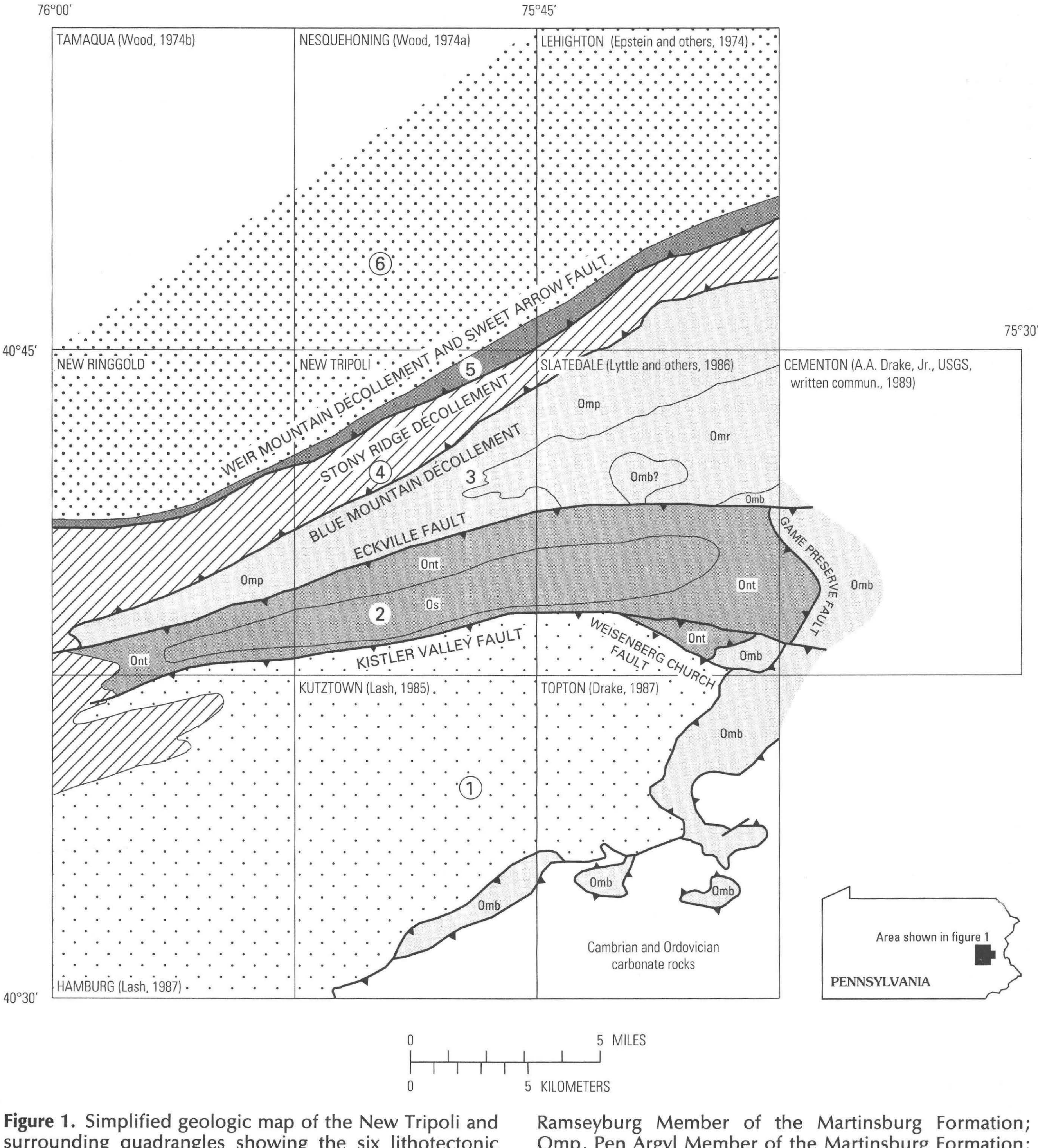

Figure 1. Simplified geologic map of the New Tripoli and surrounding quadrangles showing the six lithotectonic units discussed in text and summarized in table 1. Omb, Bushkill Member of the Martinsburg Formation; Omr, Ramseyburg Member of the Martinsburg Formation; Omp, Pen Argyl Member of the Martinsburg Formation; Ont, New Tripoli Formation; Os, Shochary Sandstone.

200 mi (320 km) (Epstein and Lyttle, 1986, 1987). To the west, a more pronounced angular unconformity exists between the same Silurian rocks and older, more complexly deformed Lower and Middle Ordovician rocks of the far-traveled Hamburg klippe.

Two major synclines separating a more complexly deformed area dominate the structure in the New Tripoli quadrangle. In the north, the Weir Mountain syncline is a very large, upright, open fold with a wavelength greater than 6 mi (10 km). In the south, the Shochary syncline is an asymmetric, slightly north verging, tight fold; its wavelength cannot be determined because the fold is bounded by two thrust faults. The regional cleavage is axial planar to these major folds and is believed to be Alleghanian in age. This cleavage is best developed in the Martinsburg Formation, where slates were extensively quarried.

Several faults cut obliquely across the Tuscarora Sandstone and Bloomsburg Red Beds. These faults are interpreted to be splays ramping off a floor thrust in the Martinsburg Formation and joining a roof thrust in the Bloomsburg.

A variety of surficial deposits, ranging from pre-Illinoian to Holocene in age, blankets most of the area. Many previous stratigraphic and structural studies in the New Tripoli quadrangle and surrounding area were summarized by Epstein and others (1974), Lash and others (1984), and Lyttle and others (1986).

STRATIGRAPHY

Windsor Township Formation

The rocks of the Windsor Township Formation of Early and Middle Ordovician age are part of the lower thrust sheet of the eastern end of the Hamburg klippe (Lash and Drake, 1984). The formation has a minimum thickness of 4,600 ft (1,400 m) in this quadrangle and is as thick as 5,700 ft (1,700 m) in the Kutztown quadrangle to the south. The formation in the New Tripoli quadrangle consists mainly of part of its Weisenberg Member, which contains shale, mudstone, claystone, silicified shale, well-sorted thin-bedded siltstone, and slightly thicker bedded graywacke. Rare polymictic conglomerate is also present in a few outcrops as well as in float. In the southeasternmost corner of the quadrangle, the Windsor Township Formation consists of several rock types that are lumped in the "Description of Map Units" (pl. 1) as red beds within the Weisenberg Member (Owtr). These consist of red and light-green mudstone, minor graywacke, chert, and limestone. The sandstones of the Windsor Township are less mature than those of the Martinsburg Formation and much less mature than those of the Shochary Ridge sequence. The Windsor Township rocks are interpreted to be slope or rise sediments deposited the farthest offshore of any in this region during Early to Middle Ordovician time. When the shelf foundered and formed the basin that eventually received the Martinsburg, a welt formed farther offshore, raising the Windsor Township and exposing it to erosion. At least some of the Windsor Township was redeposited locally in a northwestward-prograding delta of Shochary sediments.

Facies Relations in the Shochary Ridge Sequence

The Shochary Ridge sequence contains two formations, the upper Shochary Sandstone and the lower New Tripoli Formation. The total thickness of this sequence in this quadrangle is at least 8,100 ft (2,500 m). The thickness could be considerably greater because of faulting at both the bottom and top. This value contrasts with the thickness reported by Wright and Stephens (1978) of 4,900 ft (1,500 m), although their own schematic cross sections suggest a minimum of 10,000 ft (3,000 m).

The Shochary Sandstone consists of fossiliferous thin- to thick-bedded graywacke interbedded with shale, calcisiltite, and minor thin beds of conglomerate; it ranges in thickness from at least 2,250 ft (686 m) in the west to 4,200 ft (1,300 m) in the eastern part of the New Tripoli quadrangle. The New Tripoli Formation consists of fossiliferous thin-bedded calcareous graywacke interbedded with thin- to thick-bedded slate and calcisiltite beds; it ranges in thickness from at least 3,675 ft (1,120 m) in the west to 3,900 ft (1,200 m) in the east. Shelly faunal debris is abundant in rusty-weathering channels in graywackes in the Shochary Sandstone and is less common in the New Tripoli Formation. Many previous workers have noted the abundance of fossils in the Shochary Sandstone (for example, Bretsky and others, 1969; Wright and Stephens, 1978).

Fossils have been collected from the Shochary Sandstone by us and Avery A. Drake, Jr. (of the U.S. Geological Survey (USGS)), in the New Tripoli and adjacent quadrangles. These fossils have been examined by Robert B. Neuman (USGS, written commun., 1970, 1977, 1978); some identified fossils are listed in table 2 (sites 1–3), and collecting localities are shown on the map (pl. 1). Collections include brachiopods, bryozoans, trilobites, gastropods, ostracodes, pelecypods, crinoids, and pelmatozoans. The less common components of the brachiopod assemblages support an age of late Middle Ordovician for the Shochary Sandstone, equivalent to the Sherman Fall Formation of the Trenton Group in New York. Most brachiopod specimens are disarticulated, but the few that are not suggest that these fossils were not transported far beyond the places where they lived.

The greatest faunal diversity appears in collections from the coarser sandstone beds of the Shochary Sandstone; mollusks are commonly found in the finer shale beds. This distribution may explain apparent differences in collections made by different geologists.

Graptolites, interpreted to be shallower water species than those found in the Martinsburg, are present in slates throughout the Shochary Ridge sequence (W.B.N. Berry, University of California, Berkeley, written commun., 1977). Sedimentary structures are in places obliterated by bioturbation in the Shochary Sandstone. On the basis of the presence of bioturbation, the abundance of shelly fauna, and the facies evidence provided by the graptolites, as well as differences in current-direction patterns, this sequence is interpreted to be a prodelta deposit formed in shallower water than the Martinsburg Formation. Most likely the Shochary Ridge sequence was deposited in a relatively

Table 2. Fossil identifications and sample numbers at sites 1–7 shown on map on plate 1

[U.S. Geological Survey (USGS) sample numbers have prefix CO for Cambrian and Ordovician or suffix SD for Silurian and Devonian. Localities 4–7 are mentioned in the "Description of Map Units" on plate 1 and are not discussed in the text]

1. USGS CO–6968, Shochary Sandstone; fossils identified by R.B. Neuman, USGS:
   "Dalmanella" sp.
   Rafinesquina sp.
   Sowerbyella sp.
2. USGS CO–6969, Shochary Sandstone; fossils identified by R.B. Neuman, USGS:
   "Dalmanella" sp.
   Plaesiomys ulrichi Foerste
   Sowerbyella sp.
3. USGS CO–8782, Shochary Sandstone; fossils identified by R.B. Neuman, USGS:
   "Dalmanella" sp.
   Fascifera sp.
   Rafinesquina sp.
   Sowerbyella sp.
4. Seven samples collected 1, 6, 8, 17, 18, 20, and 59 ft (0.3, 1.8, 2.4, 5.2, 5.5, 6.1, and 18.0 m) above the base of the Decker Formation; fossils identified by Jean M. Berdan and John Pojeta, Jr., USGS:
   Bolbiprimitia sp.
   Dizygopleura sp.
   Dizygopleura? sp.
   Eukloedenella? sp.
   Kloedenella sp.
   ?*Kloedeniopsis barretti* (Weller, 1903)
   Kloedeniopsis sp. cf. *K. hartnageli* Berdan, 1972
   Kloedeniopsis? sp.
   Leperditia altoides Weller, 1903
   Leperditia elongata Weller, 1903
   ?*Leperditia elongata* Weller, 1903
   Leperditia? sp.
   Saccarchites sp.
   Zygobeyrichia sp. cf. *Z. ventripunctata* Ulrich and Bassler, 1923
   arthropod? fragment, possibly part of a eurypterid
   inarticulate brachiopod fragment
   pholadomyoid cf. *Grammysia*
   pteriomorph pelecypod, indet.
5. USGS 10914–SD, 13 ft (4 m) above the base of the Oriskany Group; fossils identified by J.T. Dutro and Jean M. Berdan, USGS:
   Brachyprion cf. *B. schuchertanum* Clarke
   Costistrophonella cf. *C. punctulifera* (Conrad)
   Hipparionyx? sp.
   Levenea sp.
   stropheodontid, indet.
6. USGS 10915–SD, 28 ft (9 m) above the base of the Oriskany Group; fossils identified by J.T. Dutro and Jean M. Berdan, USGS:
   Coelospira? sp.
   Leptocoelia? sp.
   brachiopod debris, indet.
   echinoderm debris, indet.
   stropheodontid fragments, indet.
7. USGS 10913–SD, Selinsgrove Limestone; fossils identified by J.T. Dutro and Jean M. Berdan, USGS:
   Bollia sp. cf. *B. diceratina* Swartz and Swain, 1941
   Eodevonaria sp. (abundant)
   Parachonetes sp.
   Pholidops sp.
   Pleurodictyum cf. *P. lenticulare* Hall
   Ranapeltis sp. cf. *R. trilateralis* (Swartz and Swain, 1941)
   Reticestus? sp. cf. *R.*? *altireticulatus* (Swartz and Swain, 1941)
   Tentaculites elongatus (Hall)
   fenestrate bryozoans, indet.
   spiriferid, indet.

restricted area along the west-facing slope of the northeast-trending trough in which the Martinsburg was deposited farther offshore by longitudinal currents (McBride, 1962). The raised welt that was the source for the Shochary sediments was most likely the more proximal part of the Windsor Township Formation.

Facies Relations in the Martinsburg Formation

Throughout most of eastern Pennsylvania, the Martinsburg Formation of Middle and Late Ordovician age contains three members; from bottom to top, they are the Bushkill, the Ramseyburg, and the Pen Argyl. The composite thickness of the three members in several quadrangles east of the New Tripoli quadrangle exceeds 10,000 ft (3,000 m). In this quadrangle, only the Pen Argyl Member and part of the Ramseyburg Member are exposed (pl. 1); the Bushkill Member is cut out by the Eckville fault in the adjacent Slatedale quadrangle (fig. 1).

In the New Tripoli quadrangle, the maximum stratigraphic thickness of the Martinsburg is approximately 7,000 ft (2,100 m); the base is cut out by the Eckville fault, and the upper part is unconformably overlain by the Tuscarora Sandstone. The Pen Argyl contains thin- to very thick bedded slate interbedded with thin- to medium-bedded graywacke. The Ramseyburg contains thin- to medium-bedded slate interbedded with thin- to very thick bedded graywacke. The graywacke beds commonly exhibit typical turbidite sedimentary features such as graded, planar, cross-laminated, and convolute beds and load casts, and they are interpreted to be fairly deep water deposits. Shelly fauna are widely scattered in graywacke beds, and graptolites can be found by diligent search in the slate. All rocks in the Martinsburg contain an excellent penetrative slaty cleavage and have been intensely folded. The slate has been extensively quarried, but all quarries in the quadrangle are now abandoned (Behre, 1933; Lash, 1978).

For nearly a century, geologists have disagreed on the number of members in the Martinsburg Formation and their thickness. On the bases of faunal and structural interpretations, most workers who have studied the Martinsburg west of the Lehigh River have divided it into two parts: a lower slate unit and an upper sandstone unit (for example, see Stose, 1930; Willard and Cleaves, 1939; Willard, 1943; Wright and others, 1979). In the Delaware Valley, many geologists (for example, Behre, 1927, 1933) have favored a three-part subdivision: two slate belts separated by a middle graywacke-bearing unit. This threefold subdivision was not accepted on the geologic map of Pennsylvania by Gray and others (1960); nevertheless, the map clearly shows the three belts of rock. Those who believe in two members maintain that the northern slate belt is the southern slate belt repeated by folding and that the Martinsburg is as thin as 3,000 ft (900 m). Detailed field mapping in the Delaware Valley by Drake and Epstein (1967) showed that the Martinsburg there can be divided into three mappable members in almost the same way as defined by Behre (1933) and that the Martinsburg is more than 12,000 ft (3,700 m) thick. The most recent geologic map of Pennsylvania (Berg and others, 1980) neatly avoids the issue by showing the three belts on the map, with the northern and southern belts apparently repeated by folding, but also showing slate units above and below the graywacke-rich rocks (the Ramseyburg Member) in the explanation.

In the area near Mosserville, Behre (1933) mapped a southwest-plunging anticline cored by his middle sandstone member (the Ramseyburg Member), around which his upper "soft slate" member (the Pen Argyl Member) crops out. Behre believed the Shochary Sandstone of this report and the shales that underlie it (the New Tripoli Formation) in the Shochary syncline to be part of his middle member. He mapped a fault along the north limb of the Shochary syncline, which brought the lower part of his middle member (the New Tripoli Formation in this report) against both his upper and middle members in the Mosserville anticline. Farther west, north of Wanamakers, Behre mapped a sliver of his middle sandstone member along this fault in a series of low hills, called the hogback. He named this structure the Eckville fault for its westward extension into the New Ringgold quadrangle just north of Eckville. The main evidence for the Eckville fault was the juxtaposition of upright, south-dipping shales in the north limb of the Shochary syncline against younger north-dipping or overturned south-dipping graywackes in the hogback.

Stose (1930, p. 651), on the other hand, believed that there are only two members in the Martinsburg and that the upper soft slate member of Behre (the Pen Argyl Member of this report) immediately south of Blue Mountain is the same as the shales south of the proposed Eckville fault (the New Tripoli Formation) and is merely repeated by folding. According to Stose, these shales are exposed in the core of an anticline and are overlain by sandstones of the upper member. Stose found no evidence for the Eckville fault. It is obvious that the relations of the Martinsburg Formation and Shochary Ridge sequence in the New Tripoli quadrangle are critical to understanding the regional stratigraphy and structure of the clastic Ordovician rocks in eastern Pennsylvania, as well as critical to our interpretation of the extent of the structural overlap of Silurian rocks above the Taconic unconformity.

On the basis of our detailed mapping, we conclude that (1) the Mosserville anticline does not exist; (2) the Ramseyburg Member of the Martinsburg Formation grades westward into the Pen Argyl Member with the decrease and loss of graywacke; (3) the outcrop pattern delimiting appreciable graywacke that led to the previous interpretation of the Mosserville anticline is the result of a series of folds superimposed on the westward pinchout of graywacke in the Ramseyburg; (4) the Eckville fault exists; (5) the oldest member of the Martinsburg, the Bushkill (the same as Behre's (1933) lower "hard slate" member), is buried beneath the Eckville fault; and (6) the Pen Argyl and Ramseyburg Members of the Martinsburg are not Shochary Sandstone and New Tripoli Formation.

Figure 2, showing the distribution of graywacke, was constructed by plotting the occurrences of appreciable graywacke outcrops and float (float fragments may be more than 2 ft (0.6 m) long), minor occurrences of graywacke, and areas with little or no graywacke on the cross sections. This plot has enabled us to define the boundary between the Ramseyburg and Pen Argyl Members. The data demonstrate that the Ramseyburg, defined here as containing graywacke that probably makes up more than 5 percent of the total section, pinches out within the Pen Argyl Member between sections *D–D′* and *E–E′*. Lentils of graywacke exist west of the pinchout. These lentils, and similar occurrences in the New Ringgold quadrangle, are probably what Behre (1933) mapped as his middle sandstone member in the hogback.

Graptolite Zonation in the Shochary Ridge Sequence and Martinsburg Formation

Attempts to use graptolite zones to date the Shochary Ridge sequence and the Martinsburg Formation in this and neighboring quadrangles have stimulated considerable debate during the last decade. Wright and others (1979) presented a revised stratigraphy of Ordovician clastic rocks

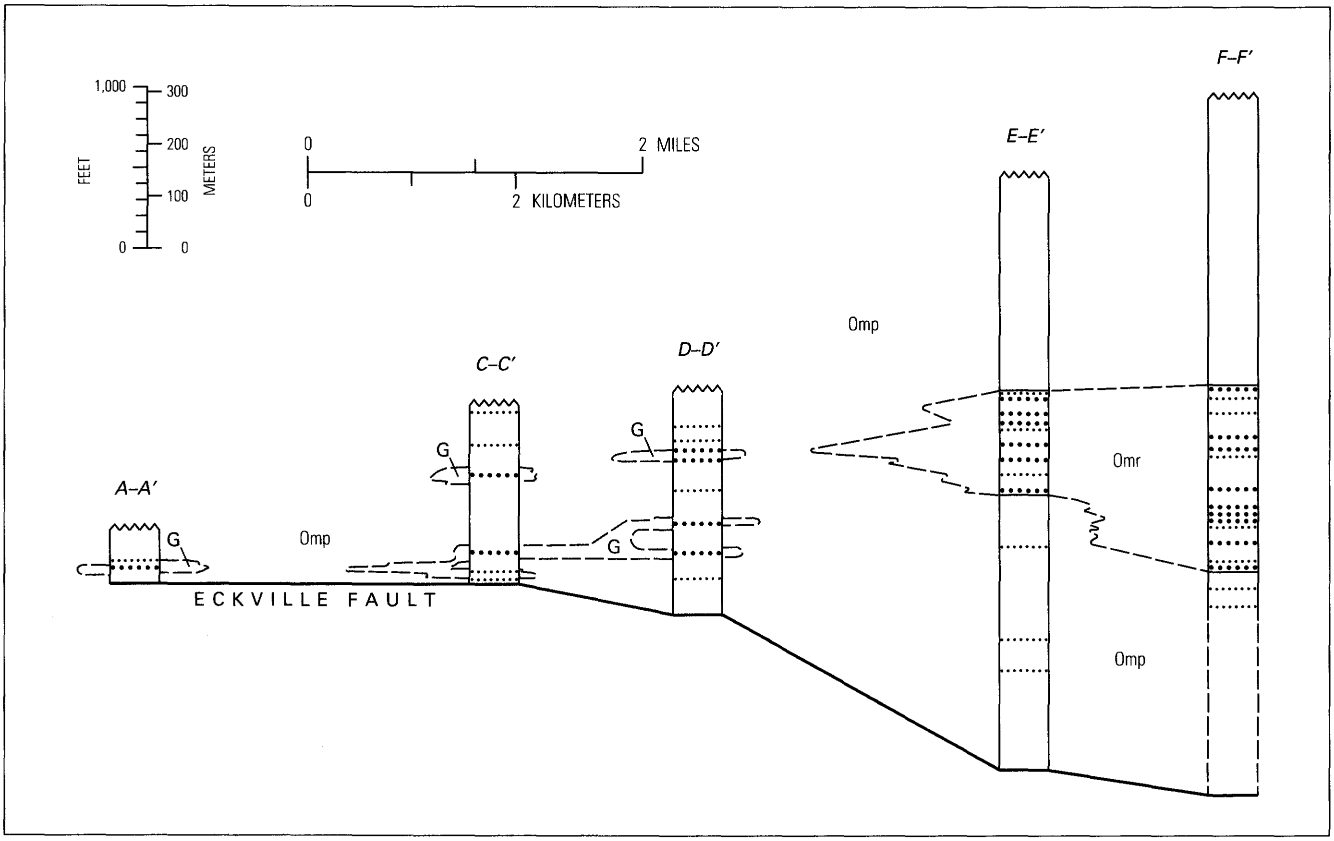

Figure 2. Stratigraphic section showing facies relations of the Pen Argyl (Omp) and Ramseyburg (Omr) Members of the Martinsburg Formation in the New Tripoli quadrangle, Pennsylvania. Columns compiled from cross sections on plate 1. Base of each column is at the Eckville fault. Dashed part of column *F–F′* inferred from geology in the Slatedale quadrangle (Lyttle and others, 1986). Much of the lower Martinsburg Formation, including all of the Bushkill Member, is buried by rocks above the Eckville fault. Lithologic details in the upper Pen Argyl Member are unknown because of cover by colluvium. Large dots show position of outcrops or areas of float containing significant graywacke (probably greater than 5 percent). Small dots indicate areas with some graywacke. Blank areas indicate outcrops or float dominated by slate with little or no graywacke. G indicates parts of the Pen Argyl Member that contain significant graywacke outcrop or float.

that differs significantly from that revealed by detailed mapping in the Great Valley of eastern Pennsylvania (Behre, 1933; Drake and Epstein, 1967; Epstein and others, 1974; Lash and others, 1984; Lyttle and others, 1986; Lyttle and Epstein, 1987). Wright and others (1979) used the zonation and faunal lists of Riva (1969, 1974) to date and map these rocks. However, we believe that the low diversity of species in their collections and the lack of accompanying detailed lithostratigraphic mapping limit the usefulness of this attempt.

Wright and others (1979) recognized four graptolite zones in the Martinsburg and suggested that the Pen Argyl and Bushkill Members are the same age and are simply repeated by folding. This assertion resurrects the old concept of Stose (1930) and Willard and Cleaves (1939). We feel that the detailed mapping in the New Tripoli and adjacent quadrangles clearly shows the Bushkill, Ramseyburg, and Pen Argyl Members to be part of a progressively younging sequence, with the added complication that the Ramseyburg grades westward into the Pen Argyl Member. Furthermore, the lithic characteristics of the Bushkill and Pen Argyl are so different as to preclude identification of these as the same unit simply repeated across a regional fold. Wright and others (1979) also stated that the Shochary Ridge sequence extends through the same four graptolite zones as the Martinsburg Formation, which may be true. Their additional contention that the rocks of the Shochary Ridge sequence have lithic characteristics identical to those of the Martinsburg rocks and can be mapped in continuous belts is shown herein to be incorrect. It is important to state the disagreements we have with Wright and others (1979) because of the relevance to many issues, such as stratigraphic thicknesses, depositional environments, construction of cross sections, and overall tectonic history of the area.

On the basis of more recent work in Canada (Walters and others, 1982) and a careful study of Riva's own faunal lists by Finney (1982), several authors (Ross and others, 1982; Finney, 1985) have suggested that the range of the *Climacograptus spiniferus* Zone of Riva may overlap the ranges of the *Corynoides americanus* and *Orthograptus ruedemanni* Zones. That is, the *Climacograptus spiniferus* Zone may be the lateral equivalent of several other zones, and the graptolites that characterize and define these zones may be influenced by environmental factors. These particular graptolite zones are of critical importance in both the Shochary Ridge and Martinsburg rocks. Therefore, a new look at the existing graptolite data in this area is warranted because of the likelihood of facies control of these fossils.

In New Jersey and easternmost Pennsylvania east of the New Tripoli quadrangle, Parris and others (1987) and Parris and Cruikshank (in press) studied graptolite distribution in the Martinsburg; they support our conclusion that the Bushkill, Ramseyburg, and Pen Argyl Members are part of a younging sequence. We feel that the low diversity of graptolite species may preclude the drawing of meaningful graptolite zonation boundaries in the manner used by Wright and others (1979); these boundaries cut abruptly across contacts and other structures in an unlikely manner. The available graptolite data, as well as our mapping, indicate that the Martinsburg comprises three distinct and mappable members.

Wright and others (1979) also contended that the rocks of the Shochary Ridge sequence rest conformably upon the rocks of the Hamburg klippe. Like that of others before us (for example Stose, 1930; Alterman, 1972), our mapping in this and the adjacent Slatedale and New Ringgold quadrangles (Lyttle and Epstein, 1987) shows that the klippe rests in fault contact upon the Shochary Ridge sequence. For this reason, we feel that the youngest age assigned to the Shochary Ridge sequence (late Barnveldian) should be used only as a limit on the earliest possible time of emplacement of the klippe on the Shochary rocks. We interpret the final movement of the klippe to its present position to be an Alleghanian event, and we discuss this more fully in the section on the Kistler Valley fault below.

Regional Relations of Upper Silurian through Lower Middle Devonian Rocks

Upper Silurian through lower Middle Devonian rocks in eastern Pennsylvania consist of thin, interbedded units of sandstone, limestone, dolomite, and shale. The sequence includes rocks from the Bloomsburg Red Beds up into the Selinsgrove Limestone. It is about 1,500 ft (460 m) thick near the Delaware River in easternmost Pennsylvania, 38 mi (61 km) northeast of the New Tripoli quadrangle (Epstein and others, 1967). It thins gradually westward, and several units become more clastic as they onlap onto a low-lying paleo-positive area, the "Harrisburg axis" of Ulrich (1911) and "Auburn Promontory" of Swartz (*in* Willard and others, 1939). On the eastern border of the New Tripoli quadrangle, this sequence is nearly 600 ft (180 m) thick. It thins to the west, and, in the adjoining New Ringgold quadrangle, it is probably less than 400 ft (120 m) thick. About 34 mi (55 km) west of there, the entire sequence is absent. Details of these stratigraphic relations and interpretation of the environments of deposition of Silurian and Devonian units were given by Lash and others (1984, p. 81–85) and Epstein (1986).

Surficial Deposits

Bedrock exposures, shown by structural symbols on the map, occupy less than 1 percent of the ground surface in the New Tripoli quadrangle. The remainder of the area is covered by residuum, alluvium, pre-Illinoian till, and products of mass wasting, as well as material derived from human activities. Short descriptions of these deposits are given in the "Description of Map Units" (pl. 1). Additional comments on some of them are given below.

Alluvium and Flood-Plain Deposits

Along Lizard Creek, the alluvium consists of dark-yellowish-brown (10*YR* 4/4[1]) clayey silt containing scattered pebbles and cobbles. Alluvium in the tributary to Lizard Creek just north of Liebeyville consists of at least 3 ft (1 m) of moderate-brown (5*YR* 4/4), slightly silty clay and scattered cobbles of various Catskill Formation lithologies as much as 6 in. (15 cm) long.

Along Ontelaunee Creek at Wanamakers, 2 ft (0.6 m) of dark-yellowish-brown (10*YR* 4/2) clayey silt containing scattered shale chips as much as 0.5 in. (1 cm) long overlies grayish-orange (10*YR* 7/4) to dark-yellowish-orange (10*YR* 6/6) clay of unknown depth. The alluvium along the tributary to Ontelaunee Creek just north of Lynnport consists of light-olive-gray (5*Y* 6/1) silty clay in the floor and dark-yellowish-orange (10*YR* 6/6) fine- to medium-grained sand in bars, along with shale chips of all sizes derived from the nearby bedrock slopes and cobbles of quartzite derived from nearby pre-Illinoian drift. At the juncture of School and Ontelaunee Creeks near New Tripoli, the alluvium consists of more than 2 ft (0.6 m) of grayish-orange (10*YR* 7/4) to dark-yellowish-orange (10*YR* 6/6) clayey silt containing abundant shale chips, derived from the local bedrock, and many rounded and subrounded cobbles of quartzite and graywacke as much as 10 in. (25 cm) long, derived from the surrounding pre-Illinoian drift.

The following section was measured along the west bank of Ontelaunee Creek 2,300 ft (700 m) due south of Wanamakers:

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[1]All rock colors were determined from the Rock-Color Chart (Goddard and others, 1948).

Alluvium:	Thickness Feet	Meters
Dark-yellowish-brown (10*YR* 4/2) to moderate-yellowish-brown (10*YR* 5/4) silty clay soil	0.5	0.15
Mottled dark-yellowish-orange (10*YR* 6/6) and moderate-yellowish-brown (10*YR* 5/4) clayey silt	1.5	.5
Mottled light-gray (*N* 7) and dark-yellowish-orange (10*YR* 6/6) silty clay	1.2	.4
Mottled light-gray (*N* 7) and dark-yellowish-orange (10*YR* 6/6) silty and sandy clay containing rounded cobbles of graywacke, red sandstone, chert, and shale as much as 4 in. (10 cm) long	.7	.2
Dark-yellowish-brown (10*YR* 4/4) sandy, pebbly silt	.8	.2
Light-gray (*N* 7) clay	.3	.1
Pebble bed; limit of augering	Not measured	

Along Kistler Creek, the alluvium is more than 3 ft (1 m) thick and consists of grayish-orange (10*YR* 7/4) clayey silt containing washed-in shale chips averaging about 1 in. (2.5 cm) in length. Near Kempton, the alluvium is more than 5 ft (1.5 m) thick and consists of 2.5 ft (0.8 m) of mottled pale-yellowish-orange (10*YR* 8/6) to dark-yellowish-orange (10*YR* 6/6) and medium- to light-gray (*N* 6) silty clay at the top, grading down into 2 ft (0.6 m) of medium-gray (*N* 5) clay and then down into medium-gray (*N* 5) clay containing shale fragments as much as 0.5 in. (1 cm) long. Alluvium in the Kistler Creek tributaries on the Windsor Township Formation consists of medium-olive-gray (5*Y* 5/1) silty clay with moderate-brown (5*YR* 4/4) mottling. The valleys formed in the Windsor Township Formation are distinctively flat floored, and many contain swamps.

Boulder Fields

The boulder field on the south slope of Blue Mountain, 100 ft (30 m) above Leaser Lake at Jacksonville, is about 5 ft (2 m) higher than the surrounding area and has a coarse, rippled surface. The boulders are shingled, and their long axes lie both parallel and transverse to the length of the field. Many of their intermediate axes are nearly vertical and suggest some frost action in the formation of the boulder field. The lower end of the field is marked by a 6-ft-high (2-m-high) crescent-shaped toe, concave downslope. Water flows out from the toe area in springs. It is possible that matrix sand and silt are presently being flushed out of the field by these springs, especially during periods of intense rainfall. Just below the toe is a 50-ft-wide (15-m-wide) area of well-sorted boulders averaging about 10 in. (25 cm) in length.

Few trees are growing on the field. The boulders are free of lichens for the most part, except in isolated areas. In the surrounding boulder-strewn colluvium, trees are abundant and lichens coat all the rocks. Trees are progressively larger away from the field, and this size increase suggests that movement by mass wasting has been intermittent and that the latest movement is fairly recent. The field relations suggest that the source for the boulders was colluvium in the slightly steeper upslope area. This colluvium may have been set into motion in debris flows during periods of intense storms; the interstitial material later washed out of the porous mass. This interpretation suggests that parts of the colluvial apron on the south slope of Blue Mountain and the boulder field are fairly recent, although deposition of this colluvium probably began during the Pleistocene. Previous interpretations had suggested that these features were entirely of periglacial (Wisconsinan) origin (for example, see Potter and Moss, 1968).

A boulder field about 1,400 ft (430 m) long and 100 ft (30 m) wide lies in a gully 300 ft (90 m) below Baers Rocks on the north slope of Blue Mountain. Many of the blocks in this field are more than 5 ft (2 m) long and were probably derived from rubble produced by frost heaving of the fault sliver of Tuscarora Sandstone just at the head of the field at an altitude of 1,200 ft (370 m).

The boulders for these fields and for the surrounding colluvium were initially derived from frost-heaved Tuscarora bedrock at or near the top of Blue Mountain. Many of the present outcrop areas of the Tuscarora consist of blocks of rock many tens of feet long that have been loosened by frost action. These masses of blocks are called block cities, and they maintain the general structural orientation of the unit. An excellent example is Baers Rocks, a block city 50 ft (15 m) high along the Appalachian Trail near the eastern edge of the quadrangle. Another block city is 5,000 ft (1,500 m) S. 70° W. of Baers Rocks. Stratigraphic units that have produced large blocks by frost heaving include the Tuscarora Sandstone, Stormville Formation, Oriskany Group, and Palmerton Sandstone. No significant block cities were found in sandstones of the Catskill Formation.

Colluvium

Colluvium is a deposit derived from the disintegration of bedrock and its transport downslope by several processes of mass wasting including creep, debris flow, slope wash, and tree throw. The composition and physical character of the material making up the colluvium are controlled by the underlying bedrock; that is, the colluvium consists of weathered bedrock in a matrix of clay, silt, and, in places, sand. Many examples of colluvium merging into bedrock folded by creep are found throughout the quadrangle.

The Windsor Township Formation yields moderate-yellowish-brown (10*YR* 5/4) to dark-yellowish-orange (10*YR* 6/6) colluvium that averages about 10 ft (3 m) in thickness. In places, the colluvium has weathered to dark reddish brown (10*R* 4/4). It is rich in clay and silt and contains shale fragments as much as 6 in. (15 cm) long, although shingled siltstone and shale pieces as long as 2 ft (0.6 m) are not uncommon. Some of the shale fragments have weathered to pale reddish brown (10*R* 5/4). In some areas, the surface of the colluvium has been washed, forming a shale-chip gravel with an open-work texture and platy fragments that average about 0.5 in. (1 cm) in length.

The New Tripoli Formation forms a pale-yellowish-orange (10*YR* 8/6) to dark-yellowish-orange (10*YR* 6/6) and grayish-orange (10*YR* 7/4) to light-brown (5*YR* 5/6) colluvium of tabular shale fragments, which weather pale olive (10*Y* 6/2) and are less than 0.25 in. (6 mm) to 3 in. (8 cm) long in a clayey-silt matrix. It is generally thinner than colluvium on the Windsor Township Formation and probably averages less than 5 ft (1.5 m) in thickness.

Colluvium from the Shochary Sandstone may be more than 10 ft (3 m) thick. It is mostly a moderate-brown (5*YR* 3/4 and 5*YR* 4/4) clayey silt and contains more sandstone fragments than the New Tripoli Formation. The fragments are generally tabular; they average about 0.5 in. (1 cm) in length, but some are 6 in. (15 cm) long or more. They weather pale yellowish orange (10*YR* 8/6) to moderate yellowish brown (10*YR* 5/4), light brown (5*YR* 5/6) to moderate reddish brown (10*R* 4/6), and light olive gray (5*Y* 6/1).

Much of the colluvium along the south slope of Blue Mountain may have been remobilized in debris flows, and the surface boulders are lag concentrates after the fine particles were winnowed out. A 4.4-lb (2-kg) sample of the colluvium collected at 880 ft (270 m) altitude along Pennsylvania Route 309 on the south side of Blue Mountain contained 57 percent gravel, 27 percent sand, and 16 percent silt and clay.

Colluvium in the Clinton Formation consists of fragments as much as several inches long, which weather moderate reddish orange (10*R* 6/6) to grayish red (5*R* 4/2) in a light-brown (5*YR* 5/6) clay-silt matrix. Clasts pebble size and larger form less than 20 percent of the colluvium.

Colluvium derived from the Bloomsburg Red Beds contains fragments that weather pale red (5*R* 6/2) and pale yellowish orange (10*YR* 8/6). The fragments are as much as 10 in. (25 cm) long in a moderate-brown (5*YR* 3/4) clay-silt matrix.

Colluvium derived from the Mahantango Formation consists of fragments that weather dark gray (*N* 3) and are partly iron stained (grayish orange (10*YR* 7/4) to dark yellowish orange (10*YR* 6/6) and moderate reddish orange (10*R* 6/6)). The fragments are as much as 1 ft (0.3 m) long and are enclosed in a light-brown (5*YR* 5/6) clay-silt matrix.

Red beds in the Catskill Formation produce colluvium consisting of pale-red (5*R* 6/2) to grayish-red (5*R* 4/2) siltstone, shale, and very fine grained sandstone chips in a moderate-brown (5*YR* 3/4) silty matrix. Non-red units in the Catskill yield siltstone to very fine grained sandstone fragments that weather light olive gray (5*Y* 6/1) in a moderate-brown (5*YR* 3.5/4) silty matrix.

Terrace Deposits

In Kistler Valley, the terrace deposits contain red shale chips, which probably were derived from the red beds in the Windsor Township Formation. Along Ontelaunee Creek, red sandstone clasts are found along with rounded cobbles from the Tuscarora Sandstone. The red clasts were derived either from the Bloomsburg Red Beds or the Catskill Formation, both north of Blue Mountain. The Tuscarora cobbles are weathered throughout their entire thickness, attesting to the antiquity of the deposit. In many areas, colluvium from the adjacent slopes has extended out over and mixed in with the terrace deposits. An erratic of Tuscarora quartzite 5 ft (1.5 m) long was found on the terrace along the abandoned railroad 2,500 ft (760 m) east of Lynnport. This locality is near the western limit of pre-Illinoian drift., The terraces along Ontelaunee and Kistler Creeks also appear to head into the limit of pre-Illinoian drift; this pattern suggests that the terraces are outwash from the pre-Illinoian glacier and are of the same age.

Pre-Illinoian Outwash(?)

Remnants of a dissected terrace lie 60–100 ft (20–30 m) above Lizard Creek. Scattered pebbles, cobbles, and boulders, some of which are more than 1 ft (30 cm) long, are found nearly everywhere north of the creek on weathered light-brown (5*YR* 5/6) to moderate-reddish-brown (10*R* 4/6) Mahantango Formation. These clasts consist of rounded to subrounded boulders of gray and red sandstone and conglomerate, probably derived from the Andreas Red Beds, Stormville Formation, Oriskany Group, and Palmerton Sandstone, very fine grained sandstone of the Trimmers Rock Formation, and possibly the Catskill Formation. These clasts are deeply weathered dark yellowish orange (10*YR* 6/6), light brown (5*YR* 5/6), and light gray (*N* 9). Small, well-rounded, red shale and siltstone pebbles and a variety of other rock types are abundant in a moderate-brown (5*YR* 3.5/4) silty-clayey matrix.

Many places north of Lizard Creek have no terrace remnant, only lag concentrates of exotic clasts. Therefore, these terrace deposits were once more extensive than shown on the map. South of Lizard Creek, flat areas at altitudes of about 700 ft (200 m) may be remnants of this terrace. They contain weathered clasts that are similar to those on the north side of the creek but that are not as well rounded. Moreover, most clasts are similar to or are derived from the underlying Upper Silurian and Lower Devonian bedrock. Thus, they may be weathered bedrock residuum, and the terrace deposits, if they were ever present, may have been removed by more extensive erosion. Similar deposits are found about 8 mi (13 km) to the northeast at Lehigh Gap, where precise evidence for their age, other than that they are pre-Illinoian, is lacking.

Pre-Illinoian Till

Braun (1988) has summarized previous work on the glacial deposits of eastern Pennsylvania and has presented evidence for the distribution of pre-Illinoian, Illinoian, and Wisconsinan glacial deposits. The Wisconsinan terminal moraine lies north and east of the New Tripoli quadrangle. The till in the quadrangle is clearly more deeply weathered than Wisconsinan drift north of the terminal moraine. It lacks constructional topography characteristic of late Illinoian drift and lies southwest of late Illinoian deposits and within the area believed by Braun (1988, figs. 2, 6) to be pre-Illinoian.

STRUCTURAL GEOLOGY

The rocks in the New Tripoli quadrangle can be divided into six structural domains or lithotectonic units, each comprising a group of individual formations having its own characteristic structural geometry (table 1). Incompetent rocks, such as the top of the Martinsburg Formation, the upper part of the Bloomsburg Red Beds, and the Marcellus Shale, are zones of detachment separating the lithotectonic packages. Taconic orogenesis resulted in thrusting of rocks of the Hamburg klippe onto the Shochary Ridge sequence, which formed the Shochary syncline beneath this major thrust fault. During the later stages of the Taconic orogeny, the Hamburg and Shochary rocks were thrust together onto the Martinsburg Formation (Lyttle and Drake, 1979). The Martinsburg was only slightly folded during this time.

Alleghanian structures overprint Taconic structures and are characterized by a thrust system of imbricate splays and a series of northeast-trending, northwest-verging, upright to overturned folds with a regional axial-plane cleavage (Epstein and Lyttle, 1986). In rocks of the Shochary Ridge sequence, the cleavage formed during a tightening of the already formed Shochary syncline. Alleghanian deformation, which produced folds, faults, and cleavage, was episodic. The folds in each of the lithotectonic units are disharmonic; that is, the amplitude and structural configuration in each are different. Zones of detachment, décollements (Epstein and Epstein, 1967, 1969; Wood and Bergin, 1970; Epstein and others, 1974), or thrust faults are interpreted to bound each unit. Planar and linear structures are abundant and include bedding, slaty and crenulation cleavages, cleavage-bedding intersections, and cleavage-cleavage intersections. Equal-area projections of these structures are shown in figure 2 on plate 1, and their significance is discussed below.

Valley and Ridge Province

Lithotectonic Unit 6 (Mahantango through Catskill Formations)

In the New Tripoli quadrangle, Middle Devonian and younger rocks, including the Mahantango through Catskill Formations that compose lithotectonic unit 6, are folded into a broad, generally upright, southwest-plunging, open fold, the Weir Mountain syncline, which has a half wavelength of nearly 2 mi (3 km). The south limb is steeper than the north limb, and, in the Lehighton quadrangle northeast of the New Tripoli quadrangle, some of the beds in the south limb are overturned (Epstein and others, 1974). The strike of the axial plane is about N. 62° E. The syncline is generally cylindrical, and the limbs of the fold are rounded, not kinked as are many folds in the Valley and Ridge province of central Pennsylvania. The fold axis plunges about 4° S. 64° W., as shown by the great circle in plate 1, figure 2, projection 6–A, and by the intersection of bedding and cleavage (pl. 1, fig. 2, projection 6–C).

A fairly well developed cleavage is found in most pelitic beds. The cleavage on the southern limb of the fold dips moderately to the south (pl. 1, fig. 2, projection 6–B), averaging about 51° and ranging from about 35° to 75°. In some outcrops outside the New Tripoli quadrangle, a later crenulation cleavage is superimposed on the earlier cleavage (Epstein and others, 1974, p. 293). A still earlier period of deformation, representing northwest shearing before the major folding and producing bedding slip and small wedges, has been documented in the Lehigh River area by Glaeser (1967). A regional cleavage related to this deformation has recently been documented by M.B. Gray (University of Rochester, oral commun., 1990). To the north, the deformation proceeded through complex stages of folding and faulting (Arndt and Wood, 1960). The base of the lithotectonic unit lies under cover within the Marcellus Shale or near the Marcellus-Mahantango contact.

Lithotectonic Unit 5 (Upper Silurian through Middle Devonian Rocks)

The thin stratigraphic units of Late Silurian and Middle Devonian age that compose lithotectonic unit 5 make a unique map pattern of complex folds that are strikingly different from structures in rocks above and below. The zone of detachment at the top of lithotectonic unit 5 is believed to lie within the poorly exposed Marcellus Shale, the few outcrops of which have sheared rock, minor folds with varied orientation, and zones of breccia and quartz veins.

The folds in lithotectonic unit 5 are overturned to completely inverted, and many individual folds disappear rapidly down-plunge. Faults are subordinate to the folds. The folds have variable plunges so that a unified girdle cannot be constructed from the bedding plot in plate 1, figure 2, projection 5–A. Each segment of the plot has a slightly different girdle and, hence, a different plunge. Thus, these folds are noncylindrical. For example, the overall plunge, as defined by the maximum of all the intersections of bedding and cleavage, is 7° N. 75° E. (β in pl. 1, fig. 2, projection 5–A). If, on the other hand, the intersections of bedding and cleavage are plotted only for rocks in the steep limbs of the folds, those that dip more than 75° NW. or are overturned (seven readings), then the maximum is 6° S. 59° W. (βa in pl. 1, fig. 2, projection 5–A). This maximum suggests that these steep and overturned limbs have been skewed and rotated counterclockwise by about 16° from the orientation of the less steep upright limbs.

All of the stratigraphic units in this lithotectonic unit are exposed in an anticline at the Huss Stone quarry at Andreas (fig. 1 on pl. 1). The sequence of deformation is complex, as indicated by overprinted bedding-plane slickensides, cleavage, and faults (Lash and others, 1984, p. 138–145). The sequence appears to be, from oldest to youngest, (1) flexural slip folding, (2) development of pressure-solution cleavage during continued folding, (3) additional flexural slip that deformed the earlier cleavage, (4) faulting of the northwest limb of the anticline, and (5) development of a later crenulation cleavage. This sequence is undoubtedly more complicated because stage 2 is represented by more than one period of cleavage formation (Lash and others, 1984, fig. 103).

These complex folds die out abruptly 1 mi (1.6 km) to the west in the New Ringgold quadrangle, where the sequence is apparently structurally conformable with the overlying rocks. This abrupt change suggests that a fault between the two areas separates the rocks within this lithotectonic unit, as suggested at depth in cross section *B–B′* (pl. 1). The belt of complexly folded rocks is 5,000 ft (1,500 m) wide in the New Tripoli quadrangle and abruptly decreases to half that width in the relatively unfolded zone in the New Ringgold quadrangle. Thus, the detachment between lithotectonic units 5 and 6 in the New Tripoli quadrangle may be missing in the New Ringgold quadrangle, and a crosscutting fault (or faults) must be present between the two areas. The fault is within a low-lying covered area about 1.5 mi (2.4 km) wide in which stratigraphic details are poorly known. Reconnaissance in the New Ringgold quadrangle suggests that the Palmerton Sandstone may pinch out westward in this area, and a blocky graywacke, which probably lies in the lower part of the Mahantango Formation, makes its easternmost appearance. Significant facies changes probably controlled the style of deformation of this unit.

Lithotectonic Unit 4 (Tuscarora Sandstone, Clinton Formation, and Bloomsburg Red Beds)

Lithotectonic unit 4 consists of the Tuscarora Sandstone, Clinton Formation, and Bloomsburg Red Beds; rocks of all three formations are complexly folded and faulted. Exposures are generally poor, but the folds appear to range from upright to overturned; some limbs are rotated more than 180°. The folds have larger wavelengths and amplitudes than those of lithotectonic unit 3 (table 1), but the attitudes of the fold axes are similar. The plunge of the folds, as determined from the girdle y to bedding in plate 1, figure 2, projection 4–A, is 3° S. 63° W., which is similar to the plunge determined to be 7° S. 59° W. from the intersections of bedding and cleavage in plate 1, figure 2, projection 4–C. A subsidiary girdle (z) in plate 1, figure 2, projection 4–A, indicates a plunge of 20° S. 40° W. and suggests a counterclockwise rotation of about 19°, similar to the rotation in lithotectonic unit 3.

The faults in lithotectonic unit 4 have displacements of at least 1,000 ft (300 m). Because the rocks are so poorly exposed, faults probably are much more numerous than shown on the map. Several major faults cut obliquely across the general structural strike of beds at an angle of about 20°. Because these faults lie at a very low angle to the structural grain, they are interpreted to be imbricate faults that ramp up from a bedding thrust in the Martinsburg Formation. These ramps connect a floor thrust in the Martinsburg with a roof thrust in the Bloomsburg as depicted in the cross sections (pl. 1). These faults define a duplex in the Tuscarora and Bloomsburg, as described below in the section entitled "Duplex in Blue Mountain."

Great Valley

Lithotectonic Unit 3 (Martinsburg Formation)

The Martinsburg Formation of Middle and Late Ordovician age forms lithotectonic unit 3. Through most of eastern Pennsylvania, the Martinsburg contains three members, the lower Bushkill Member, the middle Ramseyburg Member, and the upper Pen Argyl Member. The composite thickness of the three members in several quadrangles east of the New Tripoli quadrangle exceeds 10,000 ft (3,000 m). In this quadrangle, only the Pen Argyl and part of the Ramseyburg are exposed; the Bushkill Member is cut out by the Eckville fault here and in the adjacent Slatedale quadrangle (fig. 1). Therefore, in the New Tripoli quadrangle, the maximum stratigraphic thickness of the Martinsburg is approximately 7,000 ft (2,000 m). The Martinsburg is unconformably overlain by the Tuscarora Sandstone. Although not exposed in this quadrangle, this unconformable contact shows evidence of shearing and northwest translation of overriding rocks at exposures in nearby gaps in Blue Mountain along the Lehigh and Schuylkill Rivers.

Folds in the Martinsburg plunge on average about 3° S. 67° W. (pl. 1, fig. 2, projection 3–C) and have a wavelength of approximately 1,200 ft (370 m) and an amplitude of about 600 ft (180 m). Well-developed slaty cleavage is axial planar to these folds. The average orientation of the cleavage is N. 67° E., 59° SE., which is approximately the same strike as in lithotectonic unit 4 and 9° more northerly than the average cleavage reading for lithotectonic unit 2. The divergence in the strike of cleavage between lithotectonic units 3 and 2 marks a significant tectonic boundary that is readily seen on the map by the divergence of fold axes between the two units. Numerous bedding slickensides cut by cleavage indicate that the rocks were competent enough to fail by flexural slip early in the deformation history before passive folding and the development of cleavage. A late cleavage sporadically crenulates the slaty cleavage in this unit.

This unit is separated from lithotectonic unit 2 by two faults. The older, presumably Taconic in age, is the Game Preserve fault, which occurs in the subsurface in this quadrangle and crops out to the east in the Slatedale and Cementon quadrangles (Lyttle and others, 1986; Lyttle and Epstein, 1987; A.A. Drake, Jr., U.S. Geological Survey, unpub. data). The younger, believed to be late Alleghanian in age, is the Eckville fault. It was first recognized by Behre in 1933 and can readily be traced across the quadrangle. It is interpreted to coincide in part with the Game Preserve fault at depth.

The equal-area projections of intersections of bedding and cleavage for lithotectonic unit 3 (pl. 1, fig. 2, projection 3–C) fall along a great circle. This pattern could be due either to refolding of an earlier generation of folds and their associated cleavage or to imposition of cleavage during a later period of folding upon earlier formed folds. Because the plot of cleavage (pl. 1, fig. 2, projection 3–B) does not show a similar rotation, we conclude that cleavage was imposed on the rocks during a later generation of folding. The regional cleavage seen in rocks of this lithotectonic unit can be seen in all other lithotectonic units in this quadrangle and in rocks north of the quadrangle that are as young as Pennsylvanian. Therefore, it is Alleghanian in age. There is no evidence in this quadrangle that a cleavage formed in lithotectonic units 3 and 2 during the Taconic orogeny. Similar results were determined from structural analysis in the area nearby (Epstein and others, 1974), as well as to the northeast in New Jersey and southeastern New York (Epstein and Lyttle, 1986), where the earlier generation of folding was interpreted to have developed only broad open folds and to be of Taconic age.

The equal-area projections of bedding (pl. 1, fig. 2, projection 3–A) show that bedding falls along three great circles. The main girdle (v) defines the regional folds, which plunge 2° S. 69° W., similar to the results indicated by plate 1, figure 2, projection 3–C. An additional girdle (w) indicates a plunge of folds of 24° S. 51° W. and suggests a later counterclockwise rotation of 18°, similar to the rotation demonstrated for lithotectonic unit 4. Interestingly, there appears to be another girdle (x) that defines folds having a plunge of 24° N. 84° W. These are interpreted to be the earlier gentle Taconic folds.

Lithotectonic Unit 2 (Shochary Ridge Sequence)

The Shochary Ridge sequence of Middle and Late Ordovician age, comprising the Shochary Sandstone and New Tripoli Formation, forms lithotectonic unit 2. The major folding in this unit is the very deep Shochary syncline, which has an amplitude that is greater than 4,000 ft (1,200 m) and a half wavelength of at least 10,000 ft (3,000 m). Unlike lithotectonic units 3 and 1, both of which also contain Ordovician clastic rocks, lithotectonic unit 2 has few small-scale folds. Very tight small-scale folds, related to movement on the Eckville and Kistler Valley faults, are found in the New Tripoli Formation and are discussed below in the sections on these two faults.

The amplitude of the Shochary syncline far exceeds the amplitudes of folds in the overlying Silurian and Devonian rocks; this difference in amplitude suggests that the Shochary syncline formed, at least in part, during the last stages of the Taconic orogeny. The initial formation of the regional fold was most likely associated with movement along the Weisenberg Church fault (fig. 1) that produced a footwall syncline in the Shochary rocks. Later, during the Alleghanian orogeny when all the rocks in the New Tripoli quadrangle were severely compressed, the syncline was probably tightened and the cleavage seen in these rocks formed. Movement along the Eckville and Kistler Valley faults, which both are most likely part of a regional imbricate splay, locally rotated this cleavage. The average cleavage orientation of N. 76° E., 57° SE. in lithotectonic unit 2 (pl. 1, fig. 2, projection 2–B) dips generally more steeply than the axial plane of the Shochary syncline shown in the cross sections (pl. 1). This discrepancy is not well understood, but it may relate to the two-stage process involved in forming the Shochary syncline. Although a cleavage can be seen in most outcrops for this lithotectonic unit, it is generally not an excellent slaty cleavage as in the Martinsburg Formation of lithotectonic unit 3. The average intersection of bedding and cleavage is 2° S. 68° W. (pl. 1, fig. 2, projection 2–C), like that in lithotectonic unit 3. For the same reasons given for unit 3, we believe that the regional cleavage developed during the Alleghanian deformation.

Two girdles in the bedding plot (a and b in pl. 1, fig. 2, projection 2–A) suggest two episodes of Alleghanian folding, as indicated for lithotectonic unit 3. However, no well-defined girdle in bedding indicates Taconic folding as seen in unit 3. Perhaps Taconic folding of the Shochary Ridge sequence was nearly coaxial with the later Alleghanian deformation. A late crenulation cleavage, which is present in all rocks in the quadrangle, is well developed in this lithotectonic unit, and its average attitude is N. 56° E., 48° NW. (pl. 1, fig. 2, projection 2–D).

Lithotectonic Unit 1 (Windsor Township Formation)

The Windsor Township Formation of Early and Middle Ordovician age forms lithotectonic unit 1, which is part of the lower thrust sheet of the eastern end of the Hamburg klippe (Lash and Drake, 1984). Bedding and cleavage appear on average to have the most easterly trend of any structures in the quadrangle (pl. 1, fig. 2, projections 1–A and 1–B), and, in many outcrops, they are difficult to distinguish. Some of the rocks in this lithotectonic unit contain a scaly cleavage that predates the development of the regional slaty cleavage and is interpreted to be Taconic in age (Lash and others, 1984). The poor development of the regional slaty cleavage in many parts of this unit is probably related to the earlier development of scaly cleavage in some of these rocks.

It is possible that the rocks of the Shochary Ridge sequence are reworked Windsor Township sediments that were shed from the toe of a stack of Hamburg klippe thrust sheets carrying the Windsor Township at its base. This stack of thrust sheets moved toward the north or northwest and overrode the Shochary Ridge sequence sediments. Eventually an even lower thrust (Game Preserve fault) formed near the base of the Shochary Ridge sequence and carried these rocks, as well as the Hamburg klippe rocks structurally on top of them, farther to the north into the Martinsburg depositional basin. The fact that the eastern end of the synclinally folded thrust sheet containing rocks of the Shochary Ridge sequence (lithotectonic unit 2) coincides with the eastern end of the Hamburg klippe thrust sheets (lithotectonic unit 1) lends support to this idea (fig. 1). To the west in the adjoining New Ringgold quadrangle, the rocks of lithotectonic unit 1 are unconformably overlain by Silurian rocks of lithotectonic unit 4.

Faults

All faults exposed at the surface in the New Tripoli quadrangle are Alleghanian in age, although two important faults interpreted to be Taconic in age are truncated by Alleghanian faults in the subsurface. In order to fully understand these relations, it is necessary to examine the geologic maps of the adjoining Slatedale quadrangle (Lyttle and others, 1986) and the Cementon quadrangle (fig. 1; A.A. Drake, Jr., U.S. Geological Survey, unpub. data; Lyttle and Epstein, 1987).

Faults of Taconic Age

The two Taconic faults, the Weisenberg Church fault and the Game Preserve fault, are healed structures that formed before the cleavage and that mark the contact between groups of rocks deposited in markedly different environments. Unlike the later Alleghanian faults, they show no breccia, kink folds, quartz veins, and crenulation cleavage. The juxtaposed units may have been only partly consolidated, water-rich sediments. Subsequent deformation and low-grade metamorphism healed these faults and made them difficult to recognize.

The Weisenberg Church fault marks the northern contact of the Hamburg klippe with the underlying New Tripoli and Martinsburg Formations (Lyttle and others, 1986). It is truncated by the Alleghanian Kistler Valley fault, which is described in more detail below. Although it is impossible to know the pre-Alleghanian location of the Weisenberg Church fault, it probably coincided roughly with the present location of the Kistler Valley fault.

The Game Preserve fault marks the contact between the New Tripoli Formation and the underlying three members of the Martinsburg Formation (Lyttle and others, 1986; Lyttle and Epstein, 1987). Partly consolidated New Tripoli Formation was carried over Martinsburg rocks along the Game Preserve fault before the regional slaty cleavage formed. Subsequent deformation and regional low-grade metamorphism have also healed this fault. Cross sections accompanying the geologic map of the Slatedale quadrangle (Lyttle and others, 1986), immediately east of this quadrangle, suggest that the Weisenberg Church fault cuts the Game Preserve fault, but ambiguous field relations make this interpretation impossible to prove. The Weisenberg Church fault may have ridden along piggyback during formation of the Game Preserve fault, experiencing only minor amounts of renewed movement during the final stages of emplacement of the thrust sheet carrying the Shochary Ridge sequence and the structurally overlying Hamburg klippe thrust sheets. Because lithotectonic units 2 and 1 have roughly coincident eastern terminations, it is likely that they arrived as a single package during the last stages of their emplacement in the Martinsburg depositional basin.

The Game Preserve fault, as well as the rocks both above and below it (lithotectonic units 2 and 3, respectively), was folded into a footwall syncline beneath the Weisenberg Church fault. The regional slaty cleavage formed later during Alleghanian compression, which tightened this earlier formed syncline.

Faults of Alleghanian Age

Faults of varying types and displacement are interpreted to be present in the New Tripoli quadrangle. The location of the root zone or zones for these is not known. However, many faults of considerable displacement have been mapped as part of imbricate thrust systems in the Martinsburg Formation and older rocks in the Great Valley of Pennsylvania. These or similar faults may be the root faults. They include such faults as the Stockertown fault in the vicinity of Nazareth, Pa. (Davis and others, 1967; Aaron, 1975; Epstein, 1990), and the Portland fault along the Delaware River (Drake and others, 1969; Epstein, 1973).

Eckville Fault

The Eckville and Kistler Valley faults are moderately south-dipping thrust faults that roughly parallel one another and bracket rocks of the Shochary Ridge sequence on the north and south. During Alleghanian time, the Eckville and Kistler Valley faults probably formed as part of the same imbricate splay that formed the Sweet Arrow fault, which cuts younger rocks in the northern part of this quadrangle. Various structures are associated with these faults over a zone as much as several hundred feet (a hundred meters) wide. These characteristic structures include very tight folds having high amplitude-to-wavelength ratios and axes of varying azimuth and plunge, conjugate kink folds associated with late north-dipping fractures that commonly are filled with vein quartz, breccia zones that commonly contain vein quartz, and small- and large-scale folds that postdate the regional slaty cleavage.

The Eckville fault on the north side of the Shochary syncline was first recognized by Behre (1933, p. 345), when he noted that the slaty cleavage and bedding of the Pen Argyl Member of the Martinsburg Formation just north of the fault are rotated to a nearly recumbent position in the Hess quarry in the town of Lynnport. For most of its length, the Eckville fault probably coincides exactly with the northern limb of the earlier Game Preserve fault. Thus, in the New Tripoli quadrangle, the Eckville fault can be considered to be a reactivated part of the Game Preserve fault. To the east, the two faults diverge, and the Eckville fault appears to die out within the belt of the Bushkill Member of the Martinsburg of the Cementon quadrangle (fig. 1). It may continue farther to the east, but the lack of marker beds makes tracing it impossible. To the west, the Eckville fault appears to be on strike with a minor upthrust mapped by Behre (1933) and Stephens (1969) in Silurian rocks on Hawk Mountain in the New Ringgold quadrangle. However, a talus slope of Tuscarora Sandstone boulders covers the critical area and makes a definite correlation impossible. If these two faults are indeed the same, then the Eckville fault must cut the Blue Mountain décollement (a detachment surface separating lithotectonic units 4 and 3) and must not have experienced more than a few hundred feet (a few hundred meters) of movement. If, however, part or all of the movement along the Eckville fault was taken up along the Blue Mountain décollement, then movement on it could have been greater. The latter alternative does not seem very likely, because the Blue Mountain décollement dips moderately northward, whereas these younger faults dip moderately southward.

Along a 3-mi-long (5-km-long) section of the Eckville fault west of Lynnport in the New Tripoli quadrangle, the rocks in the hanging wall have been severely deformed as much as 3,000 ft (900 m) from the fault, whereas, at Hawk Mountain in the New Ringgold quadrangle to the west, the deformation and offset are confined to the area immediately around the fault. It is difficult to explain why this wide deformation zone is found along only a short section of the fault, but perhaps some of the deformation is Taconic in age and is associated with the Game Preserve fault.

Kistler Valley Fault

In the New Tripoli quadrangle, the Kistler Valley fault bounds the Shochary syncline on the south side. It appears to die out in the Cementon quadrangle to the east and is on strike with another minor upthrust cutting Silurian rocks to the west at Hawk Mountain. However, the Kistler Valley fault definitely truncates the Weisenberg Church fault and does not use it as a reactivation surface. The best exposure of the Kistler Valley fault is in a roadcut within the New Tripoli Formation, 0.4 mi (0.6 km) northeast of Weidasville, in the southeastern corner of the Slatedale quadrangle (Lash and others, 1984, p. 131–133). Numerous minor faults splay through this outcrop, dismembering and rotating bedding, cleavage, and folds. The roadcut also contains complex folds of slaty cleavage and strongly developed crenulation cleavage; vein quartz and minor calcite are concentrated in the hinges of folds in slaty cleavage as well as parallel to both slaty cleavage and crenulation cleavage planes. The orientation of some of the folds in slaty cleavage is highly variable and is, in some places, at a high angle to the strike of the thrust faults. Either the folds were rotated in the plane of the fault, or perhaps early movement along the fault was dominated by north or northwest thrusting and late movement was dominated by more east-west strike-slip faulting.

At several localities in the New Tripoli quadrangle, movement along the Kistler Valley fault has produced a shear fabric that has totally transposed both bedding and cleavage. In addition, several silicified zones are exposed in Kistler Valley where no other rocks crop out.

Décollements

Décollements within incompetent rocks in lithotectonic units 3–6 are interpreted to separate these units and to account for the differences in shortening between them (Epstein and Epstein, 1967, 1969; Wood and Bergin, 1970; Epstein, 1971, 1973, 1990, in press; Epstein and others, 1974). Movement of the overriding plates on the décollements was to the northwest, as interpreted from fold geometry and minor structures. Many of the fold axes do not cross lithotectonic unit boundaries. The intensity and complexity of structures increase westward in eastern Pennsylvania from the Delaware River toward the New Tripoli quadrangle.

Northwest shearing along the Blue Mountain décollement, which lies near the contact between the Martinsburg Formation and Tuscarora Sandstone, is indicated by bedding-plane slickensides, minor drag folds, gouge, and breccia at Lehigh Gap, 8 mi (13 km) northeast of the New

Tripoli quadrangle (Epstein and Epstein, 1969). The amount of displacement is uncertain, although Lyttle and Epstein (1987) offered the interpretation that the décollement is the roof of a thrust system. As discussed below, it is now believed to be nearly coincidental with the floor thrust of the Blue Mountain duplex. Most folds in the Martinsburg Formation are overturned. These folds have been mapped for many miles, but poor exposures make them difficult to trace. Wavelengths in these folds average about 1,200 ft (370 m). In contrast, the folds in the overlying lithotectonic unit 4 are larger and are cut by a series of faults in a duplex. Additionally, in the nearby Lehighton and Palmerton quadrangles, northwest translation along many bedding planes in lithotectonic unit 4 is indicated by numerous slickensides and wedges (Epstein and others, 1974). These features indicate that the entire sequence in the Tuscarora Sandstone and Bloomsburg Red Beds above the Blue Mountain décollement has been translated northwestward like a deck of sheared cards. Because this shear direction is rotated in all parts of folds, it is considered to be earlier than the folding in unit 4 and earlier than the Blue Mountain duplex.

The Stony Ridge décollement separates lithotectonic units 4 and 5. It is nowhere exposed in the quadrangle but is marked by a dramatic change in fold geometry (see map and sections, pl. 1) near the top of the Bloomsburg Red Beds.

An equally dramatic change in structural configuration between the rocks in lithotectonic units 5 and 6 takes place within the Marcellus Shale. This zone of extensively sheared rocks (the Weir Mountain décollement) is at least 300 ft (90 m) wide and is exposed near the Lehigh River 16 mi (26 km) southwest of the New Tripoli quadrangle (Epstein and others, 1974). Many exposures of the Marcellus are sheared and brecciated in the New Tripoli quadrangle, and several minor folds of varying orientation have been mapped in the zone.

Duplex in Blue Mountain

The rocks of lithotectonic unit 4 are cut by a series of faults that trend approximately 20° more northerly than the general strike of bedding. Similar faults were mapped in the Lehighton and Palmerton quadrangles to the northeast (Epstein and others, 1974), including the Lehigh Furnace Gap fault, which was traced for more than 5 mi (8 km). In the cross sections of the Lehighton and Palmerton quadrangles, the Lehigh Furnace Gap fault was interpreted to be a thrust on which the overriding beds moved down to the northwest and cut bedding at very high angles. However, because this fault and similar faults in the New Tripoli quadrangle lie at a very low angle to the structural grain, and because they terminate within the Martinsburg Formation just below the contact with the Tuscarora Sandstone, they are now reinterpreted to be imbricate faults that ramp up from a bedding thrust in the Martinsburg, and the entire fault system in the Tuscarora and Bloomsburg is now considered to be a duplex (pl. 1). These ramps join the floor thrust in the Martinsburg. The roof thrust is inferred to be in the Bloomsburg in the New Tripoli quadrangle, as depicted in the cross sections (pl. 1).

In 1990, a fault zone believed to be the floor thrust was exposed during construction of a new tunnel through Blue Mountain along the Northeast Extension of the Pennsylvania Turnpike. The exposed fault zone is about 5 mi (8 km) northeast of the New Tripoli quadrangle and is about 350 ft (110 m) south of the contact between the Martinsburg Formation and the Shawangunk Formation (the lateral equivalent of the Tuscarora) (Epstein and Buis, 1991). The zone is about 25 ft (7.6 m) wide and contains intensely sheared, slickensided, and rotated rocks and abundant quartz veins. If this zone is indeed the floor thrust of the duplex, it must extend for many miles to the northeast and southwest, parallel to the south slope of Blue Mountain. However, it has been seen only in the tunnel; elsewhere it is buried by thick colluvium and glacial deposits.

Some of the beds in the Tuscarora have been rotated more than 180° in response to the faulting and are highly sheared. Many of the ramps in the duplex, along with adjacent beds, change strike within short distances. They are therefore rotated about a vertical axis. Thus, they are not the youngest structural features in the quadrangle. The bounding faults of the duplex are also believed to be folded, as depicted in the cross sections (pl. 1).

Sweet Arrow Fault

The Sweet Arrow fault is a major structure that has been mapped for more than 80 mi (130 km) to the southwest of the New Tripoli quadrangle (for example, see Wood and Kehn, 1961; Wood and others, 1969; Wood, 1973, 1974a). It is a single fault or two faults that dip moderately to the southeast and flatten at depth. Displacement is as much as 3.5 mi (5.6 km) in places, as estimated on the basis of structural anomalies and truncated stratigraphic units. The Sweet Arrow fault was also mapped northeast of the New Tripoli quadrangle by Epstein and others (1974) on the basis of significant divergence of dips of lithotectonic units on either side of the exposed Marcellus Shale. The fault is exposed within a highly deformed zone that is at least 300 ft (90 m) wide along the Northeast Extension of the Pennsylvania Turnpike. The trace of the fault there is coincident with the Weir Mountain décollement. The Sweet Arrow fault, therefore, must pass through the New Tripoli quadrangle and lie in the Marcellus Shale under alluvium in the valley of Lizard Creek. However, evidence for significant displacement, similar to that found in the surrounding areas, is lacking in the New Tripoli quadrangle, and the fault is shown on the cross sections (pl. 1) as having only minor displacement.

Timing of Deformation

The sequence of deformation of rocks in the New Tripoli quadrangle and the surrounding area is complex and has been the subject of much discussion. Many outcrops provide evidence for overlapping periods of cleavage development, folding, and faulting. The following summarizes our interpretation to date.

Most of the structures in the New Tripoli quadrangle are of Alleghanian (late Paleozoic) age, although the Ordovician rocks contain elements of Taconic deformation. Taconic orogenesis also produced the coarse Silurian clastic wedge that rests unconformably on the Martinsburg. Clastic rocks of the Catskill Formation and younger units indicate that the Devonian Acadian orogeny produced a mountainous area to the southeast, which supplied the sediments. However, the rocks in the New Tripoli quadrangle were not deformed at that time.

Taconic deformation was characterized by emplacement of the Windsor Township Formation over the Shochary Ridge sequence in the lower thrust sheet of the Hamburg klippe along the Weisenberg Church fault during the Middle Ordovician. The deep Shochary syncline initially formed as a footwall syncline at this time. A scaly cleavage also formed while the sediments were semiconsolidated. Further thrusting of the klippe along a lower thrust fault, the Game Preserve fault, carried rocks of both the Hamburg klippe and Shochary Ridge sequence, along with the Weisenberg Church fault, onto the Martinsburg sediments. The Martinsburg was folded only gently during this period. During later Alleghanian deformation, the regional cleavage was superimposed on these rocks, the faults were healed, and the Shochary syncline was tightened coaxially along the Taconic trend.

The gentle Taconic folding in the Martinsburg has been documented along the entire Taconic unconformity northeastward for 100 mi (160 km) to near Ellenville, N.Y., by Epstein and Lyttle (1987), who noted that the angular difference in bedding between the Martinsburg and the overlying Tuscarora Sandstone or Shawangunk Formation does not exceed 15°. The northern limit of intense Taconic deformation in the New Tripoli quadrangle lies along the Alleghanian Eckville fault, where it is coincident with the Taconic Game Preserve fault. A similar limit of Taconic deformation was noted in southeastern New York by Epstein and Lyttle (1987), who believed that it was the same as "Ruedemann's Line," which extends northward under the Catskill Plateau and reappears west of Albany, N.Y.

The major folds and associated cleavage in the New Tripoli quadrangle extend to the north and deform rocks as young as Pennsylvanian, indicating that they are Alleghanian in age. The Alleghanian folds can be traced down through the Taconic unconformity into the underlying Martinsburg Formation. The regional slaty cleavage above and below the unconformity is axial planar to these folds and, thus, is Alleghanian in age. The analysis of minor structures presented in the discussion of lithotectonic units shows that these Alleghanian structures were superimposed on the gentle Taconic folds discussed above.

Alleghanian deformation involved a complex sequence of overlapping events. An early period of northwest shearing is indicated in the nearby Lehigh Gap area by an early cleavage and bedding slickensides with accompanying tectonic wedges. These structures were noted in the Martinsburg and younger rocks by Epstein and Epstein (1969) and Epstein and others (1974), although their significance was not entirely understood. Recent work by M.B. Gray (University of Rochester, oral commun., 1989), who is doing a regional tectonic analysis of the area from Blue Mountain northward to the anthracite basin, has shown that these structures are of regional importance.

The early cleavage, bedding slickensides, and wedges were later rotated during formation of the major folds seen in post-Silurian rocks. The Shochary syncline was probably tightened at this time, and the major regional cleavage (fig. 2 on pl. 1) developed in all rocks of the quadrangle. The folding was continuous—overturned limbs of some of the folds were rotated past the horizontal. There were periods of overlapping cleavage formation, culminating in the formation of a late crenulation cleavage in some of the rocks. The lithotectonic units deformed somewhat independently of each other, and bounding décollements formed to take up the differential shortening. Faults, including the duplex in Blue Mountain, are unimportant internal structures in the lithotectonic units east of the Lehigh River but become abundant in the area to the west, including the New Tripoli quadrangle. These faults appear to be both partly synchronous with and slightly later than the folding, because they cut the folds and are themselves slightly rotated. The latest structures in the quadrangle are the Kistler Valley, Eckville, and Sweet Arrow faults, which appear to cut all previous structures, although the Eckville fault coincided with the Taconic Game Preserve fault for some of its length.

Both Alleghanian and Taconic structures probably become progressively more intense to the southeast. Separating the effects of the two orogenies is a major problem in the structural analysis of eastern Pennsylvania.

REFERENCES CITED

Aaron, J.M., 1975, Geology of the Nazareth quadrangle, Northampton County, Pennsylvania: U.S. Geological Survey Open-File Report 75–92, 353 p.

Alterman, I.B., 1972, Structure and history of the Taconic allochthon and surrounding autochthon, east-central Pennsylvania: New York, Columbia University, Ph.D. thesis, 287 p.

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

Behre, C.H., Jr., 1927, Slate in Northampton County, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Bulletin M9, 308 p.

———1933, Slate in Pennsylvania: Pennsylvania Geological Survey, 4th ser., Bulletin M16, 400 p.

Berg, T.M., and others, 1980, Geologic map of Pennsylvania: Harrisburg, Pa., Pennsylvania Geological Survey, 4th ser., scale 1:250,000.

Braun, D.D., 1988, Glacial geology of the anthracite and North Branch Susquehanna lowland regions, *in* Inners, J.D., ed., Bedrock and glacial geology of the North Branch Susquehanna lowland and the eastern middle anthracite field, northeastern Pennsylvania—Guidebook for the 53rd Annual Field Conference of Pennsylvania Geologists: Hazelton, Pa., Pennsylvania Geological Survey, p. 3–25.

Bretsky, P.W., Flessa, K.W., and Bretsky, S.S., 1969, Brachiopod ecology in the Ordovician of eastern Pennsylvania: Journal of Paleontology, v. 43, no. 2, p. 312–321.

Davis, R.E., Drake, A.A., Jr., and Epstein, J.B., 1967, Geologic map of the Bangor quadrangle, Pennsylvania-New Jersey: U.S. Geological Survey Geologic Quadrangle Map GQ–665, scale 1:24,000.

Drake, A.A., Jr., 1987, Geologic map of the Topton quadrangle, Pennsylvania: U.S. Geological Survey Geologic Quadrangle Map GQ–1609, scale 1:24,000.

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. Geological Survey Bulletin 1244–H, 16 p.

Drake, A.A., Jr., Epstein, J.B., and Aaron, J.M., 1969, Geologic map and sections of parts of the Portland and Belvidere quadrangles, New Jersey-Pennsylvania: U.S. Geological Survey Miscellaneous Geologic Investigations Map I–552, scale 1:24,000.

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. Geological Survey Bulletin 1243, 74 p.

Epstein, J.B., 1971, Geology of the Stroudsburg quadrangle and adjacent areas, Pennsylvania-New Jersey: U.S. Geological Survey Open-File Report, 339 p.

———1973, Geologic map of the Stroudsburg quadrangle, Pennsylvania-New Jersey: U.S. Geological Survey Geologic Quadrangle Map GQ–1047, scale 1:24,000.

———1984, Onesquethawan stratigraphy (Lower and Middle Devonian) of northeastern Pennsylvania: U.S. Geological Survey Professional Paper 1337, 35 p.

———1986, The Valley and Ridge province of eastern Pennsylvania—Stratigraphic and sedimentologic contributions and problems: Geological Journal, v. 21, p. 282–306.

———1987, Regional relations of Upper Silurian-Lower Devonian rocks, Bossardsville, eastern Pennsylvania, *in* Stratigraphic notes, 1985–86: U.S. Geological Survey Bulletin 1775–A, p. A17–A26.

———1990, Geologic map of the Wind Gap quadrangle, Pennsylvania: U.S. Geological Survey Geologic Quadrangle Map GQ–1645, scale 1:24,000.

———in press, Geologic map of the Saylorsburg quadrangle, Pennsylvania: U.S. Geological Survey Geologic Quadrangle Map GQ–1638, scale 1:24,000.

Epstein, J.B., and Buis, P.F., 1991, The second Lehigh Tunnel; Geology and the new Austrian tunneling method: Pennsylvania Geology, v. 22, no. 1, p. 2–9.

Epstein, J.B., and Epstein, A.G., 1967, Geology in the region of the Delaware to Lehigh Water Gaps—Guidebook for the 32nd Annual Field Conference of Pennsylvania Geologists: Harrisburg, Pa., Pennsylvania Bureau of Topographic and Geologic Survey, 89 p.

———1969, Geology of the Valley and Ridge province between Delaware Water Gap and Lehigh Gap, Pennsylvania, *in* Subitzky, Seymour, ed., Geology of selected areas in New Jersey and eastern Pennsylvania and guidebook of excursions: Brunswick, N.J., Rutgers University Press, p. 132–205.

Epstein, J.B., and Lyttle, P.T., 1986, Chronology of deformation along the Taconic unconformity from eastern Pennsylvania to southern New York [abs.]: Geological Society of America Abstracts with Programs, v. 18, no. 1, p. 15.

———1987, Structure and stratigraphy above, below, and within the Taconic unconformity, southeastern New York, *in* Waines, R.H., ed., New York State Geological Association, 59th annual meeting, Kingston, N.Y., November 6–8, 1987, Field Trip Guidebook: New Paltz, N.Y., State University of New York, College at New Paltz, p. C1–C78.

Epstein, J.B., Sevon, W.D., and Glaeser, J.D., 1974, Geology and mineral resources of the Lehighton and Palmerton quadrangles, Carbon and Northampton Counties, Pennsylvania: Pennsylvania Geological Survey Atlas 195 c and d, 460 p.

Finney, S.C., 1982, Ordovician graptolite zonation, *in* Ross, R.J., Jr., and Bergstrom, Stig, eds., The Ordovician System in the United States, correlation chart and explanatory notes: International Subcommission on Ordovician Stratigraphy Publication No. 12, p. 14–23.

———1985, A re-evaluation of the upper Middle Ordovician graptolite zonation of North America [abs.]: Geological Society of America Abstracts with Programs, v. 17, no. 1, p. 19.

Glaeser, J.D., 1967, Bedding-plane slips, wedge faulting and facies changes in the Parryville syncline, Carbon County, Pennsylvania: Pennsylvania Academy of Sciences Proceedings, v. 15, p. 95–98.

Goddard, E.N., and others, 1948, Rock-color chart: Washington, D.C., National Research Council, 6 p. (Republished by Geological Society of America, 1951.)

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

Lash, G.G., 1978, The structure and stratigraphy of the Pen Argyl Member of the Martinsburg Formation in Lehigh and Berks Counties, Pennsylvania: U.S. Geological Survey Open-File Report 78–391, 225 p.

———1985, Geologic map of the Kutztown quadrangle, Berks and Lehigh Counties, Pennsylvania: U.S. Geological Survey Geologic Quadrangle Map GQ–1577, scale 1:24,000.

———1987, Geologic map of the Hamburg quadrangle, Pennsylvania: U.S. Geological Survey Geologic Quadrangle Map GQ–1637, scale 1:24,000.

Lash, G.G., and Drake, A.A., Jr., 1984, The Richmond and Greenwich slices of the Hamburg klippe in eastern Pennsylvania—Stratigraphy, structure, and plate tectonic implications: U.S. Geological Survey Professional Paper 1312, 40 p.

Lash, G.G., Lyttle, P.T., and Epstein, J.B., 1984, Geology of an accreted terrane; the eastern Hamburg klippe and surrounding rocks, eastern Pennsylvania—Guidebook for the 49th Annual Field Conference of Pennsylvania Geologists, Oct. 5–6, 1984: Harrisburg, Pa., Pennsylvania Geological Survey, 151 p., scale 1:125,000.

Lyttle, P.T., and Drake, A.A., Jr., 1979, Discussion—Regional implications of the stratigraphy and structure of Shochary Ridge, Berks and Lehigh Counties, Pennsylvania: American Journal of Science, v. 279, p. 721–728.

Lyttle, P.T., and Epstein, J.B., 1987, Geologic map of the Newark 1°×2° quadrangle, New Jersey, Pennsylvania, and New York: U.S. Geological Survey Miscellaneous Investigation Series Map I–1715, scale 1:250,000.

Lyttle, P.T., Lash, G.G., and Epstein, J.B., 1986, Bedrock geology of the Slatedale quadrangle, Pennsylvania: U.S. Geological Survey Geologic Quadrangle Map GQ–1598, scale 1:24,000.

McBride, E.F., 1962, Flysch and associated beds of the Martinsburg Formation (Ordovician), central Appalachians: Journal of Sedimentary Geology, v. 32, p. 39–91.

Parris, D.C., and Cruikshank, K.M., in press, New biostratigraphic information on the Ordovician Martinsburg Formation of New Jersey and adjacent areas: New Jersey State Museum Investigations.

Parris, D.C., Cruikshank, K.M., and Rich, J.L., 1987, New biostratigraphic information on the Ordovician Martinsburg Formation of New Jersey and adjacent areas, *in* Gallagher, W.B., ed., Paleontology and stratigraphy of the lower Paleozoic deposits of the Delaware Water Gap area; Field guide and proceedings of the 4th Annual Meeting of the Geological Association of New Jersey, Oct. 16–18, 1987: Geological Association of New Jersey Guidebook No. 4, [39] p.

Potter, Noel, Jr., and Moss, J.H., 1968, Origin of the Blue Rocks block field and adjacent deposits, Berks County, Pennsylvania: Geological Society of America Bulletin, v. 79, p. 255–262.

Riva, John, 1969, Middle and Upper Ordovician graptolite faunas of St. Lawrence lowlands of Quebec and of Anticosti Island, *in* North Atlantic geology and continental drift: American Association of Petroleum Geologists Memoir 12, p. 513–556.

———1974, A revision of some Ordovician graptolites of eastern North America: Paleontology, v. 17, p. 1–40.

Ross, R.J., Jr., and others, 1982, The Ordovician System in the United States: International Union of Geological Sciences Publication No. 12, 73 p.

Stephens, G.C., 1969, Stratigraphy and structure of a portion of the basal Silurian clastics in eastern Pennsylvania: Washington, D.C., George Washington University, M.S. thesis, 50 p.

Stose, G.W., 1930, Unconformity at the base of the Silurian in southeastern Pennsylvania: Geological Society of America Bulletin, v. 41, p. 629–658.

Swartz, C.K., and Swartz, F.M., 1941, Early Devonian and Late Silurian formations of southeastern Pennsylvania: Geological Society of America Bulletin, v. 52, p. 1129–1191.

Ulrich, E.O., 1911, Revision of the Paleozoic systems: Geological Society of America Bulletin, v. 22, p. 281–680.

Walters, Martin, Lesperance, P.J., and Hubert, Claude, 1982, The biostratigraphy of the Nicolet River Formation in Quebec and intra-North American correlations in Middle and Upper Ordovician strata: Canadian Journal of Earth Sciences, v. 19, no. 3, p. 571–588.

Willard, Bradford, 1936, The Onondaga Formation in Pennsylvania: Journal of Geology, v. 44, p. 578–603.

———1943, Ordovician clastic sedimentary rocks in Pennsylvania: Geological Society of America Bulletin, v. 54, p. 1067–1122.

Willard, Bradford, and Cleaves, A.B., 1939, Ordovician-Silurian relations in Pennsylvania: Geological Society of America Bulletin, v. 50, p. 1165–1198.

Willard, Bradford, Swartz, F.M., and Cleaves, A.B., 1939, The Devonian of Pennsylvania: Pennsylvania Geological Survey, 4th ser., General Geology Report 19, 450 p.

Wood, G.H., Jr., 1973, Geologic map of the Orwigsburg quadrangle, Schuylkill County, Pennsylvania: U.S. Geological Survey Geologic Quadrangle Map GQ–1029, scale 1:24,000.

———1974a, Geologic map of the Nesquehoning quadrangle, Carbon and Schuylkill Counties, Pennsylvania: U.S. Geological Survey Geologic Quadrangle Map GQ–1132, scale 1:24,000.

———1974b, Geologic map of the Tamaqua quadrangle, Carbon and Schuylkill Counties, Pennsylvania: U.S. Geological Survey Geologic Quadrangle Map GQ–1133, scale 1:24,000.

Wood, G.H., Jr., and Bergin, M.J., 1970, Structural controls of the Anthracite region, Pennsylvania, *in* Fisher, G.W., Pettijohn, F.J., Reed, J.C., and Weaver, K.N., eds., Studies of Appalachian geology—Central and southern: New York, Wiley, p. 147–160.

Wood, G.H., Jr., and Kehn, T.M., 1961, Sweet Arrow fault, east-central Pennsylvania: American Association of Petroleum Geologists Bulletin, v. 45, p. 256–263.

Wood, G.H., Jr., Trexler, J.P., and Kehn, T.M., 1969, Geology of the west-central part of the Southern Anthracite field and adjoining areas, Pennsylvania: U.S. Geological Survey Professional Paper 602, 150 p.

Wright, T.O., and Stephens, George, 1978, Regional implications of the stratigraphy and structure of Shochary Ridge, Berks and Lehigh Counties, Pennsylvania: American Journal of Science, v. 278, p. 1000–1017.

Wright, T.O., Stephens, George, and Wright, E.K., 1979, A revised stratigraphy of the Martinsburg Formation of eastern Pennsylvania and paleogeographic consequences: American Journal of Science, v. 279, p. 1176–1186.