# The Shawangunk Formation (Upper Ordovician(?) to Middle Silurian) in Eastern Pennsylvania

GEOLOGICAL SURVEY PROFESSIONAL PAPER 744

*Work done in cooperation with the Pennsylvania Department of Environmental Resources, Bureau of Topographic and Geological Survey*

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*By* JACK B. EPSTEIN *and* ANITA G. EPSTEIN

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*Statigraphy, petrography, sedimentology, and a discussion of the age of a lower Paleozoic fluvial and transitional marine clastic sequence in eastern Pennsylvania*

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By JACK B. EPSTEIN and ANITA G. EPSTEIN


### ABSTRACT

The Shawangunk Formation of Early and Middle Silurian age, and possibly Late Ordovician age, in eastern Pennsylvania and northwestern New Jersey forms a thick clastic wedge of sediments derived from sourcelands to the southeast uplifted during the Taconic orogeny. The formation is divided into four newly defined members, from bottom to top: Weiders Member (coarse conglomerate and quartzose sandstone), Minsi Member (quartzose conglomeratic sandstone and minor argillite), Lizard Creek Member (complex sequence of quartzose sandstone, siltstone, shale, and a few red beds, with sparse fauna), and Tammany Member (quartzose conglomeratic sandstone and minor argillite). The Weiders Member pinches out to the east near Smith Gap. The Tammany Member cannot be conveniently mapped west of Smith Gap because of interfingering with and replacement by beds of the Lizard Creek Member. The contact of the Shawangunk with the underlying Martinsburg Formation is an angular unconformity. The boundary between the Shawangunk and overlying Bloomsburg Red Beds is irregular and transitional through about 130–700 feet of red, green, and gray rocks. Sedimentary features in the Shawangunk indicate that the sediments were deposited by streams and in a complex transitional marine-continental environment, including tidal flats, barrier bars, estuaries, and lagoons.


## INTRODUCTION

The Shawangunk Formation of Early and Middle Silurian, and possibly Late Ordovician, age has been mapped for 40 miles between Delaware Water Gap, N.J., and Bake Oven Knob, Pa. (fig. 1). It forms a prominent ridge known as Kittatinny Mountain in the northeastern part of the area and as Blue Mountain in the southwestern part. The Shawangunk is folded, and in many places the rocks are overturned to the southeast. The structure is more complex in the southwest part of the report area; there the Shawangunk is faulted and in places doubly overturned to the northwest. Several wind and water gaps transect the ridge; the formation is well exposed only in these gaps. Between gaps, good exposures are generally lacking, but some lithologic information can be obtained by tracing float; thicknesses can be determined by constructing cross sections. Figure 2 shows a stratigraphic section of the Shawangunk compiled from sections measured at Delaware Water Gap, Wind Gap, Lehigh Gap, and Bake Oven Knob and from mapping between sections. Maps of some areas are already published—Portland quadrangle (Drake and others, 1969) and Stroudsburg quadrangle (Epstein, 1971, 1972). Some details from other quadrangles are given in Epstein and Epstein (1967, 1969). Table 1 gives chemical and semiquantitative spectrographic analyses of rocks in the Shawangunk Formation.

The Shawangunk Formation consists predominantly of quartzose sandstone (quartzite), quartz-, chert-, shale-, and quartzite-pebble conglomerate, siltstone, and shale, as well as a few beds of sandstone and siltstone containing nodules of collophane, siderite, and chlorite. Red beds are not uncommon in the western part of the report area, and dolomite occurs at Delaware Water Gap. Fossils are rare. Four distinct lithic assemblages have been mapped. These are herein defined as members and include, in general ascending order, the Weiders, Minsi, Lizard Creek, and Tammany Members (fig. 2).

We wish to thank Gary E. Redline for assisting in measurement of stratigraphic sections. Wallace deWitt, Jr., U.S. Geological Survey, and W. D. Sevon and D. M. Hoskins, Pennsylvania Geological Survey, made many helpful suggestions on the original manuscript.

## SHAWANGUNK FORMATION

The Shawangunk Grit was named by Mather (1840) for sandstones and conglomerates in southeastern New York that are part of the same outcrop belt as rocks in eastern Pennsylvania called Levant by Rogers (1858) and Oneida and Medina by White (1882). Grabau (1909) first used the term Shawangunk Conglomerate for these rocks in eastern Pennsylvania. The lithic modifier was changed from conglomerate to formation in the Delaware Water Gap area by Drake, Epstein, and Aaron (1969). A history of the early nomenclature is given by Schuchert (1916) and Swartz and Swartz (1931).

Swartz and Swartz (1931) traced the Tuscarora Sandstone and Clinton Formation from central Pennsylvania eastward to Delaware Water Gap; there,

TABLE 1.—*Chemical and semiquantitative spectrographic analyses of rocks from the Shawangunk Formation*

[Rapid-rock analyses by P. Elmore, G. Chloe, J. Kelsey, S. Botts, H. Smith, J. Glenn, and L. Artis, U.S. Geological Survey. Semiquantitative spectrographic analyses by J. L. Harris, U.S. Geological Survey. N, not detected or at limit of detection; L, detected but below limit of determination. The following elements were looked for and not detected or were found in amounts at the limit of detection: As, Au, Bi, Cd, Eu, Ge, Hf, In, Li, Nd, Pd, Pr, Pt, Re, Sb, Sm, Sn, Te, Th, Tl, U, W. The following elements were not looked for in samples 1–5 and were looked for but not detected in sample 6: Dy, Er, Gd, Ho, Lu, Tb, Tm]

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| | | | **Chemical analysis** [Weight percent] | | | |
| $SiO_2$ | 76.6 | 67.3 | 92.2 | 72.3 | 82.9 | 67.7 |
| $Al_2O_3$ | 11.0 | 18.3 | 2.5 | 12.3 | 5.3 | 4.8 |
| $Fe_2O_3$ | .68 | 1.6 | 1.0 | 5.3 | 2.2 | 6.6 |
| FeO | 2.2 | .76 | 1.1 | 1.3 | 3.5 | 2.5 |
| MgO | 1.7 | 1.2 | .37 | 1.0 | 1.1 | 1.0 |
| CaO | .24 | .32 | .13 | .14 | .81 | 5.5 |
| $Na_2O$ | .03 | .18 | .00 | .00 | .12 | .02 |
| $K_2O$ | 3.2 | 5.7 | .26 | 3.5 | .98 | 1.3 |
| $H_2O-$ | .24 | .38 | .09 | .29 | .11 | .65 |
| $H_2O+$ | 2.3 | 2.5 | 1.2 | 2.5 | 1.6 | 2.2 |
| $TiO_2$ | .75 | 1.1 | .28 | 1.1 | .45 | .43 |
| $P_2O_5$ | .11 | .04 | .00 | .06 | .27 | 4.1 |
| MnO | .04 | .02 | .04 | .03 | .02 | .81 |
| $CO_2$ | <.05 | .10 | <.05 | <.05 | .05 | 1.7 |
| Total | 99.1 | 99.5 | 99.2 | 99.8 | 99.4 | 99.3 |
| | | | **Spectrographic analysis** [Parts per million] | | | |
| Ag | N | N | N | N | N | 5 |
| B | 70 | 100 | L | 50 | 30 | L |
| Ba | 500 | 500 | 50 | 200 | 150 | 200 |
| Be | 2 | 5 | N | 1 | N | 2 |
| Co | 7 | 7 | N | 15 | 15 | 15 |
| Cr | 50 | 70 | 5 | 70 | 30 | 50 |
| Cu | 30 | 15 | 10 | 3 | 7 | 50 |
| La | 70 | 100 | N | 70 | 70 | 50 |
| Mo | N | N | N | N | N | 5 |
| Nb | 20 | 20 | 7 | 20 | 7 | 7 |
| Ni | 30 | L | L | 30 | 30 | L |
| Pb | N | N | N | 2 | N | 3 |
| Sr | 10 | 30 | 3 | 50 | 10 | 200 |
| V | 70 | 100 | 20 | 70 | 30 | 50 |
| Y | 15 | 50 | 10 | 50 | 20 | 100 |
| Zr | 200 | 500 | 100 | 700 | 700 | 500 |
| Ce | 300 | 500 | 200 | 500 | 500 | 500 |
| Ga | 7 | 15 | 2 | 10 | 7 | 10 |
| Yb | 1.5 | 5 | 1 | 5 | 2 | 10 |

1. Lithic graywacke, Weiders Member of the Shawangunk Formation, 5 ft above base of the Shawangunk Formation (measured section 3, unit 3), abandoned Lehigh and New England Railroad grade, Lehigh Gap, Northampton County, Pa. Figure 4 is photomicrograph of sample.
2. Dark-gray siltstone, Minsi Member of the Shawangunk Formation, 102 ft above base of the Shawangunk Formation (measured section 1, unit 11), roadcut along U.S. Interstate 80, Delaware Water Gap, Warren County, N.J.
3. Orthoquartzite, Lizard Creek Member of the Shawangunk Formation, 860 ft above the base of the Shawangunk Formation (measured section 3, unit 43), abandoned Lehigh and New England Railroad grade, Lehigh Gap, Carbon County, Pa.
4. Very fine grained hematitic graywacke, Lizard Creek Member of the Shawangunk Formation, 1,000 ft above the base of the Shawangunk Formation (measured section 3, unit 54), abandoned Lehigh and New England Railroad grade, Lehigh Gap, Carbon County, Pa.
5. Fine-grained phosphatic siliceous protoquartzite, Lizard Creek Member of the Shawangunk Formation, 508 ft above the base of the Shawangunk Formation (measured section 1, unit 46), roadcut along U.S. Interstate 80, Delaware Water Gap, Warren County, N.J. Figure 11 is photograph of outcrop.
6. Calcareous and chloritic sandstone and siltstone with nodules of collophane and siderite, Lizard Creek Member of the Shawangunk Formation, 1,280 ft above the base of the Shawangunk Formation (measured section 3, unit 69), roadcut along Pa. Route 45, Carbon County, Pa. Figure 18A shows sample.

according to them, these units lose their identity and merge into the Shawangunk Formation. Detailed mapping by Epstein and Epstein (1967, 1969), Drake, Epstein, and Aaron (1969), and Epstein (1972 and unpub. data), has shown that the Clinton Formation of Swartz and Swartz (1931) (Lizard Creek Member of the Shawangunk Formation of this report) can be traced from the Lehigh Gap area eastward to Delaware Water Gap and that there it forms a tongue in the Shawangunk (fig. 2). Similarly, the Tuscarora of Swartz and Swartz (1931) (Weiders and Minsi Members of the Shawangunk Formation of this report) can be traced beneath the Clinton. Because the name Shawangunk has priority over the Tuscarora (named by Darton and Taff in 1896) and Clinton (named by Conrad, 1842), the Shawangunk Formation is used in the area of this report for rocks above the Martinsburg Formation and below the Bloomsburg Red Beds. The names Clinton and Tuscarora are abandoned in the area of this report for reasons given in the discussion of the Lizard Creek Member.

The Shawangunk is 1,632 feet thick at Lehigh Gap. In the Delaware Water Gap, about 1,390 feet was measured along U.S. Interstate 80 (Epstein, 1971). However, because of the extremely irregular contact with the overlying Bloomsburg Red Beds, the thickness can be as great as 2,100 feet. This may account for the wide variation of reported thicknesses at Delaware Water Gap: Chance (1882), 1,565 feet; Grabau (1913), 1,900 feet; Swartz and Swartz (1931), 1,823 feet; Willard (1938), 2,000 feet.

#### WEIDERS MEMBER

The type section of the Weiders Member is along the abandoned Lehigh and New England Railroad in Lehigh Gap (fig. 1), Palmerton quadrangle, Northampton County, Pa. The member is named for Weiders Crossing about 1,000 feet south of the gap.

The Weiders Member consists predominantly of crossbedded and planar-bedded conglomerate and quartzite (fig. 3). Large quartz pebbles distinguish the Weiders from the overlying Minsi Member. The contact between the two members is the top of the highest bed containing pebbles more than 2 inches long, a characteristic that is readily mapped in the report area.

The Weiders Member is well exposed at the type section in Lehigh Gap and at Bake Oven Knob and Little Gap. Good exposures are found at many places between these localities where the member forms cliffs and steep dip slopes on the south side of Blue Mountain. In the southwestern part of the Lehighton quadrangle, the Weiders, repeated by faulting, holds up narrow ridges as much as 50 feet high on top of Blue Mountain.

The Weiders Member has been mapped for a distance of 19 miles, and float of the member has been found along U.S. Route 309, 4 miles southwest of Bake Oven Knob. Its extent farther southwest is unknown. A cursory examination of equivalent beds at Schuylkill Gap, 21 miles southwest of Bake Oven

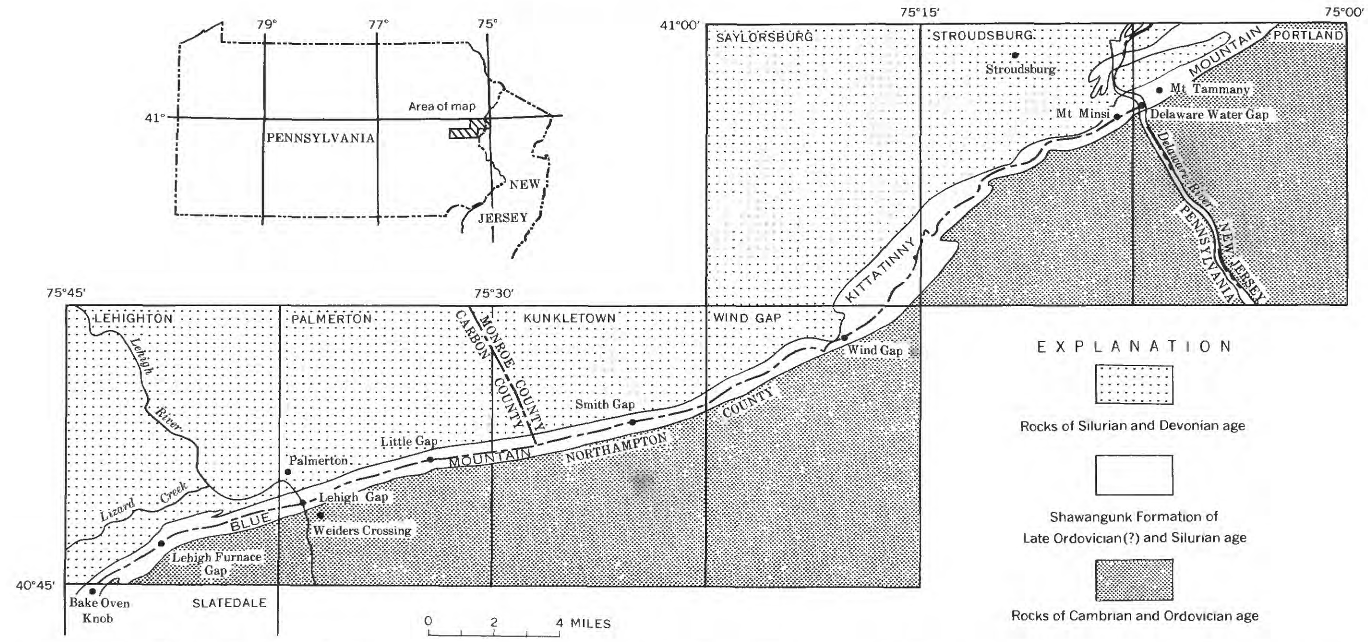


**FIGURE 1.**—Generalized geologic map showing outcrop belt of the Shawangunk Formation in eastern Pennsylvania and northwestern New Jersey and 7½-minute quadrangle coverage.

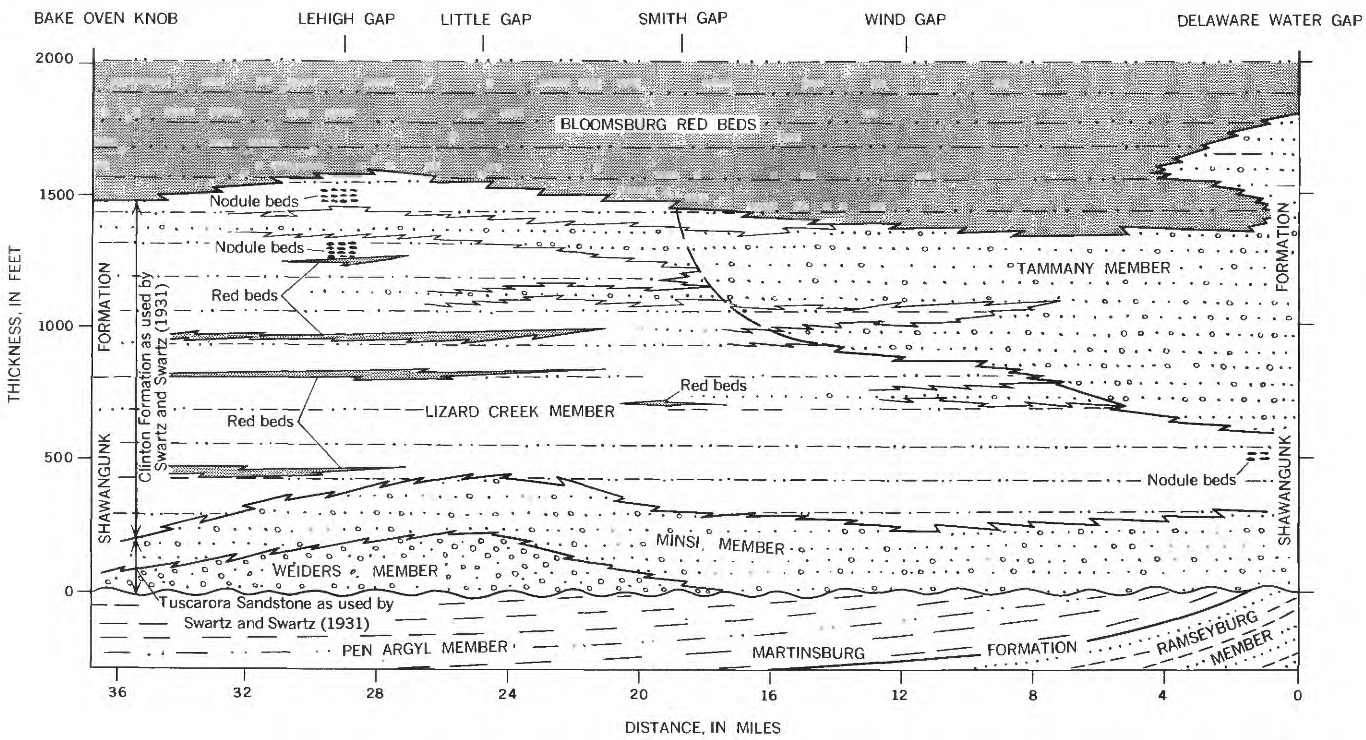


**FIGURE 2.**—Stratigraphic section of the Shawangunk Formation between Delaware Water Gap, N.J., and Bake Oven Knob, Pa. (modified from Epstein and Epstein, 1967, fig. 4).

Knob, indicates that pebbles at that locality are less than 2 inches long. Consequently, the Weiders does not extend to the Schuylkill.

Conglomerates in the Weiders are generally massive and planar bedded; beds are as much as 3 feet thick. The pebbles and cobbles are subrounded to rounded and consist of quartz, chert, and sandstone. At Lehigh Gap they are as much as 3 inches long;

FIGURE 3.—Interbedded planar-bedded conglomerate and crossbedded medium- to very coarse grained quartzite in the Weiders Member of the Shawangunk Formation, Lehigh Gap. Rounded to subangular white quartz and dark-gray chert pebbles and cobbles are as much as 3 inches long.

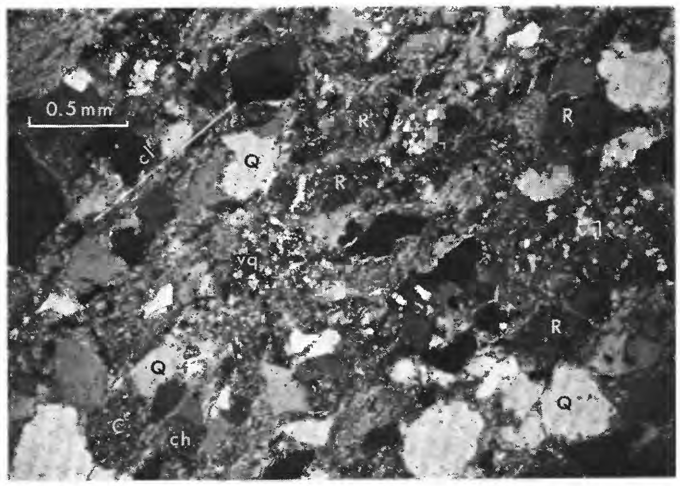


FIGURE 4.—Photomicrograph (crossed polarizers) of lithic graywacke, Weiders Member of Shawangunk Formation, 5 feet above base of Shawangunk at abandoned Lehigh and New England Railroad grade, Lehigh Gap, Northampton County, Pa., measured section 3, unit 3. The framework grains make up 72 percent of the rock and are quartz (Q), vein quartz (vq), chert (C), and quartzite (not seen in photograph) 54 percent; and rock fragments (R, mostly shale), 18 percent. The remaining 28 percent of the rock consists of a fine-grained matrix of muscovite, quartz, and biotite. Very light green spherulitic chlorite (ch) fills a few pores. Some rock fragments have indistinct borders (at X) and are partly drawn out parallel to rock cleavage (cl). Chemical analysis of this sample is given in table 1, sample 1.

they are largest at Lehigh Furnace Gap (fig. 1) where quartz cobbles are as much as 6.5 inches long. At several other localities, 4-inch cobbles are not uncommon. In general, the rock breaks through the pebbles, except for the basal 2.3 feet (exposed only at Lehigh Gap) where the rock is leached of cement (weathered to moderate brown (5*YR* 4/4)[1] to dark-yellowish orange (10*YR* 6/6)), and the pebbles are easily removed from the matrix. Flattened mud galls as much as 8 inches long are scattered throughout the member. In general, vein quartz is the most abundant pebble type, especially in the upper part of the unit where it makes up more than 70 percent of the pebbles and cobbles greater than ¾ inch in length. Near the bottom of the Weiders, siliceous sandstone pebbles are abundant and make up more than 70 percent of the pebbles in the basal bed. Chert pebbles generally do not exceed 2 inches in length and make up about 20–50 percent of the pebbles throughout the Weiders. Mud galls and shale chips do not constitute more than 10 percent of the larger pebbles, but argillite rock fragments less than half an inch long may account for as much as 15 percent of the pebbles of some beds. Polymictic conglomerates are most common in basal beds.

The matrix of the conglomerates is similar to the interbedded quartzites. The quartzites are medium-dark-gray (*N*4) to medium-light-gray (*N*6) and greenish-gray (5*GY* 6/1) medium- to very coarse grained conglomeratic sandstones in beds 1 inch to 6 feet thick. The quartzites are evenly to unevenly bedded; many beds are planar. Planar and trough crossbedding are common. Lentils, no more than a few feet long, are common. In a few places ripple marks have wavelengths of as much as 2 feet. Limonite and hematite specks and sand-sized grains of grayish-orange (10*YR* 7/4)-weathering shale are scattered throughout most beds. In thin section, the quartzites contain 47 to about 85 percent quartz, chert, and sandstone grains. Quartz grain contacts are generally sutured, although silica overgrowths are common. Quartz generally occurs as single grains with slight to strong undulose extinction. Bubble trains and vermicular chlorite inclusions are very common. The matrix of the quartzites is composed predominantly of quartz and muscovite with a small amount of chlorite. It forms about 9–37 per-

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

cent of most rocks. Feldspar is rare. The quartzites in the Weiders Member are, therefore, lithic graywackes, siliceous subgraywackes, and siliceous protoquartzites; the less mature varieties are more abundant toward the base of the member (fig. 4). Orthoquartzites containing more than 97 percent quartz are rare.

Heavy minerals in the quartzites are chiefly muscovite and rounded to euhedral zircon and tourmaline. Biotite is rare, and only one grain of hornblende was seen. Slightly pleochroic very light green spherulitic chlorite fills pore spaces in several samples.

Greenish-gray (5*GY* 6/1) argillite (indurated claystone and siltstone) beds occur but nowhere abundantly. They are lenticular and generally from 0.5 to 7 inches thick, although a 2-foot-thick bed is present at Lehigh Gap.

Basal beds of the Weiders Member rest abruptly and with angular discordance on shale and graywacke of the Pen Argyl Member of the Martinsburg Formation. Fault gouge, breccia, and slickensides indicate that the interval at and just below the contact is also a zone of detachment (Epstein and Epstein, 1969).

The contact between the Weiders and overlying Minsi Member is the top of the highest bed containing pebbles more than 2 inches long. Defining the top of the member in this way, the Weiders is 189 feet thick at the type section in Lehigh Gap and about 50 feet thick at Bake Oven Knob. The thickness varies according to the presence or absence of pebbles more than 2 inches long. At Bake Oven Knob, for example, the top 6 inches of the upper 39 feet is coarsely conglomeratic. If this bed were missing, the Weiders would be only 11 feet thick there. The Weiders is apparently thickest (about 220 ft on the basis of construction of cross sections) at Little Gap.

#### MINSI MEMBER

The Minsi Member of the Shawangunk Formation is named for Mount Minsi, overlooking Delaware Water Gap, Monroe County, Pa. The type section is along U.S. Interstate 80 in Delaware Water Gap, Warren County, N.J. (figs. 1 and 19); there the Minsi contains quartzite, conglomerate (with quartz, chert, and sandstone pebbles less than 2 inches long), and minor amounts of siltstone (fig. 5). It forms a cliff along the middle of the south slope of Blue and Kittatinny Mountains northeast of Smith Gap. Southwest of Smith Gap, the Minsi forms the break

FIGURE 5.—Interbedded quartzite and quartz- and chert-pebble conglomerate in the Minsi Member of the Shawangunk Formation at the type section, Delaware Water Gap, Warren County, N.J. Note channels at bases of many of the beds.

FIGURE 6.—Crossbedded and planar-bedded conglomeratic quartzite and quartzite containing quartz pebbles not more than 1 inch long, Minsi Member of the Shawangunk Formation, Delaware Water Gap, roadcut along U.S. Interstate 80, Warren County, N.J.

in slope at the top of Blue Mountain. It is 303 feet thick at its type section and thins gradually to 225 feet at Lehigh Gap (fig. 2).

In the Delaware Water Gap, the Minsi consists of light-gray (*N*7) to medium-dark-gray (*N*4) and light-olive-gray (5*Y* 6/1) medium- to very coarse grained crossbedded to planar-bedded locally rippled limonitic pyritic unevenly to moderately evenly bedded and lenticular (beds 1 inch to more than 3 feet thick) thin- to thick-bedded quartzite, conglomeratic quartzite, and quartz-, chert-, and argillite-pebble conglomerate (fig. 6). Some quartz pebbles are nearly 2 inches long, but most are less than 1 inch long. Argillite pebbles are mostly flattened shaly siltstone and are as much as 4 inches long. About 7 percent of the Minsi is dark-gray (*N*3) to light-olive-gray (5*Y* 6/1) siltstone that is locally shaly and mud cracked. The siltstone is in lenticular beds as well as short lenses less than 1 inch to 1 foot thick. A chemical and semiquantitative spectrographic analysis of a typical siltstone is given in table 1, sample 2.

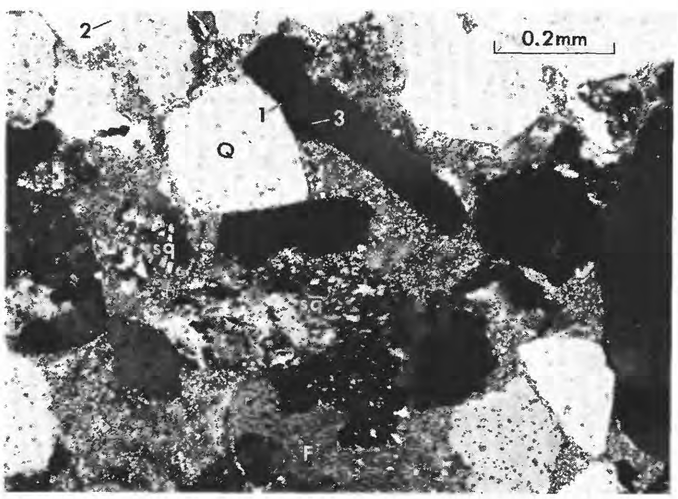


FIGURE 7.—Photomicrograph (crossed polarizers) of poorly sorted, conglomeratic, fine- to medium-grained feldspathic sandstone from lowest exposed bed of the Minsi Member of the Shawangunk Formation, Delaware Water Gap, Portland quadrangle, New Jersey (measured section 1, unit 2). Matrix minerals (13 percent) are not readily identified but appear to consist mainly of muscovite and quartz with minor chlorite, limonite, and hematite. Framework grains are quartz (Q, 80 percent), as much as 5 mm long, sericitized potash feldspar (F, 5 percent), partly perthitic and as much as 1 mm long, and chert (2 percent). Many quartz grains are composite with sutured contacts (sq). Grains are angular to subround. Quartz-grain contacts are straight or concave with (at 1) or without (at 2) a clay coating, or are overgrown with optically continuous quartz (at 3). The quartz contains abundant vacuole inclusions. The heavy-mineral suite is mature and consists of subhedral to rounded zircon and subordinate tourmaline and rutile. One grain tentatively identified as monazite is included in a quartz grain. Rock fragments (shale) are not common ($<$ 1 percent).

The contact of the Minsi with the Martinsburg Formation is not presently exposed at Delaware Water Gap, but Beerbower (1956) described it as abrupt and unconformable. The angular unconformity between the Shawangunk and Martinsburg Formations is indicated by mapping in the area (Drake and others, 1969; Epstein, 1971, 1972). An abrupt unconformable contact is exposed 5 miles northeast of Delaware Water Gap at the Yards Creek hydroelectric project on Kittatinny Mountain north of Blairstown, N.J. (Epstein and Epstein, 1969, p. 169). There the Minsi Member rests on the middle member (Ramseyburg) of the Martinsburg Formation; accordingly, more than 5,000 feet of rock are missing at the unconformity (Drake and Epstein, 1967). The contact between the Ramseyburg and overlying Pen Argyl Member of the Martinsburg emerges from beneath the Shawangunk 1.2 miles southwest of Delaware Water Gap (Epstein and Epstein, 1969, p. 201).

The Minsi Member is uniformly similar throughout its outcrop. West of Smith Gap, it overlies and interfingers with the Weiders Member and probably extends for many miles southwest of Bake Oven Knob, probably to and beyond Schuylkill Gap, where it was mapped as the Tuscarora Sandstone by Wood, Trexler, and Kehn (1969).

FIGURE 8.—Mud-cracked shaly siltstone, Minsi Member of the Shawangunk Formation. Underside of bed exposed about 60 feet above U.S. Interstate 80 at south entrance of Delaware Water Gap, Warren County, N.J. (measured section 1, unit 9). Mud-crack polygons about 1 foot across.

The sandstones or quartzites of the Minsi Member are submature (matrix averages about 12 percent in the thin sections studied). At Delaware Water Gap, they contain 3–5 percent feldspar and are classed as feldspathic sandstones (fig. 7). Fragments of shale and siltstone generally form less than 2 percent of the rock. The quartz grains are sutured or have silica overgrowths. Single grains are most common, but many are composite and stretched, indicating a partly metamorphic or presolved sedimentary quartzite source. The heavy-mineral suite is mature and includes mostly zircon, subordinate tourmaline, and rare rutile. These minerals are well rounded to subhedral, and their association with quartz grains containing small inclusions of biotite and vermicular chlorite, as well as clastic grains of orthoclase, suggests a reworked sedimentary source with possibly minor contributions from a granitic terrane containing quartz veins. Conceivably, the total mineral assemblage could have been derived directly from a sedimentary source whose rocks themselves were derived from a complex source area. Labile minerals, such as hornblende, are extremely rare. West of Delaware Water Gap, feldspar was not seen in thin section, and the rocks at Lehigh Gap, for example, are mainly siliceous protoquartzites.

The siltstones in the Minsi are made up of medium to very coarse silt-sized angular quartz grains and a few chert grains floating in a matrix of muscovite and subordinate chlorite. Argillaceous rock fragments are rare. The siltstones are generally sandy and laminated, features best seen on polished surfaces. Mud cracks were seen in one siltstone bed at Delaware Water Gap (fig. 8).

#### LIZARD CREEK MEMBER

The sequence of siltstone, shale, sandstone, and scattered red beds, conglomeratic and calcareous sandstone, and other lithic types that are herein named the Lizard Creek Member of the Shawangunk Formation have been included in the Clinton Formation by most previous workers in eastern Pennsylvania. The underlying coarse clastic rocks herein assigned to the Weiders and Minsi Members were placed in the Tuscarora Sandstone west of Lehigh Gap. We are abandoning the names Clinton and Tuscarora in the area of this report. The historical development of nomenclature of these rocks has been confused. (See summaries by Schuchert, 1916; Swartz, 1923; and Swartz and Swartz, 1931.) The following are pertinent details for purposes of this discussion:

The Shawangunk was named by Mather in 1840 for rocks exposed in the Shawangunk Mountains in southeastern New York. The Shawangunk was shown to extend in outcrop across northern New Jersey to Delaware Water Gap by Weller (1903). The Tuscarora Sandstone was named by Darton and Taff (1896), presumably for Tuscarora Mountain in south-central Pennsylvania. The name Clinton was first used by Conrad (1842) for exposures near Clinton, N.Y. It was later applied by White (1882) to the red beds at Delaware Water Gap which are now called Bloomsburg and which overlie rocks that were subsequently called Clinton by Swartz and Swartz (1931). Swartz (1923) raised the Clinton to group rank in Maryland and included in it, in ascending order, the Rose Hill Formation, Keefer Sandstone Member at the base of the Rochester, and Rochester Formation. The Tuscarora Sandstone, Rose Hill, Keefer, and Rochester were traced with some degree of uncertainty northeastward from Maryland by Swartz and Swartz (1931) to Swatara Gap, 30 miles southwest of Bake Oven Knob. From Swatara Gap east to Lehigh Gap, the Swartzes were unable to recognize the formations of their Clinton Group, and they designated the unit the Clinton Formation. From Lehigh Gap east to Delaware Water Gap, they were unable to differentiate the Clinton Formation from the subjacent Tuscarora Sandstone. Consequently, they dropped the names Clinton and Tuscarora and recognized the combined interval as the Shawangunk Formation at Delaware Water Gap.

The Swartzes' usage has been partly accepted on

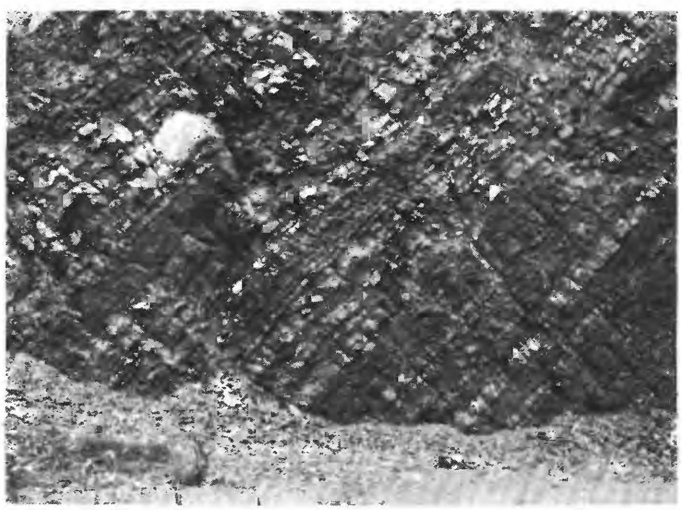

FIGURE 9.—Evenly bedded siltstone, shale, and quartzite in the Lizard Creek Member of the Shawangunk Formation in roadcut along Pa. Route 145, Lehigh Gap, just north of Aquashicola Creek. Thickest quartzite bed is about 1.5 feet thick.

the geologic map of Pennsylvania (Gray and others, 1960)—the name Shawangunk is applied to those rocks east of Swatara Gap and the names Tuscarora and Clinton are used to the west, on the assumption that use of the Clinton is limited to those areas where the Rose Hill, Keefer, and Rochester could be distinguished. To the east, where the Clinton could not be so divided, it is combined with the Tuscarora to form the Shawangunk. However, in two 7½-minute quadrangles immediately west of Swatara Gap, Wood, Trexler, and Kehn (1969) could not divide the Clinton into mappable units, but nonetheless retained the name Clinton and mapped the Tuscarora Sandstone below it.

As mentioned previously, the Clinton, as defined by Swartz and Swartz (1931), at Lehigh Gap was placed in the Shawangunk Conglomerate (now Formation) and informally termed the "quartzite-argillite unit" by Epstein and Epstein (1967, 1969). This unit extends eastward to Delaware Water Gap and there intertongues with two quartzite and conglomerate units (the Minsi and Tammany Members of this report). Because the name Clinton had had widespread usage, it was recently retained as the name for a member in the Shawangunk (Epstein, 1971), although this usage was not adopted by the U.S. Geological Survey. Because these rocks do not meet the tripartite division of the Clinton recognized by Gray and others (1960), the Clinton is herein abandoned for use in eastern Pennsylvania, at least east of Bake Oven Knob. This usage agrees with current practice of the Pennsylvania Geological Survey (D. M. Hoskins, oral commun., 1971). Interestingly, the name Clinton was not applied to coeval rocks in southeastern New York (Fisher, 1959) that are part of the outcrop belt that extends into Pennsylvania. Thus, in eastern Pennsylvania, the Clinton Formation of previous usage is the Lizard Creek Member of the Shawangunk Formation of this report, and the Tuscarora Sandstone is the Weiders and Minsi Members.

The Lizard Creek Member of the Shawangunk Formation is named for Lizard Creek, which joins the Lehigh River 3 miles west of Lehigh Gap. The type section is in Lehigh Gap, where the member is 1,225 feet thick. Schuchert (1916) believed that the member (his "Upper Shawangunk") is 900 feet thick at Lehigh Gap, and Swartz and Swartz (1931) measured 1,093 feet for their equivalent Clinton. The Lizard Creek has been mapped east from Bake Oven Knob to the Delaware Water Gap area where it thins to 273 feet. It is nearly completely exposed at Lehigh Gap and at Delaware Water Gap, but only the lower 172 feet is exposed at Wind Gap; elsewhere in the area it is generally very poorly exposed.

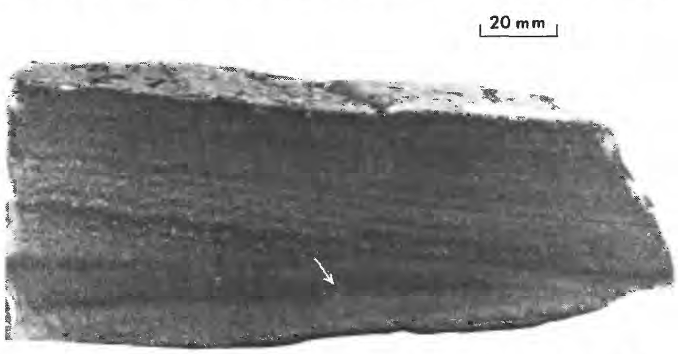


FIGURE 10.—Laminated, well-sorted, fine-grained calcitic sandstone in the Lizard Creek Member (measured section 1, unit 35), Delaware Water Gap. Primary current lineation (not readily apparent in photograph) is present on the upper bedding surface and parallels the dip of the laminae. Small ridges on bedding surface are not ripples but offsets of small soft-rock faults (arrow). The rock is believed to be a beach or barrier-bar deposit, and the faults may have formed parallel to the ancient strand line. (See section on environments of deposition.)

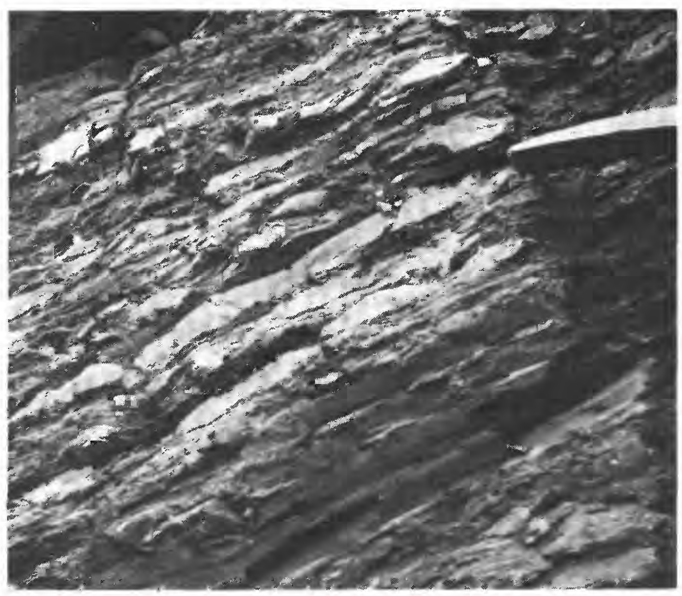

FIGURE 11.—Flaser-bedded (ripple lensing) and lenticular fine-grained sandstone (light) irregularly interbedded with burrowed shaly siltstone (dark). Load casts show as sole markings in many of the sandstones. Black phosphate nodules, as much as 1.5 inches long, are scattered throughout; these nodules weather dull white. The nodules are angular, and some have a partial mud rind. These beds were probably reworked by storm waves while the sediment was still soft (see section on environments of deposition). Sample 5, table 1, is a chemical and semiquantitative spectrographic analysis of a rock from this unit. Hammer head gives scale. Lizard Creek Member of the Shawangunk Formation, Delaware Water Gap, Warren County, N.J. (measured section 1, unit 46).

The Lizard Creek Member is characterized by interbedded sandstone, siltstone, and silty shale (figs. 9 and 19). It is gradational into the underlying Minsi Member but is readily differentiated because of its abundant medium- to dark-gray siltstone and shale.

The sandstones in the Lizard Creek are generally fine to medium grained but range from very fine to very coarse grained and locally are conglomeratic or silty. Quartz pebbles are as much as 0.5 inch long. Sorting is fair to good. Most sandstones are limonitic, a few have carbonate cement, and some contain rare specks of graphite, about 2 mm in diameter. They are evenly to unevenly bedded, laminated (fig. 10) to thick bedded (beds range from less than 0.5 to 8.5 feet thick), and also are in discontinuous lenses (fig. 11). Some beds contain convolutions (fig. 12). Thin shale intercalations and flat argillite clasts (clay galls) as much as 4 inches long are numerous. The sandstones are planar bedded to crossbedded, and a few are rippled (fig. 13). Both trough and planar crossbeds are common. Crossbed sets range from less than 0.5 inch to more than 2 feet thick. Colors on fresh surfaces are generally very light gray (*N*8) to medium dark gray (*N*4) and light olive gray (5*Y* 6/1), but some sandstones are light greenish gray (5*GY* 8/1) to moderate greenish gray (5*GY* 5/1), very light bluish white (5*B* 8/1) to light bluish gray (5*B* 7/1), light brownish gray (5*YR* 6/1), and yellowish gray (5*Y* 8/1). They weather shades of gray and very pale orange (10*YR* 8/2), light brown (5*YR* 6/4), moderate brown (5*YR* 4/4),

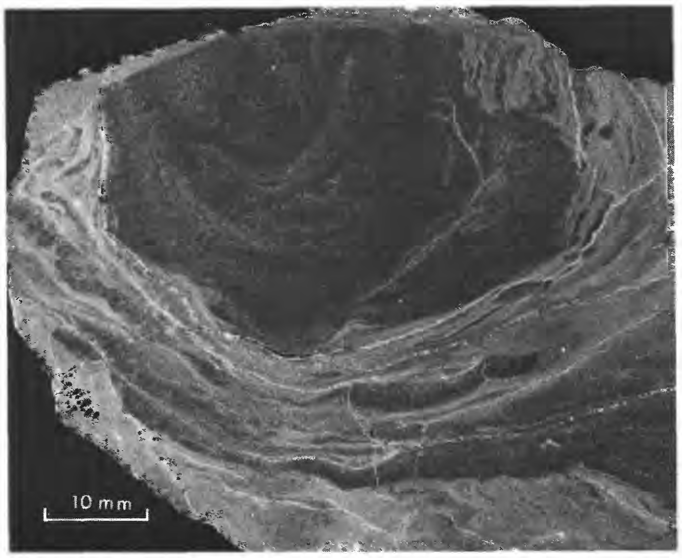


FIGURE 12.—Convolutions (ball-and-pillow structure) due to soft-rock slumping, in very fine grained sandstone and siltstone. Note overturned and refolded flow fold at top. Negative print of acetate peel. Lizard Creek Member of the Shawangunk Formation, Delaware Water Gap, N.J. (measured section 1, unit 43).

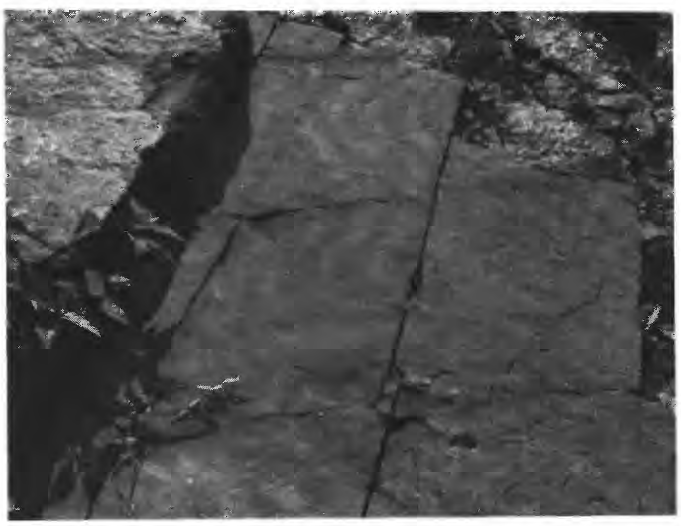

FIGURE 13.—Asymmetric ripples in fine-grained sandstone, Lizard Creek Member of the Shawangunk Formation, Delaware Water Gap, Warren County, N.J. (measured section 1, unit 35). The ripples have wavelengths of about 3.5 inches and amplitudes of 0.5 inch.

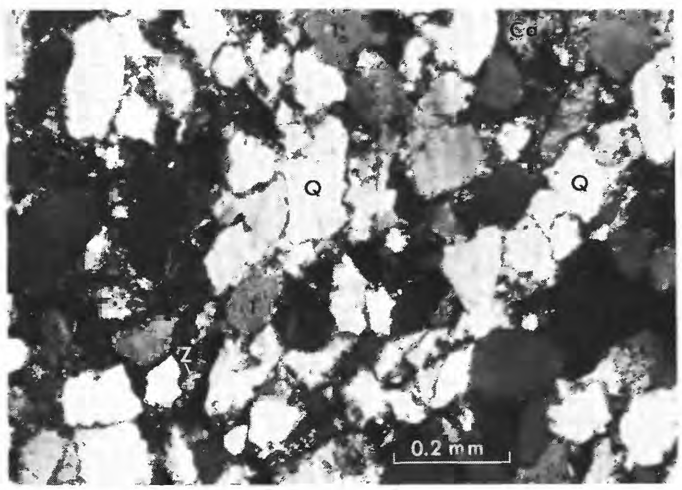


FIGURE 14.—Photomicrograph (crossed polarizers) of fine-grained quartzite, Lizard Creek Member of the Shawangunk Formation, Delaware Water Gap, N.J. (measured section 1, unit 35). Quartz (Q) and minor chert (86 percent) are the dominant minerals in a muscovite and chlorite matrix. Some matrix is entirely recrystallized to chlorite (pennine). Note the straight to interlocking contacts between quartz grains. Limonite-stained carbonate (probably calcite, Ca) forms a cement in some areas and makes up about 4 percent of the rock. Minor potash feldspar ($< 1$ percent) and rock fragments (shale, about 1 percent) were noted. Heavy minerals are fairly abundant and include subrounded to rounded tourmaline (T), zircon (Z), and lesser rutile. The composition of the rock is near the borderline between a protoquartzite and orthoquartzite. Figure 10 is a photograph of the rock sample.

to dark yellowish orange (10*YR* 6/6). The sandstones are in sharp to gradational contact with beds above and below. Many basal surfaces are filled channels of low relief.

As seen in thin section, the sandstones range from lithic graywackes to orthoquartzites (fig. 14). Sorting is poor to excellent. Quartz ranges from more than 95 percent to less than 50 percent of the sand fraction of the rock. Sample 3, table 1, is the chemical and semiquantitative spectrographic analysis of a typical orthoquartzite. Most quartz is in single grains with undulose extinction, although nearly every thin section examined contained scattered composite grains derived from preexisting quartzite. Chert is ubiquitous, generally making up less than 5 percent of the grains. Where quartz grains are in contact, their borders are sutured. Quartz overgrowths are common, and calcite and light-green spherulitic chlorite form pore fillings or replace quartz in many samples. Sand-size muscovite grains are common, and biotite grains, partly altered to chlorite, were seen in many samples. Matrix minerals are mostly fine-grained muscovite and quartz, with subordinate chlorite. They range in volume from thin clay coatings on larger clastic grains to more than half the rock. The heavy-mineral suite forms as much as 2 percent of some rocks and is dominated by round to subround zircon and tourmaline grains. Leucoxene, limonite, black opaque minerals (probably magnetite), and hematite are also common. The limonite and hematite are mostly alteration products of iron-bearing minerals, such as chlorite and biotite. Rock fragments, mostly shale and siltstone, are locally absent but make up more than 3 percent of some beds. In some rock fragments, there is good preferred alinement of micas—these may be meta-argillites.

FIGURE 15.—Feeding burrows on bedding plane of siltstone in Lizard Creek Member of the Shawangunk Formation, Delaware Water Gap, Warren County, N.J. (measured section 1, unit 31).

Beds of finer clastic rocks in the Lizard Creek are shaly and sandy siltstone and silty shale. Silt- and sand-size grains of mica are common on bedding planes. The fine-grained rocks are medium light gray (*N*6) to grayish black (*N*2), light olive gray (5*Y* 6/1) to medium olive gray (5*Y* 5/1), greenish gray (5*GY* 6/1) to dark greenish gray (5*GY* 4/1), and rarely, light bluish gray (5*B* 7/1) on fresh surfaces. They weather various shades of gray, green, orange, brown, and pink. They are indistinctly bedded to laminated; beds range in thickness from less than 0.5 to more than 6 feet. Many of the fine-grained rocks are irregularly laminated, lenticular, cross laminated, flaser bedded, and have small-scale scour and fill. Subordinate lenses of fine- to medium-grained sandstone are common. Many siltstones and shales are burrow mottled. Discrete burrows are generally circular, 0.25–0.5 inch in diameter, and may be perpendicular or parallel to bedding (fig. 15). At Delaware Water Gap, some vertical sand-filled burrows are 1 inch in diameter and as much as 1 foot deep. Olive-gray shales are common above the lower 150 feet of the Lizard Creek Member at Lehigh Gap but are absent at Delaware Water Gap and Wind Gap. Most of these are unevenly laminated to flaser bedded.

The Lizard Creek Member contains scattered red-bed intervals, not more than 7 feet thick, consisting of sandstone, siltstone, and shale. They are not found east of Smith Gap (fig. 2). The sandstones are dusky red purple (5*RP* 3/2) and grayish red purple (5*RP* 4/2) to brownish gray (5*YR* 4/1) and may be color laminated or mottled with moderate greenish gray (5*GY* 5/1) to dark greenish gray (5*G* 4/1). Most are silty and very fine to fine grained, although a few are coarse grained. Most of the finer grained red sandstones are hematitic graywackes with abundant rock fragments, muscovite, and biotite. (See sample 4, table 1, for chemical and semiquantitative spectrographic analysis.) The hematite and fine-grained muscovite-quartz matrix forms more than 30 percent of the rock. These sandstones are transitional into grayish-red-purple (5*RP* 4/2) to moderate-red-purple (5*RP* 5/2) and pale-red (5*R* 6/2) shaly and sandy siltstones that are color mottled and interlaminated with similar rocks that are moderate greenish gray (5*GY* 5/1) and light brownish gray (5*YR* 6/1). The mottling is due to burrowing of organisms, the remains of which have not been found (fig. 16).

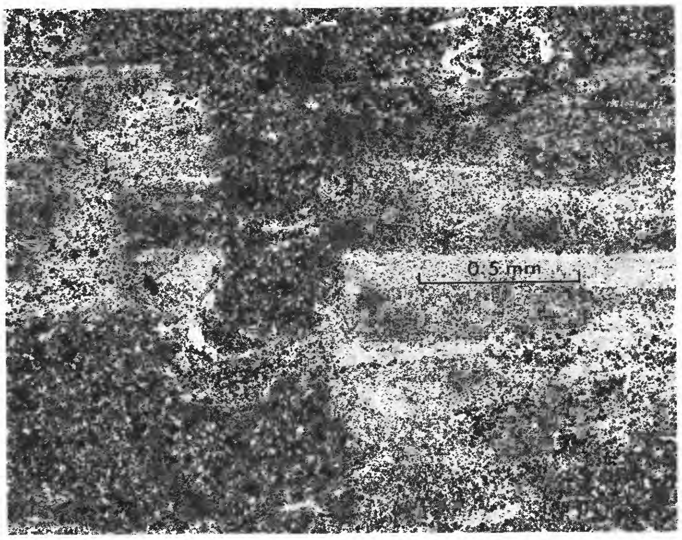


FIGURE 16.—Vertical burrow disrupts laminae in hematitic shaly siltstone to fine-grained sandstone. The laminae have been completely churn-burrowed in the lower part and in other parts of the sample. Negative print of thin section. Lizard Creek Member of the Shawangunk Formation, Lehigh Gap, Northampton County, Pa. (measured section 3, unit 40).

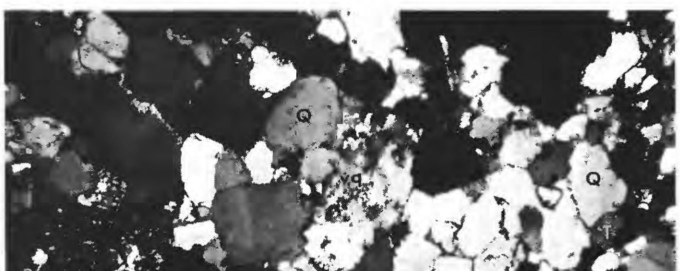


FIGURE 17.—Photomicrograph (crossed polarizers) of moderately sorted fine-grained hematitic orthoquartzite. The rock is made up predominantly of single-crystal quartz grains (Q) (about 95 percent). Rare shale and siltstone rock fragments (R), vein quartz (vq), chert (C), and rounded tourmaline (T) make up the remainder. Most quartz grains have a thin coating of hematite which shows the outline of the detrital grain adjacent to silica overgrowths (arrow). Lizard Creek Member of the Shawangunk Formation, Lehigh Gap, Northampton County, Pa. (measured section 3, unit 67).

Some of the red sandstones are hematitic orthoquartzites and are strikingly different from the graywackes in thin section. The orthoquartzites are fine to coarse grained and generally well sorted (fig. 17). Intermediate red siliceous protoquartzites are also present, indicating that the sorting capabilities of the transporting media and the depositional environments were varied.

In the upper half of the Lizard Creek Member at the type section in Lehigh Gap, generally in the upper 380 feet, there are more than 12 beds, 2–8 inches thick, of irregularly laminated sandstone to silty shale containing ovoid and irregular nodules of siderite, collophane, and chlorite; quartz pebbles; phosphatic siltstone and shale intraclasts; and fragments of linguloid brachiopods (fig. 18). The siderite nodules are generally elliptical, 2–20 mm long, are dark yellowish orange (10*YR* 6/6) to pale yellowish orange (10*YR* 8/6), and may be rimmed with or partly replaced by dark-yellowish-green (10*GY* 4/4) chlorite. Green pleochroic chlorite also fills interstices; replaces other minerals, linguloid brachiopod shells, and possibly pellets; and occurs as nodules. Chlorite grains in the Lizard Creek have low birefringence, are optically homogeneous, and have a strong 14 A reflection on X-ray diffractograms and are, therefore, not chamosite. Chamosite, however, has been found in concentrically banded oolites in ironstones of the Clinton Group of New York, Ohio, and West Virginia (Alling, 1947; Hunter, 1960, 1970; and Schoen, 1964). Some of the chlorite in the Lizard Creek may have originally been chamosite that was altered during low-grade metamorphism to chlorite (James, 1966), for high 7 A/14 A peak-height ratios (as much as 5:1 in some samples) indicate that the chlorite is iron rich. X-ray diffraction analysis indicates that the collophane is carbonate fluorapatite. The collophane is grayish black (*N*2) to dark gray (*N*3) and may weather dull white, especially in the linguloid fragments. Some of the phosphatic siltstone intraclasts are as much as 3.5 inches long and are flattened parallel to the bedding; many are spherulitic. In general, the nodule beds are between laminated sandstones, siltstones, or shale (fig. 18).

The nodule-bearing beds were not seen in the incompletely exposed Lizard Creek at Wind Gap, but at Delaware Water Gap they are present between 205 and 258 feet above the base of the member. They differ from the beds at Lehigh Gap by containing black (*N*1) to grayish-black (*N*2) dull white-weathering rounded and irregular phosphate nodules as much as 1.5 inches long (fig. 11). Neither siderite


A


B

FIGURE 18.—Nodule beds in the Lizard Creek Member of the Shawangunk Formation, Lehigh Gap, Pa. *A*, Nodules and oolites of carbonate fluorapatite (1), carbonate fluorapatite rimming iron-rich shale pebbles (2), quartz pebbles as much as 8 mm long (3), and shale pebbles (4) that were probably ripped up from substrate similar to the shale at 5. This nodule bed lies between laminated well-sorted medium-grained quartzite. The shale and phosphate nodules may have been deposited in the reducing environment of a lagoon and washed onto a sandbar during a storm. Chemical analysis of the shale (5) shows it to contain 8.2 percent iron expressed as $Fe_2O_3$ and 0.19 percent $P_2O_5$. Sample 6, table 1, is a chemical and semiquantitative spectrographic analysis of this rock. Photograph of polished section from measured section 3, unit 72. *B*, Nodules of siltstone partly replaced by collophane (1), siderite (2) rimmed with chlorite (3) and penetrated by quartz grain (4) (showing that the nodule was soft at time of deposition), and fragments of linguloid brachiopods (5). Note lapping of irregularly laminated shale and very fine grained sandstone on large siltstone clast (6). Serial sections of the siltstone clasts show that they are extremely irregular in shape, suggesting deposition while the siltstone was wet and plastic. Negative print of acetate peel from measured section 3, unit 66.

nor chlorite nodules nor fragments of linguloid brachiopods were found at Delaware Water Gap.

Parts of the Lizard Creek Member are rich in iron (some samples contain nearly 10 percent total iron). Much of the iron is contained in hematite, magnetite, goethite, lepidocrosite, iron-rich chlorite, and siderite.

The boundary between the Lizard Creek and Tammany Members is transitional in the eastern half of the area and is placed at the top of the highest siltstone or shale of the mixed siltstone-shale-quartzite sequence of the Lizard Creek. The contact can be placed at a bedding surface in exposures at Delaware Water Gap. In areas of nonexposure where the contact is mapped on float, the boundary is less definite.

In the western part of the area, the upper contact of the Lizard Creek is placed at the base of the lowest red bed of the dominantly red sequence of the overlying Bloomsburg Red Beds. The Bloomsburg and Lizard Creek are transitional through 163 feet of red, green, and gray sandstone, siltstone, and minor shale at Lehigh Gap.

### TAMMANY MEMBER

The Tammany Member of the Shawangunk Formation is herein named for Mount Tammany overlooking Delaware Water Gap, Warren County, N.J. (fig. 1). The type section is in Delaware Water Gap (fig. 19); there, along U.S. Interstate 80 in New Jersey, the member is 816 feet thick, but thickens to about 1,500 feet to the northwest in the gap at the expense of the overlying Bloomsburg Red Beds.

The Tammany consists of medium-gray (*N*5) to medium-dark-gray (*N*4) crossbedded, limonitic, pyritic, evenly to unevenly bedded quartzite and about 2-percent dark-gray shaly siltstone. Flattened shale pebbles are common. Quartz pebbles are as much as 2 inches long. The quartzites are predominantly protoquartzites (fig. 20). The sandstones of the Tammany Member are similar to those of the Minsi Member at Delaware Water Gap, except that feldspar is not as abundant in the Tammany (<1 percent in thin sections examined).

Unique dolomite beds crop out near the top of the Tammany Member about 400 feet south of the contact with the overlying Bloomsburg Red Beds and a few hundred feet north of the tollgate on U.S. Interstate 80 at the north end of Delaware Water Gap near the village of Delaware Water Gap, Pa. These beds are about 4 feet thick and consist of a


FIGURE 19.—The Shawangunk Formation at Delaware Water Gap, N.J. Om, Martinsburg Formation; SOsm, quartzite and conglomeratic quartzite of the Minsi Member; SOsl, interbedded quartzite, siltstone, and shale of the Lizard Creek Member; SOst, quartzite and conglomerate of the Tammany Member. Type section of the Minsi and Tammany Members of the Shawangunk Formation. The contact between the Martinsburg and Shawangunk Formations is covered by talus along the base of Mount Tammany. Note prominent kink fold in the Tammany Member and disharmonic folds and faults in the Lizard Creek Member. Beds generally dip northwest.

lower medium-gray dolomite that weathers moderate brown and an upper greenish-gray dolomitic shale or shaly dolomite (fig. 21). The medium-gray dolomite is nearly pure ferroan dolomite (determined by X-ray diffraction and staining techniques). Small amounts of calcite, quartz, muscovite, and a 14 A mineral, probably chlorite, were noted on the X-ray trace. The rock reacts slightly with cold dilute hydrochloric acid. The greenish-gray dolomitic shale or shaly dolomite consists of ferroan dolomite with about equal amounts of muscovite, quartz, and chlorite. No calcite was noted, and the rock does not react with dilute HCl. Concretions of dolomite and calcite, ½–3 inches in diameter, with concentric structure, are abundant. The dolomite beds are overlain and underlain by crossbedded and planar-bedded, predominantly medium grained, partly conglomeratic quartzite and siltstone. The lower dolomite bed contains irregular patches of rock similar to the upper bed. In thin section, the medium-gray dolomite consists of a mosaic of slightly clouded dolomite grains averaging about 0.04 mm in diameter that replace the dolomitic shale or shaly dolomite. Ferroan dolomite occurs in scattered beds overlying and underlying this horizon, as well as in the overlying Bloomsburg Red Beds.

The Tammany Member forms most of the crest of Kittatinny and Blue Mountains. It is thickest at Delaware Water Gap and thins southwestward as its quartzites and conglomerates are replaced by finer clastic rocks of the Lizard Creek Member (fig. 2). Tongues from the Tammany extend into the Lizard Creek, but because beds typical of the Lizard Creek make up more than 50 percent of the interval southwest of Smith Gap, the Tammany is separated from the Lizard Creek at Smith Gap by an arbitrary cutoff.

The upper contact of the Tammany Member is placed at the base of the oldest red bed of the overlying Bloomsburg Red Beds. The color boundary is extremely irregular, transects bedding, and rises about 700 feet within a horizontal distance of less than 1 mile in Delaware Water Gap (see fig. 2; also, Epstein, 1972). The lithologic contrast between the Bloomsburg and Shawangunk is likewise indistinct, so that lithologies could not be used conveniently for a mappable boundary. The color change was used because it has been the accepted method of separating the two formations (Willard, 1938, p. 10) and

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because it is the most satisfactory method where mapping float (the contact is covered in most areas other than at Delaware Water Gap).

### AGE OF THE SHAWANGUNK FORMATION

The Shawangunk Formation of eastern Pennsylvania has been regarded as Early to Middle Silurian in age (Swartz and others, 1942). This age assignment was based primarily on the presence of eurypterids and *Arthrophycus* and on regional stratigraphic considerations. The evidence appears to be equivocal and needs reevaluation. The base of the Shawangunk conceivably could be latest Ordovician in age.

In central Pennsylvania, the clastic rocks immediately overlying the Martinsburg Formation are, in ascending order, the Bald Eagle Member of the Juniata Formation of Willard and Cleaves (1939), the Juniata Formation, and the Tuscarora Sandstone. Diagnostic fossils have not been found in the Bald Eagle and Juniata, and the age of these units is still uncertain (Willard, 1943, p. 1091; Swartz, 1942, p. 178), although they are generally believed to be Maysvillian and Richmondian in age (Twenhofel and others, 1954). East of the Susquehanna River, near Harrisburg, Pa., the Bald Eagle and Juniata pinch out, and at the Lehigh River, the Shawangunk Formation, which is laterally continuous with the Tuscarora, rests directly on the Martinsburg Formation. For this reason, it was assumed that the base of the Shawangunk is Early Silurian in age. However, it is not unreasonable to believe that parts of the basal Shawangunk are correlative with rocks of the Juniata or Bald Eagle. Lack of diagnostic fossils in these rocks makes this suggestion a possibility. In southeastern New York, basal Shawangunk beds are believed to be Middle Silurian in age, but lack of key fossils makes this age assignment questionable (Fisher, 1959).

Regional stratigraphic relations suggest that lowermost Silurian and uppermost Ordovician clastic rocks, derived from highlands uplifted during the Taconic orogeny, overlap underlying shales and become younger to the northeast. Thus, in central Pennsylvania, where deposition was uninterrupted, boundaries between the Reedsville Shale and the successively younger Bald Eagle, Juniata, and Tuscarora are conformable. In eastern Pennsylvania, New Jersey, and southeastern New York, the Shawangunk Formation lies unconformably on the Martinsburg Formation; the hiatus presumably increases in duration to the northeast. (See Willard and Cleaves, 1939.) Graptolites collected from the top of the Pen

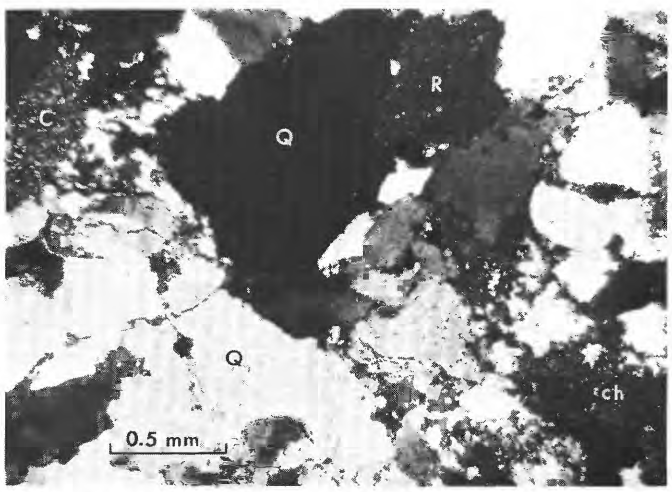


FIGURE 20.—Photomicrograph (crossed polarizers) of conglomeratic coarse-grained protoquartzite, Tammany Member of the Shawangunk Formation, Delaware Water Gap (measured section 1, unit 58). Framework minerals are quartz (Q, 80 percent), chert (C, 1 percent), rock fragments (R, shale and siltstone, 1 percent), and minor muscovite and zircon. The quartz is rutilated and contains abundant vacuoles and scattered inclusions of vermicular chlorite. The quartz grains are angular to subround, simple to composite, and have straight to undulose extinction. Grain contacts are straight to concave. The matrix (18 percent) is composed of fine quartz, muscovite, and chlorite. Some areas are recrystallized to spherulitic chlorite (ch). Note peripheral growth of mica on some quartz grains.

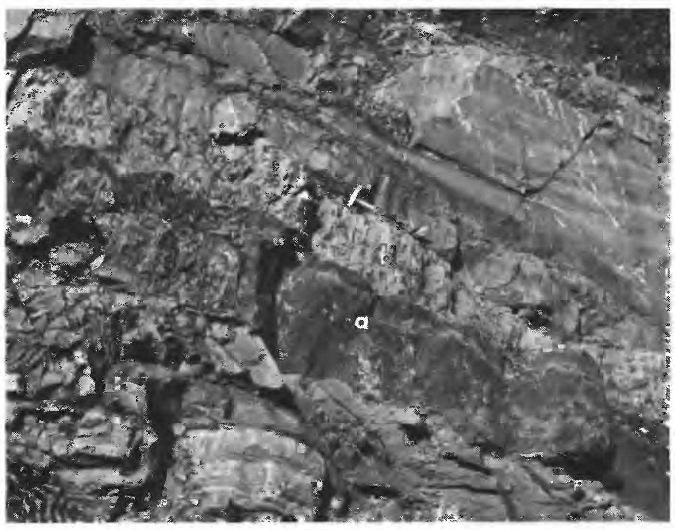


FIGURE 21.—Medium-gray dolomite that weathers moderate brown (*a*, about 2 ft thick) overlain by greenish-gray dolomitic shale or shaly dolomite with nodules of calcite and dolomite with concentric structure (*b*, about 1.8 ft thick). Hammer is at contact with overlying fine- to medium-grained feldspathic sandstone. Tammany Member of the Shawangunk Formation, near tollgate on U.S. Interstate 80, at village of Delaware Water Gap, Pa.

Argyl Member, the upper member of the Martinsburg Formation at Lehigh Gap, have been identified by W. B. N. Berry and are indicative of the upper subzone of zone 13 (Berry, 1970; Epstein, 1970). According to Berry, this subzone is equivalent to the *Climacograptus spiniferus* zone of Riva (1969). Riva showed that the *C. spiniferus* zone is limited to the lower half of the Utica Shale in the Mohawk Valley, N.Y., which he correlated with the Cobourg Limestone of Raymond (1921). On the basis of conodont studies, Sweet and Bergström (1971) correlated the Cobourg with the entire Edenian and lower Maysvillian of the Cincinnati area. Thus, the top of the Martinsburg in eastern Pennsylvania lies within the Edenian-early Maysvillian interval (early Late Ordovician).

The Juniata-Tuscarora contact, which supposedly marks the Ordovician-Silurian boundary in central Pennsylvania, is complex and may be time transgressive (Swartz, 1942, p. 186). The two formations are transitional, and the contact is drawn with difficulty (Folk, 1960, p. 5–6). Clearly, therefore, the Juniata-Tuscarora boundary may not be a time line separating Ordovician and Silurian rocks. This point is emphasized by Thompson (1970).

Further confusion regarding the Ordovician-Silurian boundary in eastern Pennsylvania stems from Willard and Cleaves' (1939, p. 1185) belief that a remnant of the Bald Eagle can be found at Lehigh Gap and east into Northampton County. If this were true, the basal clastic rocks underlying Blue Mountain in this area could be Maysvillian in age (Willard, 1943, p. 1118). We doubt the identification of the Bald Eagle at Lehigh Gap. In this report and as suggested by Epstein and Epstein (1967, 1969), the basal conglomerates at Lehigh Gap are placed in the Shawangunk. Except for clast size, we recognize no difference between the basal conglomerates and the conglomerates in the overlying beds. Thus we do not recognize the disconformity that Willard and Cleaves (1939) postulated, based on the absence of the intervening Juniata between the beds they believed to be Bald Eagle and Shawangunk.

The age of these rocks is further clouded by the previously held supposition that unconformities mark systemic boundaries. Thus, Willard and Cleaves (1939, p. 1165) maintained that the Juniata is either Silurian or Ordovician depending on acceptance of one of two proposed hiatuses in eastern Pennsylvania as the Ordovician-Silurian boundary.

Bald Eagle, Juniata, Tuscarora, and Shawangunk rocks in central and eastern Pennsylvania are shallow-marine and fluvial clastic rocks derived from highlands uplifted to the southeast as the result of the Taconic orogeny (for example, Swartz, 1948; Thomson, 1957; Folk, 1960; Yeakel, 1962; Horowitz, 1966; Epstein and Epstein, 1967, 1969; Smith, 1967a). The environment of deposition interpreted for these rocks is in sharp contrast with the deep-water origin suggested for most of the Martinsburg (McBride, 1962). Because the Taconic orogeny may have been more or less synchronous in central and eastern Pennsylvania, the detritus that makes up the Juniata and Bald Eagle in central Pennsylvania could be partly of the same age as the Shawangunk in eastern Pennsylvania, even though "layer cake" interpretations suggest that the Juniata and Bald Eagle are older.

The Shawangunk Formation is sparsely fossiliferous. No fossils have been found in the Weiders or Minsi Members except for *Arthrophycus,* 40 feet above the base of the Minsi at Lehigh Gap and also in a large block of rock in the retaining wall about 300 feet south of the Martinsburg-Shawangunk contact along U.S. Interstate 80 in Delaware Water Gap. Schuchert (1916, p. 546) reported *Arthrophycus* 225 feet above the base of the Shawangunk (Minsi Member of this report) in Delaware Water Gap.

In the overlying interbedded shales, siltstones, and sandstones (Clinton Formation of Swartz and Swartz, 1931; quartzite-argillite unit of Epstein and Epstein, 1967, 1969; Clinton Member of Epstein, 1970, 1971; Lizard Creek Member of this report), the only fossils reported are rare specimens of *Arthrophycus* (Schuchert, 1916), eurypterids (Clarke and Ruedemann, 1912), Dipleurozoa (Johnson and Fox, 1968), and *Lingula* (Epstein and Epstein, 1969). *Lingula,* a long-ranging facies fossil, and dipleurozoans, very rare as fossils, cannot be used for correlation.

*Arthrophycus alleghaniense,* in the Shawangunk-Tuscarora of Pennsylvania, New Jersey, and New York, was believed to be a guide fossil for the Lower Silurian (Medinan) by Schuchert (1916), Willard (1928), and Swartz and Swartz (1930). *Arthrophycus* has been regarded as a fossil worm or plant remains (Becker and Donn, 1952) but is now generally recognized as a feeding burrow (Häntzschel, 1962), a conclusion reached long ago by Sarle (1906). However, according to Seilacher (1955), these ichnofossils generally have no age significance but only paleoecological significance. Amsden (1955), Pelletier (1958), and Yeakel (1962) showed that *Arthrophycus* was strongly facies controlled, apparently limited to transitional fluvial and marine environments.

It is obvious, therefore, that *Arthrophycus* is a facies fossil and cannot be used to date the Shawangunk.

Eurypterid remains found in the Shawangunk Formation at Otisville, N.Y., and Delaware Water Gap, Pa., and in the Tuscarora Sandstone at Swatara Gap, Pa. (Clarke and Ruedemann, 1912; Swartz and Swartz, 1930, 1931) have been considered to be Early Silurian in age. Swartz and Swartz (1930, p. 473), however, sounded a note of caution, "It would seem inevitable to conclude that the Shawangunk is early Silurian unless the eurypterids are without significance for correlation." Grabau (1913) gave arguments for the fact that eurypterids were river-dwelling organisms, have long stratigraphic ranges, and do not form "exact horizon markers" (p. 526). Clarke and Ruedemann (1912) were likewise a bit cautious, indicating that the age assignment at Delaware Water Gap was tentative because (1) the eurypterids were altered and fragmented, (2) the evolution of eurypterids may have been slow and the complete ranges of species unknown, and (3) eurypterids are apparently facies controlled. Both Amsden (1955) and Størmer (1955) emphasized the scarcity and environmental control of eurypterids. Apparently, eurypterids were confined to brackish and fresh waters, which agrees with the environmental interpretation of the Shawangunk as a fluvial-transitional marine sequence. (See section "Depositional Environments and Paleogeography.")

Thus, neither the eurypterids in the Shawangunk Formation and Tuscarora Sandstone, nor *Arthrophycus*, can be used for precise age determination because of facies control and uncertainty of species ranges. It is interesting, in this regard, that Willard (1928, p. 257) compared the Shawangunk eurypterids with those found in the Pittsford Shale (Upper Silurian) and Frankfort Shale (Upper Ordovician, Edenian) of New York. He found the closest faunal similarity with the Frankfort and concluded that the Shawangunk must be Early Silurian in age because "the presence of *Arthrophycus* in the Shawangunk points to its being Lower Silurian, since that organism is conceded to be of that age."

In summary, the evidence used to date the Shawangunk Formation of eastern Pennsylvania has been based on insecure stratigraphic data and fossils that are strongly environmentally controlled and whose ranges are poorly known because of rare occurrences. The evidence needs reevaluation. It is conceivable that the Shawangunk is Late Ordovician in age as well as Early Silurian; the same conclusion was also reached by Berry and Boucot (1970, p. 224). Perhaps intensive investigations of the phytoplankton assemblages, such as the one made by Cramer (1969) for the Rose Hill and Tuscarora Formations of central Pennsylvania, can provide the information needed to accurately date these clastic rocks.

## DEPOSITIONAL ENVIRONMENTS AND PALEOGEOGRAPHY

Regional stratigraphic relations, sedimentary structures, and petrographic characteristics suggest that rocks of the Shawangunk Formation are a clastic wedge of material shed from a linear highland source uplifted during the Taconic orogeny to the southeast and deposited by rapidly flowing streams (Weiders, Minsi, Tammany Members) and in a transitional marine-continental environment (Lizard Creek Member) (fig. 22). Incomplete data indicate that the source rocks were chiefly sedimentary and low-grade metamorphic types, shot through with quartz veins.

The major environments of deposition that we previously interpreted for Silurian clastic rocks in eastern Pennsylvania (Epstein and Epstein, 1967, 1969) are in general agreement with those of Smith (1967a, b) and Smith and Saunders (1970), who made an independent study of these rocks from New York to central Pennsylvania.

In general, previous workers on the Shawangunk have considered it to be predominantly deltaic or fluvial in origin (for example, Grabau, 1909, 1913; Swartz, 1948; Yeakel, 1962; Hunter, 1970), although an exclusively littoral origin (Schuchert, 1916; Willard, 1928) and tidal origin (Clarke and Ruedemann, 1912) have also been proposed.

Initially, uplift of the source area was rapid, for the basal Shawangunk rocks in the Weiders Member are coarse. These rocks were possibly present southeast of the Delaware Water Gap area but were removed by erosion. Shallow-marine sediments that would have heralded the arrival of the initial fluvial sediments presumably overlay the Martinsburg at one time but were eroded by the streams that ultimately deposited the basal Weiders and Minsi rocks. In general, the sediments are finer grained higher in the Shawangunk and to the southwest, representing a transgressive phase and lowering of the source area concomitant with basin subsidence. A regressive phase, or progradation of fluvial sands over marginal marine sediments of the Lizard Creek Member, is indicated by the overlapping of the coarse-grained rocks of the Tammany Member and its southwestward-extending tongues.

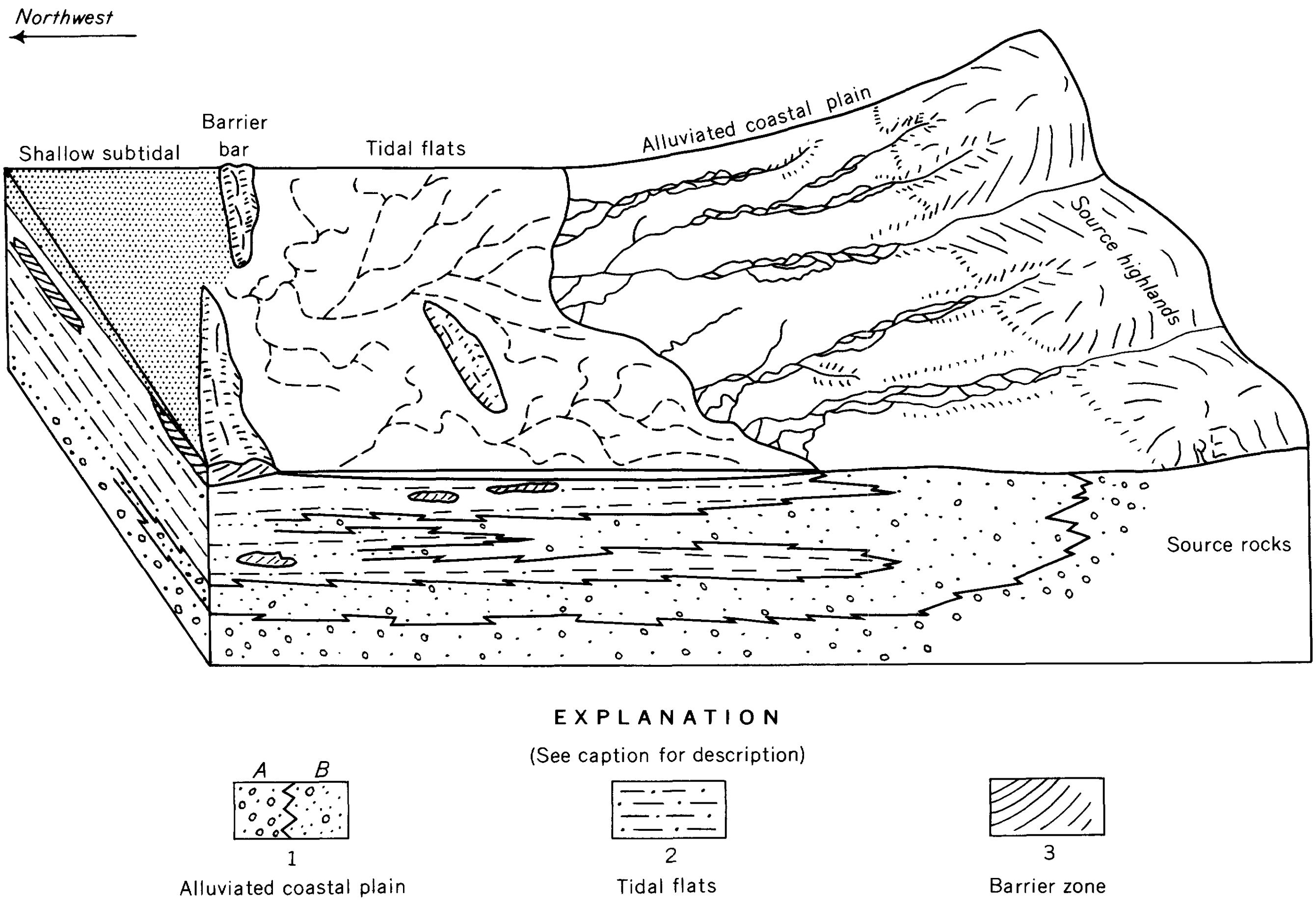


FIGURE 22.—Generalized block diagram showing sedimentary environments and major lithofacies in the Shawangunk Formation. Alluviated coastal plain: 1, Streams of high gradient, coarse load, low sinuosity (braided). *A*, Bedforms in upper flow regime (planar beds, antidunes) and upper lower flow regime (dunes); chiefly conglomerate and sandstone; Weiders Member. *B*, Bedforms in lower upper flow regime (planar beds) and upper lower flow regime (dunes); chiefly conglomeratic quartzite and quartzite; Minsi and Tammany Members; tongues of Tammany Member in Lizard Creek Member. Tidal flats: 2, Intertidal flats, may include narrow supratidal flats, tidal creeks, estuary, lagoon, beach. Shale, siltstone, sandstone, minor nodules of collophane, siderite, and chlorite. Irregularly bedded and laminated, graded, rippled, flaser-bedded, cut-and-fill, ball-and-pillow structure, burrowed, restricted fauna. Lizard Creek Member. Barrier zone: 3, Offshore bar and beach. Conglomerate, sandstone, and siltstone. Foreshore laminations, crossbedding, scouring, wave-tossed shell debris, textural maturity. Lizard Creek Member.

The Weiders Member is characterized by abrupt alternations of conglomerate beds, medium- to very coarse grained sandstone, and very minor argillite. The conglomerates contain quartz pebbles as much as 6 inches long and are indistinctly bedded to planar bedded. The sandstones are planar bedded to crossbedded, indicative of relatively rapid flow (upper lower flow regime to upper flow regime; Simons and Richardson, 1962; Fahnestock and Haushild, 1962; Gwinn, 1964), and are probably channel and bar deposits of streams. One possible antidune was recognized at Lehigh Gap (Epstein and Epstein, 1969, fig. 50). Grain size is variable, and pebbles are well rounded to subangular, indicative of a fluviatile environment (Sames, 1966). The conglomerates are partly polymictic, and the sandstones are generally poorly sorted and submature to immature with a muscovite- and chlorite-rich matrix (graywackes and protoquartzites are most common). Paleocurrent trends in the Weiders, as well as in all units considered to be fluvial, are unidirectional to the northwest (fig. 23), as first recognized by Yeakel (1962), who supported a fluviatile environment for the Shawangunk.

The bedforms and sedimentary structures indicate deposition by streams that had great competency and steep gradients. The abrupt superposition of beds with varied grain size, internal structure, and

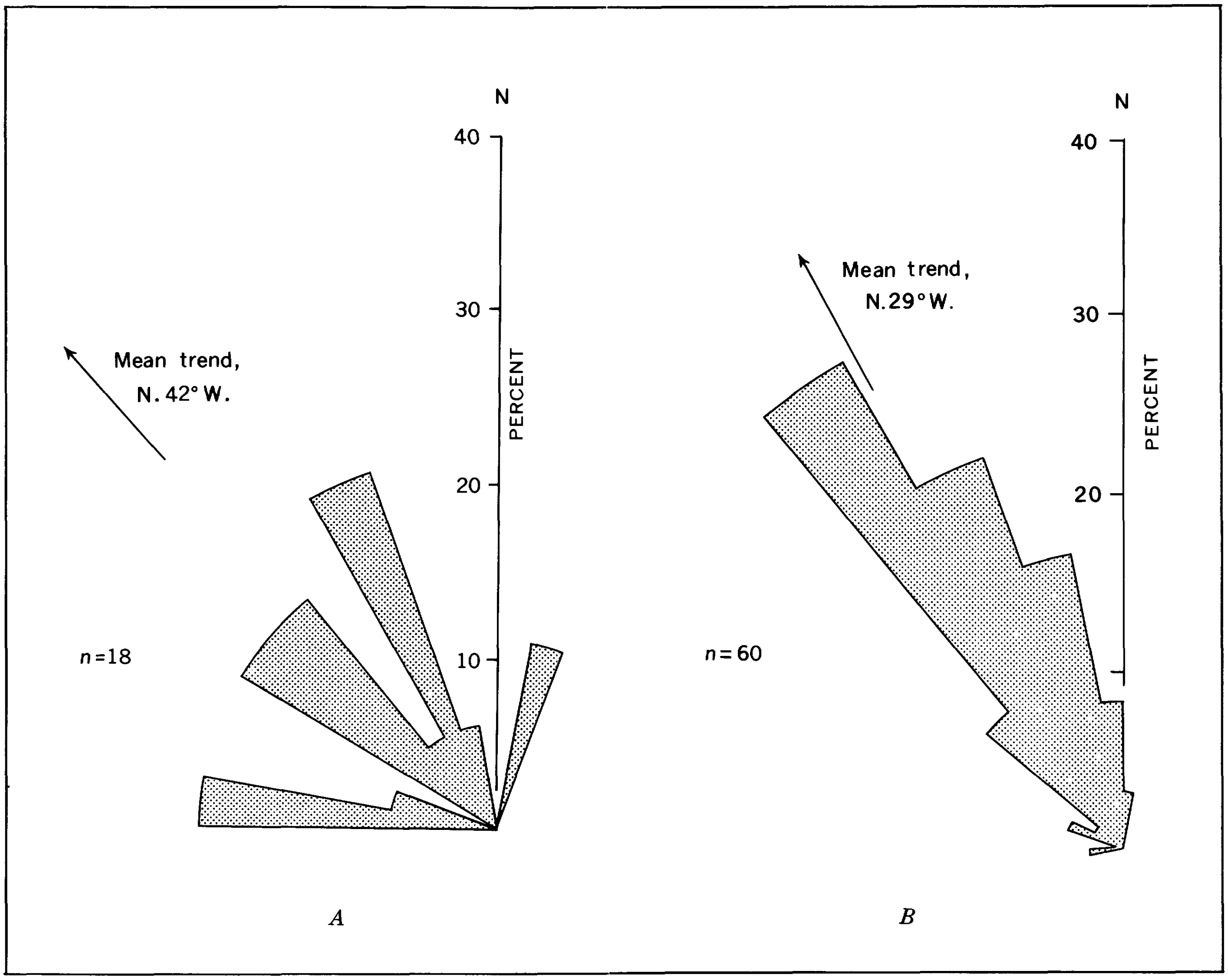


FIGURE 23.—Histograms showing current trends from crossbedding in the Shawangunk Formation at Lehigh Gap (*A*) and Delaware Water Gap (*B*). Beds rotated to horizontal.

thickness (fig. 3) suggests erratic fluctuations in current flow and channel depth. These features are characteristic of braided streams. The characteristics of modern braided streams, similar to those described above, have been discussed in many papers (for example, Leopold and Wolman, 1957; Doeglas, 1962; Allen, 1965; Coleman, 1969). Smith (1970) compared characteristics of the Shawangunk with the braided South Platte-Platte River in Colorado and Nebraska. Scour and fill is common, and, in general, basal channel surfaces have a relief no greater than 5 feet, indicating that the streams flowed in constantly shifting anastomosing channels. The nearly complete absence of fine siltstone and shale in the Weiders is also characteristic of braided stream deposits. Braided streams shift so rapidly across the fluvial plain that they are able to remove most fine-grained sediment. The few thin pelites present are mere relicts of these finer deposits. Some of the mud and silt was incorporated in the coarser sediment as flattened mud balls.

Glaciofluvial deposits of Pleistocene age in eastern Pennsylvania are very similar to the conglomerates and sandstones in the Weiders. (See Epstein, 1969.) The glacial sediments were undoubtedly deposited by braided streams with high velocity and coarse load. Fahnestock (1963) described similar deposits of the White River, Mount Rainier, Wash.

The Minsi Member, which overlies the Weiders at Lehigh Gap and forms the basal unit of the Shawangunk Formation at Delaware Water Gap (fig. 2), is similar to the Weiders except that pebbles are smaller (less than 2 inches long) and argillites, probably representing overbank and backwater deposits, are more abundant. Mud cracks in at least one siltstone bed (fig. 8) show that these deposits were subject to subaerial exposure. Numerous sedimentary units are superposed as in the Weiders Member, and here also represent deposition by braided streams. The finer grain size, however, suggests that the source highlands were lowered or eroded back at this time.

The coarse clastic rocks of the Minsi Member grade abruptly up into interbedded sandstone, siltstone, and shale of the Lizard Creek Member which is interpreted to indicate that the Minsi alluviated coastal plain merged into broad flats in a complex transitional continental-marine environment (fig. 22). The following subenvironments were probably represented: Tidal flat, barrier bar or beach, estuary, tidal channel and gully, lagoon, and shallow subtidal. In addition, other complex environments characteristic of deltas described by many workers, for example, Shepard and Lankford, 1959; Coleman and Gagliano, 1965; Bernard and LeBlanc, 1965; Donaldson, 1966, were probably also represented, but more detailed studies are needed for their differentiation.

Both currents and waves shaped the sedimentary structures on tidal flats, so irregularly bedded, laminated, and lenticular sandstone, siltstone, and shale are abundant. (For recent examples, see Häntzschel, 1939; Straaten, 1955, 1961; Evans, 1965; Reineck, 1967.) Flaser bedding (ripple lensing, figs. 11, 24), scour-and-fill structure, minute load-cast structures, and crossbedding are common and are analogous to features in modern sediments reworked by tidal currents (Häntzschel, 1939), especially in tidal channels (Straaten, 1955), or are due to rippled sand deposited between beds of mud in deeper subtidal areas during storms (H. E. Reineck, oral commun., 1968). The Lizard Creek also contains mud flasers, formed by settling of mud in troughs of ripples in sand beds during slack water at the turn of the tide. These are similar to structures found in recent tidal channels (Reineck and Singh, 1967) and are characteristic of tidal-flat sediments. Load casts are found at the bases of many sandstones. Laminated shales to fine sandstones, locally common in the Lizard Creek, probably represent sediment deposited from suspension under tranquil water conditions—at periods of slack tide or in protected bodies of water, such as lagoons (McKee, 1957). Some of the laminated beds are red and may have been deposited on high tidal flats and partly bound by algae, as described in The Wash (England) by Evans (1965). Similarly, red burrow-mottled siltstones may have formed as supratidal deposits in the oxidizing zone above mean-tide level; these would be landward equivalents of intertidal green beds (McKee, 1957; Nichols, 1962).

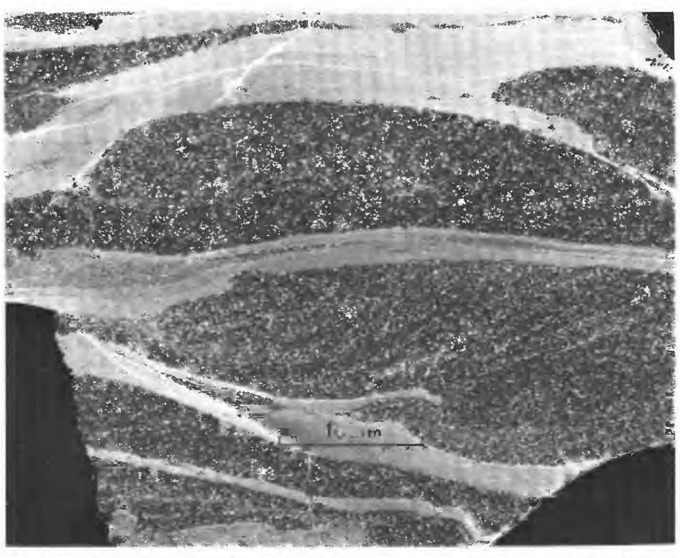

FIGURE 24.— Flaser bedding (ripple lensing) showing oblique bedding in rippled sandstone lenses surrounded by shale laminae, Lizard Creek Member of the Shawangunk Formation, roadcut along State Route 45, Carbon County, Pa. This structure is typical of the tidal-flat environment (compare with Reineck, 1967, fig. 9). Negative print of acetate peel from measured section 3, unit 66.

Tidal-flat sediments may be reworked considerably (burrow mottled) by organisms, so burrows are common (figs. 15, 16). The animals that were responsible for the burrows have not generally been preserved as fossils. Similar lack of preservation has been noted on recent tidal flats in the Netherlands (Straaten, 1955) and has been attributed to decay by bacteria, scavenging by other organisms, and lack of hard parts (organisms probably worms). The few fossils that have been found are consistent with the interpretation of a tidal-flat environment: linguloid brachiopods (see following discussion), *Arthrophycus*, eurypterids, and Dipleurozoa (see section on age of the Shawangunk).

Some crossbedded sandstones, many having pronounced truncated bases, contain flattened mud clasts or mud galls; these sandstones may be tidal-channel or tidal-gully deposits. (See Straaten, 1961). The clasts were derived either from reworked curled mud cracks or from slumped mud banks undercut by the tidal creeks. The latter cause was probably the more important one, because mud cracks were not seen in the Lizard Creek. The presence of the mud clasts indicates that the mud that made up the banks was very cohesive. Many of the sandstones at Lehigh Gap grade up into flaser-bedded and laminated siltstone, fine sandstone, and shale, and are probably fining-upward deposits of meandering tidal creeks. These intervals are generally a few feet thick. Some of these beds grade up into red bioturbated shaly siltstone that may represent sediments oxidized and organically reworked above mean high tide. Similar cycles of high- and low-tidal-flat sediments were described by Smith (1968) at Schuylkill Gap.

Some thicker crossbedded sandstone, as much as 8 feet thick, containing mud clasts, may be fluviatile sediments that prograded onto the flats or may be estuarine sediments, that is, sands that were carried into the transitional environment under the influence of currents generated by streams. The distinction between tidal-channel estuarine and fluviatile sands may be difficult to make because the sedimentary features are similar in the two (Land and Hoyt, 1966). The lateral change in facies between the Tammany Member (believed to be fluviatile) and the Lizard Creek Member, as well as the gradation between the fluviatile beds of the Minsi Member and the Lizard Creek, supports the interpretation that some of the beds in the Lizard Creek are estuarine. Clean red sandstones may have been deposited in an agitated and well-oxygenated estuarine environment, perhaps near streams that carried colloidal iron to be deposited as a cement.

Many sandstones in the Lizard Creek appear evenly textured and massive in outcrop, but on polished or wet sawed surfaces they are finely bedded to laminated (fig. 10). These mature calcareous sandstones (generally orthoquartzites, fig. 14) contain heavy minerals concentrated in laminae and have primary current lineation. They are interpreted as beach or bar deposits associated with the tidal flats. If our interpretation is correct, the paleogeography may have been similar to the chenier plains along the southern coast of Louisiana. (See Hoyt, 1969.) These marginal delta plains are downdrift from active delta progradation. Sediments are carried into this area by longshore currents from areas of stream debouchment. Beach ridges (cheniers) form by the sorting action of waves on the mudflats during periods of slack sedimentation. Shifting streams may then bring more sediment into the area, so that the flats prograde. The sediments are then reworked during a decrease in sedimentation, and another beach ridge forms. Thus, the chenier plain develops with alternations of beach-ridge sands and mud-flat silts and clays.

Other sandstones in the Lizard Creek Member are ripple topped (fig. 13) and are similar to the sand-flat sandstones described by Evans (1965). Rare silty sandstones have ball-and-pillow structure, due to soft-rock slumping (fig. 12), that were possibly produced during storms. Ore (1964), however, described similar intraformational deformation in deposits of braided streams and attributed them to movement of saturated sediment, a condition also prevalent on tidal flats.

Collophane (calcium fluorapatite), siderite, and chlorite nodules found at Lehigh Gap and collophane nodules at Delaware Water Gap (fig. 2) are unique to the Lizard Creek. The thin rim of chlorite on some siderite nodules, the flattening of some nodules over clastic grains, the protrusion of quartz grains from the nodules into the surrounding matrix, the presence of coarser quartz grains and broken brachiopod shells in the nodular beds, and other soft-rock features (fig. 18) indicate that the nodules formed as early diagenetic replacements in an agitated environment and that transport of the nodules was slight. Shell fragments of linguloid brachiopods, probably *Lingula*, suggest that these nodules formed in shallow warm waters, possibly brackish, at depths probably less than 60 feet (Craig, 1952). Thompson (1968) noted linguloid brachiopods in silty clays and sands in troughs or swales between sandbars in the lower intertidal zone of the Colorado River delta. Thus, finding *Lingula* reworked in beach sands (fig. 18) is not unusual.

If some of the chlorite in the Lizard Creek was originally chamosite (found in equivalent rocks in States adjacent to Pennsylvania), as mentioned previously, this would have important environmental significance. Porrenga (1967a, b) has shown that chamosite is presently found in tropical waters at depths generally less than 60 meters and temperatures greater than 20°C, whereas glauconite forms in deeper and colder waters. Hunter (1960, 1970) showed a northeast-trending belt of chamosite, succeeded by a glauconite belt to the northwest, in the Appalachian basin in Clinton time. The association of siderite with chamosite is considered by Hunter to indicate deposition in quiet waters that were deeper than the agitated, oxygenated waters closer to shore, in which hematite was deposited. It has been suggested that siderite forms beneath the water-sediment interface in a reducing environment with restricted water circulation (Curtis and Spears, 1968) and that siderite and chlorite are diagenetic products of the reaction between limonite, quartz, and organic reducing material (Bubenicek, 1969).

These conditions may be satisfied in lagoons (Sheldon, 1964) and estuaries.

Collophane nodules are associated with the chlorite and siderite nodules and with shell fragments of *Lingula*. Formation of these associated nodules, all of apparently very early diagenetic or penecontemporaneous origin, requires a unique set of physical, chemical, and biological conditions. The collophane appears to have formed as concretionary masses or by precipitation of carbonate fluorapatite from sea water (the presumably authigenic nodules at Delaware Water Gap are dominantly carbonate fluorapatite and contain lesser amounts of muscovite and quartz, as indicated by X-ray diffraction analysis) and as replacements of siltstone and shale (as seen in thin sections of rocks from Lehigh Gap). *Lingula* may have been the main intrabasin source for the phosphate, but the ultimate source was either dissolved phosphorous carried in by streams or brought into the shallow nearshore waters by downwelling currents from farther offshore (Gulbrandsen, 1969). The phosphate was tied up in and concentrated by organisms such as *Lingula* and eurypterids. Under favorable conditions the phosphate was concentrated into nodules upon death of the animals. Solution and reprecipitation of the phosphatic shell material at or just below the water-sediment interface probably produced phosphatized silt and mud locally (Clarke, 1924). Many of the phosphate nodules have the same soft-rock deformation features that were described for siderite nodules. Occasionally, waves and tidal currents churned these muds and also comminuted some of the phosphatic shell material. Many of the *Lingula*-nodule beds are heavy lag concentrates in well-sorted sandstones having laminations typical of foreshore beach deposits (fig. 18A). There can be little doubt that the phosphate nodules are of very shallow water origin. (See Bushinski, 1964, and references cited therein.) The interpretation that parts of the Lizard Creek Member are estuarine in origin is in harmony with the conclusion of Pevear (1966) that phosphatization probably occurred in estuaries of the Atlantic Coastal Plain.

The Tammany Member is very similar to rocks in the Minsi Member and indicates progradation of fluviatile sediments (or a deltaic topset plain) out over the transitional environment of the Lizard Creek (fig. 2). The progradation shows that the amount of material entering the basin exceeded the removal capacity of ocean waves and currents. This localized regression may have been caused by the shifting of the locus of major stream debouchment rather than by uplift in the source area, because the coarse deposits of the Tammany die out southwest of Delaware Water Gap.

The occurrence of ferroan dolomite beds and dolomite and calcite nodules in the Tammany Member (fig. 21) indicates proximity to a body of salt water that supplied magnesium for dolomitization, possibly in the same manner described for the penecontemporaneous dolomitization of limestone in supratidal environments. (For example, see Shinn and others, 1965.) Implied in this scheme are brines in the ground water, evaporation exceeding rainfall so that water reaching the surface by capillary action is enriched in salts, magnesium-to-calcium ratio increasing by precipitation of gypsum, and dolomitization of calcareous shales by the magnesium-rich waters. The water body close by may have been the sea, a lagoon, or a lake on the alluviated coastal plain.

Fluvial conditions persisted into Bloomsburg time, but the fining-upward cycles and higher content of siltstone and shale in the Bloomsburg indicate that the braided streams of the Tammany gave way to meandering streams as the southeastern source area was progressively lowered by erosion. For a discussion of the Bloomsburg Red Beds see Epstein and Epstein (1969) and Epstein (1971).

The long linear outcrop belt of the Weiders and Minsi Members suggests that these lower coarse clastic sediments of the Shawangunk Formation were deposited on a coastal plain of alluviation with a linear source to the southeast (fig. 22). Yeakel (1962) noted loci of thicker deposition for Tuscarora and "equivalent beds" in the Delaware Water Gap area and farther southwest in the Harrisonburg area, Virginia and West Virginia. However, at Delaware Water Gap his reported thickness included the Lizard Creek and Tammany Members, whereas, at Lehigh Gap, where his reported thickness is one-fourth as much, he included only the Weiders and Minsi Members of this report.

The large pebbles in the Weiders Member (more than 6 inches long in places) suggest that the Fall Line could not have been far to the southeast, perhaps in the area of the Reading Prong. (See Yeakel, 1962.) Abundant pelitic fragments in basal conglomerates argues against long-distance transport of these clasts. The maturity of the pebbles (quartz, chert, sandstone, and quartzite) and of the nonopaque heavy minerals (preponderantly zircon and tourmaline, many grains of which are rounded) suggests a sedimentary source. Biotite, fragments of metaquartzites (composite grains of stretched quartz), and rare grains of slate, as well as abundant sand-sized grains of detrital muscovite, indicate that the source rocks were partly made up of low-grade metamorphic rocks. The source area also had abundant quartz veins, because most of the pebbles are vein quartz with an irregular mosaic of interlocking quartz crystals; many contain inclusions of vermicular chlorite.

Basal beds in the Minsi Member contain enough potash feldspar (fig. 7) to suggest that the source was also partly composed of granitic or gneissic rocks. It might be argued that granitic and gneissic rocks were major components of the source area and that the mineralogical maturity of sandstones and conglomerates of the Shawangunk is due to deep weathering in the source area. Facts against this view are (1) the well-rounded condition of many zircon and tourmaline grains, indicating multicycle transport, (2) the presence of some feldspar in the Minsi Member at Delaware Water Gap, showing that weathering was insufficient to remove it, (3) the absence of kaolinite in the clay-size fraction (as shown by X-ray diffraction studies), which indicates that weathering was not intense enough to produce kaolinite from feldspar (however, any kaolinite that may have been present could have converted to muscovite by diagenesis or by metamorphism following deep burial), and (4) the large size of the pebbles, which indicates short transport, bold valleys in the supposed deeply weathered source area to supply the pebbles and exposure of fresh bedrock in the valley walls. Less stable minerals, such as feldspar, amphibole, and pyroxene, which would have been deposited with the quartz-bearing conglomerates and sandstones, should be abundantly present, but they are not. The absence of feldspar, amphibole, and pyroxene in most Shawangunk rocks apparently cannot be attributed to stream abrasion, for Russell (1937) has shown that these minerals persist in the Mississippi River and are only slightly diminished after transport of more than 1,000 miles.

Perhaps, mature sediments cannot be derived from active erosion of youthful mountains in humid tropical areas, even though the rate of chemical weathering is high. For example, in Papua, New Guinea, Ruxton (1970) noted that fluvial sediments are derived mostly from rapid erosion of steep mountain slopes, where only weakly weathered soils are developed. The source rocks are metamorphic, mafic, and ultramafic. Rock fragments and unstable mineral grains are common in the alluvium, even though soils on the interfluves contain abundant kaolin and quartz. Studies in other areas, such as the Andes (Gibbs, 1967) and the mountains of Venezuela (Van Andel and Postma, 1954) and Dominica (Elliot, 1951), show that physical weathering dominates chemical weathering in active orogenic mountain areas, and extensive maturation of the eroded mineral suite is not to be expected. Physical weathering was also probably favored during Silurian time because of the lack of extensive protective vegetation cover, if indeed any was present at all.

The absence of limestone pebbles and the presence of chert supposedly derived from cherty limestones is difficult to explain. Possibly the chert was derived from bedded (radiolarian?) chert generally associated with marine pelites and graywacke. This possibility is favored by the presence of siliceous slate fragments in the basal part of Weiders Member at Lehigh Gap. The composition of Shawangunk conglomerates and sandstones, thus, does not seem to be compelling evidence for a deeply weathered source area. Not necessarily contrary to this view is Hunter's (1970) conclusion that iron in the rocks of the Clinton Group and its equivalents was derived from weathering of iron-bearing rocks in the source area. He noted that the fluvial environment was one in which iron was transported but not deposited in any great quantity. This is in accord with the sparsity of fine-grained sediments in the fluvial sediments of the Weiders, Minsi, and Tammany Members. The iron was precipitated when the streams debouched into the nearshore marine environment. Hunter maintained that the degree of weathering increased as the source area was lowered by erosion and that, for this reason, feldspar, chert, and polycrystalline quartz, which are selectively separated from single-crystal quartz during increased weathering, are less abundant higher in the section. On the basis of this supposition, then, the Weiders and Minsi represent intense erosion and little weathering in the source area, and the Lizard Creek Member, with its red beds and abundant iron-rich minerals, indicates more intense weathering. This hypothesis would be most attractive were it not for the fact that the Tammany Member, which is similar to the Minsi Member and thicker than the Minsi at Delaware Water Gap, grades laterally into the Lizard Creek.

If the higher iron concentrations were due to greater chemical weathering in the source rocks and if the nature of the source rocks remained unchanged, the red beds should contain less unstable or semistable minerals than the nonred beds. However, the thickest red-bed sequence in the area, the Bloomsburg Red Beds, is petrographically distinctive from the underlying Shawangunk rocks in that feldspar and chlorite, and to a lesser extent biotite, are abundant. Therefore, we conclude that the mineralogy of the source rocks, and not the degree of chemical weathering, controlled the mineralogy of clastic Silurian rocks in eastern Pennsylvania. The probability that the climate was warm and arid at least during Bloomsburg time, is supported by the occurrence of correlative thick salt deposits in New York (Rickard, 1969). Lotze (1964) included the Silurian rocks of Pennsylvania in the worldwide belt of evaporites of Silurian time, concluding that the area was extremely warm and arid. Schmalz (1969, 1971) argued that evaporite deposition does not require an arid climate, but only one in which evaporation exceeds runoff and precipitation. However, he (Schmalz, 1969, p. 798) did state that an environment "characterized by a dry and usually hot climate with a high net evaporation rate," is one of the basic conditions for the accumulation of geologically significant evaporite sequences.

Recognition of the precise source area is problematical and open to speculation. Feldspathic and quartzose metasedimentary rocks and smaller amounts of amphibolite, marble, and granitic rocks are now mainly exposed in the Reading Prong (Drake, 1969). Conceivably, equivalent rocks that may have been exposed during Silurian time could have been the source for some of the Shawangunk, and chert-bearing carbonates and quartzites of Cambrian and Ordovician age could have supplied other components. However, hornblende is extremely rare in the Shawangunk, and pyroxene and epidote, all common in Prong rocks, were not seen in any thin sections of Shawangunk rocks examined. Moreover, the Reading Prong characteristically lacks abundant quartz veins and is, therefore, not an enticing possibility as a source area for the Shawangunk. Could it be that rocks dissimilar to those now found to the southeast were the source for the Shawangunk, emplaced in their position in thrust sheets or nappes but long since eroded? Drake (1970) reported that a sequence of low-grade metasedimentary and metavolcanic rocks is found on the north border of the Prong. These are apparently younger than the more highly metamorphosed rocks they overlie and once could have been more extensive. They could have been a source for much of the Shawangunk.

The scattered specks of graphite in the Lizard Creek Member are unique and indicate a metamorphic source. A possible source area is the Piedmont of southeastern Pennsylvania. Here, Miller (1912) reported graphite in the Pickering Gneiss and limestones ("Franklin Limestone") of Precambrian age. In general, graphite is disseminated in these rocks as flakes averaging $\frac{1}{16}$–$\frac{1}{8}$ inch in diameter, about the same size found in the Shawangunk. If the Piedmont rocks were the source, the graphite may have been transported by flotation in streams and would have undergone very little reduction in size. However, the Pickering Gneiss is feldspar rich, and, as mentioned, the Shawangunk contains rather small quantities of feldspar.

In summary, judging from the available data, we conclude that during Shawangunk time the climate was warm and at least semiarid, and that the source area had high relief. The mineralogy of the Shawangunk was controlled by the nature of the source rocks, which were composed predominantly of sedimentary and low-grade metamorphic rocks with abundant quartz veins and small local areas of feldspathic gneisses or granites. Erosion was intense, although enough broad interfluves may have been present so that a regolith developed that could supply iron to the depositional basin.

## MEASURED SECTIONS

### *Section 1*

[Shawangunk Formation along U.S. Interstate 80, Delaware Water Gap, Portland quadrangle, Warren County, New Jersey. Beds generally dip moderately northwest but are interrupted by two small folds. Measurement begins within an estimated 3 ft of the covered contact between the Shawangunk Formation and Martinsburg Formation and ends at the contact between the Shawangunk Formation and Bloomsburg Red Beds. Type section of the Tammany and Minsi Members of the Shawangunk Formation]

| | *Thickness (ft)* |
|---|---|
| Shawangunk Formation: | |
| Tammany Member: | |
| 65. Quartzite and quartz-pebble conglomerate, medium-gray (*N*5) to medium-dark-gray (*N*4), limonitic; quartz pebbles as much as 1.0 in. long; dark-gray (*N*3) argillite clasts as much as 2.0 in. long; beds as much as 12.0 ft thick; crossbedded and planar-bedded; uppermost few feet consists of brownish-gray (5*YB* 5/1) fine- to medium-grained quartzite and of conglomeratic quartzite that has angular pebbles as much as 1.0 in. in diameter; top of unit forms dip slope in contact with red sandstone and siltstone of the Bloomsburg Red Beds; basal contact gradational; thickness of unit approximate | 241.0 |
| 64. Quartzite, medium-gray (*N*5) to medium-dark-gray (*N*4), fine-grained, hematitic, crossbedded; in massive beds as much as 5.0 ft thick; some interbedded dark-gray (*N*3) argillite | 125.0 |
| 63. Argillite, dark-gray (*N*3); thins updip; basal contact abrupt | 3.2 |
| 62. Quartzite, medium-gray (*N*5), fine-grained, limonitic, massive; basal contact gradational | 4.8 |

***Section 1—Continued***

Shawangunk Formation—Continued — *Thickness (ft)*

Tammany Member—Continued

61. Quartzite and argillite. Medium-gray (*N*5) to medium-dark-gray (*N*4) fine-grained quartzite interbedded with dark-gray (*N*3) argillite. Beds about 3.0 in. thick. Unit forms base of steep cliff at an elevation of 660 ft. Dark-gray argillite abruptly overlies dense massive quartzite at base ---------- 5.8
60. Quartzite, medium-gray (*N*5) to medium-dark-gray (*N*4), fine- to medium-grained, limonitic, massive; a few beds of dark-gray (*N*3) argillite; basal contact concealed ---------- 69.1
59. Covered ---------- 7.0
58. Quartzite, shaly siltstone, and silty shale. Medium-gray (*N*5) to medium-dark-gray (*N*4), fine- to medium-grained, conglomeratic, limonitic, massive, crossbedded and planar-bedded quartzite in beds as much as 5 ft thick interbedded with dark-gray (*N*3) lenticular argillite in beds as much as 2 ft thick and argillite intraclasts as much as 5 in. long. Unit is more conglomeratic towards top. Basal contact abrupt 295.0
57. Shaly siltstone, dark-gray (*N*3), laminated; thins and pinches out 50 ft updip; basal contact abrupt ---------- 1.5
56. Quartzite, medium-light-gray (*N*6) to dark-gray (*N*3), very fine to very coarse grained; quartz pebbles as much as 2.0 in. long; crossbedded and planar bedded. Scattered beds of dark-gray siltstone and scattered siltstone pebbles as much as 3 in. long. Basal contact abrupt and disconformable ---------- 2.9
55. Argillite and quartzite. Dark-gray (*N*3), quartzitic, arenaceous, limonitic, laminated shaly siltstone interbedded with medium-gray (*N*5) fine-grained quartzite. Unit thins updip as dark-gray agillite pinches out. Basal contact abrupt and disconformable ---------- 3.5
54. Quartzite and silty shale. Medium-gray (*N*5) to medium-dark-gray (*N*4), fine- to medium-grained, partly conglomeratic, massive, crossbedded and planar-bedded quartzite with quartz pebbles as much as ½ in. long and dark-gray (*N*3) argillite pebbles as much as 2 in. long interbedded with dark-gray argillite as much as 6 in. thick which thins updip. Pyrite cubes scattered throughout. Basal contact abrupt ---------- 25.4
53. Shaly siltstone, dark-gray (*N*3) with pyrite cubes approximately 1 mm long, medium- to coarse-grained, massive, crossbedded and planar-bedded; conglomeratic quartzite bed 11 in. thick in middle of unit, separated from an overlying fine- to medium-grained quartzite 7 in. thick by a 2-in. siltstone bed. Unit thins updip. Basal contact abrupt ---------- 5.7
52. Quartzite and argillite. Medium-gray (*N*5) to medium-dark-gray (*N*4), fine- to coarse-grained, conglomeratic (angular to rounded quartz pebbles as much as ½ in. long and dark-gray angular to discoidal argillite pebbles as much as 3 in. long), crossbedded and planar-bedded, massive quartzite with lenticular beds of dark-gray (*N*3) shaly siltstone as much as 4 in. thick. Unit more conglomeratic towards top. Basal contact gradational-- 14.8
51. Quartzite, medium-gray (*N*5) to medium-dark-gray (*N*4), fine- to medium-grained, limonitic, crossbedded and planar-bedded, massive; beds average 1.5 ft thick; conglomeratic in uppermost foot; small pyrite cubes scattered throughout unit, especially in upper part; a few dark-gray (*N*3) burrow-mottled shaly siltstone and siltstone beds as much as 3 in. thick which pinch out within a few tens of feet are scattered throughout unit; basal contact abrupt ---------- 11.1

Total thickness of Tammany Member ---------- 815.8

Lizard Creek Member:

50. Quartzite, dark- to medium-gray, very fine to fine-grained, silty, argillaceous; contains dark-gray discoidal silty shale clasts as much as 2 in. long; unevenly bedded; basal contact gradational ---------- 3.4
49. Silty shale, dark-gray, alternating with medium-gray (*N*5) fine-grained limonitic quartzite in uneven beds less than 1 to 8 in. thick. Basal dark-gray (*N*3) argillite lying abruptly in contact with massive quartzite ---------- 5.3
48. Quartzite, medium-gray (*N*5), fine-grained, with scattered limonite flecks and dark-gray (*N*3) argillite pebbles averaging about ½ in. in length; massive; vaguely parallel bedded to structureless; ripples with 3-in. wavelengths 1.5 ft below top; beds less than 1 to 15 in. thick; a few thin interbeds of dark-gray (*N*3) silty shale; basal contact irregular and gradational - 6.8
47. Quartzite, shaly siltstone, and silty shale. Dark-gray, siliceous, very unevenly bedded and lenticular shaly siltstone and silty shale beds as much as 5 ft thick with thin lenses and beds of quartzite interbedded with medium-gray (*N*5) to dark-gray (*N*3) fine-grained, massive, lenticular, partly crossbedded, locally very limonitic (limonite specks as much as ¼ in. in diameter), partly conglomeratic

*Section 1—Continued*

Shawangunk Formation—Continued — *Thickness (ft)*

Lizard Creek Member—Continued

(intraclasts of dark-gray silty mudstone derived from underlying beds range in length from less than ¼ in. to as much as 2 in.) quartzite. Quartzite in beds 1–18 in. thick. Many bedding planes contorted and show flow structures, channeling, some load casts, flaser bedding, and burrow mottling. Some beds rippled. Basal contact consists of dark gray (*N*3) silty mudstone in disconformable contact with massive quartzite. Some quartzite beds contain phosphatic intraclasts as much as 1 in. long. Base of unit has small scattered phosphatic intraclasts ---------- 46.9

46. Quartzite, silty shale, and siltstone. Medium-dark-gray (*N*4), fine-grained, massive quartzite (with limonite flecks in upper half) underlain by medium-gray (*N*5) fine-grained limonitic quartzite unevenly finely to moderately bedded (flaser bedding and burrowed where siltstone and silty shale are interbedded with finer grained quartzite), interbedded with dark-gray (*N*3) muddy siltstone and silty mudstone in beds and lenses ¼–12 in. thick (mud flasers). Basal beds lenticular, very unevenly bedded, contain black phosphatic nodules. Basal 2 ft consists of very irregularly interbedded lenticular quartzite and flaser-bedded shale with abundant phosphatic nodules. Bases of many quartzite lenses have load casts and sole marks. Phosphatic intraclasts weather white; they are rounded to angular and as much as 1.5 in. long. Many nodules are partly penetrated by quartz sand grains. Contact between units 45 and 46 is at road level at northwest end of stone retaining wall and is abrupt ---------- 5.5

45. Silty shale, shaly siltstone, and silty quartzite, medium- (*N*5) to dark-gray (*N*3), fine-grained, partly limonitic; weather pale yellowish orange (10*YR* 8/6) to light brown (5*YR* 5/6); laminated but appear massive in part; partly burrow mottled, vertical burrows in upper 6 ft of unit; basal contact abrupt ---------- 10.1

44. Quartzite, medium-dark-gray (*N*4), fine-grained, partly limonitic; weathers light gray (*N*7); massive; some beds contain dark-gray silty shale clasts as much as 1 in. long; bedding characteristic—crossbedded and planar bedded; basal contact abrupt ---------- 4.4

43. Shaly siltstone, silty shale, and quartzite. Dark-gray (*N*3) arenaceous shale and siltstone interbedded and interlensed with thin quartzite in upper half of unit. Light- to medium-gray, partly silty, laminated,

*Section 1—Continued*

Shawangunk Formation—Continued — *Thickness (ft)*

Lizard Creek Member—Continued

crossbedded, and massive quartzite with a few thin beds of dark-gray mudstone in beds as much as 5 in. thick make up lower half of unit. A 3-in.-thick bed of fine-grained convoluted quartzite 2.5 ft below top of unit. Convolutions of laminated medium-light-gray (*N*6) to medium-gray (*N*5) very fine grained quartzite and medium-dark-gray (*N*4) siltstone. Basal contact abrupt ---------- 7.2

42. Quartzite and silty shale. Medium-light-gray (*N*6) to medium-gray (*N*5), fine-grained, massive, crossbedded quartzite containing dark-gray (*N*3) argillite fragments as much as 1 in. long. Quartzites are rippled and occur in beds 2–15 in. thick and are unevenly interbedded and interlaminated with dark-gray shaly siltstone. Unit partly burrow mottled. Silty shale makes up 12 percent of unit. Basal contact consists of quartzite abruptly overlying dark-gray silty shale ---------- 6.2

41. Quartzite and shaly siltstone. Dark-gray (*N*3) laminated shaly siltstone interbedded with dark-gray fine-grained to very fine grained silty crossbedded quartzite with clasts of siltstone as much as ½ in. long. Unit partly burrow mottled at top with shale-filled burrows. Unit faulted at road level and repeated 50 ft to northwest on northwest limb of small anticline. Basal contact abrupt ---------- 2.3

40. Quartzite, medium-gray (*N*5), fine-grained, massive; a few intercalations of dark-gray (*N*3) silty shale; crossbedded and planar bedded; basal contact abrupt ---------- 4.3

39. Quartzite, light-olive-gray (5*Y* 5/2) to medium-dark-gray (*N*4), fine-grained, crossbedded and planar-bedded; silty above basal foot and very limonitic towards top of unit; basal foot consists of medium-gray (*N*5) quartzite resting disconformably on dark-gray (*N*3) shaly siltstone and silty shale of unit 38. Quartzite-filled limonitic burrows in upper half (approx ¼ in. in diameter and as much as 10 in. long) occur in silty fine-grained quartzite. Very conspicuous vertical burrows in upper 7 ft. Overlying units folded and faulted. Contact between units 39 and 40 is abrupt and is repeated 50 ft to northwest ---------- 9.2

38. Shaly siltstone and shale, dark-gray (*N*3), laminated, alternating with light-olive-gray (5*Y* 5/2) and medium-gray (*N*5) fine-grained limonitic crossbedded quartzite that contains thin beds of dark-gray shale and clasts as much as 1 in. long; beds from less than ½ to 12 in. thick.

*Section 1—Continued*

| Shawangunk Formation—Continued<br>Lizard Creek Member—Continued | *Thickness (ft)* |
|---|---|
| Upper 3 ft consists predominantly of laminated dark-gray argillite. Basal contact abrupt | 8.1 |
| 37. Quartzite, medium-gray (*N*5), fine-grained, limonitic, crossbedded; a few thin intercalations of dark-gray (*N*3) silty shale constitute about 5 percent of unit; beds 4–20 in. thick; basal contact abrupt and disconformable | 5.9 |
| 36. Silty shale and shaly siltstone, dark-gray (*N*3), in uneven laminae and beds (beds as much as 3 in. thick), interbedded with light-olive-gray (5*Y* 5/2), fine-grained, limonitic, thin-bedded quartzite which constitutes about 15 percent of unit. Many sand-filled burrows parallel to bedding. Basal contact abrupt and disconformable | 7.4 |
| 35. Quartzite, moderate-brown (5*YR* 3/4) and medium-gray (*N*5), fine-grained, very limonitic (with limonite concretions as much as 1 in. in diameter), unevenly bedded; bedding plane 1 ft above base has ripple marks with amplitude of about ½ in. and wavelength of about 3.5 in.; basal contact abrupt and disconformable | 1.5 |
| 34. Shaly siltstone and silty shale, dark-gray (*N*3); contain spherical limonitic concretions averaging about 1 in. in diammeter; unevenly interbedded with light-olive-gray (5*Y* 5/2) to medium-gray (*N*5) fine-grained, limonitic, thin-bedded quartzite containing dark-gray (*N*3) argillite pebbles as much as 1 in. long. Upper ¾ ft is a light-gray (*N*7) fine-grained quartzite with dark-gray argillite pebbles as much as 1 in. long. Basal contact is abrupt and undulatory with many limonite concretions at or near the contact | 7.1 |
| 33. Silty shale, shaly siltstone, and quartzite. Siltstone contains some clay clasts ¼ in. in diameter and is partly burrow mottled. Medium-gray (*N*5) to medium-light-gray (*N*6) fine-grained limonitic crossbedded even-bedded quartzite makes up 50 percent of unit and is interbedded with dark-gray (*N*3) partly silty shale. A 3-in.-thick laterally discontinuous quartzite bed, 4 ft above base of unit, contains thin (0.1–1¼ in.) branching argillite-filled burrows about 1 in. long. The finer grained quartzites are ripple topped. Ripples have wavelengths of 3 in | 8.7 |
| 32. Quartzite, medium-gray (*N*5), fine-grained; limonite flecks; massive; crossbedded; laminated; basal contact abrupt and disconformable | 5.8 |
| 31. Quartzite, medium-gray (*N*5) to medium-light-gray (*N*6), fine- to medium-grained, limonitic, massive, partly rippled; contains minor shale clasts as much as 1 in. long; in beds 4 in. to 2.5 ft thick, alternating with dark-gray (*N*3) silty shale, partly burrowed, in beds 1 in. to 1 ft thick. Basal contact abrupt | 13.6 |
| 30. Siltstone, shaly, dark-gray (*N*3), with fine sand-filled burrows and fine-sand lenses; basal contact abrupt | 1.3 |
| 29. Quartzite, medium-gray (*N*5), fine-grained, crossbedded, with ½-in.-long clay galls; alternating with dark-gray (*N*3), limonitic silty shale and shaly siltstone in beds as much as 2 in. thick which constitutes less than 20 percent of unit. Basal contact abrupt and consists of a 2-ft quartzite abruptly overlying dark-gray argillite | 7.6 |
| 28. Quartzite, medium-gray (*N*5), fine-grained, crossbedded, unevenly bedded, with rare clay galls as much as 1 in. long; constitutes 70 percent of unit; alternating with dark-gray (*N*3) burrow-mottled silty shale and shaly siltstone. Basal contact gradational | 7.0 |
| 27. Quartzite, medium-gray (*N*5), fine- to medium-grained, limonitic, crossbedded, massive; basal contact abrupt and disconformable | 5.8 |
| 26. Quartzite, medium-dark-gray (*N*4), fine-grained, thin-bedded to laminated, crossbedded, alternating with dark-gray (*N*3) silty shale and shaly siltstone; beds ½–3 in. thick. Basal contact abrupt | 4.0 |
| 25. Quartzite and muddy siltstone to silty mudstone. Medium-dark-gray (*N*4), limonitic (limonite flecks about 0.1 in. in diameter scattered throughout), massive, unevenly bedded quartzite; contains scattered dark-gray (*N*3) argillite clasts as much as 2 in. long; in beds 1–11 in. thick; constitutes more than 90 percent of unit. Thin beds of dark-gray partly burrow-mottled shaly siltstone. Graphite grains as much as 0.1 in. long scattered throughout | 3.8 |
| 24. Quartzite and silty claystone. Light-olive-gray (5*Y* 5/2), fine-grained, laminated, partly limonitic, evenly bedded, crossbedded quartzite alternating with dark-gray (*N*3), silty, slabby, burrow-mottled shale, which constitutes about 65 percent of unit. Beds 1–8 in. thick. Basal contact gradational | 4.8 |
| 23. Quartzite and shaly siltstone. Medium-light-gray (*N*6), medium- to fine-grained, limonitic, crossbedded quartzite with scattered dark-gray (*N*3) argillite clasts as much as 1 in. long; in beds 1–19 in. thick; | |

***Section 1—Continued***

Shawangunk Formation—Continued — Thickness (ft)

Lizard Creek Member—Continued

makes up about 60 percent of unit. Quartzites interbedded with medium-dark-gray to dark-gray shaly siltstone and minor amounts of silty shale. Unit unevenly laminated to evenly bedded. Widely scattered irregular grains of graphite as much as 0.1 in. long. Some fine to medium sand fills burrows ¼ in. in diameter. Basal contact covered ........ 16.0

22. Quartzite and shaly siltstone interbedded, in beds 1 in. to 3 ft. thick. Covered at road level but exposed in gully above ........ 30.0

21. Covered. Probably consists mostly of siltstone and shale ........ 23.0

Total thickness of Lizard Creek Member ........ 273.0

Minsi Member:

20. Quartzite, light- (*N*7) to medium-gray (*N*5), medium-grained to conglomeratic; has quartz pebbles as much as ½ in. long; massive; crossbedded and planar bedded; uppermost bed is massive conglomerate about 2 ft thick and is exposed in culvert on east side of road; 1 in.-thick medium-greenish-gray (5*G* 5/1) siltstone 5.3 ft above base. Basal contact gradational ........ 12.8

19. Siltstone, shaly, dark-gray (*N*3), finely laminated, interbedded with medium-dark-gray (*N*4), conglomeratic, silty, fine-grained quartzite. Basal contact abrupt ........ 1.5

18. Quartzite, medium-gray (*N*5), fine- to medium-grained, limonitic; scattered angular quartz and chert pebbles as much as ½ in. long; crossbedded and planar bedded; massive; a few interbedded dark-gray (*N*3) shaly siltstone beds 1 in. thick or less; basal contact abrupt and disconformable ........ 11.5

17. Siltstone and silty shale, dark-gray (*N*3), compose about 65 percent of unit; interbedded with medium-gray (*N*5), medium-grained, crossbedded quartzite and quartz- and chert-pebble conglomerate. Basal contact abrupt ........ 3.7

16. Quartzite, light-olive-gray (5*Y* 5/2) to light-gray (*N*5), medium- grained, partly conglomeratic (angular to subrounded quartz pebbles as much as ½ in. long and shale clasts as much as 1 in. long); local ripples; lenticular; dark-gray (*N*3) laminated shaly siltstone in beds 1–8 in. thick composes about 10 percent of unit. Basal contact abrupt ........ 37.8

15. Siltstone, shaly, dark-gray (*N*3), interbedded with light-olive-gray (5*Y* 5/2) and medium-dark-gray (*N*4), medium-grained, limonitic, crossbedded quartzite. Unit from top to bottom consists of:

Siltstone ........ 0.8

***Section 1—Continued***

Shawangunk Formation—Continued — Thickness (ft)

Minsi Member—Continued

Quartzite ........ 5.3

Siltstone ........ 2.2

Basal contact abrupt and disconformable ........ 8.3

14. Conglomerate and quartzite. Light-olive-gray (5*Y* 5/2) to medium-dark-gray (*N*4) conglomerate with clasts as much as ¾ in. long composed predominantly of quartz; also scattered dark-gray (*N*3) shale pebbles as much as 1 in. long; conglomerate alternates with medium-gray (*N*5) to dark-gray (*N*3) medium- to coarse-grained quartzite. Unit massively bedded and crossbedded. Basal ½ ft is a conglomerate bed which locally grades into underlying light-gray (*N*7) quartzite ........ 24.3

13. Quartzite, light-gray (*N*7) to light-olive-gray (5*Y* 5/2), fine- to medium-grained, planar-bedded; weathers to a lighter color than units above and below; few thin lenses of darker gray quartzite; basal contact gradational ........ 8.0

12. Quartzite, conglomeratic quartzite, and conglomerate, light-olive-gray (5*Y* 5/2) and medium-dark-gray (*N*4) to light-gray (*N*7), predominantly medium grained, massively bedded, crossbedded and finely laminated; a few intercalations of dark-gray (*N*3) shaly siltstone totaling no more than 3 in.; some siltstone pebbles as much as 4 in. long. Basal contact abrupt ........ 89.0

11. Siltstone, shaly, arenaceous, dark-gray (*N*3), siliceous, laminated, alternating with light-olive-gray (5*Y* 5/2) and medium-dark-gray (*N*4) medium- to coarse-grained partly conglomeratic (pebbles no more than ¼ in. long) quartzite. Basal contact abrupt and disconformable ........ 4.8

10. Quartzite and conglomerate, light-olive-gray (5*Y* 5/2) and medium-dark-gray (*N*4), fine- to medium-grained, massively bedded, crossbedded; a few thin intercalations and channel fillings of dark-gray (*N*3) siltstone constitute about 4 percent of unit; conglomerate constitutes about 10 percent of unit. Basal contact abrupt and disconformable ........ 31.8

9. Conglomerate and quartzite, light-olive-gray (5*Y* 5/2) to medium-dark-gray (*N*4), crossbedded and planar-bedded; quartzitic conglomerate has clasts as much as ¾ in. in diameter and scattered silty shale clasts as much as 4 in. long; conglomerate is interbedded with dark-gray (*N*3) fine-grained argillaceous quartzite and siltstone. At road level are four dark-gray siltstone beds which are as much as 1 ft thick; these beds thicken and thin laterally. Conglomerates and

*Section 1—Continued*

| Shawangunk Formation—Continued<br>Minsi Member—Continued | *Thickness (ft)* |
|---|---|
| quartzites between the siltstones are lenticular. This unit is persistent for at least 100 ft updip. Mud cracks found updip at edge of cliff, approximately 60 ft above road level. Basal contact abrupt and disconformable | 7.2 |
| 8. Quartzite, alternating medium-gray (*N*5) and light-olive-gray (5*Y* 5/2) to light-gray (*N*7), fine- to medium-grained; planar-bedded beds 2 in. to 3 ft thick; basal contact gradational | 4.7 |
| 7. Conglomerate and conglomeratic quartzite, light-olive-gray (5*Y* 5/2) to medium-dark-gray (*N*4), crossbedded and planar-bedded; clasts as much as 1 in. long in a matrix of medium-grained quartzite; form basal 2.5 ft and grade up into medium-gray medium-grained laminated to fine-bedded quartzite. Basal contact abrupt | 6.0 |
| 6. Quartzite, light-olive-gray (5*Y* 5/2), fine- to medium-grained; a few scattered pebbles about ¼ in. long; basal few feet contains lenses of medium-dark-gray (*N*4) medium- to coarse-grained quartzite; upper half of unit crossbedded; basal half of unit planar bedded; basal contact abrupt | 9.5 |
| 5. Quartzite, light-olive-gray (5*Y* 5/2), medium-gray (*N*5) to medium-dark-gray (*N*4), predominantly medium grained, partly coarse grained; a few scattered angular pebbles as much as ½ in. long; crossbedded; basal contact abrupt | 8.2 |
| 4. Conglomerate and quartzite, light-olive-gray (5*Y* 5/2) and light-gray (*N*7) to medium-gray (*N*5), medium- to coarse-grained, limonitic, partly crossbedded, lenticular; pebbles of angular quartz and dark-gray (*N*3) chert as much as 2 in. in diameter and averaging ½ in. in diameter. Base of many conglomerate beds disconformable, with channels about ½ ft deep. There are six pronounced conformable contacts within this unit at road level. Conglomerate grades up into or is interbedded with finer quartzite. Conglomerate beds 1 in. to 1 ft thick. A few light-olive-gray (5*Y* 5/2) shaly siltstone lenses averaging about 2 in. in length scattered throughout unit. Basal contact abrupt | 11.3 |
| 3. Quartzite and conglomeratic quartzite. Angular pebbles of milky quartz predominate in a matrix of medium-dark-gray (*N*4) medium- to coarse-grained quartzite; matrix also contains scattered dark-gray (*N*3) chert and argillite pebbles as much as 1 in. long. Unit is conglomeratic and feldspathic at base becoming finer grained toward top. Unit is unevenly bedded; conglomeratic beds lenticular. Basal contact gradational | 1.8 |
| 2. Quartzite, light-olive-gray (5*Y* 5/2) and medium-light-gray (*N*6) to medium-gray (*N*5), fine-grained to conglomeratic; crossbedded to planar bedded; partly limonitic; angular to rounded quartz pebbles with a few dark-gray (*N*3) to grayish-black (*N*2) chert pebbles approximately ½ in. long; irregular bedded and crossbedded; conglomeratic, medium- to coarse-grained, and fine-grained quartzite beds 1 in. to 1 ft thick alternate; thin lenses of light-olive-gray (5*Y* 5/2) shaly siltstone not more than 1 in. thick and as much as 10 ft long; limonitic concretions, 1–1½ in. in diameter are scattered throughout but occur in zones along bedding planes; basal contact covered | 18.4 |
| 1. Covered; contact between Shawangunk and Martinsburg Formations covered by colluvium; covered interval about 2 ft thick | 2.0 |
| Approximate thickness of Minsi Member | 302.6 |
| Total thickness of Shawangunk Formation | 1,391.2 |

*Section 2*

[Part of the Shawangunk Formation exposed in roadcut on southwest side of Pa. Rte. 115 in Wind Gap in Blue Mountain at Wind Gap, Wind Gap quadrangle, Northampton County, Pa. Beds near vertical]

| Shawangunk Formation (part):<br>Lizard Creek Member (part): | *Thickness (ft)* |
|---|---|
| 41. Quartzite and argillite, partly exposed and weathered; quartzite predominates. Unit light olive gray (5*Y* 6/1), medium dark gray (*N*4), and medium gray (*N*5); weathers grayish orange (10*YR* 7/4) to dark yellowish orange (10*YR* 6/6). Quartzite, very fine to medium-grained, burrowed. Uppermost 23 ft exposed on shoulder 10 ft above road and contains several beds, as much as 3 ft thick, of interlaminated argillite and quartzite. Top of unit 550 ft south of intersection of Pa. Rte. 115 and old Pa. Rte. 115. Upper contact concealed; basal contact abrupt | 31.0 |
| 40. Quartzite and argillite. Medium-dark-gray (*N*4) to medium-light-gray (*N*6), very fine to medium-grained, irregularly bedded (flaser bedded) quartzite; beds 1–3 in. thick. Dark-gray (*N*3) argillite; occurs as clasts and fine streaks in the quartzite and as beds as much as 7 in. thick; argillite has many sand-filled burrows. Unit partly covered; basal contact abrupt | 23.0 |

*Section 2—Continued*

Shawangunk Formation (part)—Continued — *Thickness (ft)*

Lizard Creek Member (part)—Continued

39. Quartzite, dark-gray ($N3$) to medium-dark-gray ($N4$), fine-grained; numerous flecks of limonite; one massive bed; basal contact abrupt — 1.0
38. Quartzite and argillite, like unit 40. Quartzite in beds from 1 to 6 in. thick. Argillite in beds as much as 3 in. thick; also as flattened clasts and as thin lenses as much as several inches long. Unit partly burrowed and irregularly flaser bedded. Basal contact gradational — 4.6
37. Quartzite, medium-dark-gray ($N4$) to medium-light-gray ($N6$), very fine to coarse-grained; minor amounts of medium-light-gray ($N6$)-weathering argillite; beds massive and as much as 1 ft thick. Lower 2 ft consists of interlaminated argillite and quartzite. Unit crossbedded near base. Basal contact abrupt — 8.1
36. Quartzite and argillite, in equal amounts, interlaminated and interbedded. Dark-gray ($N3$) argillite; laminae uneven and wavy with scattered quartzite-filled burrows which range from parallel to perpendicular to bedding. Light-olive-gray ($5Y$ 6/1) to dark-gray ($N3$), fine-grained quartzite; beds 2–6 in. thick. Basal contact abrupt — 8.3
35. Quartzite, light-gray ($N7$) to medium-dark-gray ($N4$), fine- to coarse-grained, limonitic; generally massively bedded; contains some laminae; beds 2 in. to 1.5 ft thick; some beds with scattered dark-gray ($N3$) flattened argillite clasts as much as 1 in. long and irregular laminae; beds 0.5 in. thick to laminae of light-olive-gray ($5Y$ 6/1) medium-grained quartzite are interbedded with dark-gray argillite 14 in. above base of unit. Lower 14 in. of unit contains a 0.5-ft-thick zone with vertical burrows more than 1 in. deep and ¼ in. in diameter. Minor amounts of dark-gray ($N3$) argillite and medium-gray ($N5$) very fine grained quartzite form 3 ft of upper part of unit. Basal contact abrupt — 11.7
34. Argillite, dark-gray ($N3$). Unit contains two beds, 0.75 in. thick, of light-gray ($N7$) medium-grained quartzite; unit pinches out updip; basal contact abrupt — 0.9
33. Quartzite, medium-dark-gray ($N4$) to very light gray ($N8$), fine- to medium-grained, massively bedded; beds 1–14 in. thick. Argillite-filled burrows, ¼ in. in diameter, scattered in quartzite. Argillite clasts as much as 1 in. long occur in a few quartzite beds. Interbedded coarse-grained quartzite and dark-gray ($N3$) argillite in beds 1–3 in. thick make up about 1 ft of unit. Basal contact abrupt — 14.7
32. Argillite, dark-gray ($N3$); basal contact abrupt — 0.8
31. Quartzite, medium-gray ($N5$), fine- to medium-grained, massive; abundant limonite specks approximately 1 mm in diameter; basal contact abrupt — 3.1
30. Quartzite, light-gray ($N7$), fine- to coarse-grained; numerous dark-gray ($N3$) argillite clasts as much as 0.5 in. long, averaging about 0.5 mm thick and flattened parallel to bedding; crossbedded; basal contact channeled and abrupt — 0.9
29. Quartzite and argillite, interbedded and interlaminated, containing mud flasers. Argillite, dark-gray ($N3$). Quartzite, medium-gray ($N5$), fine-grained. Basal contact abrupt — 1.5
28. Quartzite, medium-dark-gray ($N4$), medium-grained; massive bed; basal contact abrupt — 1.7
27. Quartzite and argillite, interbedded. Argillite, medium-dark-gray ($N4$) to medium-gray ($N5$). Quartzite, medium-gray ($N5$) to medium-dark-gray ($N4$), fine-grained. Beds 1–4 in. thick; basal contact abrupt — 1.2
26. Quartzite, medium-dark-gray ($N4$) to light-gray ($N7$), medium- to coarse-grained, laminated to massive; contains rounded and flat argillite intraclasts ¼–2 in. long; most beds 1 in. to 2.5 ft thick and together with thin beds (less than 1 in.) of dark-gray ($N3$) argillite they make up about 5 in. of unit; unit partly crossbedded and flaser bedded; basal contact abrupt — 8.3
25. Sandstone, medium-gray ($N5$), very fine to fine-grained, micaceous; weathers light olive gray ($5Y$ 6/1); unevenly laminated; a 6 in. dark-gray ($N3$) argillite at top of unit; partly burrow mottled; basal contact abrupt — 3.3
24. Quartzite, medium-gray ($N5$), medium-grained, limonitic; beds as much as 2 ft thick; some dark-gray ($N3$) argillite clasts a few inches long; basal contact abrupt — 7.0
23. Quartzite, medium-dark-gray ($N4$), medium- to coarse-grained; laminated; basal contact abrupt — 0.6
22. Quartzite, like unit 24 but without argillite clasts; basal contact abrupt — 9.5
21. Argillite and quartzite. Argillite, dark-gray ($N3$) to medium-dark-gray ($N4$). Quartzite, medium-gray ($N5$) to medium-light gray ($N6$), very fine to fine-grained. Beds as much as 8 in. thick. Basal contact abrupt — 3.1

***Section 2—Continued***

| Shawangunk Formation (part)—Continued<br>Lizard Creek Member (part)—Continued | *Thickness (ft)* |
|---|---|
| 20. Quartzite, medium-light-gray ($N6$), medium-grained, limonitic, massive and laminated; basal contact abrupt | 2.0 |
| 19. Argillite and quartzite. Dark-gray ($N3$) to medium-dark-gray ($N4$) argillite; beds as much as 6 in. thick. Medium-gray ($N5$) and very light gray ($N8$), fine-grained, indistinctly laminated quartzite; beds averaging about 2 in. thick. Contact between beds sharp; basal contact abrupt | 2.5 |
| 18. Quartzite, medium-gray ($N5$) to medium-light-gray ($N6$), fine- to coarse-grained, limonitic; massive beds as much as 1 ft thick; unevenly bedded; partly crossbedded and laminated; a few medium-dark-gray ($N4$) argillite clasts, 1–2 in. long, occur in the quartzite; basal contact abrupt | 7.2 |
| 17. Argillite and quartzite. Argillite, dark-gray ($N3$) to medium-gray ($N5$), laminated, and quartzite, dark-gray ($N3$) to light-gray ($N7$), fine- to medium-grained, limonitic, laminated, with some cross laminations, to massive; in beds as much as 4 in. thick. Unit partly covered. Basal contact abrupt | 6.2 |
| 16. Sandstone, light-gray ($N7$), fine-grained, quartzose, slightly limonitic; argillaceous at base; indistinctly laminated; basal contact abrupt | 0.7 |
| 15. Quartzite and argillite. Medium-gray ($N5$) to medium-dark-gray ($N4$), medium- to coarse-grained quartzite; beds as much as 1 ft thick. Medium-gray ($N5$) to medium-dark-gray ($N4$) argillite. Beds of dark-gray ($N3$) argillite with low-angle crossbedding; beds of unit as much as 1.5 ft thick; basal contact abrupt | 9.5 |
| Incomplete thickness of Lizard Creek Member | 172.4 |
| **Minsi Member:** | |
| 14. Quartzite, medium-light-gray, medium-grained; weathers light brown (5*YR* 5/5); limonitic; crossbedded and indistinctly laminated; basal contact abrupt | 3.6 |
| 13. Quartzite and argillite. Dark-gray ($N3$) to medium-dark-gray ($N4$) quartzite; very fine to fine-grained; argillaceous and pyritiferous; irregularly laminated; low-angle trough crossbedding. 8 ft from base, a 1-ft-thick medium-grained, limonitic quartzite occurs. Medium-dark-gray ($N4$) to dark-gray ($N5$) argillite makes up 20 percent of unit. Basal contact gradational | 11.1 |
| 12. Quartzite, medium-light-gray ($N6$), fine- to medium-grained; weathers grayish orange (10*YR* 7/4) to light brown (5*YR* 5/6); a few irregular laminae of medium-dark-gray argillite; basal contact abrupt | 1.4 |
| 11. Argillite, dark-gray ($N3$), containing medium-gray ($N5$) fine-grained sandstone laminae; basal contact abrupt | 0.8 |
| 10. Quartzite, medium-gray ($N5$), very coarse to medium-grained, conglomeratic, containing pebbles as much as ¼ in. long; massively bedded; beds as much as 3.5 ft thick; thin beds (1–2 in. thick) of dark-gray ($N3$) to medium-dark-gray ($N4$) argillite. Argillite clasts, as much as 5 in. long scattered in quartzite beds. Unit crossbedded and laminated; some beds contain pyrite euhedra. Basal contact abrupt and forms base of channel | 13.7 |
| 9. Argillite and quartzite, interbedded and interlaminated. Dark-gray ($N3$) argillite; stained on joint surfaces to light brown (5*YR* 5/6). Light-gray ($N7$), fine-grained, argillaceous quartzite; ripple bedded; beds from laminae to 1.5 ft thick. Basal contact abrupt | 2.0 |
| 8. Quartzite, medium-light-gray ($N6$), medium-grained to very coarse grained, containing pebbles as much as ¼ in. long; weathers grayish orange (10*YR* 7/6); scattered light-brown (5*YR* 5/6) limonite specks, 1–2 mm in diameter; basal contact abrupt | 3.0 |
| 7. Argillite and quartzite, like unit 9; cross laminated to laminated; basal contact abrupt | 2.8 |
| 6. Quartzite, argillite, and conglomerate; chiefly quartzite. Very light gray ($N8$) to medium-dark-gray ($N4$) quartzite; some beds dark gray ($N3$) and moderate greenish gray (5*GY* 5/1); predominantly medium grained, but ranges from fine to coarse grained, conglomeratic, locally containing pebbles as much as ¼ in. long; beds 4 in. to 4.5 ft thick, averaging 1.5 ft thick. Medium-dark-gray ($N4$) to dark-gray ($N3$) argillite; occurs as thin beds and as flat clasts as much as 2 in. long; beds 0.25 to 4.5 in. thick, averaging about 1 in. thick. Conglomerate occurs as thin beds 0.5–6 in. thick, averaging about 3 in. thick; pebbles mostly white quartz, but some are chert. Unit limonitic, crossbedded, and unevenly bedded to laminated. Sand-filled burrows 0.5 in. wide occur in a 1-in.-thick dark-gray argillite 96.3 ft above base of unit. Conglomerate forms about 2 ft of unit and argillite about 2.5 ft. Basal contact abrupt | 136.0 |
| 5. Argillite and sandstone; argillite predominates. Dark-gray ($N3$) argillite; weathers medium gray ($N5$) to medium | |

*Section 2—Continued*

Shawangunk Formation (part)—Continued — *Thickness (ft)*

Minsi Member—Continued

dark gray ($N4$). Medium-gray ($N5$), medium- to coarse-grained sandstone; thin beds (1 cm thick) scattered throughout unit. Unit partly concealed. Basal contact abrupt ---------- 3.3

4. Quartzite, medium-dark-gray ($N4$), fine- to medium-grained, and very light gray ($N8$) to medium-gray ($N5$), medium- to coarse-grained quartzite with pebbles as much as ½ in. long; limonitic; slightly crossbedded; crossbed sets about 3 in. thick; basal contact and base of unit concealed ---------- 12.0
3. Quartzite, dark-gray ($N3$) and pale-reddish-brown ($10R$ 5/4), medium- to coarse-grained, limonitic, conglomeratic, containing quartz pebbles as much as ¼ in. long; dark-gray ($N3$) to grayish-black ($N2$) argillite clasts as much as 1.5 in. long, averaging less than ¼ in. thick, lie parallel to bedding; argillite also occurs as laminae (less than 0.5 mm thick). Unit laminated and crossbedded; basal contact abrupt ---------- 1.6
2. Quartzite, medium-light-gray ($N6$), containing some light-brownish-gray ($5YR$ 6/1) beds, medium- to coarse-grained with some thin (10 cm) very coarse grained beds; weathers grayish orange ($10YR$ 7/4) to dark yellowish orange (10 $YR$ 6/6); limonitic. Basal foot of unit conglomeratic, containing pebbles as much as ½ in. long, averaging about ¼ in. long. Unit unevenly bedded and massive; beds 4 in. to 1 ft thick; basal contact abrupt ---------- 4.5
1. Covered. Contact of Martinsburg and Shawangunk Formations at base of covered unit; bedrock covered by drift of pre-Wisconsin age ---------- 25.0

Total thickness of Minsi Member ---------- 220.8

Incomplete thickness of Shawangunk Formation ---------- 393.2

*Section 3*

[Shawangunk Formation and part of the Bloomsburg Red Beds and Martinsburg Formation exposed along abandoned Lehigh and New England Railroad grade and Pa. Rte. 145, Lehigh Gap, Palmerton quadrangle, Northampton County, Pa. Type section of the Weiders and Lizard Creek Members of the Shawangunk Formation. Beds dip moderately to steeply northwest except in a structural terrace 1,000 feet south of Aquashicola Creek]

Bloomsburg Red Beds (part): — *Thickness (ft)*

95. Siltstone and shale, grayish-red ($5R$ 4/2) to dark-reddish brown ($10R$ 3/4). Uppermost beds exposed on railroad cut behind second north house at northeast corner. Section covered at least to Delaware

*Section 3—Continued*

Bloomsburg Red Beds (part)—Continued — *Thickness (ft)*

Ave., Palmerton, where older outwash overlies red float; basal contact concealed ---------- 17.0

94. Covered. Float same lithic type as unit 95 22.0
93. Shaly siltstone to fine-grained sandstone, grayish-red ($5R$ 4/2) and greenish-gray ($5GY$ 6/1) ---------- 18.0
92. Covered. Float same lithic type as unit 91 -- 57.0
91. Like unit 87 except for four beds of grayish-red-purple ($5RP$ 4/2) very coarse to medium-grained, crossbedded and planar-bedded quartzite that has quartz grains as much as ¼ in. long and contains flattened dark-reddish-brown ($10R$ 3/4) silty shale intraclasts as much as 3 in. long. These beds are 1–2.6 ft thick and are 103, 156, 182, and 189 ft above base of unit. Scattered sandstone dikes about 2 in. long and ¼ in. thick extend across siltstones and shales connecting sandstone beds; basal contact abrupt ---------- 419.0
90. Quartzite, grayish-red-purple ($5RP$ 4/2), fine- to coarse-grained; conspicuous bed; basal contact abrupt ---------- 3.2
89. Like unit 87; basal contact abrupt ------ 117.0
88. Shaly siltstone to very fine grained sandstone, greenish-gray ($5GY$ 6/1) and pale-red-purple ($5RP$ 6/2) to grayish-red-purple ($5RP$ 4/2), laminated to mottled; color changes vertically and laterally; basal contact gradational ---------- 3.2
87. Sandstone, siltstone, and silty shale, in fining-upward cycles. Sandstones at base of cycle are generally red purple ($5RP$ 5/2), very fine to medium grained (some beds are coarse to very coarse grained and a few contain quartz pebbles as much as ¼ in. in diameter), and planar bedded to crossbedded and may contain flattened siltstone or shale intraclasts as much as 3 in. in diameter. Sandstone beds are 0.3–5.6 ft thick, and the basal 1–2 in. of each bed is medium gray ($N5$). The base of the sandstones is generally abrupt and fills channels in the underlying siltstone or shale, but some sandstones have a gradational base. The upper contact of some basal sandstone beds is abrupt, but this contact may have been accentuated by bedding slippage. The basal sandstones grade up into grayish-red ($5R$ 4/2) horizontally laminated and cross laminated partly mud-cracked and burrow-mottled very fine grained sandstone to siltstone with scattered irregular dark-yellowish-orange ($10YR$ 6/6)-weathering ferroan dolomite concretions. Pale-green ($5G$ 7/2) to greenish-gray ($5GY$ 6/1) reduction spots are numerous. These beds gradually grade up into grayish-red ($5R$ 4/2)

*Section 3—Continued*

Bloomsburg Red Beds (part)—Continued — *Thickness (ft)*

to dark-reddish-brown (10*R* 3/4) mudcracked and burrow-mottled sandy siltstone and silty shale that contain more abundant ferroan dolomite concretions. The concretions may occur as irregular vertical tubes about ½ in. thick and as much as 8 in. long that have spread out along bedding lamina by apparently replacing the host rock. The very fine grained sandstone, siltstone, and shale overlying the basal sandstone are 0.3–7.9 ft thick. Individual fining-upward cycles are 0.5–13.3 ft thick. Basal contact gradational ---- 79.6

86. Shale, siltstone, and sandstone. Laminated greenish-gray (5*GY* 6/1) and dark-greenish-gray (5*GY* 4/1) silty shale to fine-grained sandstone with as much as 2 ft of grayish-red-purple (5*RP* 5/2) shaly siltstone to very fine grained sandstone interlaminations and thin lenses in middle of unit. Color changes rapidly from red to green within 50 ft above road level; a few interbedded light-greenish-gray (5*GY* 7/1), fine- to medium-grained, chloritic quartzites as much as 1.5 ft thick; quartzites have very low angle crossbedding and horizontal laminations. Minor flaser bedding associated with laminae. Some intraclasts and convoluted bedding in laminated beds (very small scale convolutions). Basal contact abrupt 22.4

85. Shale, siltstone, and sandstone. Grayish-red (5*R* 4/2) shaly siltstone and silty shale from laminae to beds as much as 5 ft thick; mottled green locally; 1.5-ft.-thick red shaly siltstone bed in middle of unit mud cracked; basal 6-in. bed of red and green, very fine to fine-grained, laminated (with small-scale crossbedding) sandstone. Basal contact gradational ---- 13.4

84. Sandstone and shaly siltstone; predominantly laminated, containing burrow mottles (burrows are as much as ½ in. wide and depress underlying laminae). Greenish-gray (5*GY* 6/1) very fine grained sandstone and dark-greenish-gray (5*G* 4/1) shaly siltstone and a few grayish-red (5*R* 4/2) siltstone and very fine grained sandstone laminae; laminae are graded. Basal contact gradational ---- 1.5

83. Sandstone and siltstone. Predominantly grayish-red (5*R* 4/2) locally mottled light-greenish-gray (5*GY* 7/1), containing small light-greenish-gray reduction spots, shaly siltstone with thin beds (approx 6 in. thick) of red-purple (5*RP* 5/2) very fine grained sandstone; 1-ft-thick greenish-gray (5*GY* 6/1) siltstone in middle of unit grades up into grayish-red siltstone; uppermost foot consists of interlaminated very fine to fine-grained sandstone grading up into shaly siltstone. Color changes toward top of this laminated sequence without regard to lithic type ---- 28.4

82. Sandstone and siltstone. Greenish-gray (5*GY* 6/1), very fine grained sandstone is predominantly well laminated and has small-scale crossbedding (flaser bedding); it is irregularly interlaminated with dark-greenish-gray (5*GY* 4/1) shaly siltstone; some burrow mottling. Basal contact gradational ---- 5.1

81. Siltstone and shale. Red-purple (5*RP* 5/1) irregularly laminated to burrow-mottled shaly siltstone and silty shale with scattered greenish-gray (5*GY* 6/1) mottles and laminae; 3-foot interval with mud cracks in middle of unit; uppermost two beds, 9 and 10 in. thick, grade from very fine grained sandstone to shaly siltstone; small ½-in. diameter ferroan dolomite concretions near top of unit. Basal contact abrupt ---- 9.3

80. Shaly siltstone, medium-greenish-gray (5*GY* 5/1), interlaminated with light-greenish-gray (5*GY* 7/1) very fine grained quartzite. Quartzite occurs as discontinuous lenses and laminae; silty shale and quartzite grade up into greenish-gray (5*GY* 6/1) silty shale which grades up into light-bluish-gray (5*B* 7/1) pyritic siltstone to very fine grained sandstone. Within the basal 10 in. of unit, which is well laminated to flaser bedded, is an intraclast bed containing convoluted intraclasts; disrupted bedding is due to flowage of clay and very fine sand; sand separated by pinching and swelling into discoidal lumps as much as 2 in. long and ½ in. thick (sedimentary boudinage). Some sand has complex flowage folds in the enclosing clay matrix. A few of the sand lumps are nearly completely surrounded by clay laminae. Basal contact abrupt ---- 3.7

79. Quartzite, siltstone, and shale. Medium-light-gray (*N*6) to medium-bluish-gray (5*B* 6/1) fine-grained quartzite in beds 2 in. to as much as 2 ft thick interbedded with medium-dark-gray (*N*4) to medium-gray (*N*5) shale in beds 0.5 to as much as 3 in. thick; shale makes up 15 percent of unit; shale contains irregular interlaminations of siltstone and very fine grained sandstone. Some beds crossbedded and contain shale fragments as much as 2 in. long. Basal bed is a light-greenish-gray (5*GY* 7/1) sandy siltstone, 1.7 ft thick; basal contact gradational ---- 14.5

*Section 3—Continued*

Bloomsburg Red Beds (part)—Continued | *Thickness (ft)*

78. Siltstone and sandstone. Mottled grayish-red-purple (5*RP* 4/2) siltstone and shaly siltstone to very fine grained sandstone; some samples contain scattered greenish-gray (5*GY* 6/1) mottles; color appears to be independent of grain size. Also laminated greenish-gray (5*GY* 6/1) and grayish-red-purple (5*RP* 4/2) shaly siltstone. Unit is unevenly bedded; beds 1 in. to as much as 4.5 ft thick. Unit is color mottled and burrow mottled. Basal contact gradational ---------- 22.0
77. Siltstone and quartzite. Regularly to irregularly interlaminated greenish-gray (5*GY* 6/1) and pale-brown (5*YR* 5/2) shaly siltstone containing a few burrow mottles interbedded with medium-greenish-gray (5*GY* 5/1) fine-grained quartzite; quartzite makes up approximately 1 ft of unit; beds from 4 in. to as much as 2 ft thick; bedding is horizontally laminated to very low angle small-scale crossbedding and flaser bedding. Basal contact gradational 11.5
76. Siltstone and sandstone. Mottled (color mottled and burrow mottled) pale-red-purple (5*RP* 6/2) to dusky-red-purple (5*RP* 3/2) to pale-red (5*R* 6/2) and greenish-gray (5*GY* 6/1) siltstone and very fine grained sandstone; unevenly bedded; beds 3 in. to as much as 3.5 ft thick; one 3.5-ft bed in middle of unit is greenish-gray (bedding vaguely discernible in hand sample); basal contact placed at base of first red bed; basal bed is lithically similar to beds in unit below ---------- 30.8

Incomplete thickness of Bloomsburg Red Beds ---------- 898.6

Shawangunk Formation:

Lizard Creek Member:

75. Shale, siltstone, and quartzite. Partly burrow mottled, medium-dark-gray (*N*4) shaly siltstone interlaminated with light-olive-gray, fine-grained quartzite in beds as much as 4 ft thick makes up about 87 percent of unit. Dark-greenish-gray (5*GY* 4/1) silty shale interlaminated with siltstone lenses (flaser bedded) and partly burrow mottled in beds as much as 6 in. thick makes up about 3 percent of unit. Greenish-gray (5*GY* 6/1), medium-dark-gray (*N*4) to light-gray (*N*7), and bluish-gray (5*B* 6/1), very fine to coarse-grained, partly laminated quartzite in beds 4 in. to as much as 1 ft thick makes up about 10 percent of unit. Unit contains 1-in.-thick quartzite bed with nodules of siderite and collophane. Basal contact abrupt ---------- 38.0
74. Quartzite and shale. Very light gray (*N*8) to light-gray (*N*7), medium-grained to

*Section 3—Continued*

Shawangunk Formation—Continued | *Thickness (ft)*

Lizard Creek Member—Continued

very coarse grained quartzite in beds 4 in. to as much as 4.5 ft thick; some beds contain pebbles as much as 0.5 in. long. Medium-dark-gray (*N*4) shale with discontinuous siltstone laminae in beds less than ¼ in. to as much as 2.2 ft thick. Some beds crossbedded. Basal contact abrupt ---------- 22.9

73. Shale and quartzite. Medium-dark-gray (*N*4) and light-olive-gray (5*Y* 6/1) shale in beds less than 1 in. to as much as 6 ft thick makes up 75 percent of unit; some beds of shale are silty and regularly interlaminated to mottled with siltstone and very fine grained quartzite (flaser bedded). Medium-gray (*N*5) to light-gray (*N*7), very fine to medium-grained quartzite in beds 1 in. to as much as 4 ft thick makes up 25 percent of unit; some beds are coarse grained and contain intraclasts as much as 2 in. long. Intraclast-nodule beds (siderite-chlorite) are thin and scattered in unit. Some beds crossbedded. Basal contact abrupt ---------- 52.4
72. Shale and quartzite. Medium-dark-gray (*N*4) to light-olive-gray (5*Y* 6/1) partly burrow mottled shale in beds less than ¼ in. to as much as 3 in. thick makes up 90 percent of unit and is interbedded with medium-light-gray (*N*6), medium-gray (*N*5), to medium-greenish-gray (5*GY* 5/1) siltstone to fine-grained quartzite in beds and lenses that range from laminae to as much as 6 in. in thickness and that contain small-scale scour-and-fill. Some quartzite contains scattered intraclasts of medium-dark-gray (*N*4) phosphatic siltstone as much as 1.5 in. long and is evenly bedded to lenticular; these intraclasts or nodules are flattened, ovoid, and irregular. Unit is partly flaser bedded. Just above base of unit is a 5-in.-thick nodule bed having a predominantly shale to fine-grained-sandstone matrix. Phosphatic siltstone to fine-grained-sandstone nodules are as much as 1 cm long. Some nodules entirely phosphatized; others are rimmed by phosphate. Siderite nodules rimmed with chlorite. One nodule has nucleus of fine-grained quartz and phosphatic sandstone which is rimmed by siltstone containing finely disseminated phosphate and quartz sand, which in turn is rimmed by very phosphatic siltstone. Some fragments of *Lingula* sp. 20.6 ft above base of unit are intermixed with subangular, subrounded, and well-rounded intraclasts of collophane (black) and collophane-rimmed siltstone and fine-grained sandstone. Clasts are as much as 2 cm long and are

*Section 3—Continued*

Shawangunk Formation—Continued — *Thickness (ft)*

Lizard Creek Member—Continued

associated with subangular to subrounded quartz sand and pebbles (some pebbles are sandstone) as well as fragments of *Lingula* sp. Siderite occurs as nodules and in matrix. Some iron-mineral nodules have phosphate rim. Many phosphate nodules are penetrated by quartz sand and pebbles. Some phosphate nodules have soft-rock deformation features. Three higher nodule beds in unit consist of intermixed collophane nodules and quartz silt to pebbles. Some phosphate rims shale, siltstone, and sandstone intraclasts. Phosphate nodules subangular to well rounded and as much as 2 mm long. Quartz, siltstone, and sandstone occur as clay- to pebble-sized clasts and are angular to subrounded ______ 45.7

71. Quartzite and shale. Very light gray (*N*8), greenish-gray (5*GY* 6/1) to medium-gray (*N*5), very fine to medium-grained (a few scattered coarse-grained beds), crossbedded (large-scale trough crossbedding) quartzite which contains rounded quartz pebbles as much as ¼ in. long and scattered medium-dark-gray (*N*4) argillite intraclasts as much as 3 in. long; laminated and evenly to unevenly bedded; many beds lenticular and channeled; beds from near zero to as much as 8 ft thick; many beds contain thin irregular medium-gray (*N*5) shale intercalations. Medium-light-gray (*N*6) to medium-dark-gray (*N*4) and dark-greenish-gray (5*GY* 4/1) laminated shale in beds less than ¼ in. to as much as 2 ft thick makes up 13 percent of unit. Shale interlaminated and finely interbedded with very fine grained quartzite locally. Olive shales become more abundant and sandstone less abundant toward top 20 ft of unit ______ 145.0

70. Quartzite, shale, and siltstone. Very light bluish white (5*B* 8/1) to medium-light-gray (*N*6) and light-olive-gray (5*Y* 6/1), very fine to fine-grained, evenly bedded and wavy bedded (rippled) partly crossbedded quartzite in beds less than ¼ in. to as much as 1.5 ft thick makes up 55 percent of unit. Medium-gray (*N*5) to light-olive-gray (5*Y* 6/1), laminated to mottled shale and siltstone in beds less than ¼ in. to as much as 4 ft thick make up 45 percent of unit. Shale intraclasts as much as 1 in. long in many sandstones. Sandstones have laminations to low-angle cross laminations. A 2-in. collophane-siderite-chlorite bed lies 23 ft 4 in. below top of unit above a 1-ft-thick fine-grained, medium-light-gray (*N*6), indistinctly horizontally laminated sandstone; this bed is overlain by well-laminated medium-gray (*N*5) to greenish-gray (5*GY* 6/1), very fine grained sandstone and siltstone. Basal contact abrupt ______ 46.9

69. Shale and quartzite. Light-olive-gray (5*Y* 6/1) to greenish-gray (5*GY* 6/1) shale in beds less than ¼ in. to as much as 5 ft thick with thin lenses and discontinuous laminae of siltstone interbedded, unevenly interlaminated, and mottled with light-gray (*N*7) and medium-greenish-gray (5*G* 5/1) very fine grained quartzite in beds less than ¼ in. to as much as 10 in. thick. An 8-in.-thick medium-light-gray (*N*6) fine-grained quartzite with abundant intraclasts as much as 2 in. long and coarse quartz grains lies 1.2 ft below top of unit. A nodule-intraclast bed also occurs 4 in. below top of unit. Its matrix is flaser-bedded shale, siltstone, and fine-grained sandstone. Nodules are siltstone to fine-grained sandstone which are phosphatic throughout or rimmed with phosphate. Nodules are as much as 2.5 cm long and are well rounded to subangular. Some iron-rich (siderite) nodules are also rimmed by chlorite. Many fragments of *Lingula* sp. Some well-rounded phosphate nodules penetrate phosphate-rimmed siltstone intraclasts. Basal contact abrupt ______ 12.0

68. Quartzite, medium-gray (*N*5) to medium-dark-gray (*N*4), very fine to fine-grained, chloritic; some beds contain greenish-gray (5*GY* 6/1) shale intraclasts as much as ½ in. in diameter; beds are unevenly bedded, 1 in. to as much as 1 ft thick. Two 3-in.-thick beds at base of unit consist of very irregularly mottled to unevenly interbedded and lenticular shale and quartzite (flaser bedded). Some nodules of collophane and scattered fragments of *Lingula* sp. that weather dull white occur in subangular to subrounded fine- to medium-grained sandstone. Grains are predominantly quartz, but 5–10 percent are sand-sized phosphate. Basal contact abrupt ______ 2.8

67. Quartzite and shale. Dark-gray (*N*3) to medium-greenish-gray (5*GY* 5/1) and dusky-red-purple (5*RP* 3/2) to grayish-red-purple (5*RP* 4/2), very fine to coarse-grained limonitic quartzite in uneven and lenticular beds, 1–11 in. thick, makes up 50 percent of unit. These beds contain scattered subangular to subrounded quartz pebbles as much as ¼ in. long; abundant intraclasts of phosphatic greenish-gray (5*G* 6/1) shale to fine-grained sandstone as much as ½ in. long; numerous siderite-

***Section 3—Continued***

Shawangunk Formation—Continued — *Thickness (ft)*

Lizard Creek Member—Continued

chlorite nodules, 1–4 mm long; and linguloid brachiopod fragments. Rest of unit is greenish-gray (5*GY* 6/1) shale in beds as much as 3 in. thick. Basal contact abrupt — 5.0

66. Shale, siltstone, and sandstone. Partly burrow mottled greenish-gray (5*GY* 6/1) to grayish-yellow-green (5*GY* 7/2) shale and irregularly interlaminated and lenticular light-gray (*N*7) siltstone and very fine grained calcareous sandstone in beds 1 in. to as much as 4 ft thick constitute about 88 percent of unit and are interbedded with light-gray (*N*7), dark-greenish-gray (5*G* 4/1), and dusky-red-purple (5*RP* 4/1) very fine to medium-grained limonitic, hematitic, and magnetitic quartzite in beds (generally less than 2 in. thick) and lenses (less than 0.5 to as much as 2 in. long). A 2-in.-thick nodule bed occurs 10 in. above base of unit. Bed is lenticular, and the shale and siltstone matrix is flaser bedded. Bed contains linguloid brachiopod fragments; color-zoned fine-grained phosphatized siltstone clasts in a pyritic, irregular, coarse siltstone to very fine grained sandstone matrix; and zoned nodules of, from center outward, dark-yellowish-orange (10*YR* 6/6) to pale-yellowish-orange (10*YR* 8/6) siderite rimmed with dark-yellowish-green (10*GY* 4/4) chlorite (chlorite rims are about 0.02 mm thick). Nodules are elliptical to very irregular in shape, 2–20 mm long, and 1–4 mm thick. Some are not zoned. Interspersed with the nodules are coarse to very coarse angular grains of sand — 7.8

65. Quartzite and silty shale. Dusky-red-purple (5*RP* 3/2) to brownish-gray (5*YR* 4/1), very fine grained quartzite in beds 2 in. to 1 ft thick with many greenish-gray (5*GY* 6/1), half-inch-thick shale intercalations and irregular lenses. Basal foot consists of light-gray (*N*7), medium-grained quartzite unevenly interbedded with greenish-gray laminated (5*GY* 6/1) shale and siltstone. Basal contact concealed — 6.0

64. Covered — 192.3

63. Quartzite, very light gray (*N*8) to light-gray (*N*7), medium-greenish-gray (5*GY* 5/1), and light-olive-gray (5*Y* 6/1), very fine to medium-grained with a few coarse-grained beds. Beds 2 in. to as much as 2 ft thick; thinner beds are finer grained and more evenly bedded to laminated, with small-scale scour-and-fill; thicker beds are coarser grained and unevenly bedded and contain scattered fragments of medium-dark-gray (*N*4) shale as much as 2 in. long. Quartzite generally unevenly bedded. A light-olive-gray (5*Y* 6/1) silty shale bed, 7 in. thick, occurs near middle of unit, and a few shale beds less than ¼ in. thick are scattered throughout unit. Basal contact abrupt — 20.0

62. Quartzite and shale, unevenly bedded and lenticular. Light-gray (*N*7), medium-grained, limonitic quartzite and medium-greenish-gray (5*GY* 5/1), very fine grained quartzite interbedded with laminated light-olive-gray (5*Y* 6/1) to greenish-gray (5*GY* 6/1) shale and shaly siltstone that weather grayish orange (10*YR* 7/4) to moderate brown (5*YR* 4/4); beds 1–4 in. thick. Basal contact abrupt — 2.7

61. Quartzite and shale. Light-gray (*N*7), fine- to coarse-grained limonitic unevenly bedded to laminated and cross-laminated quartzite in beds 8 in. to as much as 2.3 ft thick containing scattered thin intercalations and fragments (as much as 0.75 in. long) of medium-dark-gray (*N*4) silty shale. Intercalations are very irregularly bedded and contain medium- to coarse-grained, possibly burrow-mottled sandstone. Basal contact abrupt — 3.1

60. Quartzite and siltstone. Dusky-red-purple (5*RP* 3/2) and light-olive-gray (5*Y* 6/1), very fine grained, poorly bedded quartzite in beds 4–6 in. thick interbedded with mottled greenish-gray (5*GY* 6/1) and pale-red-purple (5*RP* 6/2) shaly siltstone in beds 1–3 in. thick that has interlaminated and irregular pockets of very fine grained sandstone — 3.2

59. Quartzite, light-gray (*N*7) to moderate-greenish-gray (5*GY* 5/1), fine- to medium-grained, irregularly laminated to thick-bedded with large-scale crossbedding; some beds contain scattered medium-gray (*N*5) shale pebbles as much as 4 in. long; beds 3 in. to as much as 3.5 ft thick. Basal contact abrupt — 10.1

58. Shale, siltstone, and quartzite. Light-olive-gray (5*Y* 6/1) silty shale in beds 1–8 in. thick interbedded with light-olive (5*Y* 6/1)-to medium-olive-gray (5*Y* 5/1) laminated siltstone to very fine grained vaguely laminated sandstone in beds 1–2 in. thick and scattered beds of greenish-gray (5*GY* 6/1) fine-grained quartzite in beds about 1 in. thick. Unit evenly bedded. Basal contact abrupt — 3.0

57. Quartzite, light-gray (*N*7), fine- to medium-grained; weathers light brown (5*YR* 6/1); massive; very low angle cross lam-

*Section 3—Continued*

| Shawangunk Formation—Continued<br>Lizard Creek Member—Continued | *Thickness (ft)* |
|---|---|
| inations and parallel bedding; low to moderate angle large-scale trough crossbedding; scattered pebbles of medium-dark-gray (*N*4) argillite as much as 0.75 in. long | 2.1 |
| 56. Shale, medium-olive-gray (5*Y* 5/1), silty, evenly laminated; one light-blue-gray (5*B* 7/1) very fine grained quartzite bed 1.5 in. thick; basal contact abrupt | 1.1 |
| 55. Quartzite, light-gray (*N*7) and greenish-gray (5*GY* 6/1) to moderate-greenish-gray (5*GY* 5/1), very fine to fine-grained, hematitic, generally poorly bedded, with thin discontinuous silty and fine sandy shale laminae as much as 1 in. long. A few beds contain medium-dark-gray (*N*4) silty shale fragments as much as 0.5 in. long; beds 4 in. to as much as 1 ft thick with scattered thin beds of greenish-gray silty shale making up about 4 percent of unit. Quartzite has small-scale crossbedding and parallel laminations. Basal contact gradational and based on color change | 6.3 |
| 54. Quartzite and shale. Medium-brownish-gray (5*YR* 5/1) to grayish-red-purple (5*RP* 4/2), with a few medium-greenish-gray (5*GY* 5/1) mottles, very fine to fine-grained indistinctly bedded hematitic quartzite in beds 1 in. to as much as 5 ft thick makes up most of unit, and pale-red (10*R* 6/2) to light-brownish-gray (5*YR* 6/1) shale in beds 0.25–4 in. thick makes up about 9 percent of unit. Shale is finely laminated to irregularly and indistinctly laminated with irregular sandstone-filled burrows. Scattered crossbeds. Basal contact abrupt | 22.2 |
| 53. Shale and quartzite. Medium-olive-gray (5*Y* 5/1) moderate-orange-pink (5*YR* 8/4)-weathering shale with discontinuous silt laminae and lenses; a greenish-gray very fine grained quartzite, 4 in. thick, occurs 8–12 in. below top of unit. Basal contact abrupt | 2.5 |
| 52. Quartzite, medium-light-gray (*N*6), irregularly finely bedded to irregularly laminated; fine grained at top of unit and mottled greenish gray (5*GY* 6/1) and light brownish gray (5*YR* 6/1); very fine grained at base of unit; beds 4–8 in. thick; upper half of unit crossbedded and ripple marked (ripples are current type and indicate that current flowed to southeast); crossbedding indicates northwest flow; basal contact abrupt | 1.6 |
| 51. Siltstone and silty shale, mottled light-brownish-gray (5*YR* 6/1) to moderate-red-purple (5*RP* 5/2); moderate-red-purple beds are minor and are irregularly laminated; beds 3–7 in. thick; minor magnetite; basal contact abrupt | 3.0 |
| 50. Quartzite, siltstone, and silty shale. Light (*N*7)-to medium-gray (*N*5) and greenish-gray (5*GY* 6/1) very fine to fine-grained unevenly bedded quartzite in beds 1 in. to as much as 3.2 ft thick, but averaging about 10 in. thick, makes up 75 percent of unit. Quartzite interbedded with medium-dark-(*N*4) to medium-light-gray (*N*6) shale and siltstone which weather light olive gray (5*Y* 6/1), greenish gray (5*GY* 6/1), and grayish orange (10*YR* 7/4) to grayish orange pink (5*YR* 7/2) and are in beds ½ in. to as much as 1.5 ft thick. Siltstone irregularly interlaminated with fine-grained sandstone (flaser bedded) and contains some burrow mottling. Beds and laminae even to uneven and lenticular | 34.0 |
| 49. Like unit 50. Very fine to fine-grained quartzite and siltstone in beds 1 in. to as much as 3.7 ft thick. Quartzite more abundant in upper half of unit. Shale partly micaceous and silty, laminated in beds less than 0.5 in. to as much as 2 ft thick, and makes up 4.5 ft of upper half of unit and 9.5 ft of lower half of unit. Several beds crossbedded. Thick-bedded quartzites have large-scale crossbedding and planar bedding. Quartzites have low-angle to high-angle trough crossbedding and are evenly and unevenly bedded. Quartzite and siltstone generally well laminated and have small-scale scour-and-fill | 62.0 |
| 48. Quartzite, dusky-red-purple (5*RP* 3/2) to grayish-red-purple (5*RP* 4/2), very fine grained, silty; beds 1.2–1.9 ft thick. Pale-red (5*R* 6/2) laminated silty shale bed, 2 in. thick, occurs in middle of unit. Unit burrow mottled; contains small shale pebbles; sericitic small well-sorted lenses of very fine grained sand are reworked and made poorly sorted because of bioturbation | 6.2 |
| 47. Shale, light-olive-gray (5*Y* 6/1); weathers moderate orange pink (5*YR* 8/4) to grayish orange (10*YR* 7/4); minor siltstone interlaminations and lenses (flaser bedding); indistinctly bedded; basal contact abrupt | 5.8 |
| 46. Quartzite and siltstone, moderate-yellowish-brown (10*YR* 5/2) at base to moderate-greenish-gray (5*GY* 5/1) above; laminated micaceous siltstone with minor burrowing at base to fine-grained quartzite above, limonitic and slightly pyritic; beds 3 in. to as much as 1.9 ft thick; color grades down into underlying unit | 2.3 |

*Section 3—Continued*

Shawangunk Formation—Continued — Thickness (ft)

Lizard Creek Member—Continued

45. Quartzite, well-sorted, and siltstone. Mottled and unevenly laminated grayish-red-purple (5*RP* 4/2) and dark-greenish-gray (5*GY* 4/1) very fine to fine-grained quartzite; beds 1–7 in. thick; fairly evenly bedded. A pale-red (5*R* 6/2) micaceous silty chloritic shale bed, 2 in. thick, occurs in middle of unit. Basal contact abrupt — 2.3
44. Quartzite and shale. Greenish-gray (5*GY* 6/1) to moderate-greenish-gray (5*GY* 5/1), very fine grained, evenly bedded and laminated (with minor cross laminations) quartzite in beds 2–6 in. thick interbedded with light-olive-gray (5*Y* 6/1) shale which weathers moderate orange pink (5*YR* 8/4) and moderate yellowish brown (10*YR* 5/4) and is in beds 1–5 in. thick and makes up 33 percent of unit. Low-angle cross laminations. Basal contact abrupt — 2.0
43. Shale and quartzite. Greenish-gray (5*GY* 6/1) to dark-greenish-gray (5*GY* 4/1), laminated to ripple laminated to unevenly laminated, partly burrow mottled, partly silty shale containing small-scale ripples; weathers pale yellowish orange (10*YR* 8/6) and light brown (5*YR* 6/4); beds 2 in. to as much as 4.5 ft thick. Shale interbedded and interlaminated with very light gray (*N*8) to light-greenish-gray (5*GY* 8/1) limonitic quartzite in beds less than 0.5 in. to as much as 6 in. thick; quartzite forms 10 percent of unit. Basal contact abrupt — 11.2
42. Quartzite, greenish-gray (5*G* 6/1), very fine grained; weathers into spheroidal blocks; massively bedded; minor pyrite. Basal contact abrupt — 8.5
41. Quartzite and shale. Medium-dark-gray (*N*4) and light-olive-gray (5*Y* 6/1), very fine to fine-grained quartzite in beds 1 in. to as much as 1.5 ft thick interbedded with two 1-in.-thick grayish-orange (1*YR* 8/4) irregularly laminated and burrow-mottled silty shale beds — 2.0
40. Shale and quartzite. Mottled grayish-red-purple (5*RP* 4/2) and moderate-greenish-gray (5*GY* 5/1) laminated and burrow-mottled silty shale grading up into grayish-red-purple (5*RP* 4/2) silty shale, with a 10-in.-thick mottled grayish-red-purple (5*RP* 4/2) and moderate-greenish-gray (5*GY* 5/1) very fine grained limonitic quartzite abruptly overlying shale at top of unit. Basal contact abrupt — 4.0
39. Sandstone, siltstone, and shale, interlaminated. Moderate-greenish-gray (5*GY* 5/1), very fine grained sandstone grading up into siltstone which grades up into light-olive (10*Y* 5/2) shale. Basal contact gradational — 2.2
38. Siltstone and sandstone. Mottled and color-laminated grayish-red-purple (5*RP* 4/2) and moderate-greenish-gray (5*GY* 5/1) laminated to cross-laminated (crossbed sets as much as half an inch thick) siltstone and very fine grained sandstone, 4 in. thick, overlain by grayish-red-purple (5*RP* 5/2) massive burrow-mottled siltstone. Basal contact abrupt — 2.0
37. Quartzite, siltstone, and silty shale. Light-gray (*N*7), dark-greenish-gray (5*GY* 4/1), to greenish-gray (5*GY* 6/1), very fine to fine-grained, evenly bedded to laminated quartzite in beds 2 in. to as much as 1 ft thick with thin beds of greenish-gray (5*GY* 6/1), grayish-yellow (5*Y* 8/4)- to dark-yellowish-orange (10*YR* 6/6)-weathering, laminated, micaceous siltstone and silty shale in beds 0.5–1 in. thick. Siltstone and silty shale make up about 3 percent of unit. Basal contact concealed — 6.7
36. Covered — 20.0
35. Shaly siltstone, silty shale, and quartzite. Yellowish-gray (5*Y* 8/1)-weathering to light-olive-gray (5*Y* 6/1)- and light-gray (*N*7)-weathering siltstone and shale unevenly laminated and in beds as much as 1 ft thick. Small-scale scour-and-fill structures and cross laminations. Beds contain scattered siltstone-filled burrows to very fine grained and fine-grained sandstone-filled burrows. Shaly siltstone and silty shale interbedded with light-gray (*N*7) very fine to fine-grained partly limonitic quartzite in beds 0.5–10 in. thick form 35 percent of unit; contains scattered flat argillite pebbles as much as 1.5 in. long. One 1.5-inch-long siltstone pebble collected 3 ft above base of unit has concentric rims of siltstone and very thin rims of dark-gray (*N*3) phosphate. Basal contact abrupt — 10.0
34. Quartzite, medium-light-gray (*N*6) to medium-gray (*N*5) very fine grained, well-sorted, unevenly bedded; beds 2–8 in. thick — 2.5
33. Siltstone, shale, and quartzite. Medium-light-gray (*N*6) to medium-dark-gray (*N*4) and light-olive-gray (5*Y* 6/1), unevenly to irregularly bedded and laminated, burrow-mottled silty mudstone and shaly siltstone which weather very pale orange (10*YR* 8/2) to moderate yellowish orange (10*YR* 7/6); unit contains abundant siltstone-filled to very fine grained sandstone-filled burrows. Burrows are par-