Stratigraphy of Silurian Rocks in Shawangunk Mountain, Southeastern New York, Including a Historical Review of Nomenclature

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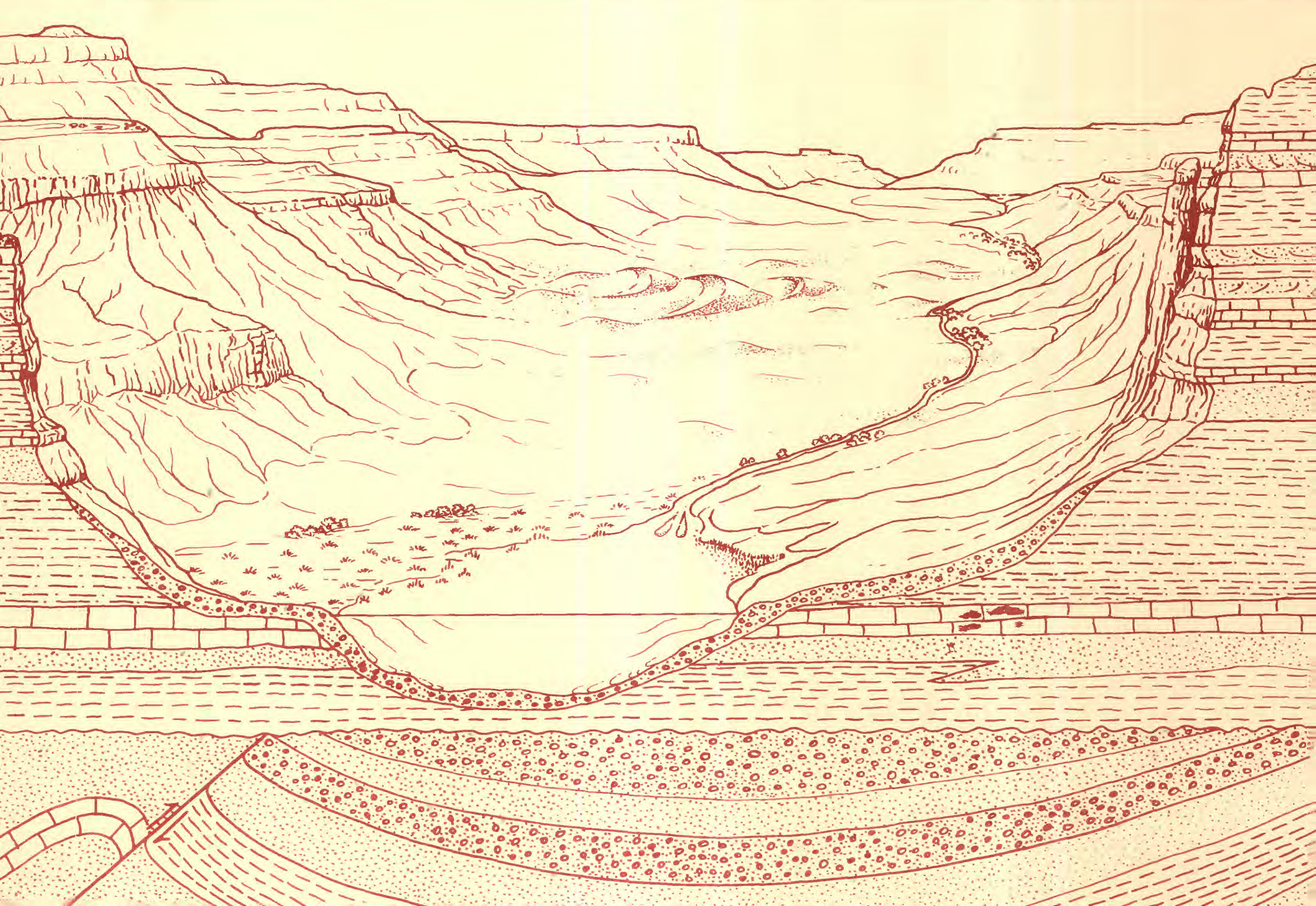

Chapter L

Stratigraphy of Silurian Rocks in Shawangunk Mountain, Southeastern New York, Including a Historical Review of Nomenclature

By JACK B. EPSTEIN

A description and partial revision of the physical stratigraphy

U.S. GEOLOGICAL SURVEY BULLETIN 1839

EVOLUTION OF SEDIMENTARY BASINS—APPALACHIAN BASIN

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Stratigraphy of Silurian Rocks in Shawangunk Mountain, Southeastern New York, Including a Historical Review of Nomenclature

By Jack B. Epstein

Abstract

Middle and Upper Silurian rocks in southeastern New York, comprising conglomerates, sandstones, siltstones, shales, and minor carbonate rocks, form a facies mosaic that is more complex than the previously recognized ascending sequence of the Shawangunk Formation, the High Falls Shale, and the Binnewater Sandstone. These rocks lie unconformably above thick shale and graywacke of the Martinsburg Formation of Ordovician age and beneath a variety of carbonate and siliciclastic rocks of Devonian and Upper Silurian age.

In southwesternmost New York, near Port Jervis, the Shawangunk Formation is overlain by the Bloomsburg Red Beds, the same stratigraphic sequence that occurs in Pennsylvania and New Jersey to the southwest. The Bloomsburg, characterized by red, green, and gray shale, siltstone, and sandstone, thins to the northeast and forms two newly defined tongues that interfinger with rocks of the Shawangunk—the lower Wurtsboro Tongue, which extends to Accord and perhaps as far as High Falls, and the upper Basher Kill Tongue, which pinches out between Ellenville and Wurtsboro.

The Shawangunk Formation, containing gray conglomerate, sandstone, and shale, thins gradually from Port Jervis to its pinchout near Binnewater. Two new tongues of the upper part of the Shawangunk are defined here: the Ellenville Tongue, which extends from the Accord–High Falls area to its feather edge just southwest of the New York–New Jersey border, and the poorly exposed High View Tongue, limited to the Wurtsboro area. The Wurtsboro Tongue of the Bloomsburg Red Beds has been mistaken for the High Falls Shale, and the Ellenville Tongue of the Shawangunk Formation has been confused with the Binnewater Sandstone by some previous workers.

Very poorly exposed gray and green dolomite and shale and scattered red beds compose the Poxono Island Formation. These rock types thin northeast of Ellenville, where they have been subdivided into several other stratigraphic units, including the Wawarsing Limestone, High Falls Shale, and Binnewater Sandstone.

The Wawarsing Limestone (possibly a dolomite) overlies the Ellenville Tongue of the Shawangunk Formation and has been described only in the subsurface. The High Falls Shale, also poorly exposed, consists of a variety of red, green, and gray shale, siltstone, and carbonate rock; it overlies the Ellenville Tongue and the Wawarsing Limestone and probably merges under cover with the Poxono Island Formation near Ellenville. The Binnewater Sandstone, containing sandstone, shale, and dolomite, overlies the High Falls Shale and likewise merges with the Poxono Island Formation to the southwest. A tongue of the Poxono Island Formation near Accord has been termed the Accord Shale in the past, but that name is here abandoned.

Red beds overlying the Shawangunk Formation in New Jersey have been named the High Falls Shale. However, this study shows that these rocks are the Bloomsburg Red Beds extending from Pennsylvania northeastward into New Jersey and not the High Falls extending southwestward from New York into New Jersey.

The Shawangunk Formation near Ellenville is divided into three mappable units that have not been given formal names: the middle unit contains appreciable shale separating the lower and upper units, comprised of quartzite with little shale. The names Otisville Shale and Guymard Quartzite, which have been applied to parts of the Silurian section in the

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past, fail the test of mappability; they are abandoned, and the rocks are reassigned to the Shawangunk Formation.

INTRODUCTION

Siliciclastic rocks of Silurian age in southeastern New York have been mapped for about 50 mi (80 km) between Port Jervis and Binnewater in New York (fig. 1). They are exposed in cliffs, in streambeds, on glacially polished pavements, and along road cuts in the Shawangunk Mountains, a ridge that rises to altitudes of more than 2,200 ft (670 m) near Ellenville. These rocks form a northwest dipping homocline from Port Jervis to Spring Glen, northeast of which they are folded into a broad arch that extends to Accord. Beyond Accord, the rocks become highly faulted (Epstein and Lyttle, 1987, 1990).

The source of these clastic rocks was mountains that rose to the southeast as the result of Taconic deformation that began during the Middle Ordovician. The initial sediments were gravel, sand, and minor mud, which were later consolidated into rocks of the lower part of the Shawangunk Formation of Silurian age. These overlie beveled folds in the Martinsburg Formation of Ordovician age that were formed during the Taconic orogeny. As the mountains were worn down, finer clastic sediments and carbonates were deposited more or less continuously into the Middle Devonian.

The Silurian rocks in southeastern New York, New Jersey, and northeastern Pennsylvania were deposited in a variety of marine and terrestrial environments that were generally transgressive to the northwest. These environments have been the subject of several studies (for example, Epstein (1986) and Prave and others (1989); also see section below, on previous investigations) and are not discussed in detail here.

A review of the history of nomenclature and stratigraphic relations of the Silurian siliciclastic rocks in southeastern New York is the subject of the first part of this report. New descriptions and interpretations of these rocks that follow are based on both detailed and reconnaissance mapping. Thicknesses of stratigraphic units are derived mainly from construction of cross sections and are, therefore, subject to minor error. Some units were measured directly at the outcrop. Additional detailed stratigraphic measurements are presented by Prave and others (1989) and Alcala (1990). Rocks of the Shawangunk Formation, Bloomsburg Red Beds, and Poxono Island Formation were examined in detail for this report. The Wawarsing Limestone is not presently exposed, and descriptions made by earlier workers during construction of the Delaware aqueduct are utilized in this report. Rocks of the High Falls Shale and Binnewater Sandstone, exposed in the northeastern part of the area, were compared with those exposed in their type areas near High Falls, N.Y.

PREVIOUS INVESTIGATIONS

During the 150 years that the Silurian rocks of southeastern New York have been examined, there has been considerable effort to subdivide, name, and correlate them with Silurian stratigraphic units of western New York (for example, Schuchert, 1916; Swartz and Swartz, 1931). Many of the exposures examined for the present study were also observed and discussed by many of the earlier geologists. However, the present analysis differs markedly from many of the earlier interpretations and is the result of regional and detailed mapping at a scale of 1:24,000 and the tracing of units between critical sections.

The following section summarizes the main conclusions of previous workers. Many of the stratigraphic names or lithic modifiers that were used by earlier workers are not accepted in this report; they are summarized in plate 1.

Rogers (1836) was the first to recognize that red beds overlay gray beds in New Jersey, and he later (Rogers, 1840) (pl. 1*A*) subdivided these into Formation IV (the gray beds below) and Formation V (the red sandstone and shale above) and noted that these units continue into the Shawangunk Mountains of New York.

Mather (1840) presented the first generalized discussion of the stratigraphic sequence in southeastern New York. He named the Shawangunk Grit (previously termed the mill-stone grit by Eaton) for the entire sequence of rocks between the Hudson River Slate Group (the Martinsburg Formation) and Helderberg Group (the Rondout Formation and younger carbonate rocks). Mather described the red beds within the Shawangunk as "red rock within the Shawangunk group." He later (Mather 1843) (pl. 1*B*) divided the entire sequence into the pyritiferous strata and red shales and grit above, and the Shawangunk Grit or Conglomerate below, and included both sequences in his Ontario division.

Cook (1868) (pl. 1*C*) referred to the Shawangunk Conglomerate or Grit of the Shawangunk Mountains in New York as the Oneida Conglomerate, which is overlain by his red Medina Sandstone, as seen along the Erie Railroad between Otisville and Guymard Station.

Barrett (1876) (pl. 1*D*) mentioned the angular unconformity between the shales of the Cincinnati Group (the Martinsburg Formation of present terminology) and the Shawangunk Grit at Otisville, and described the "reddish, banded, ripple-marked and sun-cracked surfaces" of the Medina Sandstone southwest of Otisville along the Erie Railroad.

Lesley (1892) noted that the outcrop belt of the Oneida Conglomerate or Shawangunk Grit and overlying red rocks of the Medina beds in Pennsylvania extend through New Jersey into New York, where they are about 800 ft (240 m) thick at Port Jervis. Lesley commented that the Medina is predominantly sandstone at the bottom, much of which is ripple bedded, and shale at the top. He observed

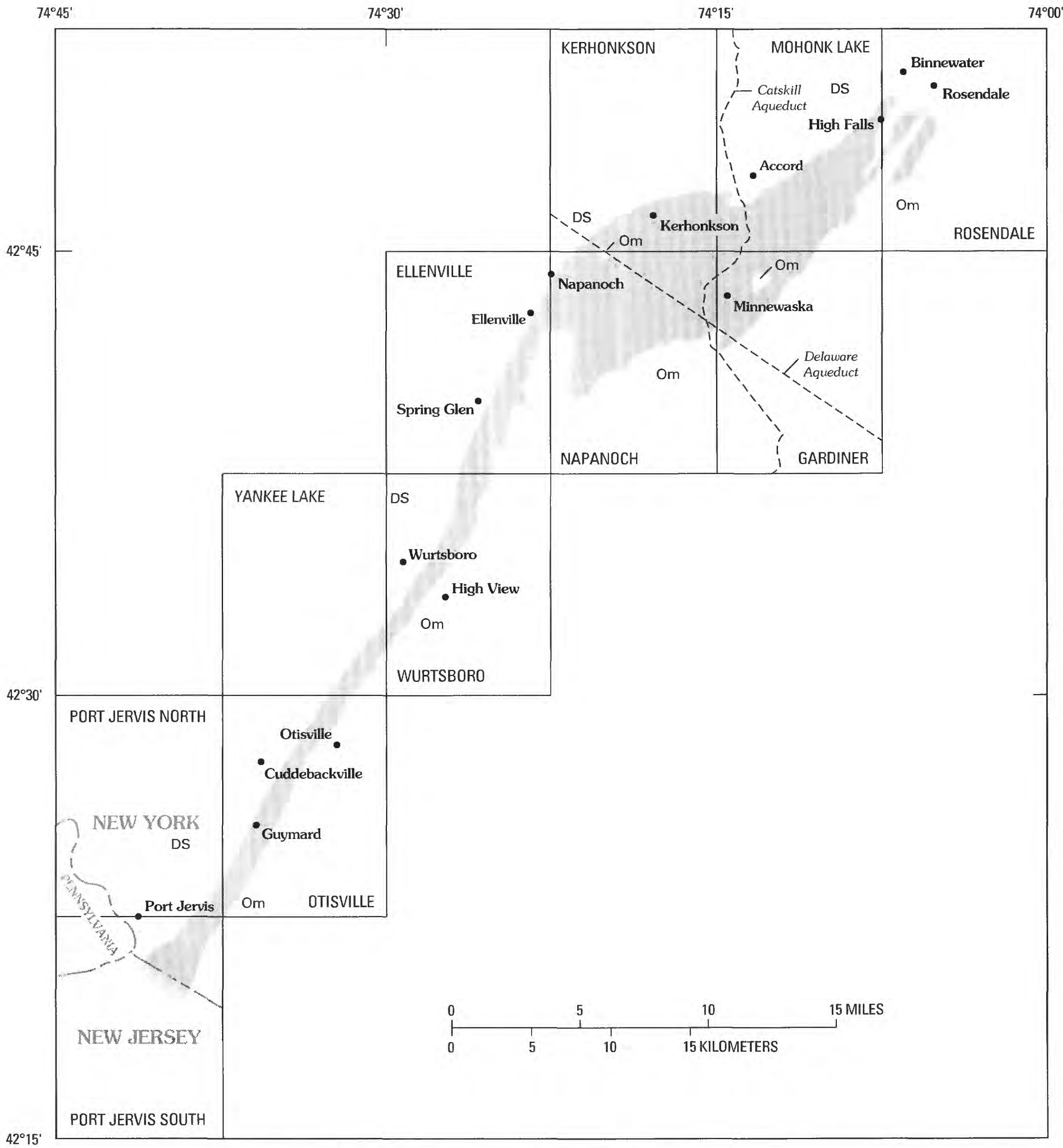

Figure 1. Generalized geologic map of southeastern New York showing the distribution of Silurian rocks discussed in this report and 7.5-min quadrangle map coverage. Shaded area is Shawangunk Formation, including the Ellenville and High View Tongues; the Bloomsburg Red Beds, including the Wurtsboro and Basher Kill Tongues; the Poxono Island Formation; Wawarsing Limestone, High Falls Shale, and Binnewater Sandstone. DS, Devonian and Silurian rocks, including the Rondout Formation and Bossardville Limestone at the base. Om, Martinsburg Formation of Ordovician age. Geology from Epstein and Lyttle (1990) and J.B. Epstein (unpub. data, 1990). The Silurian rocks in the Rosendale-Binnewater area have a complex outcrop pattern due to folding and faulting (Fisher and others, 1970).

that the Medina disappears first northeast of Port Jervis and that the Oneida persists to Rosendale, where it is probably cut out by a cross fault.

Darton (1894a,b) (pl. 1*E*) prepared the first stratigraphic sections showing the overlap, thinning, and pinch-out of the Shawangunk, Clinton, and Medina Formations from New Jersey northeastward into New York. He noted that the Shawangunk thins from about 2,000 ft (600 m) in New Jersey to 290 ft (90 m) at Ellenville, N.Y., and pinches out just northeast of Binnewater. He also recognized the facies change of the Binnewater Sandstone (part of his Clinton) from a fairly pure, white or gray, thin-bedded sandstone, which is about 20 ft (6 m) thick 2 mi (3 km) northeast of Rosendale, to a more argillaceous and calcareous interval (the Poxono Island Formation of this report) to the southwest. He correctly correlated the red beds south of Accord with the red beds at High Falls (the High Falls Shale) but incorrectly believed that the red beds on the west slope of Shawangunk Mountain south of Ellenville (the Wurtsboro Tongue of the Bloomsburg Red Beds) were the same as the red beds at High Falls.

Ries (1897) (pl. 1*F*) presented a generalized geologic map of Orange County, N.Y., showing the distribution of the Medina Sandstone, which is as thick as 750 ft (230 m). He apparently included the Oneida Conglomerate at its base. According to Ries, it passes upward into the Shawangunk Grit, then into thin-bedded red sandstones and shales of the red Medina, and finally into greenish-gray shales. He recognized the "slight but constant unconformity" between the Hudson River Formation (the Martinsburg Formation) and the Shawangunk.

Grabau (1905) made one of the earliest interpretations of the environment of deposition of the conglomerates of the Shawangunk Formation and of the overlying Silurian red beds. He believed that they were deposited in large alluvial fans, whose apex lay in eastern Pennsylvania. The red beds were derived from the erosion of an eastern landmass and grade into salt deposits to the west, indicating a desert environment. This interpretation was the beginning of a controversy on the sedimentology of these rocks that continues today.

Hartnagel (1905) (pl. 1*G*) made a comprehensive study of the Silurian stratigraphic sequence in southeastern New York and made tentative correlations with the formations of western New York. He named the High Falls Shales and Binnewater Quartzites and correlated the Shawangunk Grit with the Oneida Conglomerate, and the High Falls and the Binnewater with the Salina Formation. He noted that the Binnewater becomes more calcareous and shaly at Accord, possibly grading into two units that were originally defined in Pennsylvania by White (1882), the Poxono Island Shale and the Bossardville Limestone. Hartnagel misspelled the Poxono Island as Pox*i*no, an error carried forward by several succeeding authors.

Clarke (1907) described eurypterids from the Shawangunk Formation west of Otisville. He believed that they inhabited shallow water or lagoons. The fossils are similar to those of the Pittsford Shales of Silurian (lower Salinan) age in western New York, so he reasoned that the Shawangunk is equivalent to the Salina Formation and not the Oneida Conglomerate, but older than the Bertie Limestone, or of latest Salinan age (Late Silurian). He measured 531 ft (162 m) of the Shawangunk in detail, showing that shale makes up less than 3 percent of the entire section.

Grabau (1909) interpreted the Silurian clastics of New York and Pennsylvania to be of continental, alluvial-fan, semiarid origin and believed that the scarce intercalated fossiliferous beds represent the temporary advance of the sea upon the margins of the fans.

Billingsley (1910) stated that the Shawangunk grades into the overlying High Falls in the southern part of the study area but that the two units are disconformable in the northern part of the area. He noted that the Shawangunk contains conglomerates, sandstones, and red shales, which he thought were nonmarine, arid, alluvial-fan deposits.

Berkey (1911) (pl. 1*H*) described the stratigraphy of the Shawangunk, High Falls, and Binnewater in the Catskill aqueduct for the City of New York, which extends through the northeast corner of the Napanoch quadrangle and into the adjoining Gardiner and Kerhonkson quadrangles (fig. 1).

Grabau (1913) discussed the age, paleontology, and regional relations of the Shawangunk Formation and Longwood Shale and noted the northeastward decrease in thickness of the Shawangunk in New York, averaging 19 ft/mi (3.6 m/km). He argued that the Shawangunk is a river deposit because it thins along its outcrop in both directions away from the Delaware Water Gap in Pennsylvania and because its pebbles, composed of quartz and feldspar, become coarser to the southeast.

Brown (1914) (pl. 1*H*) presented lithologic details and thicknesses of the Shawangunk, High Falls, and Binnewater from borings made during construction of the Catskill aqueduct across the Rondout Valley and compared the rocks with those exposed at High Falls and Binnewater. Many of the sections are complicated by both normal and reverse faulting, unreported in previous investigations.

Schuchert (1916) (pl. 1*I*) discussed the controversial age assignments of the Shawangunk and overlying rocks. He suggested that the Shawangunk is equivalent to the Medina, not the Salina as others believed. He believed that the red and pink zones of the Shawangunk are probably of Clintonian age (Middle Silurian) and the High Falls is of Salinan age (Late Silurian). He interpreted the Shawangunk to be a near-shore shallow-marine deposit that thickens from its feather edge near Binnewater southwestward to Port Jervis and beyond. He presented measured sections, partly from other workers, at Rondout, High Falls–

Binnewater, the Delaware aqueduct, Otisville, and places to the southwest in Pennsylvania.

Newland (1919) described the zinc-lead deposits of the Shawangunk Mountains between Ellenville and Otisville. He noted that the High Falls Shale and Binnewater Sandstone continued southwest of the type areas to Otisville and overlay the Shawangunk Grit under the fill of the valley to the west.

Ulrich and Bassler (1923) discussed the complex evolution of nomenclature of the Silurian System in the Appalachian Mountains from the mid-1800's to 1923. They suggested that the entire Lower Silurian (Medinan) is missing in southeastern New York, that the Oneida Conglomerate and Shawangunk Formation are early Middle Silurian (Clintonian), and that the upper Middle Silurian (Lockportian) is missing, so that the Upper Silurian (Cayugan) High Falls Shale and Binnewater Sandstone rest unconformably on the Shawangunk.

Swartz (1924) claimed that the Bloomsburg Red Beds of eastern Pennsylvania is equivalent to the High Falls Shale of New Jersey; he apparently assumed that the High Falls at its type locality is the same stratigraphic unit as the Bloomsburg.

Holzwasser (1926) mapped the Shawangunk Conglomerate in the northwest corner of the Gardiner quadrangle and part of the adjoining Napanoch quadrangle. She presented lithologic and petrographic descriptions of the Shawangunk, noted some red and green shales within the formation, and discussed earlier ideas regarding the age and origin of the Shawangunk.

Bryant (1926) (pl. 1*J*) first published the name Guymard Quartzite for more than 100 ft (30 m) of gray, olive, and reddish quartzites that lie above the Shawangunk Grit along the Erie Railroad near Guymard, N.Y. The name was originally used by van Ingen, who described these rocks to Bryant in 1920 but died before publishing the descriptions. Bryant described the Guymard as transitional up into thin red shales of the Longwood Shale, which he believed is equivalent to the Bloomsburg to the south in Pennsylvania and to the High Falls to the north. Both the Guymard and Longwood are included in the Wurtsboro Tongue of this report. Bryant described the fossil fish and eurypterids in these beds and concluded that they are of marine origin.

Willard (1928) argued for an Early Silurian age for the Shawangunk because it contained the "guide fossil" *Arthrophycus allegheniensis*. Moreover, he felt that the eurypterids of the Shawangunk at Otisville, N.Y., and Delaware Water Gap, Pa., are significantly different from those of the Pittsford Shale of Salinan age of western New York and more like those in the Upper Ordovician Frankfort Shale. Thus, he argued that the Shawangunk is more probably Early Silurian than Late Silurian in age. Willard described the Shawangunk as the seaward equivalent of the alluvial Green Pond Conglomerate in the Green Pond outlier 25 mi (40 km) to the southeast. In contrast to the Green Pond, the Shawangunk has few ripple marks and lacks channeling, mud cracks, and raindrop imprints, but does have fairly regular bedding, well-rounded and sorted pebbles, and a cleaner matrix than the Green Pond. Silurian eurypterids are known to be associated with marine organisms elsewhere, while *Arthrophycus* is similar to the lobworms of English sandy beaches today, according to Willard.

Swartz and Swartz (1931) (pl. 1*K*) prepared a summary stratigraphic report on Silurian rocks in southeastern New York, New Jersey, and Pennsylvania. They named the Otisville Shale Member of the Shawangunk Formation for nearly 500 ft (150 m)of "interbedded greenish-gray arkosic sandstone and arenaceous shale" exposed near Otisville. Details in the measured section are rather poor, and they were uncertain of the regional relations of the unit. Nevertheless they presented a stratigraphic section showing this unit to extend from southeastern New York to the Delaware Water Gap in Pennsylvania. They believed that the High Falls Shale of New York was continuous with the Bloomsburg Red Beds of Pennsylvania.

Chadwick and Kay (1933) measured the Shawangunk Conglomerate and High Falls Formation at High Falls, N.Y. They believed that these units are earliest Silurian (Medinan and Clintonian) in age and that they are continental deposits that are overlain by several members of the Decker Ferry Formation, including nearshore sands of the Binnewater Sandstone at the base.

Ingham (1940) (pl. 1*L*) examined the zinc and lead deposits that occur along shear zones in bedding, in cross fractures, and in brecciated zones in the Shawangunk Formation between Ellenville and Guymard. He concluded that the deposits were derived from a magmatic source at depth of unknown origin.

Bird (1941) (pl. 1*M*) described a 95-ft-thick (29-m-thick) unit dominated by limestone just above the Shawangunk near Wawarsing in the tunnel of the Delaware aqueduct (pl. 1). It is not found at the surface along strike and was thus named the Wawarsing wedge. Bird compared the section in the tunnel with that exposed along Rondout Creek at High Falls.

Freund (1941, 1942) (pl. 1*M*) described the stratigraphy of the Shawangunk Grit through Coeymans Limestone in the Rondout–West Branch tunnel of the Delaware aqueduct near Wawarsing, N.Y., and apparently introduced the name Wawarsing wedge at the same time as Bird (1941). He described the lithology of the Wawarsing, High Falls, and Binnewater in the tunnel. He noted that the High Falls and Binnewater consist of interbedded, yellow, decayed, and leached limestone; red limy shale; and red, green, and gray sandstone. He described the Wawarsing as a light-greenish and gray limestone with some shale.

The New York City Water Board prepared unpublished engineering drawings and geologic cross sections of the Rondout–West Branch tunnel of the Delaware aqueduct in 1945 (pl. 1*M*). The cross sections contain valuable generalized lithic descriptions and approximate thicknesses of the Martinsburg Formation, Shawangunk Formation, Wawarsing Limestone, High Falls Shale, and Binnewater Sandstone in the subsurface. Many of these rocks are not exposed at the surface for many miles from the tunnel.

Sims and Hotz (1951) (pl. 1*N*) and Eilertsen (1950) described the mineral deposits at the Shawangunk mine 2.5 mi (4 km) northeast of Wurtsboro and presented logs of many diamond drill holes and a composite section measured on the west slope of Shawangunk Mountain. These data give details on the interbedded red beds and quartzites of the Wurtsboro Tongue of the Bloomsburg Red Beds and the Ellenville Tongue of the Shawangunk Formation of this report.

Gray (1953, 1961) (pl. 1*O*) examined many of the zinc-lead mines between Ellenville and Guymard and presented descriptions and thicknesses of the Silurian units. He noted that the mineralized areas are near local changes in strike of the Shawangunk Formation and believed that the ores were deposited from hypogene solutions that reached temperatures of about 350°F (176 °C) during the "Appalachian Revolution." He described the 5-in (13 cm) blue plastic clay and yellow-brown sandy clay at the Martinsburg-Shawangunk contact at Guymard as a rock flour, representing a zone of weathering on the pre-Silurian surface. Gray identified the red beds just above the Shawangunk near Wurtsboro as the High Falls Formation, and the succeeding quartzites as the Binnewater Sandstone (the Wurtsboro and Ellenville Tongues of the Shawangunk Formation, respectively, of this report). He also mapped the upper half of the Shawangunk at Otisville as the Otisville Shale Member of the Shawangunk Formation and believed that it graded northeastward into his Binnewater Sandstone and southwestward into the Bloomsburg of New Jersey. He correctly interpreted the red beds overlying the Otisville and the red beds in the upper part of his Binnewater between Guymard and Wurtsboro as tongues of the Bloomsburg Red Beds. Curiously, however, Gray (1961, fig. 3) showed the red beds of his High Falls as overlying the Shawangunk Formation and underlying the Otisville Shale Member at Otisville but omitted showing the High Falls on his geologic map of the area (Gray, 1961, p. 321). He believed that this High Falls pinched out to the southwest near Guymard, and the Bloomsburg, overlying the Otisville, pinched out near the top of the Binnewater at Wurtsboro.

Kilfoyle (1954) cataloged the type fossils in the New York State Museum from the Shawangunk Grit and Guymard Quartzite.

Amsden (1955) interpreted the thick, coarse Silurian clastics from eastern New York to eastern Pennsylvania as terrestrial deposits derived from the east and whose eurypterids and fish probably inhabited fresh water. These clastics grade westward through a transitional zone containing *Arthrophycus* into normal shallow marine sediments.

Denison (1956), in a summary of the habitats of known early Paleozoic ostracoderms and eurypterids, noted the difficulty in assigning either a marine or freshwater environment to the parts of the Shawangunk and Bloomsburg in New York and New Jersey that contain these vertebrates, in spite of similar forms occurring elsewhere in rocks of definite marine origin.

Friedman (1957) (pl. 1*P*) discussed the general stratigraphy and structure of the Ellenville area and divided the Shawangunk into three members. His Minnewaska sandstone member (thin- to medium-bedded sandstone and interbedded green shale and thin conglomerate) may include all of the middle unit of the Shawangunk of this report, as well as some rocks above and below. The Minnewaska sandstone member separates his Mohonk conglomerate member below (massive conglomerate and subordinate sandstone) from his Ellenville sandstone member (white quartzose sandstone) above. The exact relation between Friedman's units and those of this report is uncertain, however. He noted the alternations of Shawangunk and High Falls rock types in the Ellenville-Wurtsboro area and apparently relegated all of the rocks exposed along N.Y. Route 17 near Wurtsboro to his Ellenville sandstone member. These rocks are herein placed in the Wurtsboro and Basher Kill Tongues of the Bloomsburg Red Beds, and the Ellenville Tongue of the Shawangunk Formation.

Fisher (1959) (pl. 1*Q*) prepared a correlation chart of the Silurian rocks of New York State and interpreted the stratigraphic positions of the Shawangunk, Otisville, Guymard, and High Falls, but indicated that the exact ages of these units are unknown. He named the Accord Shale for calcareous shales beneath his Rosendale waterlime near Accord.

Beerbower and Hait (1959) found fossil fish at five localities in the Bloomsburg (High Falls) Formation in Pennsylvania and New Jersey that are similar to those found in the Shawangunk at Otisville, N.Y. They suggested that the fossils in both formations represent the same age (late Niagaran or early Cayugan) and interpreted them to have lived in fluvial (channel-floodplain) or brackish water environments.

Rickard (1962) (pl. 1*R*) presented a definitive description of Upper Silurian (upper Cayugan) and Lower Devonian (Helderbergian) stratigraphy in New York State. Near Rosendale, the Rondout Formation was considered late Cayugan in age by Rickard, but he noted that the underlying Binnewater Sandstone, High Falls Shale, and Shawangunk Conglomerate lack diagnostic fossils and that their precise ages are unknown. He also noted that the correlation of the High Falls and Binnewater with rocks in New Jersey and Pennsylvania was uncertain, and suggested the possibility that they grade southwestwardly into calcareous shales or limestones of the Decker Ferry Formation, Bossardville Limestone, or Poxono Island Formation of northwestern New Jersey.

Yeakel (1962) and Meckel (1970) described the regional variations in thickness, lithofacies, texture, and paleontology of the Shawangunk Formation and equivalent Tuscarora Sandstone from New York to Virginia, and interpreted the rocks of the Tuscarora and Shawangunk as being deposited in an alluviated coastal plain.

Epstein and others (1967) gave definitive descriptions of the Poxono Island Shale and overlying Upper Silurian and Lower Devonian rocks between eastern Pennsylvania and Cuddebackville, N.Y.

Epstein and Epstein (1967, 1969, 1972) redefined and contributed a detailed stratigraphic study of the Shawangunk Formation and Bloomsburg Red Beds in eastern Pennsylvania and northwesternmost New Jersey.

Smith's (1967a) (pl. 1*S*) sedimentologic study of the Shawangunk Conglomerate, Tuscarora Quartzite, Bloomsburg Formation, and High Falls Formation in Pennsylvania, New Jersey, and New York resulted in a detailed interpretation of the environments of deposition of these rocks. He subdivided the units in New York into braided stream, meandering stream and floodplain, and tidal flat deposits. He believed that the Guymard Quartzite of Bryant (1926) and Otisville Shale Member of the Shawangunk Formation of Swartz and Swartz (1931) were both the same unit and were genetically related to the High Falls rather than the Shawangunk. Thus, he considered the Otisville Shale Member to be a member of the High Falls rather than the Shawangunk, as in previous interpretations.

Smith (1967b) (pl. 1*T*) later revised his stratigraphic interpretation, after becoming aware of the an additional red bed sequence in the Delaware aqueduct (Bird, 1941; New York City Water Board, unpub. data, 1945). He applied the name Wurtsboro shale and sandstone to the rocks that he previously (Smith, 1967a) called the High Falls. He felt that this unit lay below the resurrected Guymard Quartzite (which he previously had termed the Binnewater Sandstone) and above the Shawangunk Conglomerate. He also felt that the Binnewater Sandstone and High Falls Formation that are exposed in the High Falls area are younger than the Guymard Quartzite; these units lie under cover of surficial deposits northwest of Shawangunk Mountain in the Ellenville-Otisville area. His Wurtsboro, he believed, grades into the Otisville Shale Member as red beds are lost to the southwest.

Hoar and Bowen (1967) and Waines and Hoar (1967) described the facies relationships of the Rondout Formation and adjacent units in southeastern New York. They showed that the Binnewater, which is 35 ft (105 m) thick at High Falls, grades into and is replaced by dolomite of the Bossardville(?) Limestone (also called the Accord Shale by Fisher (1959)) at Accord.

Fagan (1968) found *Lingula*, mud cracks, and symmetrical ripples in the High Falls Shale (equivalent to the Longwood Shale of Darton (1894c) in Pine Hill, near Central Valley, N.Y., 25 mi (40 km) east-southeast of the correlative Bloomsburg Red Beds at Port Jervis. He interpreted the 105-ft-thick (32-m-thick) sequence as a tidal mud flat deposit.

Rickard (1969) interpreted geophysical well logs in rocks of Salinan (Late Silurian) age from Michigan to New York. He correlated several of the units in southeastern New York with those in eastern Pennsylvania: the Wawarsing Limestone with the lower part of the Poxono Island Shale, the High Falls Shale with the upper part of the Poxono Island Shale and the lower part of the Bossardville Limestone, and the Binnewater Sandstone with the upper part of the Bossardville Limestone and Decker Formation. His conclusions are confirmed by this report.

Johnsen and Waines (1969) noted the dissimilarity of 62 ft (19 m) of rock in a core near Accord that they assigned to the Binnewater with rocks in the Binnewater at its type section.

Fisher and others (1970) portrayed the distribution of generalized groupings of the Silurian rocks of southeastern New York at a scale of 1:250,000 and changed the lithic modifier of the Wawarsing Wedge of Bird (1941) and Freund (1941) to the Wawarsing Limestone.

Rickard (1970) indicated the possible correlation of the Wawarsing and lower part of the High Falls of southeastern New York with the Poxono Island of eastern Pennsylvania, and the Binnewater with the upper part of the Bossardville and lower part of the Decker.

Moxham (1972) investigated geochemical anomalies in surficial materials in the area of zinc and lead mining in the Shawangunk Mountains. He depicted the upper part of the Shawangunk Formation as grading southwestward into the Otisville Shale and Guymard Quartzite, and these grading into the Bloomsburg Formation. He described the Wawarsing Limestone in the water supply tunnel at Wawarsing as consisting of friable, shaly limestone, differing somewhat from the description of Bird (1941).

DeWindt (1972) believed that oriented ostracoderm fragments in the Bloomsburg of central Pennsylvania and in the High Falls (equivalent to the Longwood Shale) of the Skunnemunk outlier near Central Valley, N.Y., indicated the southwestward progradation of nonmarine deltaic deposits of the Bloomsburg into marine deposits. This finding agreed with previous interpretations of a fluvial-deltaic genesis for most of the Bloomsburg magnafacies and a shallow-marine origin (tidal-lagoon) for more westerly parts.

DeWindt (1973) discovered the trace fossil *Rusophycus*, a trilobite resting mark, in quartzite at Delaware Water Gap, Pa., which he believed was the Poxono Island Formation, but is actually in the transitional beds of the uppermost Shawangunk Formation or lowermost Bloomsburg Red Beds (Epstein, 1973), indicating a marine environment for these beds.

Rickard (1975) (pl. 1*U*) revised the correlation of the Silurian siliciclastic rocks of southeastern New York by accepting the Otisville, Wurtsboro, and Guymard terminology of Smith (1967b).

Waines (1976) observed that sandstone in the Binnewater becomes less abundant southwest from High Falls so that at Accord it contains more than 50 percent dolomite.

Martino and Zapecza (1978) found *Rusophycus* (trilobite resting tracks) and *Cruziana* in red beds of the High Falls Formation (the Bloomsburg Red Beds of this report) of northwestern New Jersey. These traces, along with fossil fish found elsewhere, were used to interpret the rocks as deposits of brackish water interdistributary bays of a delta.

Rubin (1981) indicated that the Shawangunk of southeastern New York can be subdivided based on texture and occurrence of interbedded shale, some of which is red, but he did not present specifics.

Friedman and others (1982) illustrated the stratigraphy of Silurian rocks in New Jersey and southeastern New York and showed the High Falls as a facies of the Bloomsburg and the Binnewater as a facies of the Poxono Island.

Waines and others (1983) presented a general lithologic description of the Shawangunk Formation in southeastern New York and described the unconformity at its base. They believed that the Shawangunk was deposited in a shallow-marine, high-energy, tidal flat to beach environment.

Fluhr and Terenzio (1984, p. 73) described the Wawarsing wedge of Bird (1941) and referred to it as the "Wawarsing Limestone in Poxono Island Shales" in the Delaware aqueduct.

Faul (1987) collected eurypterids from dark-gray and black shales in the Shawangunk Formation near Delaware Water Gap. She indicated that these are associated with nautiloid cephalopods, a bivalve, and probable coprolites. Although she did not specify, these fossils suggest that the unit is marine.

O'Brien (1987) presented a general description of some of the rocks in the Shawangunk and Bloomsburg along U.S. Interstate 84 east of Port Jervis.

Epstein and Lyttle (1987) and Epstein (1989) (pl. 1*V*) described the details of the stratigraphy of the Silurian rocks in southeastern New York and presented a facies model upon which much of this report is based. They assigned the highest rocks exposed on Shawangunk Mountain near Wurtsboro to the High Falls Shale, which are assigned to the Basher Kill Tongue of the Bloomsburg Red Beds of this report.

Prave and others (1989) (pl. 1*V*) and Alcala (1990) presented sedimentologic and petrographic details of the Wurtsboro Tongue of the Bloomsburg Red Beds, Ellenville Tongue of the Shawangunk Formation, and High Falls Shale at Port Jervis, Wurtsboro, and Ellenville based on the stratigraphic framework of Epstein and Lyttle (1987).

Epstein and Lyttle (1990) mapped the distribution of the Silurian siliciclastic rocks in the Napanoch, Ellenville, and Kerhonkson quadrangles.

STRATIGRAPHY

Silurian Sequence in New Jersey and Eastern Pennsylvania

The Silurian sequence thins dramatically between eastern Pennsylvania and southeastern New York (fig. 2). The Shawangunk Formation of eastern Pennsylvania consists of three quartzite conglomerate units (Weiders, Minsi, and Tammany Members) and a unit containing appreciable shale and some red beds (Lizard Creek Member) (Epstein and Epstein, 1972). Farther southwest, only a basal quartzite (Tuscarora Sandstone) and shale-sandstone sequence (Clinton Formation) can be recognized (Lyttle and others, 1986). In New Jersey, the shales of the Lizard Creek become less abundant, and the unit becomes too thin to map in the middle of the State. However, scattered beds and intervals of shale persist into southeastern New York, where they appear to be present at various levels within the Shawangunk.

The Bloomsburg Red Beds, comprising shale, siltstone, and sandstone, overlie gray sandstone, conglomerate, and shale of the Shawangunk Formation in eastern Pennsylvania and New Jersey (fig. 2). The contact, placed at the base of the lowermost red bed, is transitional in places through about 700 ft (213 m) of rock, as at Delaware Water Gap at the New Jersey–Pennsylvania border (Epstein, 1973). The contact has been traced to near the New Jersey–New York boundary. The Bloomsburg in Pennsylvania and New Jersey is overlain by poorly exposed dolomite and shale of the Poxono Island Formation, which in turn is overlain by the Bossardville Limestone.

Silurian Siliciclastic Rocks of Southeastern New York

The present study shows that rocks of the Shawangunk Formation, Bloomsburg Red Beds, and Poxono Island Formation form a facies mosaic northeast of Port Jervis, N.Y., that is more complex than that to the southwest and that a revision of the stratigraphic nomenclature is necessary. Figure 3 shows the present stratigraphic interpretation. The generally accepted sequence of Silurian rocks in southeastern New York has been, from the base upward, the Shawangunk Formation, High Falls Shale, Binnewater Sandstone, and Rondout Formation (see table 1 for a

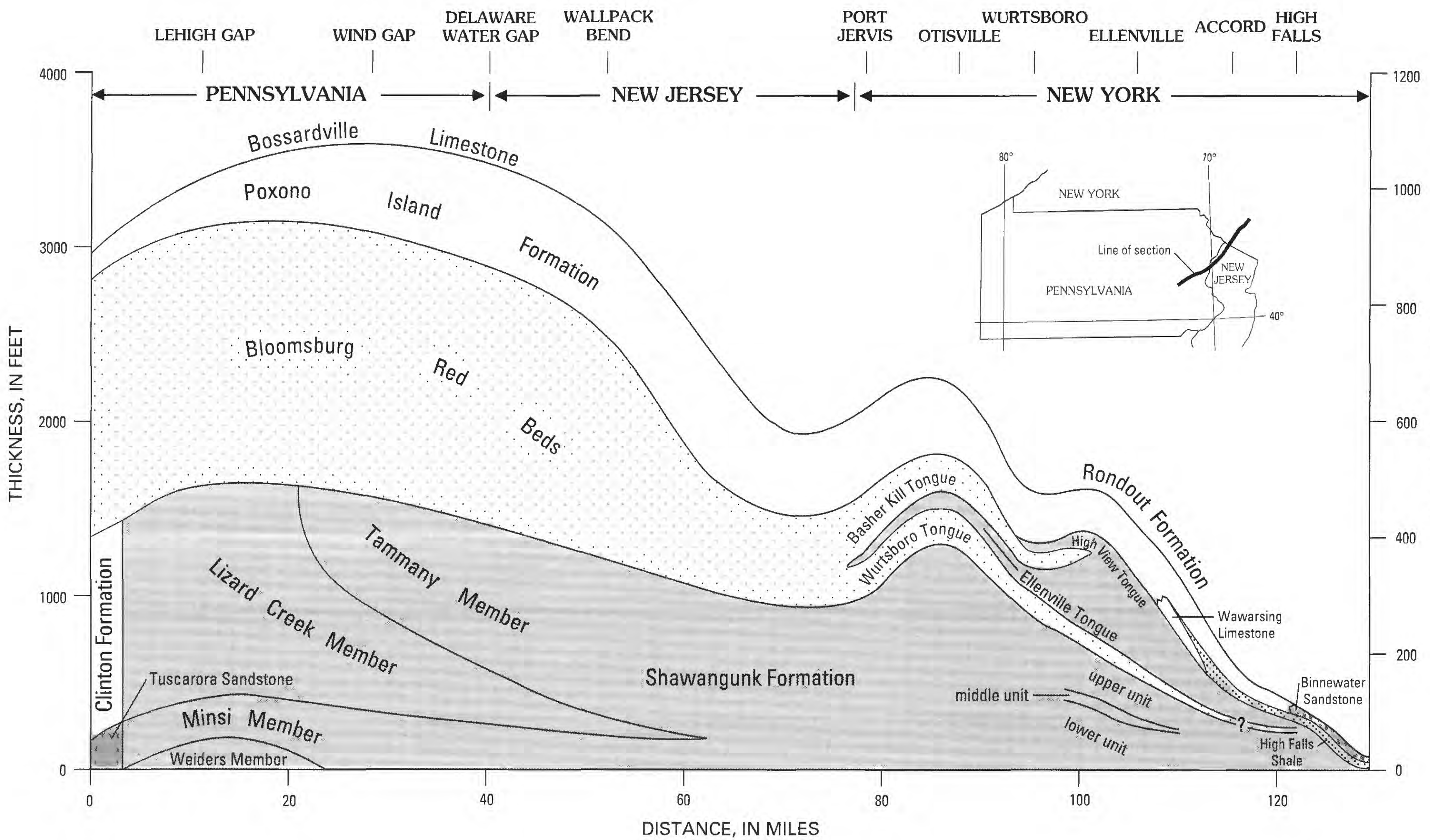

Figure 2. Generalized stratigraphic section of Silurian rocks from Lehigh Gap in eastern Pennsylvania to High Falls, N.Y. (modified from Epstein and Lyttle, 1987, fig. 4).

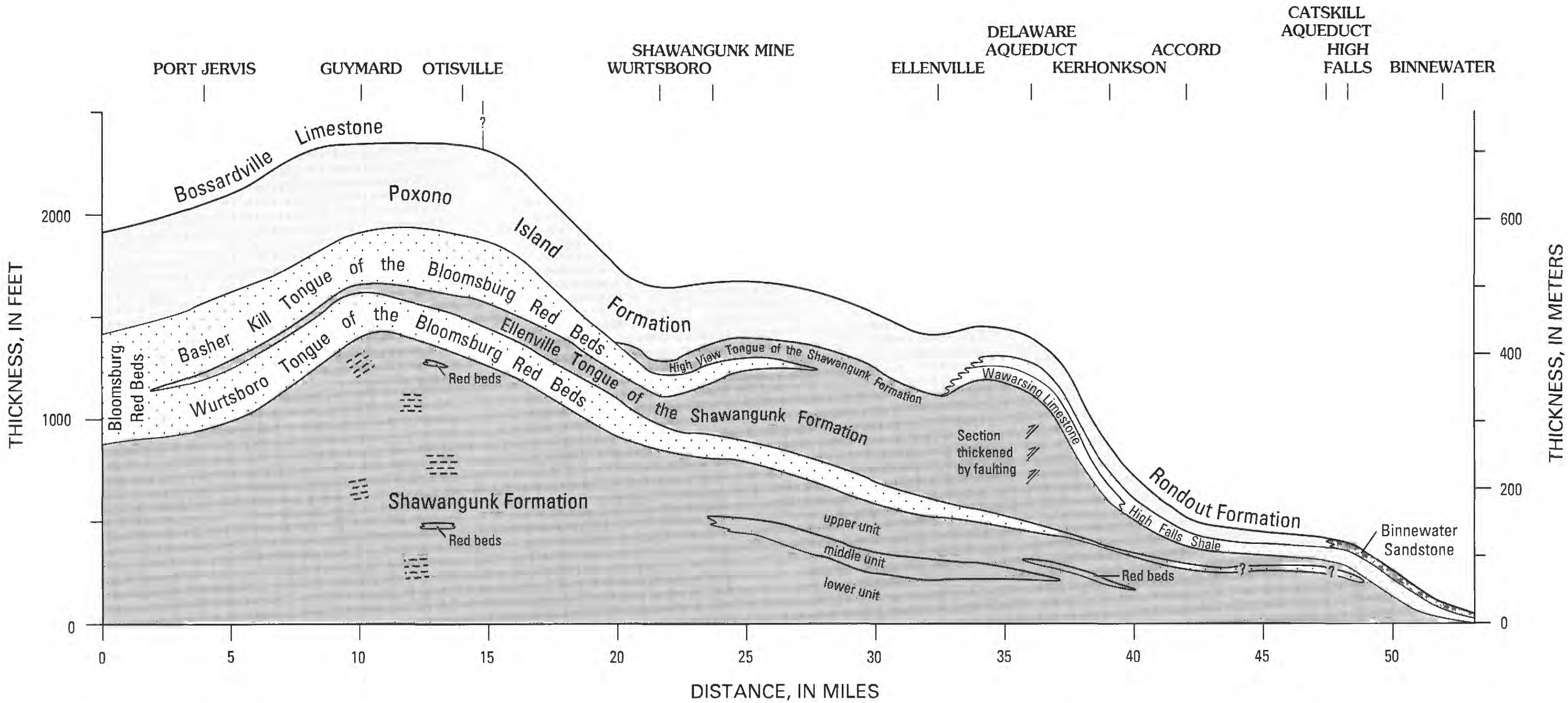

Figure 3. Stratigraphic section of Silurian rocks in southeastern New York in the area shown on figure 1. Most thicknesses are from construction of cross sections, a few are from direct measurements, and some, such as at High Falls, the Catskill and Delaware aqueducts, and the Shawangunk mine, are from published data, as indicated in the text. Short dashes are shale intervals in the Shawangunk Formation.

Table 1. Generalized stratigraphy of Silurian rocks, southeastern New York

Rock name	Description	Thickness
Rondout Formation (Lower Devonian and Upper Silurian)	Fine-to coarse-grained, thin- to thick-bedded limestone and laminated, argillaceous dolomite.	30–50 ft (9–15 m) thick
Binnewater Sandstone (Upper Silurian)	Fine-grained, thin- to thick-bedded, crossbedded and planar-bedded, ripple-bedded quartz arenite with gray shale and shaly carbonate. Grades to southwest into the Foxono Island formation.	0–68 ft (0–21 m)
High Falls Shale (Upper Silurian)	Red and green, laminated to massive, calcareous shale and siltstone, and sparse, thin, argillaceous limestone and dolostone. Ripple marks, desiccation cracks.	0–100 ft (0–30 m)
Wawarsing Limestone (Upper Silurian)	Gray and greenish-gray limestone (or dolomite), partly shaly and sandy. Reported only in the Delaware aqueduct.	0–90 ft (0–27 m)
Poxono Island Formation (Upper Silurian)	Poorly exposed gray and greenish dolomite and shale, possibly red shale in the lower part.	0–550 ft (0–170 m)
Bloomsburg Red Beds (Upper Silurian)	Grayish-red and gray shale, siltstone, and sandstone.	0–650 ft (0–200 m)
Basher Kill Tongue of the Bloomsburg Red Beds (Upper Silurian)	Grayish-red, grayish-purple, brownish-gray, and olive-gray shale, siltstone, and sandstone. Ripple bedded and mud cracked.	
Wurtsboro Tongue of the Bloomsburg Red Beds (Upper Silurian)	Grayish-red siltstone and shale slightly conglomeratic, partly crossbedded sandstone with pebbles of milky quartz, jasper, and rock fragments, and gray sandstone.	0–300 ft (0–90 m)
Shawangunk Formation (Upper and Middle Silurian)	Crossbedded and planar-bedded, channeled, quartz pebble conglomerate (rose quartz conspicuous in upper part), quartzite, minor gray shale and siltstone, and lesser red to green shale. Lower contact unconformable. In Ellenville area subdivided into three informal mappable units: an upper and lower quartzite and conglomerate unit separated by a middle unit containing shale and sandstone.	0–1,400 ft (0–425 m)
High View Tongue of the Shawangunk Formation (Upper Silurian)	Gray sandstone and minor green shale.	0–90+ ft (0–27+ m)
Ellenville Tongue of the Shawangunk Formation (Upper Silurian)	Crossbedded, cross-laminated (distinctive very light and medium-dark-gray laminae), and planar-bedded, thin- to thick-bedded, medium-grained quartzite and conglomerate with quartz pebbles as much as 2 in. (5 cm) long and greenish-gray silty shale and siltstone.	0–350+ ft (0–105+ m)
Diamictite (Lower Silurian or Upper Ordovician)	Colluvium with exotic pebbles and fault gouge of sheared clay and quartz veins. Lower contact unconformable. Described by Epstein and Lyttle (1987).	>1 ft (30 cm)
Martinsburg Formation (Upper and Middle Ordovician)	Thin- to medium-bedded, medium-dark-gray shale interbedded with very thin to thick-bedded graywacke (as much as 6 ft (2m) thick) alternating with thinner sequences of medium-bedded graywacke interbedded with thin- to medium-bedded shale.	<10,000 ft (3,000 m)

general description of these rocks). This sequence is firmly established near High Falls in the northeastern part of the area of this report (fig. 1). However, the relation of these rocks near High Falls with those to the southwest has been poorly understood (Fisher, 1959; Rickard, 1962). This report proposes two new tongues of the Bloomsburg (the Wurtsboro and Basher Kill Tongues), which interfinger with two new tongues of the Shawangunk (the Ellenville and High View Tongues). The Poxono Island grades northeastward into a sequence of red beds, sandstones, and carbonate rocks, which have been given a variety of names, including the Wawarsing Limestone, High Falls Shale, and Binnewater Sandstone. The entire sequence beneath the Rondout Formation thins rapidly to the northeast and disappears near Binnewater, N.Y.

This study demonstrates that the rocks assigned to the High Falls Shale on the New Jersey State geologic map (Lewis and Kummel, 1910–1912) are the lateral continuation of the Bloomsburg Red Beds in Pennsylvania and not of the younger High Falls of southeastern New York.

The complex Silurian sequence in southeastern New York described above is capped by the Bossardville Limestone of Late Silurian age near Otisville (Epstein and others, 1967). The Bossardville pinches out under glacial cover to the northeast, and the Binnewater is overlain by the Rondout Formation in the High Falls area.

Shawangunk Formation

The name Shawangunk Grit or Shawangunk Conglomerate was first applied by Mather in 1840 to the coarse clastic rocks exposed in the Shawangunk Mountains of southeastern New York. No type section was established. The name is derived from an old Indian term meaning "white stone" (Mather, 1843, p. 355). The name has been applied by many workers to the lower part of the Silurian sequence, which is characterized by conglomerate and quartzose sandstone (quartzite), although shale and siltstone are locally abundant and red beds are found in a few places. The conglomerate and sandstone form picturesque cliffs and hold up Shawangunk Mountain, which rises to more than 2,200 ft (670 m) near Ellenville.

The Shawangunk is about 900 ft (270 m) thick at the New Jersey–New York border. It thickens to about 1,400 ft (430 m) near Guymard and, from there, gradually thins to the northeast, so that at Binnewater it is only 10 ft (3 m) thick. Beyond that point, it pinches out. Between Port Jervis and Binnewater the average decrease in thickness is about 16 ft/mi (3.0 m/km), close to the figure of 19 ft/mi (3.6 m/km) given by Grabau (1913).

The following discussion concerns the rocks of the Shawangunk Formation, excluding the Ellenville and High View Tongues of the Shawangunk, which interfinger with the overlying Bloomsburg Red Beds.

The construction of cross sections indicates that the thickness of the Shawangunk is about 950 ft (290 m) at Port Jervis, although thicknesses of 800 ft (240 m) (Lesley, 1892) and 2,000 ft (600 m) (Darton, 1894a) have been reported; 1,350 ft (410 m) at Otisville (thicker than the 800 ft (240 m) reported by Schuchert (1916) and Smith (1967a)); 840 ft (260 m) at Wurtsboro (compared with the 700+ ft (215+ m) of Gray (1953) and 670 ft (200 m) of Smith (1967a)); about 500 ft (150 m) in the Ellenville area (similar to the figure given by Gray (1953) but thicker than the 280–300 ft (85–90 m) of Darton (1894a), Holzwasser (1926), and Ingham (1940)); about 350 ft (105 m) near Kerhonkson; 250 ft (75 m) at Accord; about 280 ft (85 m) in the Catskill aqueduct and at High Falls (Berkey, 1911; Brown, 1914; Chadwick and Kay, 1933; Gray, 1953; Swartz and Swartz, 1931); 10 ft (3 m) at Binnewater (Brown, 1914); and 3 ft (1 m) (Waines and Hoar, 1967) and 5 ft (2 m) (Rickard, 1962) a few miles north of Binnewater.

The Shawangunk rests on the underlying Martinsburg Formation of Ordovician age at an abrupt unconformable contact. The basal surface of the Shawangunk is irregular and has downward projecting structures described as mullions by Epstein and Lyttle (1987). The angular discordance with the underlying medium-gray (*N*5) to dark-gray (*N*3) interbedded shale, siltstone, and fine-grained graywacke of the Martinsburg is less than 15° throughout most of the area, although it increases east of Ellenville (Epstein and Lyttle, 1987). This contact is exposed along U.S. Interstate 84 near Port Jervis (fig. 4*A*), in an abandoned mine 1 mi (1.6 km) east of Guymard, in the railroad cut at Otisville (a classic exposure, discussed by Clarke (1907), Schuchert (1916), Fink and Schuberth (1962), and Epstein and Lyttle (1987)), along N.Y. Route 17 near Wurtsboro (fig. 4*B*), and at several places along the base of the cliff held up by the lower Shawangunk Formation in the northern part of the area, such as near Minnewaska. The exposure reported by Epstein and Lyttle (1987) to be the contact between the Shawangunk and Martinsburg at Mount Meenahga near Ellenville is incorrect. The contact is the result of the slumping of a large block of conglomerate and quartzite of the Shawangunk Formation, many tens of feet long, on top of shale-chip gravel derived from the Martinsburg Formation. The shale-chip gravel probably was the result of weathering during the late Wisconsinan.

The uppermost rocks of the Martinsburg Formation are of Middle or Late Ordovician age, and the lowest rocks in the Shawangunk Formation are probably of Middle Silurian age. Thus, the Taconic hiatus in southeastern New York is about 20–30 million years, nearly as long as the entire Silurian Period itself.

A dark-yellowish-orange, clayey fault gouge a few inches thick containing angular Martinsburg fragments is found along many of the exposed contacts of the Shawangunk and Martinsburg. Thus, the contact also represents a zone of tectonic movement; the amount of displacement is not known. Epstein and Lyttle (1987) provided a discussion of the relative effects of the Taconic and Alleghanian orogenies.

At the contact between the Martinsburg and Shawangunk Formations near Wurtsboro and Otisville, there is an interval, generally less than 1 ft (0.3 m), of a diamictite composed of poorly sorted clay, silt, and pebbles. The pebbles are rounded to subangular, as much as 4 in. (10 cm) long, and consist of rocks of the underlying Martinsburg as well as graywacke, orthoquartzite, feldspathic and chloritic sandstone, cross-laminated feldspathic conglomeratic quartzite, red fine-grained sandstone and siltstone, vein quartz, coarse-grained quartzite with pyrite, graywacke, medium-gray siliceous siltstone, laminated micaceous siltstone, and medium dark-gray shale. Some of the quartz and quartzite pebbles are similar to the rocks in the overlying Shawangunk; many of the others are exotic in that they are dissimilar to rock types immediately above or below the unconformity. The diamictite is interpreted to be colluvium, deposited during the post-Martinsburg, pre-Shawangunk interval, derived from source rocks that are no longer exposed, possibly brought near the site of deposition by thrust faults during the Taconic orogeny (Epstein and Lyttle, 1987; Epstein, 1989).

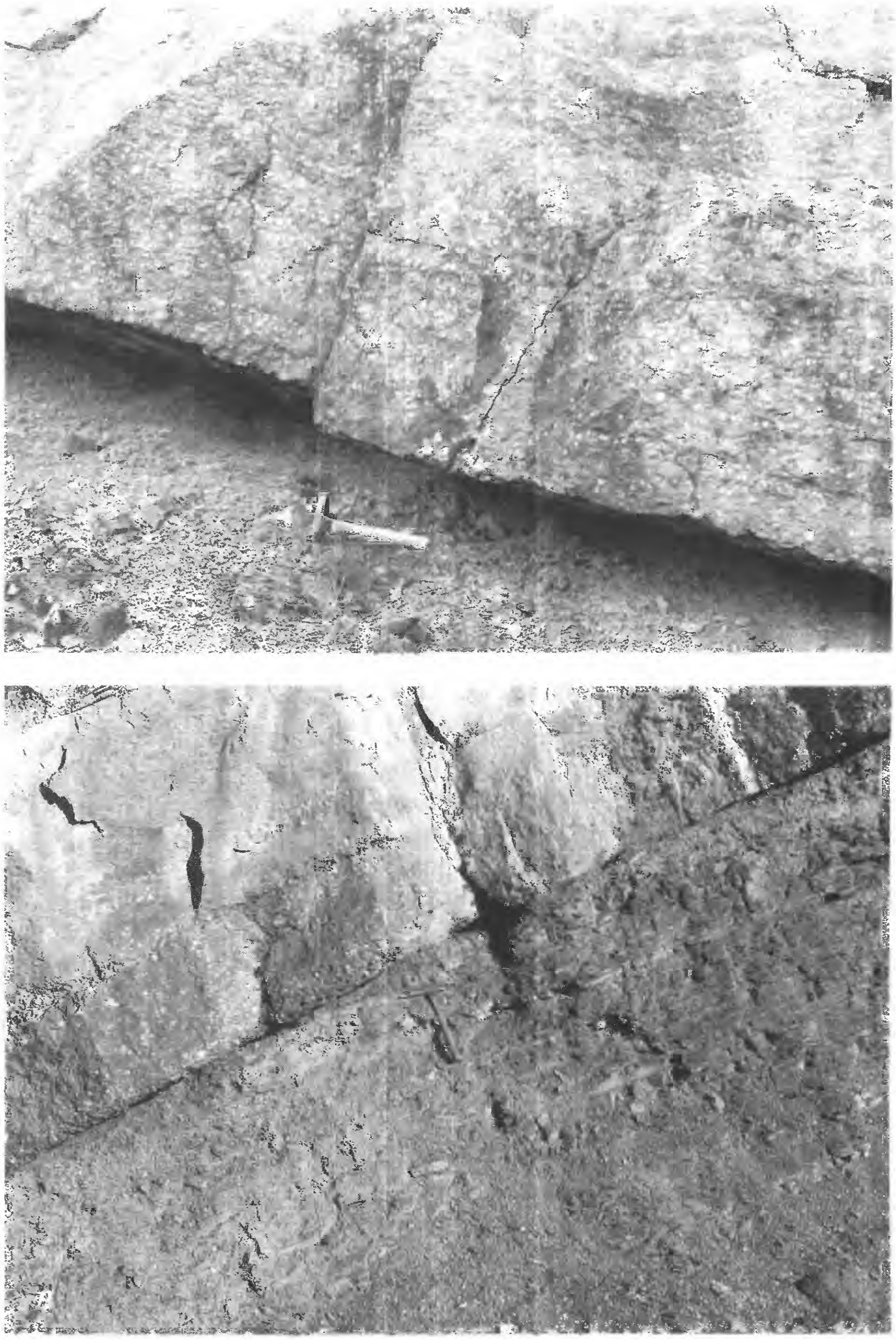

Figure 4. Unconformable contact between interbedded shale and graywacke of the Martinsburg Formation (Ordovician) and quartz-pebble conglomerate of the basal Shawangunk Formation (Silurian). *A*, U.S. Interstate 84, 3 mi (4.8 km) east of Port Jervis. *B*, N.Y. Route 17, 1.5 mi (2.4 km) southeast of Wurtsboro. The angular discordance at this locality is 15°. The lowest 10 ft (3 m) of the Shawangunk consist of massive, medium-gray to medium-light gray, planar-bedded, quartz- and chert-pebble conglomerate in a medium- to coarse-grained sandstone matrix. Quartz pebbles are rounded to well rounded and as much as 3 in. (8 cm) long. The chert is generally not more than 1 in. (2.5 cm) long. The overlying 12 ft (3.7 m) consist of finer, slightly feldspathic, quartz-pebble conglomerate and crossbedded conglomeratic sandstone with pebbles that are less than 1.5 in. (4 cm) long. The basal Shawangunk bed rests with sharp contact on dark-gray to medium-gray shale and graywacke of the Martinsburg Formation; the angular discordance is 5°.

In all sections examined, the lowest 10–25 ft (3–8 m) of the Shawangunk consists of massive (beds may be more than 3 ft (1 m) thick), medium-gray (*N*5) to medium-light-gray (*N*6) quartz- and chert-pebble, planar-bedded conglomerate in a medium- to coarse-grained, locally feldspathic, sandstone matrix (fig. 4). Quartz pebbles are rounded to well rounded and generally range up to 2 in. (1 cm) in length. However, the largest pebbles seen are as long as 4.5 in. (11 cm) and are located 1,300 ft (400 m) southeast of Verkeerder Falls in the Napanoch quadrangle, about 60 ft (18 m) above the base of the formation. Pebbles as much as 3.7 in. (9.4 cm) long are located in the lowest beds exposed near a pond, 0.8 mi (1.3 km) east of Shin Hollow in the Otisville quadrangle. Chert pebbles are generally not more than 1.5 in. (4 cm) long. At many places the basal few inches of the Shawangunk are pyritic. Both trough and planar crossbedding are common. The trough axes of many crossbeds are well exposed on glacially scoured surfaces. They record a unidirectional current trend to the northwest (Epstein and Lyttle, 1987, fig. 15), at least in the lower parts of the formation, which, along with other sedimentologic characteristics, suggest a northwest flowing, braided fluvial system draining the Taconic highlands (Yeakel, 1962; Smith, 1967a; Epstein and Epstein, 1967, 1972; Prave and others, 1989). Many of the sedimentary structures and the petrology of the Shawangunk Formation have been described by Smith (1967a), Prave and others (1989), and Alcala (1990).

None of the pebbles in the Shawangunk consist of rock types that were obviously derived from the unconformably underlying graywacke, siltstone, and shale of the Martinsburg Formation. The provenance of the pebbles in the Shawangunk along its entire outcrop belt, from eastern Pennsylvania to southeastern New York, has eluded a good sedimentologic explanation (Epstein and Epstein, 1972; Friedman and others, 1982).

The basal conglomerates of the Shawangunk pass upward into finer, slightly feldspathic, planar-bedded and crossbedded, quartz-pebble conglomerate, and crossbedded, fine- to coarse-grained, conglomeratic sandstone, in beds as much as 2 ft (0.6 m) thick. The pebbles in the conglomerates are generally less than 1.5 in. (4 cm) long and seldom exceed 0.5 in. (1 cm), especially near the top of the formation. The pebbles are mostly milky quartz, although jasper is locally present, and rose quartz becomes abundant northeast of Ellenville, chiefly in the upper part of the Shawangunk. Some of the coarse-grained sandstones contain medium-dark-gray (*N*4) to dark-gray (*N*3), and light-olive-gray (5*Y* 4/1) to greenish-gray (5*GY* 6/1) silty shale and siltstone intraclasts as much as 3 in. (8 cm) long. These rocks are medium dark gray (*N*4) to very light gray (*N*8). The conglomerates are interbedded with medium-gray (*N*5) to medium-light-gray (*N*6) and medium-olive-gray (5*Y* 5/1), fine- to medium-grained quartzite and conglomeratic quartzite in beds 6 in. (15 cm) to 1 ft (0.3 m) thick. Minor constituents are shale and siltstone that generally make up less than 2 percent of the formation, although locally may make up as much as one-fourth of sections of the formation that are many tens of feet thick. The shale is medium dark gray (*N*4) and dark gray (*N*3) to olive gray (5*Y* 6/1), partly silty, and in beds as thick as 1 ft (0.3 m). Lenticular light-olive-gray to medium-gray, poorly bedded, shaly and sandy siltstone occurs in laminae and beds as much as 5 ft (1.5 m) thick. Some of the sandstone is platy, planar-bedded and crossbedded, very fine to fine-grained, medium-gray, light-olive-gray to olive-gray, micaceous, and in beds generally between 3 in. (8 cm) and 1.5 ft. (.5 m) thick. Some of these rocks are in upward fining cycles with basal sandstones having sharp channeled bases. The sandstones generally weather to shades of gray to nearly white (*N*9) but locally weather to grayish orange (10*YR* 7/4) to dark yellowish orange (10*YR* 6/6) and moderate brown (5*YR* 4/4) to moderate reddish brown (10*R* 4/6).

The shales in the Shawangunk contain eurypterids. These fossils are abundant in the abandoned quarry just west of Otisville, where, according to Schuchert (1916), they are found 420, 650, and 750 ft (130, 200, and 230 m) above the base of the formation.

The contact between the Wurtsboro Tongue of the Bloomsburg Red Beds and the underlying Shawangunk Formation is gradational. It can be seen along U.S. Interstate 84 near Port Jervis, where fine- to medium-grained, laminated, medium-light-gray (*N*6) quartzite of the Shawangunk underlies grayish-red (10*YR* 4/2) silty shale. The contact is also well exposed slightly more than 1 mi (2 km) southwest of Otisville, where the rocks were termed the Guymard Quartzite by Bryant (1926). These rocks are discussed in the section on the Guymard below.

Usage of Otisville Shale

Shale and siltstone make up a small fraction of the Shawangunk Formation and generally do not exceed 10 percent of any significant part of the formation. However, Swartz and Swartz (1931) believed that shales were abundant enough near the top of the Shawangunk near Otisville to warrant designating the interval the Otisville Shale Member of the Shawangunk Formation. They established the type section in a quarry along the north slope of a small stream valley, at an altitude of 850 ft (60 m) above Lake Helen, 150 ft (50 m) east of the Lackawanna Railroad grade, and 1.7 mi (2.7 km) southwest of Otisville. They described the Otisville as consisting of 484 ft (148 m) of "interbedded greenish-gray arkosic sandstone and arenaceous shale." Their measured section lacks detail, nothing is mentioned of the proportion of shale to sandstone, and the upper and lower contacts are not discussed. Smith (1967a) later described the type Otisville as consisting of only 175 ft (53 m) of olive- to dark-gray shale and siltstone, making up

30 percent of the unit, interbedded with medium- to coarse-grained, slightly arkosic, white to gray sandstone.

About 55 ft (17 m) of rock are presently well exposed in the abandoned quarry (see table 2). These rocks consist of planar-bedded and crossbedded, thin- to medium-bedded (3 in. to 3 ft (8 cm to 1 m) thick), medium-gray (*N*5) and light-olive-gray (5*Y* 4/1), very fine to medium-grained, partly conglomeratic quartzite in beds as much as 4 ft (1 m) thick (making up 74 percent of the exposure), and interbedded, platy, light-olive-gray (5Y 4/1) and medium-dark-gray (N4) siltstone and silty shale (making up 26 percent of the exposure) in beds less than 1 in. to as much as 3 ft (2 cm to 1 m) thick. Above these rocks are about 115 ft (35 m) of partly exposed quartzite and siltstone; the proportion of shale to quartzite may be the same as in the quarry, or possibly less. The rocks ascribed to the Otisville are clearly not at the top of the Shawangunk Formation because about 320 ft (97 m) of the Shawangunk, predominantly quartzite, overlie them along and west of the old railroad track near the quarry.

The amount and vertical distribution of siltstones and shales in the interval defined as the Otisville Shale Member by Swartz and Swartz (1931) are quite variable along strike and cannot be readily mapped for any appreciable distance. For example, the rocks of the Otisville are on strike with rocks exposed 1.2 mi (2 km) to the northeast in the old ballast quarry just northeast of the intersection of N.Y. Route 211 and Otisville Road (fig. 5; see Ries (1897, pl. XXI, p. 448 ff.) and Schuchert (1916, fig. 2, pl. 20) for early photos of the quarry). These rocks are near the middle of the Shawangunk Formation and consist of northwest dipping quartzites and conglomerates interbedded with scattered shale that is much less abundant than at the type section 1.2 mi (2 km) to the southwest. Clarke (1907) described the Shawangunk in great detail in the quarry, and of the 531 ft (162 m) that he measured, less than 3 percent are shale beds, which are scattered throughout the sequence.

Smith (1967a) believed that the Otisville of Swartz and Swartz (1931) is the same unit described as the Guymard Quartzite by Bryant (1926). However, the rocks described as Guymard by Bryant (1926) are a few hundred feet stratigraphically above the Otisville and are exposed along the Erie-Lackawanna Railroad bed 600 ft (180 m) west and updip of the type Otisville. Smith (1967a) extended his Otisville Shale Member 9 mi (14 km) northeastward to Wurtsboro, where it is exposed along N.Y. Route 17; there, its base is marked by the lowest "good shale bed," approximately 670 ft (200 m) above the base of the Shawangunk. Here, the Otisville consists of light- to dark-gray sandstone alternating with gray to olive siltstone and shale. According to Smith, it is about 90 ft (30 m) thick, lying below the first red sandstone at the base of the High Falls Formation (the Wurtsboro Tongue of the Bloomsburg Red Beds of this report). Smith (1967b) later

Table 2. Measured section of shale, siltstone, and quartzite of the upper part of the Shawangunk Formation

[Thickness in inches; the former type section of the Otisville Shale Member of the Shawangunk Formation of Swartz and Swartz (1931) in abandoned quarry, 1.7 mi (2.7 km) southwest of Otisville. Youngest beds at top]

Bed	Thickness
Quartzite	34
Siltstone	24 (Partly covered)
Siltstone	10 (Covered)
Siltstone	33
Quartzite	2
Siltstone	5
Quartzite	8
Siltstone	2
Quartzite	6
Siltstone	5
Quartzite	10
Siltstone	4
Quartzite	6
Siltstone	5
Quartzite	10
Siltstone	4
Quartzite	13
Quartzite	15
Quartzite	26
Siltstone	5
Quartzite	4
Shale	6
Siltstone	2
Quartzite	15
Quartzite	40
Siltstone	36
Quartzite	8
Quartzite	36
Quartzite	13
Quartzite	45
Quartzite	43
Siltstone	1
Quartzite	10
Siltstone	4
Quartzite	7
Quartzite	46
Siltstone	22
Quartzite	17
Quartzite	41
Quartzite	6
Siltstone	20
Siltstone	22
Quartzite	31
Quartzite	29
Siltstone	1
Quartzite	23
Siltstone	2
Quartzite	25
Siltstone	10
Siltstone	9
Quartzite	36
Quartzite	48
Total	
Inches	885
Feet	73.8
Meters	22.5

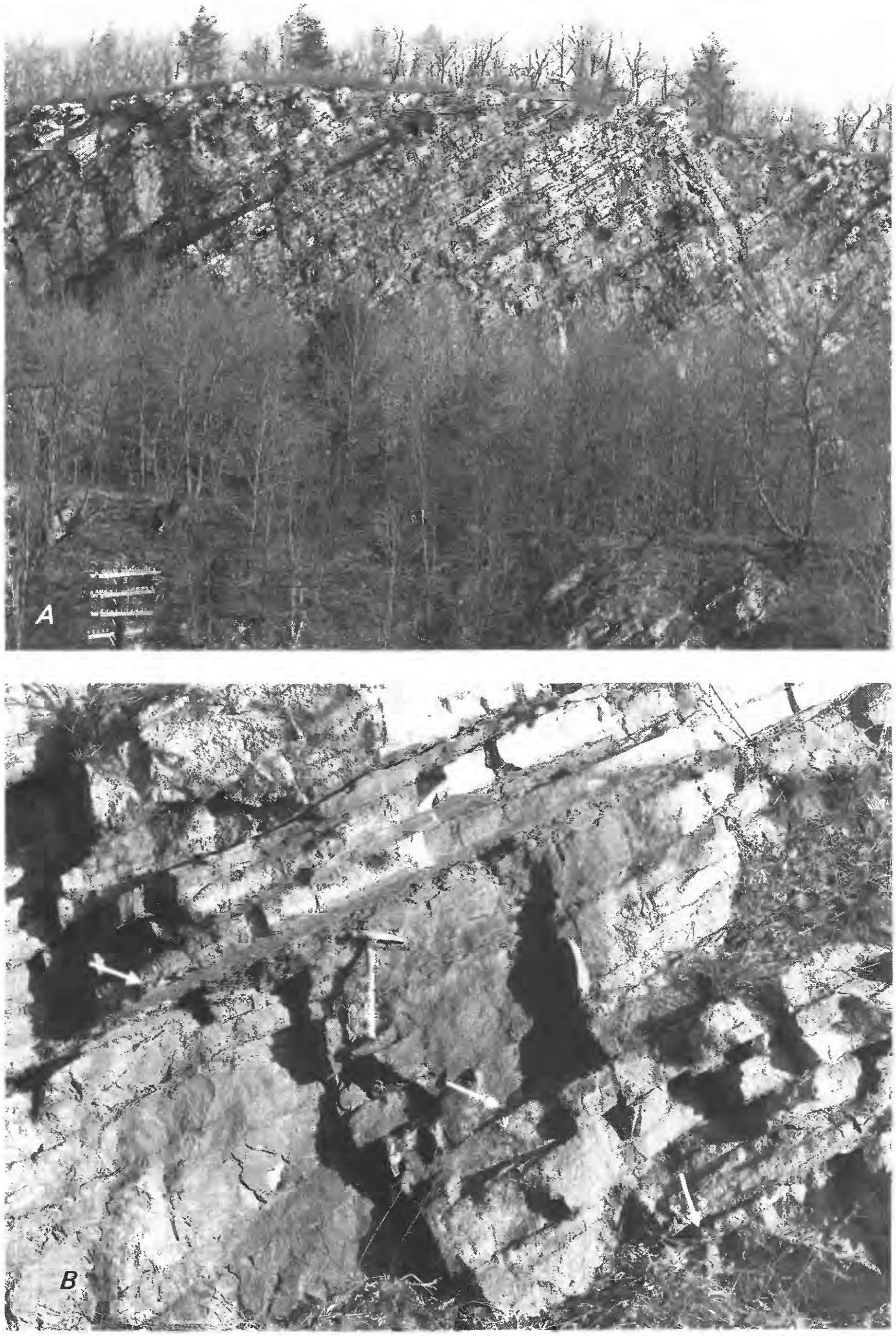

Figure 5. Interbedded quartzite and conglomerate of the Shawangunk Formation, for which minor gray shale and siltstone make up less than 5 percent of the rock. This is the Otisville Shale Member of the Shawangunk Formation of Swartz and Swartz (1931). *A*, High wall of the quarry is 0.5 mi (0.8 km) northeast of Otisville and was illustrated by Schuchert (1916, fig. 2, pl. 20). The dark layers are shale and siltstone. *B*, Close-up showing silty shale beds (arrows) as much as 4 in. (10 cm) thick in road cut along N.Y. Route 211 just south of quarry.

revised the thickness of his Otisville near Wurtsboro to 65 ft (20 m) and indicated that the unit cannot be readily recognized southwest of Wurtsboro and is definitely absent near Port Jervis. Smith claimed that the rocks of the Otisville at the type locality and near Wurtsboro are similar because both localities display upward fining sequences.

This is true for the Wurtsboro area (Prave and others, 1989) but not so for the type locality, where the quartzites and siltstones have abrupt contacts. Moreover, the rocks at the type locality are probably several hundred feet stratigraphically below those at Wurtsboro.

Eilertsen (1950), who described the mineral deposits at the Shawangunk mine near Wurtsboro, presented logs of four diamond drill holes that encountered red and gray rocks herein assigned to both the Wurtsboro Tongue of the Bloomsburg Red Beds and to the underlying part of the Shawangunk Formation. These include rocks that Smith (1967b) would have assigned to the Otisville. According to the log descriptions, these sequences consist of red, dark-red, reddish-brown, dark-purplish, and locally green shale, siltstone, and medium-grained sandstone interbedded with gray, greenish-gray, medium-grained sandstone. These overlie at least 350 ft (100 m) of white to dark-gray and greenish-gray, medium- to coarse-grained and conglomeratic sandstone and conglomerate interbedded with greenish-gray, green, and dark-gray shale. Even though the holes are spaced only 550 ft (170 m) apart, the red and gray sequences vary in lithic composition and color. Thus, the gray rocks in the Otisville of Smith (1967b) are quite variable along strike, substantiating the conclusion that they cannot be mapped and do not deserve a separate stratigraphic designation.

I conclude that the shales in the Shawangunk Formation relegated to the Otisville by previous workers in the area between Guymard and Wurtsboro vary considerably both in abundance and stratigraphic position within short distances along strike. They cannot be defined as a distinct mappable stratigraphic unit over any appreciable distance. The name is thus abandoned. However, farther to the northeast, in the area around Ellenville, there is a mappable unit containing shale that is herein informally designated the middle unit of the Shawangunk Formation.

Usage of Guymard Quartzite

The contact between the Shawangunk Formation and Wurtsboro Tongue of the Bloomsburg Red Beds is well exposed for 1.7 mi (2.7 km) along the abandoned Erie-Lackawanna Railroad grade, 1.2 mi (1.9 km) west-southwest of Otisville. The rocks on both sides of the contact, described below, were named the Guymard Quartzite by Bryant (1926). It is suggested that the name Guymard be abandoned.

The contact of the Shawangunk Formation with the Wurtsboro Tongue along the railroad grade is placed at the top of olive-gray (*5Y* 4/1), very fine grained sandstone and medium-greenish-gray (*5GY* 5/1) siltstone of the Shawangunk Formation in sharp contact with blocky moderate-grayish-brown (*5YR* 4/2) siltstone, and grayish red (*5R* 4/2), limonitic, very fine grained sandstone, shaly siltstone, and silty shale of the Bloomsburg. The 100 ft (30 m) of the Shawangunk immediately underlying the contact consists of crossbedded, thin- to thick-bedded (5 in to 4 ft (13 cm to 1.2 m) thick), limonitic, feldspathic, fine- to medium-grained (with few coarse grains), very light gray (N8) to medium-dark-gray (*N*4) and medium-olive-gray (*5Y* 5/1) to light-olive-gray (*5Y* 6/1) quartzite, some beds with dark-greenish-gray (*5GY* 4/1) shale clasts as much as 1/2 in. (1 cm) long; laminated and cross-laminated, very fine to fine-grained quartzite; minor slightly feldspathic, limonitic, light-olive-gray (*5Y* 6/1) to medium-olive-gray (*5Y* 5/1), silty, partly limonitic, very fine grained sandstone, a few beds of which are rippled; platy, olive-gray (*5Y* 4/1) siltstone; and scattered light-olive-gray (*5GY* 6/1) to pale-olive (*10Y* 6/2) shale and silty shale in lenticular beds as thick as 6 in. (15 cm). About 100 ft (30 m) below the top of the Shawangunk is a 1-ft-thick (0.3-m-thick) bed of grayish-red (*5R* 4/2) shaly siltstone that grades laterally to medium olive gray (*5Y* 5/1). This singular and discontinuous red bed is placed in the Shawangunk but is indicative of the northeastward transition of red strata in the Wurtsboro Tongue of the Bloomsburg Red Beds into gray beds of the Shawangunk Formation. This section will be discussed under the Wurtsboro Tongue.

Red Beds in the Shawangunk Formation

In addition to the thin red bed described in the section above, several other occurrences of such rocks in the Shawangunk Formation were seen during the present study and were reported by previous workers. They are in thin beds less than a few feet thick, some of which are scattered throughout intervals of gray rock as thick as 50 ft (15 m).

Gray (1953) reported 13 ft (4 m) of red, sandy shale in the Washington mine on the west slope of Shawangunk Mountain, at an altitude of 1,160 ft (350 m), west of Otisville and 3,000 ft (920 m) southwest of the intersection of N.Y. Route 211 and Otisville Road. He believed that these beds belong to the High Falls. However, it is herein concluded that these rocks are within the Shawangunk Formation and about 500 ft (150 m) above its base. Unfortunately, exposures at the mine site are poor. No red beds were seen on the dumps or in nearby float, nor were they seen by Smith (1967a). Only gray, partly conglomeratic, very fine to medium-grained quartzite and silty shale were seen.

Holzwasser (1926) reported a 50-ft (15-m) red shale unit lying 100 ft (30 m) above the base of the Shawangunk at Peterskill Falls, 3.3 mi (5.3 km) south of Accord, although she presented a measured section, taken from Billingsley (1910), that showed only 10 ft (3 m) of red shale, sandstone, and conglomerate lying about 150 ft (46 m) above the Martinsburg-Shawangunk contact. An examination of the rocks at the base of Peterskill Falls showed only the presence of a 15-ft-thick (5-m-thick) interval of laminated, light-olive-brown (*5Y* 5/4) silty shale. Although not proved by mapping as yet, this unit may be continuous with the middle unit of the Shawangunk Formation.

At the base of Stony Kill Falls, 3.1 mi (5 km) south of Kerhonkson, at an altitude of 1,230 ft (375 m), there is a sequence containing red beds, about 50 ft (15 m) thick, just below quartzites typical of the upper unit of the Shawangunk. This sequence is at a stratigraphic level too low to be a continuation of the Wurtsboro Tongue of the Bloomsburg Red Beds. It overlies several tens of feet of gray quartzite, which in turn overlies gray shale and sandstone, probably of the middle unit of the Shawangunk Formation. It consists of thin-bedded (beds as much as 4 in. (1 cm) thick), light-olive-gray (*5Y* 6/1) shale; light-brownish-gray (*5YR* 6/1), very fine grained sandstone (beds as much as 6 in. (15 cm) thick); pale-red (*5R* 6/2), very fine to coarse-grained sandstone; crossbedded, medium-bedded (beds as much as 1.5 ft (0.5 m) thick), medium-gray (*N5*) and red-purple (*5RP* 6/2), fine- to coarse-grained sandstone; and moderate-brown (*5YR* 3.5/4) to grayish-red (*10R* 4/2) shale.

A similar unit is located in the streambed of Coxing Kill at an altitude of 400 ft (120 m) in the Mohonk Lake quadrangle, although faulting in that area raises the possibility that this unit is the High Falls Shale.

The occurrence of these units suggests that other local lenticular bodies of red beds may be scattered throughout the main body of the Shawangunk Formation.

Lower Unit of the Shawangunk Formation

Epstein and Lyttle (1990), mapping in the Ellenville and Napanoch area, subdivided the Shawangunk Formation into upper and lower quartzite-conglomerate units, which are separated by a middle shale and siltstone-bearing unit that is as much as 110 ft (36 m) thick. Epstein and Lyttle (1987) earlier used the term shale unit for the middle unit. Friedman (1957) divided the Shawangunk in the Ellenville area into three members. The middle unit of this report may be his informal Minnewaska sandstone member, separating his Mohonk conglomerate member below from his Ellenville sandstone member above. The exact relation between his units and those of this report is uncertain, however. It is possible that his Ellenville sandstone member may contain some rocks that are herein placed in the Wurtsboro Tongue of the Bloomsburg Red Beds and the Ellenville Tongue of the Shawangunk Formation.

The lower unit of the Shawangunk Formation is generally similar to the lower half of the Shawangunk Formation farther southwest. Its lateral extent is controlled by the mapped distribution of the overlying middle unit (fig. 3). The lower unit ranges between about 200 ft (60 m) and 480 ft (150 m) in thickness. Light-gray (*N7*) to medium-gray (*N5*), crossbedded and planar-bedded, channeled, quartz-pebble conglomerate, which locally weathers grayish orange (*10YR* 7/4) to moderate brown (*5YR* 4/4), is characteristic of the lower several tens of feet. The conglomerate beds range from less than 2 ft (0.6 m) to more than 7 ft (2 m) thick. They are lenticular and pass laterally into finer quartzites. Pebbles are generally smaller here than to the southwest and generally do not exceed 2.5 in. (6 cm) in length, although one pebble, with a length of 3.4 in. (8.6 cm) was observed. The larger pebbles are mainly subrounded to well rounded, but smaller ones are subrounded to subangular. Chert pebbles as much as 1 in. (2.5 cm) long are locally present.

More than 60 ft (20 m) of the basal lower unit is exposed in a cliff at Sam's Point in the Napanoch quadrangle. The locality is about 2,000 ft (600 m) south of the highest point in the Shawangunk Mountains (2,289 ft, or 698 m). The rocks are medium-grained to pebbly quartzite, lying above coarse, medium- to thick-bedded conglomerates. They contain trough crossbedding, cosets averaging about 1 ft (0.3 m) thick, and low-amplitude channels (Epstein and Lyttle, 1987, p. C63). Similar rocks are found at Bear Hill, 3.5 mi (5.6 km) south of Ellenville (Prave and others, 1989, p. 134). The crossbeds indicate current trends ranging between S.80°W. and N.70°W. Here, as elsewhere in the basal Shawangunk, none of the pebbles in the conglomerates appears to have been derived from the underlying Martinsburg Formation, an enigma that eludes a good sedimentologic explanation.

The massive conglomerates and quartzites along the cliffs in the lower unit of the Shawangunk have been separated into huge blocks along joints and have moved outward from the face of the cliff along the shales of the underlying Martinsburg Formation. This process is well developed at the Ice Caves, 0.5 mi (0.8 km) east of Sam's Point, where the joints parallel the cliff face of the mountain. Cold air is trapped in the maze of blocks, and snow may persist throughout the summer, hence the name.

The upper part of the lower unit is well exposed in North Gully at Ellenville, in other ravines, and along the northwest dip-slope of Shawangunk Mountain. Quartz-pebble conglomerate is much less abundant here than lower in the section. The rocks are generally medium-gray (*N5*) to light-gray (*N7*), medium- to coarse-grained, locally pebbly, medium- to thick-bedded quartzite that locally weathers to light brown (*5YR* 6/4). Bases of units are generally sharp and occupy shallow channels in the underlying unit, the relief averaging about 4 in. (10 cm).

Middle Unit of the Shawangunk Formation

The middle unit of the Shawangunk Formation consists of more than 80 ft (24 m) of interbedded, laminated, ripple cross-laminated, olive-gray silty shale and moderate-brown and light-olive-gray very fine to medium-grained, crossbedded, lenticular sandstone, slightly conglomeratic in places. Many of the sandstone beds have sharp, erosional

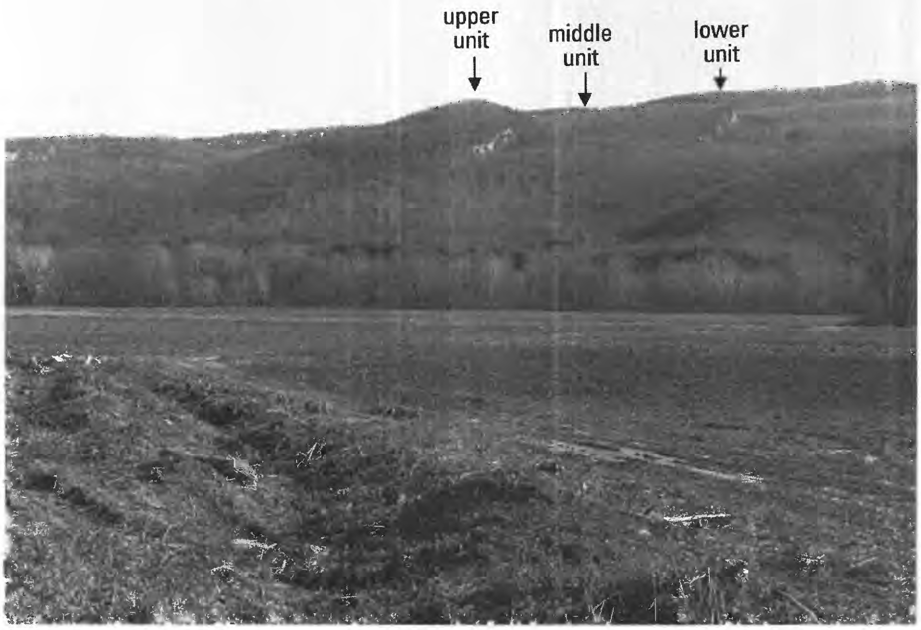

Figure 6. Two flatirons held up by the upper and lower units of the Shawangunk Formation separated by a valley underlain by the middle unit of the Shawangunk. View looking east from Napanoch toward the moderately dipping rocks in the northwest limb of the Ellenville arch.

bases, and some are ripple topped. Mapping of the unit is facilitated because it underlies topographic lows between flatirons of the lower and upper units (fig. 6). The middle unit has not been mapped in detail beyond the limits shown on figure 3; it may be more extensive than shown. The unit probably merges laterally into quartzites, siltstone, and shale near Otisville, similar to the rocks described in the section on usage of Otisville Shale, but which are unmappable for reasons stated previously.

The middle unit of the Shawangunk Formation is best exposed along N.Y. Route 52, 3 mi (5 km) south of Ellenville, at an altitude of 1,210 ft (370 m; fig. 7). Thirty-four feet (10 m) of rock are exposed (table 3), but the total thickness of the unit may be as much as 84 ft (26 m). The exposed unit consists of interbedded platy, laminated and ripple-laminated, olive-gray (5Y 4/1) silty shale that weathers dark yellowish orange (10*YR* 6/6) to moderate brown (5*YR* 3/4), and lenticular, medium-olive-gray (5*Y* 5/1) to light-olive-gray (5*Y* 6/1), medium-grained, crossbedded, thin-bedded (beds as much as 1 ft (30 cm) thick), lenticular sandstone with quartz grains as long as 0.3 in. (0.8 cm) and shale intraclasts as long as 2 in. (5 cm). The sandstone weathers moderate brown (5*YR* 4/4) to moderate yellowish brown (10*YR* 5/4). Many of the sandstone beds have abrupt, erosional bases, and many of their top surfaces are rippled.

Elsewhere the siltstone is light olive gray (5*Y* 6/1), lying in beds as thick as 2 ft (0.6 m), and interbedded with medium-dark-gray (*N*4), medium- to coarse-grained quartzite. The unit may be as thick as 120 ft (37 m) in places. The middle unit characteristically contains friable, leached, thin-bedded, slabby, crossbedded, medium- to coarse-grained, locally pebbly, siliceous sandstones, ranging from 1 in. (2.5 cm) to 1.5 ft (0.5 m) in thickness. These are transitional into the underlying lower unit of the Shawangunk Formation and can be seen in many places, such as at Verkeerder Kill Falls, 4 mi (6 km) southeast of Ellenville; on the lane 100 ft (30 m) below Castle Point, 6 mi (10 km) east of Ellenville; and 1,000 ft (300 m) south of Napanoch Point, 2.1 mi (3.4 km) southeast of Napanoch. The thin-bedded sandstones are typically less resistant than the quartzites above and below, and form reentrants along the cliffs under the upper unit of the Shawangunk Formation. They weather pale yellowish orange (10*YR* 8/6) to very pale orange (10*YR* 8/2) to light brown (5*YR* 5/6).

Within a distance of 2,000 ft (600 m) northeast of Stony Kill Falls in the Napanoch quadrangle, there are exposures of the middle unit on both sides of the valley. The rocks consist of crossbedded, thin-bedded, very fine grained sandstone and medium-gray (*N*5) shale. The contacts of this sandstone and shale unit have not been mapped beyond the valley into the main body of the unit; the unit might be an erosional inlier.

Figure 7. Interbedded lenticular sandstone and silty shale in the middle unit of the Shawangunk Formation exposed 3 mi (5 km) south of Ellenville along N.Y. Route 52.

Table 3. Measured section of parts of the lower, middle, and upper units of the Shawangunk Formation along N.Y. Route 52, 3 mi (5 km) south of Ellenville

	Thickness	
	Feet	Meters
Upper unit of the Shawangunk Formation		
10. Very light gray (*N*8) to white (*N*9), thin- to thick-bedded (beds 2 in. (5 cm) to 2.5 ft (0.8 m) thick), planar-bedded, crossbedded, channeled, medium-grained, very light gray (*N*8) weathering, conglomeratic (pebbles as much as 0.5 in. (1 cm) long) quartzite, scattered lenticular silty shale, and very fine grained sandstone in beds as much as 2 in. (5 cm) thick	100+	30+
9. Light-gray (*N*7) to very light gray (*N*8), thin-bedded (beds 1–8 in. (3–20 cm) thick), medium-grained, partly conglomeratic (pebbles as much as 0.3 in. (8 cm) long), slightly feldspathic, limonitic (particularly at the base), cross-bedded, channeled quartzite, and scattered thin (1–2 in. (2.5–5 cm) thick) interbedded shale.	about 60	20
Thickness of part of upper unit	160+	50+
Middle unit of Shawangunk Formation		
8. Interbedded sandstone and shale, similar to unit 6	2.0	0.6
7. Sandstone similar to that in unit 6	2.3	1.0
6. Medium-olive-gray (5*Y* 5/1), medium-grained, crossbedded, lenticular, ripple-bedded sandstone with sharp bases, weathers moderate brown (5*YR* 4/4) to moderate yellowish brown (10*YR* 5/4), beds as much as 16 in. (40 cm) thick, quartz grains as long as 0.3 in. (0.8 cm), shale intraclasts as long as 2 in. (5 cm), and equal amounts of olive-gray (5*Y* 4/1) silty shale	11.0	3.4
5. Shale and sandstone similar to unit 3, and medium-grained lenticular sandstone with channeled bases as thick as 1 ft (0.3 m), similar to unit 4	16.0	4.9
4. Medium-olive-gray (5*Y* 5/1), medium-grained, crossbedded, lenticular sandstone that weathers moderate brown (5*YR* 4/4) to moderate yellowish brown (10*YR* 5/4), quartz grains as long as 0.3 (0.8 cm), and a few interbedded lenticular silty shale laminae	2.0	0.6
3. Interbedded olive-gray (5*Y* 4/1), laminated, ripple-laminated, platy, silty shale that weathers dark yellowish orange (10*YR* 6/6) to moderate brown (5*YR* 3/4), and light-olive-gray (5*Y* 6/1), very fine grained sandstone.	0.5	0.1
2. Covered	about 50	15
Total thickness of middle unit	about 83.8	25.6
Lower unit of Shawangunk Formation		
1. Medium-gray (*N*5) to light-gray (*N*7), light-brown-weathering (5*YR* 6/4), medium-grained, medium- to thick-bedded quartzite. Overlain by covered interval of about 50 ft (15 m).		

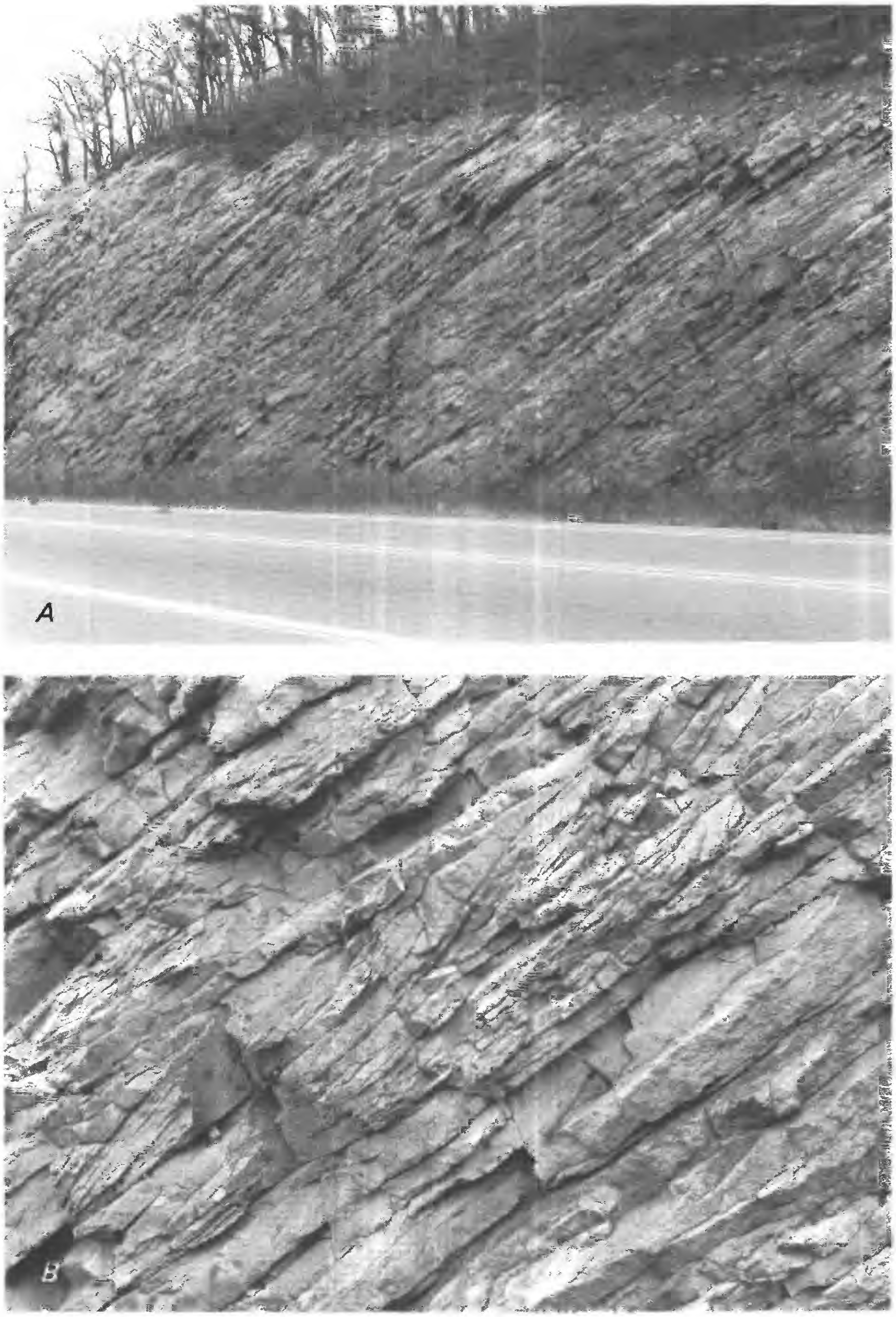

Figure 8. Upper unit of the Shawangunk Formation along N.Y. Route 52 near Ellenville, just above the shale unit shown in figure 7. *A*, Thin- to medium-bedded, planar- bedded and crossbedded quartzites and conglomeratic quartzites, typical of the lower part of the unit. *B*, Close-up showing northwest dipping epsilon crossbedding in quartzites of the upper unit.

Upper Unit of the Shawangunk Formation

The upper unit of the Shawangunk Formation ranges between 200 and 300 ft (60 and 90 m) in thickness. It is well exposed along N.Y. Route 52 south of Ellenville, where it consists of light-gray (*N*8) to white (*N*9), very light gray (*N*8) weathering, thin- to thick-bedded (beds 1 in. (2.5 cm) to 2.5 ft (0.8 m) thick), crossbedded and planar-bedded, partly conglomeratic and feldspathic, medium-grained quartzite and pea-gravel conglomerates (fig. 8), and minor thin, lenticular light-olive-gray shale (5*Y* 6/1) and greenish-gray (5*GY* 7/1) shale in beds as thick as 2 in. (5 cm).

Figure 9. Sedimentary structures in the middle part of the upper unit of the Shawangunk Formation, 2 mi (3.2 km) south of Ellenville along N.Y. Route 52. Beds dip 40° to the northwest (to the right). *A*, Conglomeratic quartzite cutting out a 1.5-ft-thick (0.5-m- thick) bed (at arrow), showing the lenticular nature of the sedimentation units. *B*, Channel (at arrow a) cut into crossbedded quartzite. Several of the crossbeds are covered with mud drapes (at arrow b). *C*, Flattened silty shale galls as long as 8 in. (20 cm) just to left of hammer.

Shallow channels are abundant, and many beds pinch out along strike (fig. 9*A*). Shale drapes in crossbeds are common (fig. 9*B*). Flattened, silty shale galls as long as 8 in. (20 cm) are seen on some bedding surfaces (fig. 9*C*). The quartzites appear to be evenly bedded from a distance, but closer scrutiny shows that they are channeled, lenticular, and unevenly bedded. Milky quartz pebbles may reach 1 in. (2.5 cm) in length. Rose quartz grains, averaging about 0.4 in. (1 cm) in diameter, are a common component in the quartzites. In the uppermost beds exposed at Spring Glen in the Ellenville quadrangle, quartz pebbles as long as 2 in. (5 cm) were seen, the largest in the upper unit.

Ellenville Tongue of the Shawangunk Formation

Between Wurtsboro and Ellenville the main body of the Shawangunk Formation is overlain by red beds, succeeded by gray sandstones. Because of a similar red and gray sequence at High Falls, several workers have identified these rocks as the High Falls Shale and Binnewater Sandstone, respectively (Darton, 1894b; Sims and Hotz, 1951; Friedman, 1957; Gray, 1961; Smith, 1967a). In contrast, detailed and reconnaissance mapping by Epstein and Lyttle (1987) indicates that the red bed sequence is a tongue of the Bloomsburg Red Beds (herein named the Wurtsboro Tongue), not the High Falls Shale, and the overlying gray sandstone is a tongue of the Shawangunk (herein named the Ellenville Tongue), not the Binnewater Sandstone.

The Ellenville Tongue is named after the town of Ellenville, N.Y., east and south of which the unit is well exposed in gullies, on the dip-slope of Shawangunk Mountain, and in an abandoned rock quarry. The type section of the Ellenville Tongue is the road cut along the north side of N.Y. Route 17, about 1 mi (1.6 km) southeast of Wurtsboro (fig. 10), where the tongue is 130 ft (40 m) thick.

Gray (1953, 1961) reported a thickness of 280 ft (85 m) for his Binnewater Sandstone (the Ellenville Tongue) at Wurtsboro, which also includes his Bloomsburg Formation (the Basher Kill Tongue of the Bloomsburg Red Beds). In the Otisville-Guymard area, the Ellenville Tongue of this report is the Guymard Quartzite of Smith (1967b), who believed that the Otisville Shale Member of the Shawangunk Formation of Swartz and Swartz (1931) and the Guymard Quartzite of Bryant (1926) were different names applied to the same unit. Smith redefined the Guymard as the gray and white sandstone that overlies his redefined Otisville Shale and Wurtsboro shale and sandstone. He reported his Guymard at Wurtsboro to be 110 ft (34 m) thick. Elsewhere, the Guymard of Smith (1967b) was apparently applied to different parts of the stratigraphic section (see pl. 1). Prave and others (1989) measured 112 ft (34 m) for their Shawangunk tongue (the Ellenville Tongue

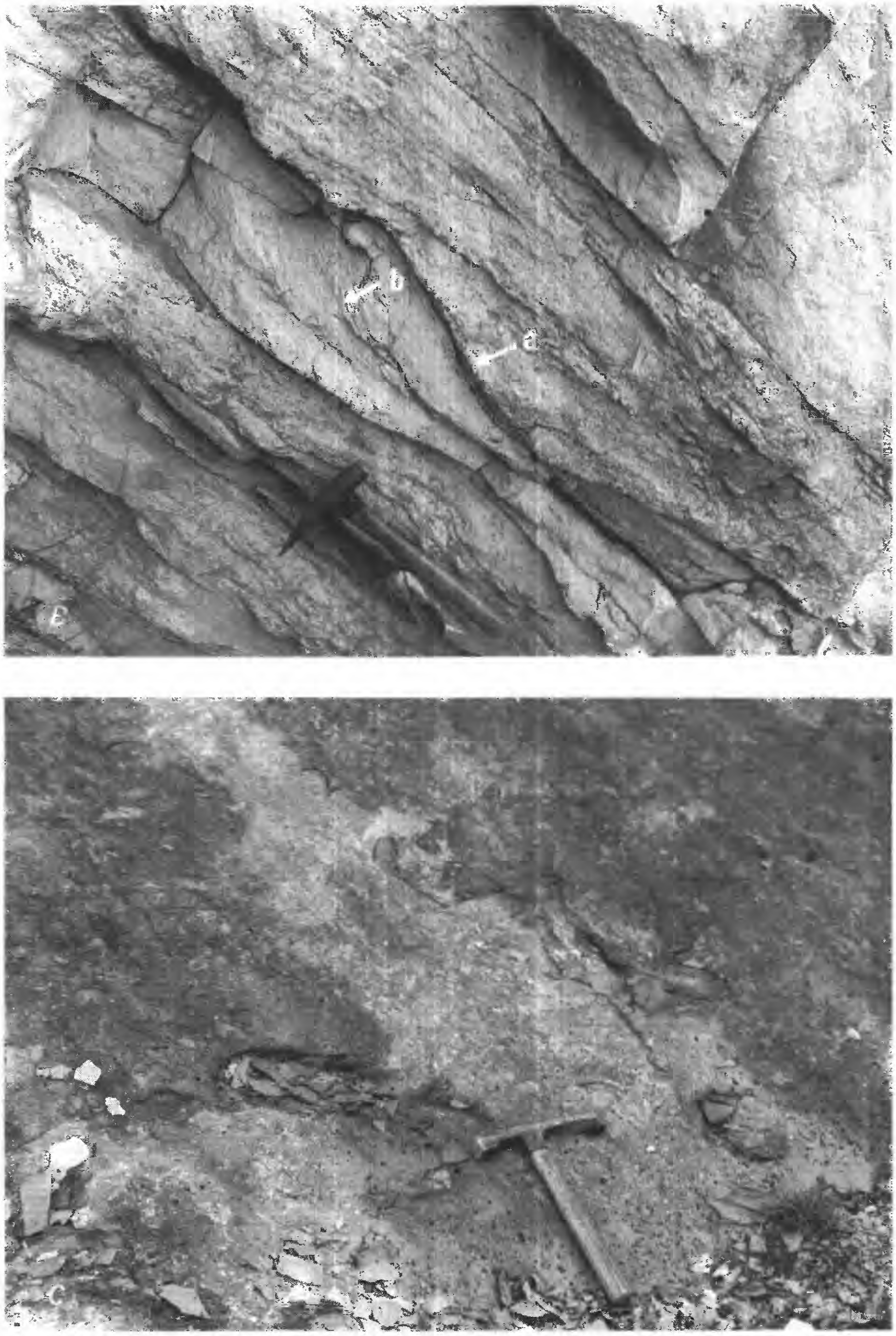

Figure 9. Continued.

of this report) at Wurtsboro but included some of the rocks that are here assigned to the underlying Wurtsboro Tongue of the Bloomsburg Red Beds.

At the type section, the Ellenville Tongue of the Shawangunk Formation consists of medium-dark-gray (*N*4) to light-gray (*N*7), medium- to thick-bedded (beds as much as 5 ft (1.5 m) thick), planar-bedded and crossbedded, fine- to medium-grained quartzite, conglomerate, and minor red and greenish-gray (5*GY* 6/1) shaly siltstone. The conglomerates are polymictic, with quartz, jasper, chert, and argillite pebbles generally 0.5 in. (1 cm) long but many nearly 2 in. (5 cm) long. The conglomerates are more abundant and become more polymictic toward the bottom.

The lower contact of the Ellenville Tongue is gradational with the Wurtsboro Tongue of the Bloomsburg Red Beds. The base is placed at the top of a red siltstone 2 ft (0.6 m) thick in the Wurtsboro. The uppermost 30 ft (9 m) of the Wurtsboro is a transition zone of nearly equal amounts of

Figure 10. Type section of the Wurtsboro Tongue of the Bloomsburg Red Beds (Sbw) and Ellenville Tongue of the Shawangunk Formation (Sse) along N.Y. Route 17, 1 mi (1.6 km) southeast of Wurtsboro.

gray and red crossbedded sandstone and red and green shale and siltstone. The rocks become less red toward the top as the sandstones become thicker and more abundant. In the lower part of the Ellenville Tongue, all the red beds are gone, and the sandstones that persist are all gray. Rare red beds are found much higher in the Ellenville Tongue, such as a red siltstone 13 in. (33 cm) thick 102 ft (31 m) above the base of the tongue at the type section.

The top of the Ellenville Tongue is not exposed at the type section; approximately 10 ft (3 m) of covered rock lie between it and the overlying Basher Kill Tongue of the Bloomsburg Red Beds.

Throughout most of the area of exposure, the sandstones of the Ellenville Tongue characteristically weather grayish orange (10*YR* 7/4) to light brown (5*YR* 5/6) and are thus generally recognizable from the main body of the Shawangunk below. Additionally, the cross laminae in sandstones of the Ellenville Tongue are distinctive in that they alternate between very light gray (*N*8) and medium dark gray (*N*4) (fig. 11*B*). Microscopic examination shows that the quartz grains in the darker laminae are replete with vacuoles, whereas the lighter laminae contain mostly clear quartz grains.

The thickness of the Ellenville Tongue is quite variable. It thins to a feather edge in northwestern New Jersey and thickens to more than 500 ft (150 m) in the Ellenville area, the upper half being covered with surficial debris. More than 900 ft (270 m) of the Ellenville Tongue is indicated in the cross section of the Delaware aqueduct (New York City Water Board, unpub. data, 1945), but that section may be repeated by faulting, and the diagram may have also exaggerated the thickness of the unit. The tongue then thins to about 75 ft (23 m) at Accord, northeast of which the underlying Wurtsboro Tongue pinches out and the Ellenville Tongue merges with and is nearly indistinguishable from the underlying rocks of the main body of the Shawangunk Formation.

The southernmost known exposure of the Ellenville Tongue is in northern New Jersey in a hill at an altitude of 880 ft (270 m) 500 ft (150 m) northeast of N.J. Route 23, about 2 mi (3 km) south of Port Jervis. There it consists of about 1 ft (0.3 m) of fine-grained sandstone weathering grayish orange (10*YR* 7/4) and overlying about 3 ft (1 m) very fine grained sandstone weathering light brown (5*YR* 6/4) and grayish orange (10*YR* 7/4). The entire unit is not exposed; it may possibly be as thick as 12 ft (4 m) there. The unit has not been recognized to the southwest in New Jersey (Don Monteverde, New Jersey Geological Survey, oral commun., 1990); it probably pinches out under cover of surficial deposits within a short distance from its last known exposure.

The Ellenville Tongue is completely exposed along U.S. Interstate 84 (fig. 12), about 2 mi (3 km) east of Port Jervis, where it consists of 17 ft (5 m) of grayish-orange-weathering (10*YR* 7/4), light-olive-gray (5*Y* 6/1), very fine to fine-grained, crossbedded, medium- to thick-bedded (beds as much as 3 ft (1 m) thick) quartzite that is slightly

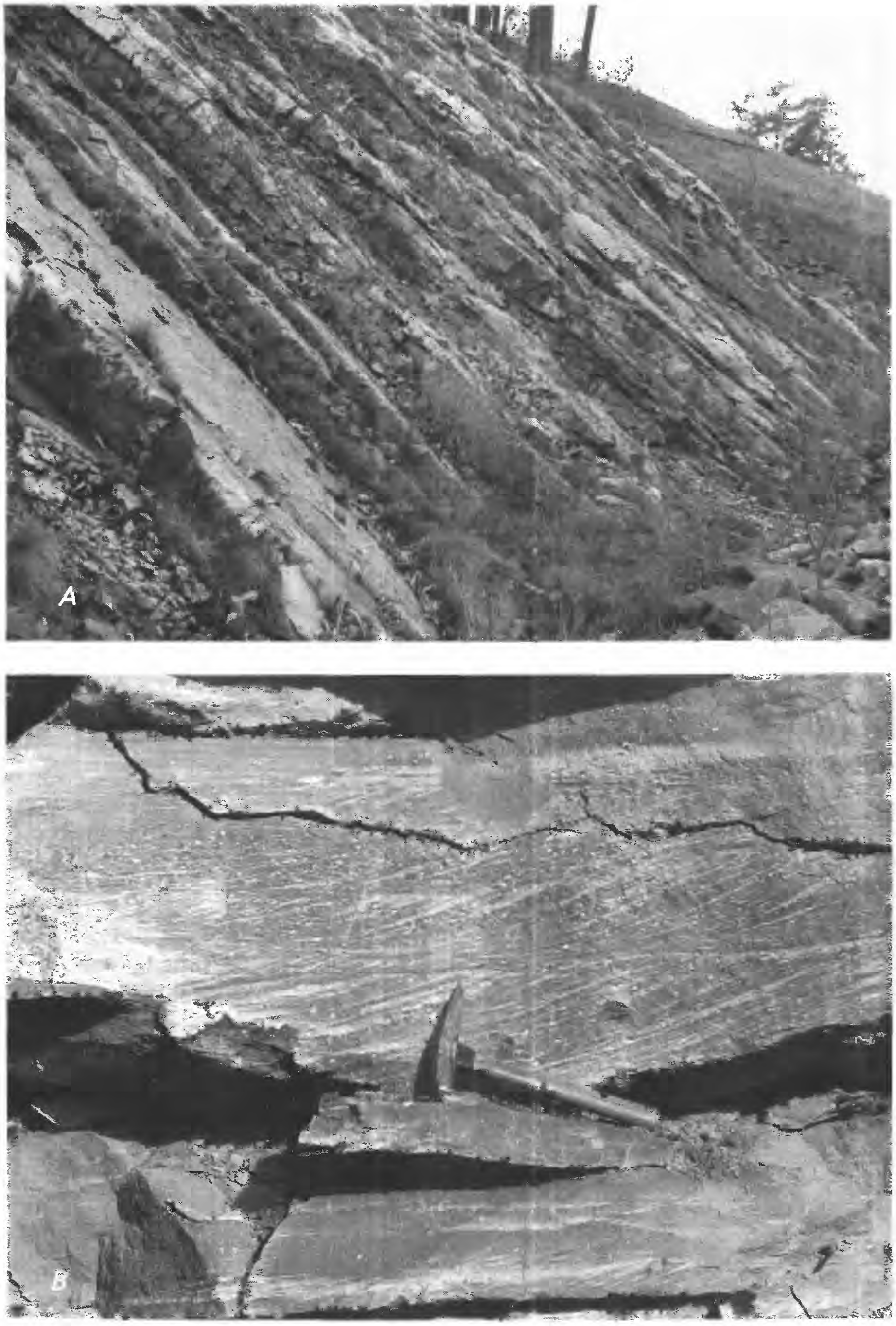

Figure 11. Ellenville Tongue of the Shawangunk Formation. *A*, Thin- to thick-bedded, very fine to coarse-grained and partly conglomeratic, crossbedded sandstones and interbedded siltstones exposed along N.Y. Route 52 just east of Ellenville at the mouth of North Gully. The Wurtsboro Tongue of the Bloomsburg Red Beds immediately underlies these rocks in the gully. *B*, Alternating very light and dark-gray cross laminae along U.S. Route 44, 0.5 mi (0.8 km) southwest of Kerhonkson.

conglomeratic in places and contains scattered milky and rose quartz pebbles as long as 0.3 in. (0.7 cm). The beds at the base of the tongue grade laterally and downward into dark-grayish-red (5*R*2/2) and grayish-red (5*R* 4/2) sandstone, shale, and siltstone of the Wurtsboro Tongue of the Bloomsburg Red Beds.

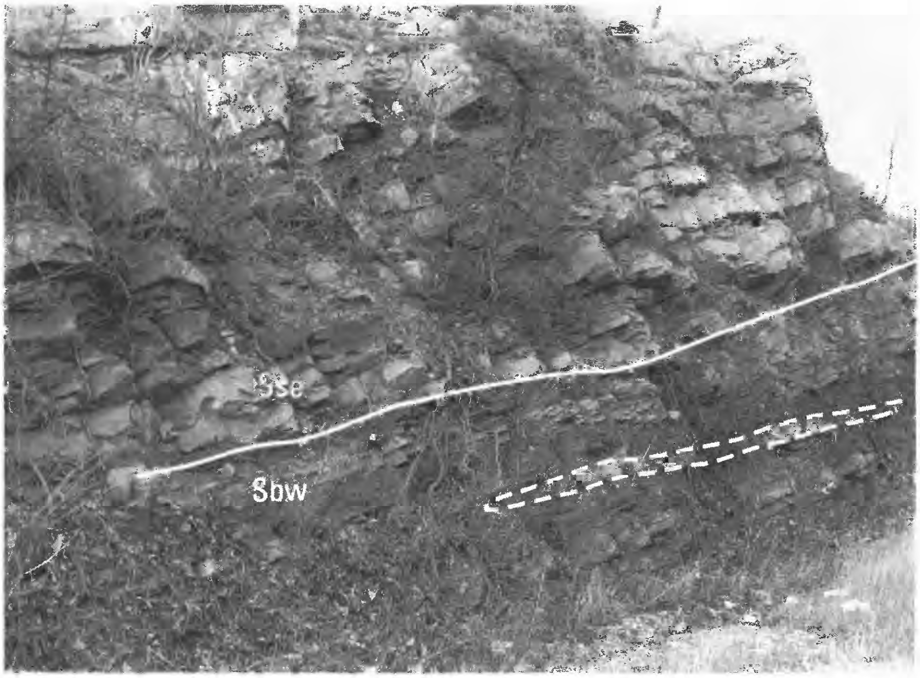

Figure 12. Ellenville Tongue of the Shawangunk Formation (Sse) along U.S. Interstate 84 near Port Jervis and transitional contact into underlying red and gray beds of the Wurtsboro Tongue of the Bloomsburg Red Beds (Sbw). The base of the Ellenville Tongue is placed at the bottom of the last prominent grayish-orange-weathering, gray quartzite. A few thin, gray sandstones are found in the underlying Wurtsboro Tongue (dashed outline).

Going northeastward, the next significant exposures of the Ellenville Tongue are found along a pipeline near Shin Hollow, 2 mi (3 km) southwest of Guymard, where they consist of medium-olive-gray (5Y 5/1), very fine to medium-grained sandstone with reddish mottles at altitudes between 840 and 870 ft (255 and 265 m).

Abundant float of the Ellenville Tongue is next seen in a hill 0.9 mi (1.4 km) southwest of Lake Helen and 250 ft (75 m) northwest of the Erie-Lackawanna Railroad. Here the float consists of light-olive-gray (5*Y* 7/1), fine- to medium-grained quartzite with rinds weathering light brown (5*YR* 5/6) (see fig. 15*A*). Fragments of red siltstone overlying Basher Kill Tongue of the Bloomsburg Red Beds are present in float in the slope immediately to the northwest.

Exposures of the Ellenville Tongue are generally poor for the next 9 mi (14 km) to the vicinity of its type section at Wurtsboro. Beyond that, about 7 mi (11 km) to the northwest near Spring Glen in the woods near a lane, an outcrop of the uppermost exposed beds of the Ellenville Tongue contains massive, quartz-pebble conglomerate with rounded pebbles as large as 2 in. (5 cm) in diameter, the largest seen in the Ellenville Tongue.

At North Gully near Ellenville, about 85 ft (26 m) of the Ellenville Tongue are exposed in the creek and along N.Y. Route 52 (fig. 11*A*). The rock consists of fine- to medium-grained, thin- to thick-bedded (beds 3 in. (8 cm) to 2.5 ft (0.8 m) thick), crossbedded, very light (*N*8) to medium-dark-gray (*N*4) sandstone that is partly conglomeratic and contains subangular to subrounded quartz pebbles as long as 1 in. (2.5 cm) and shale pebbles as long as 0.5 in. (1 cm). The sandstones are weathered dark yellowish orange (10*YR* 6/6) to moderate brown (5*YR* 4/4) and contain scattered dusky-red (5*R* 3/4) ironstone nodules as long as 3 in. (8 cm), as well as abundant pods of pyrite as long as 10 in. (25 cm). Quartz- and pyrite-vein filling is also common. Many of the sandstones have channeled bases and are lenticular. The sandstone beds are darker toward the base and are interbedded with scattered greenish-gray (5*GY* 6/1) shaly siltstone and silty shale beds as thick as 3 in. (8 cm), becoming slightly more abundant toward the base. Prave and others (1989) reported only 22 ft (7 m) for the Ellenville Tongue (their Shawangunk tongue) and a compensating greater thickness for the overlying Wurtsboro Tongue of the Bloomsburg Red Beds (their Bloomsburg tongue) at this locality. The base of the Ellenville Tongue is defined as the top of the uppermost red bed in the Wurtsboro Tongue. This criterion was selected as the most logical for geologic mapping. Prave and others (1989), who presented a detailed stratigraphic section at this locality, on the other hand, defined the Wurtsboro Tongue on sedimentologic grounds, that is, on the presence of upward fining cycles. Thus defined, their Bloomsburg tongue includes rocks that are placed in the Ellenville in this report.

The Ellenville Tongue is also well exposed in a rock quarry 1,800 ft (550 m) northeast of North Gully. The tongue there consists of at least 50 ft (15 m) of crossbedded (some of the cross laminae are distinctly banded light gray (*N*7) and dark gray (*N*3)), slightly conglomeratic, medium-grained, pyritiferous, thin- to medium-bedded (beds range from 2 in. (5 cm) to 2 ft (0.6 m) in thickness) quartzite, some beds of which have blackish-red (5*R* 2/2) to dark-yellowish-orange (10*YR* 6/6) iron staining, and minor dark-gray (*N*3) siltstone to very fine grained sandstone in beds as thick as 3 in. (8 cm).

Rocks typical of the Ellenville Tongue are exposed along U.S. Route 44, 0.5 mi (0.8 km) southwest of Kerhonkson (fig. 11B). Here, thin-bedded and laminated, medium-grained quartzites have the typical alternating very light gray (*N*8) and dark-gray (*N*3) cross laminae, similar to the rocks exposed near Ellenville, 6 mi (10 km) to the southwest.

High View Tongue of the Shawangunk Formation

A poorly exposed sequence of quartzite and shale is herein named the High View Tongue of the Shawangunk Formation. The High View overlies red beds of the Basher Kill Tongue of the Bloomsburg Red Beds (new name; see section under the Bloomsburg Red Beds), which overlies the Ellenville Tongue of the Shawangunk Formation (fig. 3).

Gray (1953, 1961) observed the red sandstones of the Basher Kill near Wurtsboro and stated that they lay about 50 ft (15 m) below the top of his Binnewater (the High View Tongue). Eilertsen (1950) and Sims and Hotz (1951) had presented an earlier description of the upper part of their Shawangunk Formation from examination of boreholes at the Shawangunk mine, 2.5 mi (4 km) northeast of Wurtsboro. Many of these rocks presently are not exposed. The boreholes showed that the Basher Kill Tongue of this report is overlain by at least 89 ft (27 m) of gray, thin-bedded quartz sandstone with well-sorted and rounded quartz grains, and some green shale, the High View Tongue of the Shawangunk Formation of this report. The name is taken from the town of High View, 2.5 mi (4 km) south of the Shawangunk mine, southeast of Shawangunk Mountain.

A potential type section for the High View Tongue is the drift of the Shawangunk mine, at an altitude of 560 ft (170 m) at the base of Shawangunk Mountain, 2.3 mi (3.7 km) northeast of Wurtsboro. Several hundred feet of rock are exposed in the drift, but because access to this section is now blocked, this report relies on the meager descriptions by Eilertsen (1950) and Sims and Hotz (1951). The mine portal is located in fine- to medium-grained quartzite of the High View Tongue, weathering pale yellowish orange (10*YR* 8/6) to dark yellowish orange (10*YR* 6/6). No outcrops of the High View were seen immediately above the portal, but the quartzite float is similar to the quartzite in the Ellenville Tongue of the Shawangunk Formation. Scattered outcrops of the High View are found within 1 mi (1.6 km) southwest of the Shawangunk mine, and the unit is not exposed beyond that locality; it presumably pinches out southwest of Wurtsboro. It can be traced in float and some outcrops for about 1 mi (1.6 km) northeast of the mine and disappears beneath surficial deposits beyond that. The High View apparently merges with the Ellenville Tongue to the northeast, where the intervening Basher Kill Tongue of the Bloomsburg pinches out (fig. 3). The lower contact of the High View is probably sharp and probably placed at the top of the highest red bed of the underlying Basher Kill Tongue of the Bloomsburg Red Beds. The upper contact with the Poxono Island Formation can only be speculated. It may be a transitional boundary within interbedded quartzite and green shale. Dolomite may be present, however, to mark the base of the Poxono Island.

Bloomsburg Red Beds

White (1883) first used the name Bloomsburg for red beds at Bloomsburg in central Pennsylvania. The Bloomsburg Red Beds, which lie above the Shawangunk Formation in eastern Pennsylvania, can be traced through New Jersey into New York, where the name was first used by Swartz and Swartz (1931), although the same rocks were termed High Falls Shale (Formation), Longwood Shale, or Guymard Quartzite by several authors (see pl. 1).

The Bloomsburg in New York is separated into two tongues by the intervening Ellenville Tongue of the Shawangunk Formation. The two tongues are named the Wurtsboro Tongue, below, and the Basher Kill Tongue, above.

Wurtsboro Tongue of the Bloomsburg Red Beds

The Wurtsboro Tongue of the Bloomsburg Red Beds is named for 115 ft (35 m) of interbedded red, green, and gray, crossbedded polymictic conglomerate, sandstone, siltstone, and shale exposed at its type section along N.Y. Route 17, about 1 mi (1.6 km) southeast of Wurtsboro (fig. 10). An additional reference section is along U.S. Interstate 84, 2 mi (3.2 km) east of Port Jervis, where about 230 ft (70 m) of the Wurtsboro are exposed. These sections were described by Epstein and Lyttle (1987) and Prave and others (1989), who termed the unit the tongue of the Bloomsburg Red Beds.

Smith (1967a) identified the rocks of the Wurtsboro Tongue as the High Falls Formation and, as noted previously, believed that they grade laterally into his Otisville Shale Member of the High Falls Formation. In an open-file report, he later (Smith, 1967b) proposed the name Wurtsboro shale and sandstone for the red, gray, and olive beds

Figure 13. Upward fining cycles of sandstones with abrupt lower bases, grading up into siltstones and shales in the Wurtsboro Tongue of the Bloomsburg Red Beds along N.Y. Route 17, 1 mi (1.6 km) southeast of Wurtsboro.

that directly underlie his Guymard Quartzite (the Ellenville Tongue of the Shawangunk Formation), which grades into his non-red Otisville Shale to the southwest, and which, in turn, grades into his Bloomsburg Formation. The regional distribution of the Wurtsboro as used in this report differs from the distribution indicated by Smith (see pl. 1). The name Guymard Quartzite was originally applied by van Ingen (Bryant, 1926, p. 259) to rocks that occupy part of the Wurtsboro Tongue of the Bloomsburg Red Beds of this report between Guymard and Otisville. As indicated previously, this name, like the Otisville Shale, should not be used to define the stratigraphy of these rocks.

At its type section along N.Y. Route 17, the rocks of the Wurtsboro Tongue characteristically occur in upward fining cycles as thick as 12 ft (3.7 m) (fig. 13). The rocks at Wurtsboro are similar to those exposed along U.S. Interstate 84 near Port Jervis, except that the polymictic conglomerates are more abundant at Wurtsboro, making up about 30 percent of the unit, and gray siltstones and shales are more abundant in the lower part of the tongue at Wurtsboro, and replace some of the red siltstones and shales prevalent at Port Jervis. Prave and others (1989) described 45 upward fining cycles at Port Jervis, 41 at Wurtsboro, and 37 at North Gully, in Ellenville, although, as mentioned previously, they included some of these cycles in the Ellenville Tongue of the Shawangunk Formation of this report.

The conglomerates in the Wurtsboro Tongue are planar bedded, crossbedded, and cross-laminated and occur in beds as much as 3 ft (1 m) thick (fig. 14). They contain milky and rose quartz and some jasper pebbles, as well as green and red shale clasts derived from the erosion of underlying beds. The conglomerates and many of the sandstones lie on the underlying beds with an abrupt, low-amplitude erosive base, above which occur occasional lenticular layers containing lag pebbles.

The conglomerates grade up into very fine to coarse-grained, pebbly, grayish-red (5*R* 4/2 to 10*R* 4/2), medium-olive-gray (5*Y* 5/1) to light-olive-gray (5*Y* 6/1), and lesser light-gray (*N*7), sandstones, similar in color to the conglomerates. Many gray sandstones are mottled grayish red (5*R* 4/2), and the color of some red beds changes to medium olive gray (5*Y* 5/1) along strike. Many sandstones are micaceous. They are laminated, planar bedded, and crossbedded (small- and large-scale trough crossbedding is most common; cosets range from about 1 in. (2 cm) to 1 ft (0.3 m) in thickness), and thin to medium bedded (beds 2 in. (5 cm) to about 3 ft (1 m) thick); some beds are amalgamated and may be thicker. The quartz pebbles are rounded to subrounded and as long as 0.5 in. (1 cm). Lesser red and dark-greenish-gray (5*GY* 4/1) chert pebbles are as long as 1.5 in. (4 cm), and scattered greenish-gray (5*GY* 6/1) and pale-red (5*R* 6/1) silty shale clasts are as long as 2 in. (5 cm). The base of many sandstones rests with sharp contact on underlying finer sediments. Rippled surfaces are found locally. Some sandstones are capped by a thin (about 1 in. (3 cm) thick), mud-cracked, pale-red (5*R* 6/2) and light-olive-gray (5*Y* 6/1) shale, which weathers to dark yellowish

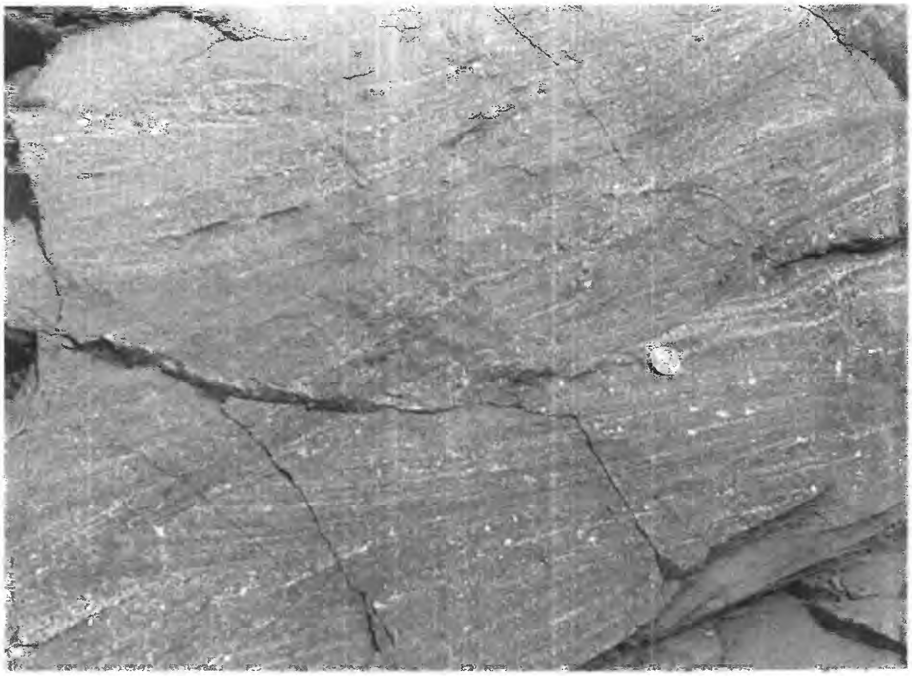

Figure 14. Crossbedded, polymictic, conglomeratic sandstone in the Wurtsboro Tongue of the Bloomsburg Red Beds along N.Y. Route 17 near Wurtsboro. The pebbles consist of white and rose quartz, jasper, and green and red shale.

orange (10*YR* 6/6). The sandstones generally fine upward into reddish siltstone, although stringers of sandstone are found scattered in some of the overlying siltstones and shales.

The siltstones and shales and some interbedded very fine grained sandstone at the top of the upward fining cycles in the Wurtsboro Tongue are grayish red (5R 4/2 to 10R 4/2) to moderate reddish brown (10*R* 4/6) and light olive gray (5*Y* 6/1). Mud cracks (see Schuchert, 1916, pl. 20, fig. 1), burrows (some bedding has been obliterated due to bioturbation), and ripples are locally present. Many siltstones and very fine grained sandstones are flaser bedded. Dark-yellowish-orange (10*YR* 6/6) nodules several inches long and irregular discontinuous layers are probably calcrete composed of siderite.

The lower contact of the Wurtsboro Tongue at the type section along N.Y. Route 17 is placed at the base of a 3-ft-thick (1-m-thick) siltstone bed, which is greenish gray (5*GY* 6/1) at the bottom and which grades upward to mottled and then to grayish red (10*R* 4/2) at the top. The base of the Wurtsboro is gradational into the underlying Shawangunk Formation. At the type section of the Wurtsboro, the upper part of the Shawangunk consists of about 50 ft (15 m) of interbedded light-olive-gray (5*Y* 6/1) shaly siltstone and medium-dark-gray (*N*4) quartzite and granule-pebble conglomerate, which are slightly darker than the quartzites of the lower part. Prave and others (1989) and Alcala (1990) placed this sequence of rock in the Wurtsboro Tongue because they identified the unit based on the presence of upward fining cycles. However, in this report, the criterion of color has the greatest utility for geologic mapping because the unit can be readily mapped by means of float where it is poorly exposed. Thus, the bottom of the Wurtsboro Tongue is placed at the base of the lowest significant red bed in a sequence of abundant red beds. As mentioned previously, the Wurtsboro Tongue grades up into the Ellenville Tongue of the Shawangunk Formation by an increase in number and thickness of crossbedded sandstones, which also lose their red color up-section. The top of the Wurtsboro Tongue is at the top of a 2-ft-thick (0.6-m-thick) red siltstone at the type section near Wurtsboro.

The Wurtsboro Tongue thickens from about 230 ft (70 m) near Port Jervis to about 300 ft (90 m) a few miles to the northeast, but then progressively thins to 180 ft (55 m) at Otisville, 115 ft (35 m) at the type section, 105 ft (32 m) near Ellenville, 75 ft (23 m) in the Delaware aqueduct, about 12 ft (4 m) at Accord, and pinches out in the vicinity of Accord or High Falls. The Wurtsboro thins northeastward, as the Ellenville Tongue of the Shawangunk Formation thickens, by gradual change in color from grayish red, through olive gray, into gray. This lateral change in color is similar to the changes seen along the transitional contact at the Delaware Water Gap in eastern Pennsylvania, where the color change migrates up-section by several hundred feet within a distance of about 1 mi (1.6 km) (Epstein, 1973).

Along the pipeline at Shin Hollow, the top of the Wurtsboro is partly exposed and consists of about 6 ft (2 m) of mottled light-gray (*N7*) and grayish-red (*5R* 4/2) conglomerate that weathers pale red (*10R* 6/2) to light brown (*5YR* 6/4), containing light-olive-gray (*5Y* 6/1) shale clasts as much as 1 in. (2.5 cm) long and rose and milky quartz pebbles.

The upper transitional contact of the Wurtsboro Tongue and the northeastward replacement of non-red rocks of the Ellenville Tongue is well exposed for 1.7 mi (2.7 km) along the Erie-Lackawanna Railroad grade, 1.2 mi (1.9 km) west-southwest of Otisville. These are the rocks to which the name Guymard was applied (Bryant, 1926, p. 259). The contact between the Wurtsboro Tongue and the underlying Shawangunk Formation, at the northern limit of the exposure just east of Lake Helen, is placed at the top of olive-gray (*5Y* 4/1), very fine grained sandstone and medium-greenish-gray (*5GY* 5/1) siltstone of the Shawangunk Formation in sharp contact with 2 ft (0.6 m) of blocky, moderate-grayish-brown (*5YR* 4/2) siltstone of the Wurtsboro Tongue. The succeeding 10 ft (3 m) of the Wurtsboro consist of grayish-brown (*5YR* 3/2) siltstone, moderate-yellowish-brown (*10YR* 5/2) shale with a reddish tinge, grayish-red (*5R* 4/2) shaly siltstone, and poorly bedded, dark-grayish-red (*10R* 3/2) shaly siltstone. The overlying 50 ft (15 m) of the Wurtsboro Tongue consist of grayish-red (*5R* 4/2) and lesser light-olive-gray (*5Y* 6/1), blocky, thin- to medium-bedded (beds 2 in. (5 cm) to 2 ft (0.6 m) thick), well- to poorly bedded shaly siltstone and fissile silty shale, some of which has low-amplitude ripples; blocky, medium-bedded (1–2 ft (0.3–0.6 m) thick)), limonitic, grayish-red (*5R* 4/2) very fine grained sandstone; and limonitic, fine-grained, mottled medium-gray (*N5*) and light-brownish-gray (*5YR* 6/1) quartzite.

Different rock types make up the lowest bed of the Wurtsboro southwestward along the Erie-Lackawanna Railroad grade just north of Guymard. For example, 1,500 ft (460 m) south of Lake Helen, the lowest 6 ft (2 m) of the Wurtsboro consists of limonitic, medium-gray (*N5*) and light-brownish-gray (*5YR* 6/1), very fine grained quartzite interbedded between red shaly siltstone and siltstone. Individual beds change color from red to gray and also are irregular in thickness along strike. The general result is that gray beds replace red beds northeastward along the railroad, showing that the Shawangunk Formation replaces the Wurtsboro Tongue to the northeast (fig. 15).

The Wurtsboro Tongue is well exposed in North Gully near Ellenville and forms a bench between the upper unit and the Ellenville Tongue of the Shawangunk Formation. There the Wurtsboro contains upward fining sequences of grayish-red (*5R* 4/2) and lesser medium-gray (*N5*) and light-olive-gray (*5Y* 6/1), limonitic, fine- to very coarse grained and slightly conglomeratic sandstone containing pebbles of milky quartz, jasper, and shale fragments as long as 3/8 in. (1 cm), grading up into dusky-red (*5R* 3/4) siltstone and silty shale, many beds of which are bioturbated.

The next substantiated exposure of the Wurtsboro Tongue is 5.5 mi (9 km) northeast of Ellenville and 0.9 mi (1.4 km) southwest of Kerhonkson in a creek at 300-ft (100-m) altitude. It is 25 ft (8 m) thick and consists of grayish-red (*5R* 4/2) siltstone that is mottled light olive gray (*5Y* 5/2); moderate-red (*5R* 5/2) sandstone; pale-brown (*5YR* 5/2), crossbedded, conglomeratic, medium-grained quartzite; and a bed 1 ft (0.3 m) thick of grayish-red (*10R* 4/2), very fine grained sandstone at the base that pinches out a short distance upstream. Within a distance of about 1,000 ft (300 m) upstream, the entire sequence thins to less than 5 ft (1.5 m). The last exposure of the Wurtsboro that was seen is 1,500 ft (460 m) to the east, on the southwest corner of a residential pond. This consists of about 2 ft (0.6 m) of interbedded grayish-red (*10R* 4/2), very fine grained sandstone and siltstone and crossbedded, medium- to coarse-grained sandstone that weathers olive gray (*5Y* 5/2) with a reddish tinge. The tongue may cease to be a continuous unit within the Kerhonkson quadrangle, although discontinuous lenticular bodies containing red beds at this stratigraphic level are present in the Mohonk Lake quadrangle to the east.

Along Stony Kill at an altitude of 340 ft (104 m), about 1,300 ft (400 m) southwest of Accord, the Wurtsboro Tongue appears to be missing and probably pinches out to the southwest. At this point, distinctively light-gray (*N7*) and dark-gray (*N3*) banded, crossbedded quartzites, similar to the Ellenville Tongue of the Shawangunk Formation at Ellenville, lie northeast of and above quartzites more typical of the Shawangunk that lies below the Wurtsboro where that tongue is exposed. The Wurtsboro Tongue, however, may be present within a few hundred feet to the south under surficial cover because, within 0.8 mi (1.3 km) to the east-southeast, in a creek 900 ft (275 m) east of a secondary road, about 12 ft (4 m) of grayish-red (*10R* 4/2) and light-olive-gray (*5Y* 6/1) siltstone underlie about 80 ft (25 m) of quartzite and quartz-pebble conglomerate, which in turn underlie red beds of the High Falls Shale updip to the north. These beds may be a continuation of the Wurtsboro Tongue, as suggested by Smith (1967b). However, the red beds that define the Wurtsboro are probably lenticular and irregular in their occurrence at the northeast feather edge of the tongue, as shown in figure 3.

Along N.Y. Route 213 at High Falls, about 20 ft (6 m) of poorly bedded, grayish-red (*5R* 4/2) shaly siltstone lies in a 200-ft-wide (60-m-wide) sag between two outcrops of quartzite and conglomerate lying to the east and west. The red beds were interpreted to be the High Falls Shale lying above the Shawangunk Formation (to the west) and suggested to be in fault contact with the Shawangunk exposure to the east (R. H. Waines, oral commun., 1967; Waines and Hoar, 1967, p. D23). If this is correct, the two sequences of the Shawangunk on either side of the High

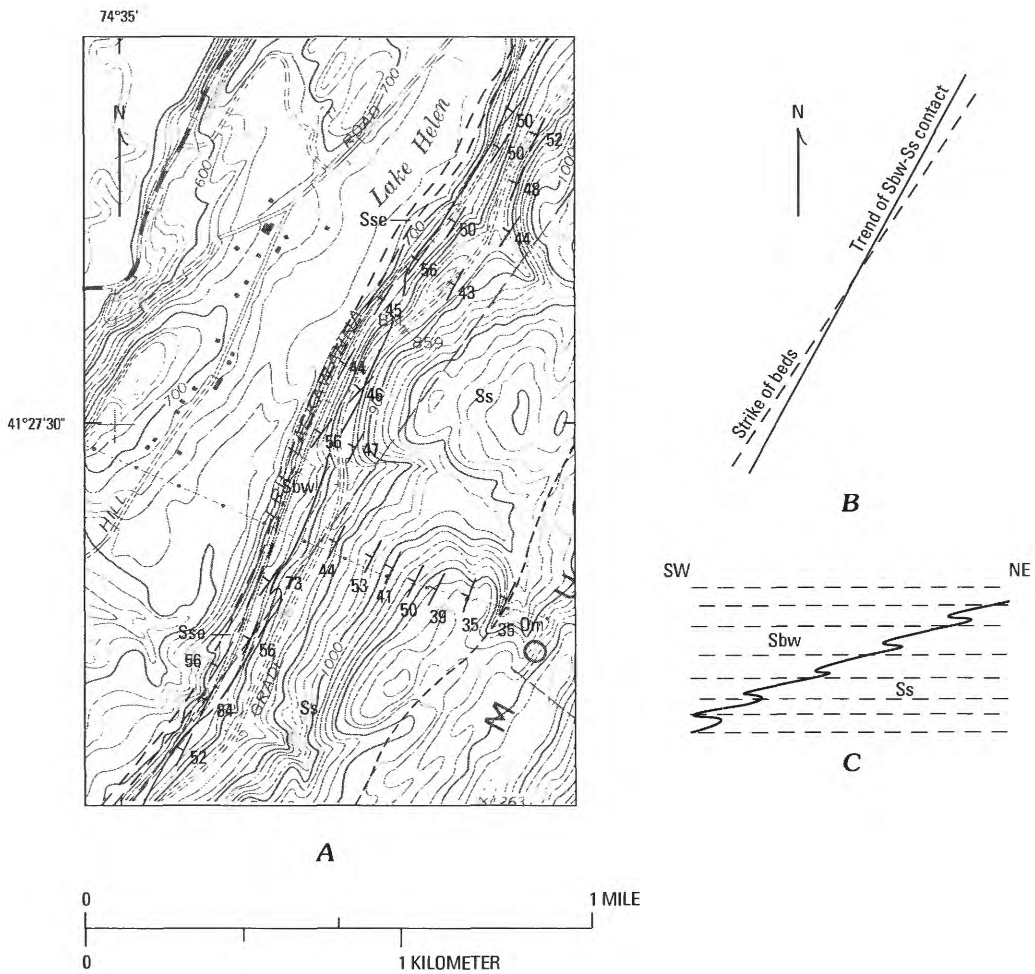

Figure 15. Contact between the Shawangunk Formation and the Wurtsboro Tongue of the Bloomsburg Red Beds along the Erie-Lackawanna Railroad grade about 2 mi (3 km) southwest of Otisville. *A*, Geologic map showing the contact between the Shawangunk Formation (Ss) and the Wurtsboro Tongue of the Bloomsburg Red Beds (Sbw), and its relationship to the strike of bedding (standard bedding symbols used). Om, Martinsburg Formation; Sse, Ellenville Tongue of the Shawangunk Formation. Solid lines are well-established contacts; long dashes are approximate contacts; short dashes are inferred contacts buried by surficial deposits. *B*, Diagram showing a 4° difference between the trend of the contact between the Wurtsboro Tongue of the Bloomsburg Red Beds and the Shawangunk Formation taken from the geologic map, and the average strike of bedding taken from 15 readings along the contact. *C*, Diagrammatic longitudinal cross section showing the northeastward and vertical replacement of the Wurtsboro Tongue (Sbw) by the Shawangunk Formation (Ss) as red beds grade to gray along strike (bedding is shown by dashed lines).

Falls should be similar. However, the rocks of the two blocks differ in a number of ways. In the sequence to the west, the Shawangunk consists of about 15 ft (5 m) of thin- to medium-bedded (beds 0.5–2 ft (0.1–0.6 m) thick) yellowish-orange-weathering (10*YR* 7/6) cross-laminated quartzite and quartz-pebble conglomerate with pebbles up to about 1 in. (2.5 cm) long, and some shale beds up to 6 in. (15 cm) thick. There is a bit more shale in this block than in the western block. The cross laminations are similar to those in the Ellenville Tongue farther southwest and are not prevalent in the eastern block. Below this block are quartzites and quartz-pebble conglomerates similar to those in the eastern block. The sequence to the east contains about 30 ft (9 m) of massive, medium- to thick-bedded, mostly planar-bedded quartzite and quartz-pebble conglomerate with pebbles as long as 1 in. (2.5 cm), and a few shale beds as thick as 2 in. (5 cm). There are some crossbeds near the top. The rocks do not weather yellowish orange. Some thin red siltstone overlies the quartzite. This cursory examination raises the possibility that there is no fault at this locality but, rather, the red bed unit is the Wurtsboro Tongue between quartzites of the Shawangunk Formation below and the Ellenville Tongue of the Shawangunk Formation above.

The sedimentary structures in the Wurtsboro Tongue suggest that it was deposited during a dry climate in an intertidal environment. Multiple crossbed trends indicate tidal transport in a WNW.–ESE. direction modified by northeastward longshore currents (Prave and others, 1989).

Basher Kill Tongue of the Bloomsburg Red Beds

In the adit to the Shawangunk mine, 2.5 mi (4 km) northeast of Wurtsboro (fig. 1), Sims and Hotz (1951) described 75 ft (23 m) of red siltstone and shale interbedded with brown to gray quartz sandstone (at the top of their Shawangunk Conglomerate); this sequence is immediately below quartz sandstones of the High View Tongue of the Shawangunk Formation of this report. These beds readily weather and form a topographic bench at an altitude of 675–710 ft (205–216 m) above the adit. The lower part of the red bed sequence extends 2.2 mi (3.5 km) southwestward to N.Y. Route 17, where Gray (1953, 1961) identified the beds as the Bloomsburg and placed them within and about 50 ft (15 m) below the top of his Binnewater. Epstein and Lyttle (1987) interpreted the Binnewater of Gray (1953, 1961) as a tongue of the Shawangunk, and the overlying red beds as an extension of the High Falls Shale at this locality, as did Prave and others (1989) (fig. 4). However, the High Falls Shale at its type locality contains lithic types that are dissimilar enough from the N.Y. Route 17 sequence to suggest that the identification of Epstein and Lyttle was incorrect. Moreover, in the Wurtsboro area these rocks are overlain by a significant thickness of quartzites typical of the Shawangunk Formation (the High View Tongue); these relations imply that the unit is at a lower stratigraphic position and cannot be the High Falls Shale. Scattered exposures of these red beds above the Ellenville Tongue of the Shawangunk Formation have been traced into the Port Jervis area to show that they merge with the main body of the Bloomsburg Red Beds and, in fact, are a tongue of that formation. These rocks are named the Basher Kill Tongue of the Bloomsburg Red Beds after exposures along N.Y. Route 17 near Wurtsboro (fig. 16). The name is taken from the Basher Kill, 1,000 ft (300 m) north of the type section.

The type section of the Basher Kill contains 33 ft (10 m) of pale-red (*5R* 6/2), light-olive-gray (*5Y* 6/1), pinkish-olive-gray (*5Y* 5/2), and light-brownish-gray (*5YR* 7/1), very fine grained to granular (milky quartz and jasper grains as much as 0.4 in. (1 cm) long), evenly bedded, thin- to medium-bedded (beds 0.5–2 ft (15–60 cm) thick), partly micaceous quartzite, generally with abrupt erosive bases and wavy tops; grayish-red (*5R* 3/2) and brownish-gray (*5YR* 4/1) to grayish-red-purple (*5RP* 4/2) shaly siltstone that weathers dark yellowish orange (*10YR* 6/6) and pale olive (*10Y* 6/2); and mottled grayish-red-purple (*5RP* 4/2) and medium-olive-gray (*5Y* 5/1) siltstone. The siltstone beds range from less than 1 in. (2 cm) to more than 2 ft (60 cm) in thickness. Trough crossbedding, parallel laminations, ripples, burrows, sand waves (fig. 16*A*) and mud cracks (fig. 16*B*) are moderately abundant features of these rocks. Prave and others (1989), who studied these structures in detail, noted a NW.-SE. bimodal current trend, which suggested to them a lower intertidal to subtidal origin for the Basher Kill Tongue.

The contact between the Basher Kill Tongue and the underlying Ellenville Tongue of the Shawangunk Formation is not exposed at the type section, but it is probably gradational and would be placed at the base of the first persistent red bed above the Ellenville. The upper part of the tongue is covered by glacial drift in the valley of the Basher Kill. The tongue is probably as much as 330 ft (100 m) thick near Port Jervis.

The Basher Kill Tongue is poorly exposed throughout the length of its occurrence on the north slope of Shawangunk Mountain. About 15 ft (5 m) of grayish-orange-pink (*5YR* 7/2) and medium-gray (*N5*), very fine grained quartzite and dark-reddish-brown (*10R* 3/4) siltstone in beds about 2 ft (0.6 m) thick are exposed 1.2 mi (1.9 km) in a gully at an altitude of 590 ft (180 m) southwest of the type section. A small exposure of red siltstone and sandstone occurs 1.8 mi (2.9 km) to the southwest in a gully at an altitude of 800 ft (240 m) in the Yankee Lake quadrangle. The Basher Kill is represented by scattered float in the 9.5 mi (15 km) between the Yankee Lake quadrangle and the pipeline and railroad cut at Shinn Hollow in the Otisville quadrangle, and for 2.5 mi (4 km) southwestward of that locality, where grayish-red (*10R* 4/2) and olive-gray (*5Y* 5/1) to light-olive-gray (*5Y* 6/1), very fine to fine-grained sandstone, shaly siltstone, and silty shale are exposed along the railroad and in gullies on the northwest slope of the mountain.

Poxono Island Formation

A laterally and vertically variable sequence of poorly exposed green and gray dolomite, shaly dolomite, calcareous and dolomitic shale and siltstone, sandstone, red and green shale and siltstone, and gray limestone is sandwiched between the Shawangunk and Bloomsburg siliciclastic rocks and the overlying limestone and dolomite of the Bossardville Limestone and Rondout Formation in southeastern New York. This sequence is subdivided into the Poxono Island Formation, Wawarsing Limestone, High Falls Shale, and Binnewater Sandstone. The Poxono Island Formation at Port Jervis, N.Y., grades laterally into the other units to the northeast (fig. 3). In the past, several different names were applied to these units, and their boundaries were selected at different places by different workers (see pl. 1).

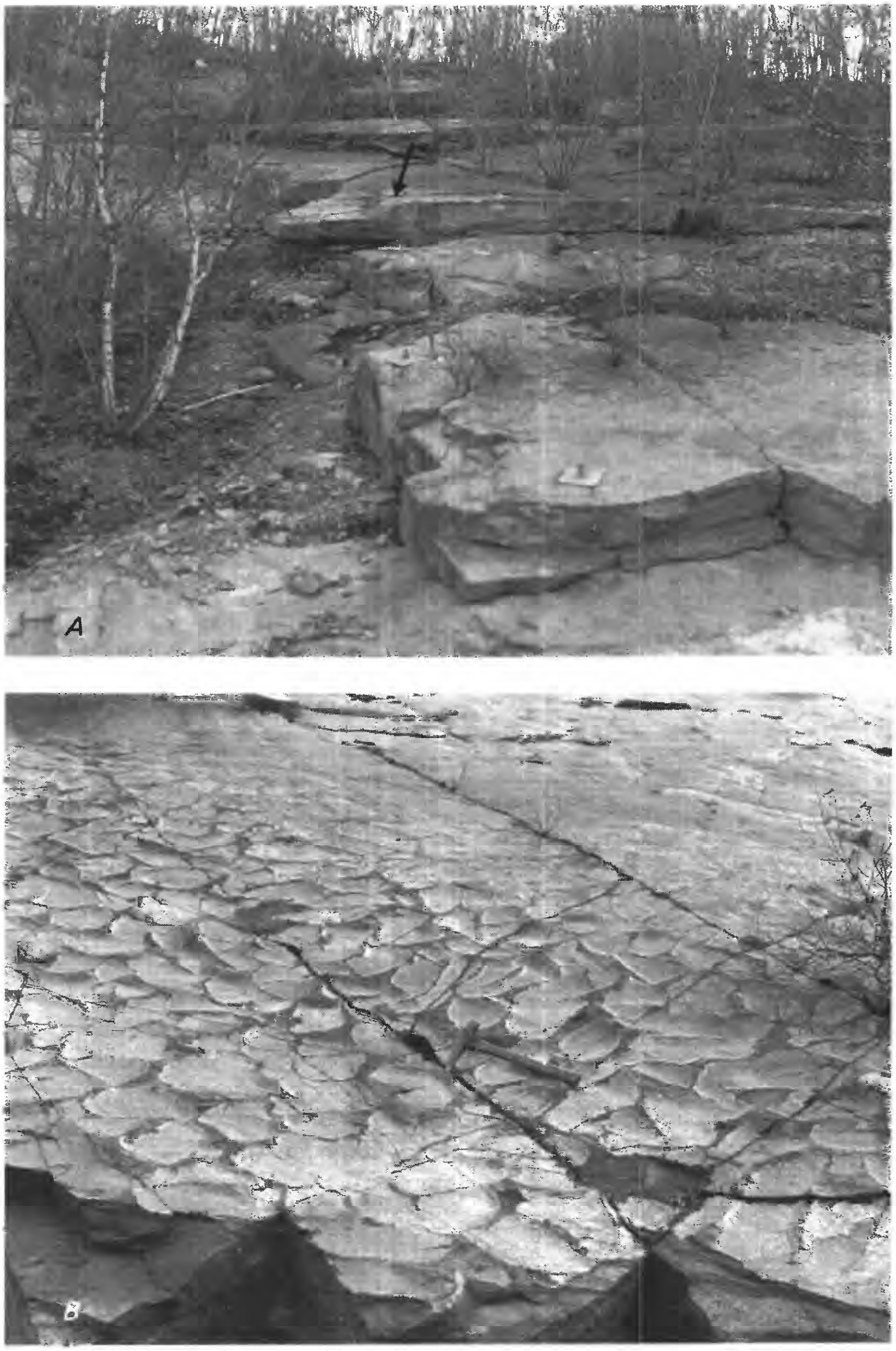

Figure 16. Basher Kill Tongue of the Bloomsburg Red Beds along N.Y. Route 17, 1 mi (1.6 km) south of Wurtsboro. *A*, Sand wave (at arrow) in olive-gray sandstone. Many of these sandstones are ripple topped. *B*, Mud cracks at top of very fine grained sandstone.

The Poxono Island Shale was named by White (1882) for buff, green, and variegated nonfossiliferous limy shales exposed along the Delaware River near Poxono Island, about 29 mi (47 km) southwest of Port Jervis. The unit was changed from Poxono Island Shale to Poxono Island Formation by Epstein and others (1967) because in scattered exposures in eastern Pennsylvania, the Poxono Island consists of laminated to finely bedded, partly mud-cracked, greenish-gray and light-bluish-gray, partly calcareous and argillaceous dolomite; argillaceous gray limestone; and green and pale-olive shale, siltstone, and some sandstone (also see Alvord and Drake, 1971; Epstein, 1973, 1987;

Epstein and others, 1974). Additionally, red beds are found in the bottom part of the formation (Depman and Parillo, 1969; Epstein, 1990).

There are very few exposures of the Poxono Island in New Jersey, between Flatbrookville, where it enters the State 25 mi (40 km) southwest of Port Jervis, and the New York border. Hartnagel (1905, p. 346) reported an exposure in the northwestern corner of the State that is presently concealed (Epstein and others, 1967, p. 51). The formation is about 500 ft (150 m) thick where it enters New York at Port Jervis under cover and thickens to about 550 ft (170 m) a few miles to the northeast. It thins gradually toward Ellenville, where it is about 300 ft (90 m) thick, northeast of which it is replaced by several other units and finally pinches out near High Falls. The most southwestern outcrop in New York, which was believed to be in the uppermost part of the Bloomsburg by Smith (1967b), is at Shin Hollow, 4 mi (6.4 km) northeast of Port Jervis. Here, in a small pit above the tracks of the Erie-Lackawanna Railroad, the exposed Poxono Island consists of about 3 ft (1 m) of laminated, platy, thin-bedded, partly mud-cracked, greenish-gray (5*GY* 6/1) calcareous siltstone, dolomite, and light-greenish-gray (5*GY* 7/1) shale with light-brownish-gray (5*YR* 6/1) mottles. It overlies grayish-red (10*YR* 4/3) silty shale seen in the tracks below. Northeastward, more than 43 ft (13 m) of limestone, dolomite, and shale, now largely covered, were measured in a quarry near Cuddebackville (Epstein and others, 1967, p. 71).

The Poxono Island Formation is also exposed in New York in the area between Accord and High Falls, where it grades laterally into the Binnewater Sandstone. This boundary is selected where sandstone makes up more than 50 percent of the section (fig. 3).

Bird (1941) and Freund (1941, 1942) described the Binnewater Sandstone below ground in the Delaware aqueduct. However, these rocks are here interpreted to be the Poxono Island Formation because they contain less than 50 percent sandstone. Freund (1941) commented that "... the Binnewater and High Falls formations, though generally noted as sandstone and shale, respectively, are a series of shale, sandstone and limestone beds of varying thickness." Table 4 is a section of Freund's Binnewater that shows that most of the formation is limestone and shale; less than 25 percent of the formation is composed of sandstone. It is probable that much or most of the rock indicated to be limestone by Freund (1941), as well as some other reports, is actually dolomite, based on examination of exposed rocks that have been called limestone by these authors.

The High Falls Shale and Binnewater Sandstone were described at High Falls by Hartnagel (1905), Brown (1914) (who also described these rocks from borings made during construction of the Catskill aqueduct across the Rondout valley), Schuchert (1916), Swartz and Swartz (1931), Chadwick and Kay (1933), Bird (1941), Freund (1941), and Rickard (1962). These authors showed that the contact between the High Falls and Binnewater is gradational and that both formations contain abundant interbedded green and gray shale and limestone typical of the Poxono Island to the southwest. The stratigraphic diagram of Swartz and Swartz (1931, pl. 1) showed the Poxono Island extending

Table 4. Measured section of the Wawarsing Limestone, High Falls Shale, Poxono Island Formation, and Binnewater Sandstone in the Rondout–West Branch tunnel of the Delaware aqueduct near Wawarsing, N.Y.

[Lithologic descriptions are from a cross section of Freund (1941). Thicknesses are reconstructed from the section. Freund identified units 15–23 as the Binnewater Sandstone]

	Thickness	
	Feet	Meters
Binnewater Sandstone		
27. Light-gray sandstone	2.9	0.9
26. Greenish-gray, well-bedded, shaly, sandy limestone	7.1	2.2
25. Gray and white, thin-bedded, crossbedded sandstone	6.0	1.8
24. Interbedded, greenish-gray sandy limestone and gray sandstone	19.1	5.8
Total thickness of Binnewater Sandstone	35.1	10.7
Poxono Island Formation		
23. Buff shaly and sandy limestone	14.6	4.5
22. Gray, massive sandstone	4.0	1.2
21. Red, greenish, and white sandstone	3.0	0.9
20. Red limy and sandy shale and thin, irregular beds of greenish-gray limestone	9.5	2.9
19. Red and gray sandstone	1.6	0.5
18. Red limy and sandy shale and thin, irregular beds of greenish-gray limestone	10.5	3.2
17. Gray sandstone	1.6	0.5
16. Red limy and sandy shale and thin, irregular beds of greenish-gray limestone	22.7	6.9
15. Greenish-gray, massive, very fine grained shaly limestone	19.4	5.9
Total thickness of Poxono Island Formation.	86.9	26.5
High Falls Shale		
14. Red limy shale	3.0	0.9
13. Greenish-gray limestone	2.6	0.8
12. Red shale	1.2	0.4
11. Greenish-gray limestone	2.8	0.8
10. Red limy shale	5.7	1.7
9. Greenish-gray limestone	15.1	4.6
8. Red limy shale	4.2	1.3
7. Gray limestone	7.6	2.3
6. Red limy shale	11.8	3.6
5. Gray limestone	3.2	1.0
4. Red limy shale	11.8	3.6
Total thickness of High Falls Shale	69.0	21.0
Wawarsing Limestone		
3. Gray, massive limestone	12.4	3.8
2. Dark-gray, well-bedded limestone	13.0	4.0
1. Gray, massive limestone becoming shaly lower down in upper part and limestone becoming more sandy toward base in lower part. Gradational contact with Shawangunk Grit below	68.6	20.9
Total thickness of Wawarsing Limestone	94.0	28.7

beneath the Binnewater at High Falls, but their measured section (Swartz and Swartz, 1931, p. 653) did not indicate the presence of the Poxono Island there. In the Delaware aqueduct, Fluhr and Terenzio (1984, p. 73) referred to the Wawarsing wedge of Bird (1941) and Freund (1941) as the "Wawarsing Limestone in Poxono Island Shales," revealing that they appreciated the similarity of the rocks in the High Falls area with those in the Poxono Island of eastern Pennsylvania. For this reason, the Poxono Island Formation is shown to grade into the Wawarsing Limestone, High Falls Shale, and Binnewater Sandstone in the High Falls area. The facies change from High Falls to Poxono Island is arbitrarily defined as the place where red beds exceed about 50 percent of the section (High Falls Shale) or where they are less abundant (Poxono Island Formation). This change probably occurs somewhere northeast of Ellenville, but there are no exposures to substantiate this conclusion.

The Binnewater Sandstone, which consists predominantly of crossbedded sandstone at and north of High Falls (Hartnagel, 1905; Rickard, 1962; Waines, 1976), becomes more dolomitic and shaly to the southwest, so that at Accord it passes into the Poxono Island Formation (named the Accord Shales by Fisher (1959)). Thus, even the Binnewater is part of the complex carbonate-clastic facies mosaic of the Poxono Island–High Falls interval. This relationship was suggested by Rickard (1962), who thought that the Binnewater was replaced by the Poxono Island Formation, Bossardville Limestone, or Decker Ferry Formation of northwestern New Jersey, and also by Hoar and Bowen (1967), who thought that the dolomite at Accord was the Bossardville(?) Formation.

Johnsen and Waines (1969) described 62 ft (19 m) of rock that they assigned to the Binnewater in a core near Accord and noted the dissimilarity of those rocks with those at the type section. According to them, the upper 47 ft (14 m) consisted of sandstone and dolostone in nearly equal proportions, overlying 15 ft (5 m) of greenish-gray dolostone, shale, and sandstone. Waines (1976), who described the regional lithologic relations of the Binnewater, noted that the Binnewater becomes more dolomitic southwest of High Falls, so that at Accord, dolomitic beds increase to more than 50 percent of the section. He presented a stratigraphic section (his fig. 2) indicating that the rocks assigned to the Binnewater at Accord consist of about 21 ft (6 m; judging from the scale in the figure) of dolostone overlying 30 ft (9 m) of interbedded red and non-red sandstone and dolostone; at the base are about 16 ft (5 m) of dolomite and beds that are transitional into the red High Falls Shale. All of the beds assigned by those authors to the Binnewater are considered to be part of the Poxono Island Formation of this report.

The nature of the Poxono Island and its facies relations with the High Falls Shale and Binnewater Sandstone can be interpreted from scattered outcrops within 1 mi (1.6 km) south and west of Accord along Stony Kill and in the adjacent bluff to the north, along the abandoned railroad track 2,000 ft (600 m) west of Accord, and in a road bank and along Rondout Creek 3,000 ft (900 m) southwest of Accord. Here, a complex sequence of interbedded green and gray dolomite, limestone, and sandstone, and red and green shale, about 77 ft (23 m) thick, gradationally overlies red beds typical of the High Falls Shale and is overlain in sharp contact by limestones of the overlying Rondout Formation. Table 5 is a composite section of the Poxono Island Formation determined from about a dozen outcrops

Table 5. Composite measured section of the Poxono Island Formation in the Accord area

	Approximate thickness	
	Feet	Meters
Rondout Formation (Wilbur Member)		
11. Massive, medium-gray (*N5*) to medium-light-gray (*N4*), fine- to medium-grained, intra clastic, pyritic limestone with brachiopod shell hash at top	12	3.7
Poxono Island Formation		
10. Laminated, massive, very fine grained, very light bluish gray (*5B 8/1*) dolomite	2	0.6
9. Slabby, wavy bedded, partly mud-cracked, laminated to thin-bedded, partly mud-cracked, pyritic, medium-light-gray (*N6*) to light-gray (*N7*), very fine grained dolomite, minor laminae of light-olive-gray (*5Y 6/1*) mudstone, and intraclastic dolomite at top	9	2.7
8. Dolomite and sandstone float	10	3.1
7. Dolomite	4	1.2
6. Greenish-gray (*5GY 6/1*) and light-olive-gray (*5Y 7/1*), thin-bedded and irregularly bedded, partly crossbedded and ripple-bedded, very fine- to fine-grained sandstone, silty sandstone, and silt shale	4	1.2
5. Float of interlaminated sandstone and dark-reddish-brown (*10R 3/4*) very fine grained, silty sandstone; slabby, medium-dark-gray (*N4*) silty, fine- to very fine grained limestone; light-olive-gray (*5Y 7/1*) dolomite, shale, and siltstone; and minor grayish-red (*5R 5/2*) shale	12	3.7
4. Poorly bedded, light-olive-gray (*5Y 6/1*) and moderate-grayish-red (*5R 5/2*) silty shale	8	2.4
3. Conspicuous bed of evenly laminated and partly cross-laminated, micro-graded, medium-gray (*N5*) and medium-dark-gray (*N4*), very fine grained dolomite and shaley limestone (probably the Powerhouse limestone of Rickard (1962) at High Falls)	6	1.8
2. Unevenly laminated, platy, slightly bluish, medium-dark-gray (*N4*), shaly dolomite	2	0.6
1. Float of thin-bedded, green and red shale and dolomite. Probably transitional down into predominantly red rocks of the High Falls Shale	8	2.4
Approximate thickness of the Poxono Island Formation	65	19.7

in the Accord area. The conspicuous dolomite and limestone bed near the base of the Poxono Island (unit 3 in table 5) may be the same bed described as the Powerhouse limestone by Rickard (1962) within the middle of the High Falls Shale at High Falls, 7.7 mi (12.4 km) to the northeast. If so, it suggests that the contact between the Poxono Island and High Falls rises up-section to the northeast, probably by replacement of green and gray beds with red beds in that direction.

Wawarsing Limestone

In the Delaware aqueduct, Bird (1941) reported 95 ft (29 m) of limestone immediately overlying the Shawangunk Grit and underlying red shale of the High Falls Shale. He named this unit the Wawarsing wedge, alluding to the fact that the longitudinal shape of the unit must be wedgelike; that is, it is not seen in exposures to the northeast or southwest.

According to Bird (1941), the upper 13 ft (4 m) of the Wawarsing consists of dark-gray to almost black, well-bedded limestone, underlain by 57 ft (17 m) of very fine to fine-grained, gray to greenish-gray limestone, and followed by 25 ft (8 m) of shaly and sandy limestone at the base. Freund (1941) apparently described the Wawarsing wedge at about the same time as Bird. His description is given in table 4. According to the New York City Water Board (unpub. report, 1945), the Wawarsing in the Rondout West Branch tunnel of the Delaware aqueduct consists of fine-grained, greenish-gray and black limestone. Its thickness was calculated from cross sections in that report and determined to be 110 ft (34 m). However, the dips drawn on the cross sections are much steeper than reality, so that the thickness is probably closer to 95 ft (29 m). Moxham (1972) next described this unit as the Wawarsing Limestone, a friable shaly limestone, differing somewhat from the description given by Bird (1941).

Because the Wawarsing is nowhere exposed and examination of the unit in the Delaware aqueduct is now impossible, we can only guess at the lithologic details of the formation. It is possible that the "limestone" is mostly, if not entirely, dolomite and may extend into the dolomite reported as the Powerhouse limestone of Rickard (1962) at High Falls and the same bed in the Poxono Island Formation near Accord (unit 3 in table 5). There may also be a significant amount of shale in the Wawarsing, suggesting a facies kinship to the Poxono Island Formation. The Wawarsing might best be included within the Poxono Island Formation as a member, as indicated by Fluhr and Terenzio (1984, p. 73), who referred to the Wawarsing as the "Wawarsing Limestone in Poxono Island Shales."

High Falls Shale

The High Falls Shale was named by Hartnagel (1905, p. 345) for the red shales lying above the Shawangunk Grit and underlying the Binnewater Quartzite in Ulster County. The name presumably was attributed to the rocks exposed at High Falls. Few lithologic details were given, and the upper and lower contacts were not defined. Subsequently, the High Falls Shale was described in the High Falls–Binnewater area by Berkey (1911), Brown (1914), Schuchert (1916), and Smith (1967a), and measured sections were presented by Swartz and Swartz (1931; the most detailed of the group), Chadwick and Kay (1933), Bird (1941), Freund (1941; see table 4), and Rickard (1962).

The basal contact of the High Falls is readily defined as the base of the first red bed above the uppermost quartzite or conglomerate of the Shawangunk Formation. The contact with the overlying Binnewater Sandstone, however, is gradational, and different workers apparently placed it at different levels. Therefore, the reported thickness in the Catskill aqueduct ranges from 67 to 100 ft (20 to 30 m); at High Falls it ranges from 46 to 96 ft (14 to 29 m), and near Binnewater it ranges from 68 to 90 ft (21 to 27 m).

The lithology of the High Falls was not studied in detail during the present investigations. Judging from the published descriptions in the type area, the High Falls consists of an upper unit, about 25 ft (8 m) thick, of gray, green, and red calcareous and silty shale and some thin beds of dolomite; a medial unit, about 12 ft (4 m) thick, of green, calcareous dolomite, a conspicuous bed of dark-gray, laminated dolomite at the base; and a lower unit, about 55 ft (18 m) thick, of red and green shale and green dolomite, partly concealed at High Falls on Rondout Creek. The beds apparently vary in thickness and lithic character over the area, so that the carbonate rocks become more abundant to the southwest as the Poxono Island Formation is approached. Many of the beds are mud cracked and some have ripples. The basal dolomite of the medial unit may continue southwestward into the Poxono Island Formation near Accord (unit 3 in table 5).

A type section for the High Falls Shale was not established. A reference section is obviously along Rondout Creek at High Falls. The unit is well exposed but not readily accessible on the north side of the creek, where it may be studied in detail.

Several stratigraphic identifications that have been made by earlier workers do not agree with the present study. For example, Swartz and Swartz (1931, p. 659) believed that the High Falls is continuous with the Bloomsburg Red Beds of New Jersey and Pennsylvania. Subsequently, other workers identified parts of the Bloomsburg as the High Falls (see pl. 1).

The High Falls Shale presumably grades into the Poxono Island Formation near Ellenville (fig. 3). It was examined between its westernmost exposure, 1.8 mi (2.9 km) east of Kerhonkson, to the area south of Accord, 1.2 mi (2 km) away. The High Falls is best exposed in a creek 3,400 ft (1,000 m) west of the east border of the Kerhonkson quadrangle (Epstein and Lyttle, 1990), where it rests with sharp contact on the Ellenville Tongue of the Shawangunk Formation. The uppermost beds of the Ellenville Tongue consist of a 1-ft-thick (0.3-m-thick) bed of medium-dark-gray (*N*4), slightly conglomeratic (rounded and subrounded milky quartz and minor jasper grains as much as 3/4 in. (2 cm) long), medium-grained quartzite that weathers grayish orange (10*YR* 7/4) to dark yellowish orange (10*YR* 6/6), which is overlain by 8 in. (20 cm) of moderate-greenish-gray (5*GY* 5/1), slightly pebbly (milky quartz and jasper grains as much as 1/4 in. (0.6 cm) long), medium- to coarse-grained sandstone. These rocks grade up into medium-olive-gray (5*Y* 5/1) sandy siltstone, herein placed in the High Falls. The siltstone is overlain by at least 10 ft (3 m) of grayish-red (10*R* 4/2 to 10*R* 4/4), poorly bedded, shaly siltstone and silty shale, some beds containing medium-grained sand laminae. All of the exposures of the High Falls in this area consist of such red silty shales and shaly siltstones. They grade upward into the green and gray beds of the Poxono Island Formation.

Binnewater Sandstone

Hartnagel (1905, p. 346) named the Binnewater quartzites, but as in the case of the High Falls Shale, he presented little stratigraphic detail. The Binnewater Sandstone grades into the Poxono Island Formation northeast of Accord, as discussed earlier. It was discussed by Brown (1914), Schuchert (1916), Swartz and Swartz (1931), Chadwick and Kay (1933), Bird (1941), Rickard (1962), and Hoar and Bowen (1967) in the type area near Binnewater and High Falls, where it has been assigned thicknesses ranging between 25 and 68 ft (8 and 21 m). However, the contacts of the Binnewater were placed at different horizons by different workers. The Binnewater was not examined in any detail in the area of its outcrop for this report but, in general, is described as consisting of interbedded, thin- to medium-bedded, crossbedded, rippled, light-gray quartzose sandstone, and partly mud-cracked, green and gray silty shale, dolomite, and limestone. It is transitional into the underlying High Falls Shale and overlying Rondout Formation at High Falls.

The Binnewater that was described in the Catskill aqueduct by Bird (1941) and Freund (1941) is considered to be the Poxono Island Formation of this report (see table 5), as is the Binnewater described in the Accord area by Johnsen and Waines (1969) and Waines (1976). Rickard (1962, p. 28) earlier advised against extending the name Binnewater to Accord. In the Accord area, only a few beds typical of the Binnewater extend into the Poxono Island. These consist of greenish-gray (5*GY* 6/1) and light-olive-gray (5*Y* 7/1), thin-bedded, irregularly bedded, crossbedded and rippled, very fine to fine-grained sandstone, silty sandstone, and silty shale.

AGE AND CORRELATION OF SILURIAN ROCKS OF SOUTHEASTERN NEW YORK

There have been several charts published that give the ages and correlatives of the Silurian rocks of southeastern New York with those of the rest of the State, the United States, and North America. These include Ulrich and Bassler (1923), Swartz and others (1942), Fisher (1959), Rickard (1969, 1975), Berry and Boucot (1970), Colton (1970), and Patchen and others (1984). Many authors have proposed that the age of these rocks ranges from Late Ordovician to Late Silurian, but poor paleontologic controls have made these suggestions controversial. The fossils that have been found in the siliciclastic rocks of southeastern New York do not yield precise ages. These include eurypterids in the Shawangunk Formation (Clarke, 1907; Clarke and Ruedemann, 1912; Grabau, 1913; Schuchert, 1916; Bryant, 1926; Willard, 1928; Swartz and Swartz, 1930, 1931; Denison, 1956; Faul, 1987), fish in the Bloomsburg Red Beds and Shawangunk Formation (Bryant, 1926; Denison, 1956; Beerbower and Hait, 1959), *Lingula* in the Shawangunk (Epstein and Epstein, 1969), and trace fossils such as *Arthrophycus* (Schuchert, 1916; Bryant, 1926; Willard, 1928; Epstein and Epstein, 1972; Martino and Zapecza, 1978). The eurypterids are generally considered to be Early Silurian in age (Clarke and Ruedemann, 1912), but Epstein and Epstein (1972) reviewed the paleontologic arguments for that age in Pennsylvania and suggested that these rocks could conceivably be latest Ordovician. Most recently, Rickard (1984) traced Silurian rocks in the subsurface of central New York to the outcrops in eastern Pennsylvania and to Port Jervis, N.Y. He concluded that the Shawangunk at Port Jervis is no older than the Grimsby Sandstone of Early Silurian age and may even be slightly younger (earliest Middle Silurian). This finding establishes the age of the base of the Silurian section in southeastern New York. Because the Bloomsburg Red Beds of New Jersey and eastern Pennsylvania are considered to be Middle Silurian in age (Epstein, 1973, for example) and because the Ellenville and High View Tongues of the Shawangunk Formation intertongue with the Bloomsburg Red Beds, the upper part of the Shawangunk Formation in southeastern New York must also be Middle Silurian in age. The Rondout Formation, which caps the siliciclastic sequence of rocks discussed in this report, is latest Silurian in age (Rickard, 1975).

MINERALIZATION IN THE SHAWANGUNK FORMATION

The Shawangunk Mountains in the area between Ellenville and Guymard have been mined for zinc and lead in the past (Newland, 1919; Ingham, 1940; Eilertsen, 1950; Sims and Hotz, 1951; Gray, 1953, 1961; Friedman, 1957).

In general, these investigators believe that the mineralization resulted from hydrothermal solutions derived from an unknown plutonic source at depth. Interestingly, the mineralized locations are confined to specific stratigraphic and structural environments. They are found in the Ellenville Tongue of the Shawangunk Formation along the northwest dipping limb of the Ellenville arch. An exception is the concentration of pyrite along the contact of the Shawangunk and Martinsburg Formations at Otisville, N.Y. This raises the question whether the mineralization is due to remobilization of minerals from nearby rocks, such as the Bloomsburg Red Beds and Wurtsboro Tongue of the Bloomsburg Red Beds, as well as from the Ellenville Tongue itself. Epstein and Lyttle (1987) postulated that the Ellenville arch may have resulted as a fold formed above a blind fault that ramped up from a detachment in the Martinsburg Formation at depth. The mines in the Shawangunk, therefore, may lie above the tip line of this ramp, which could account for the fracturing along which mineralization took place and the channelways along which mineralizing fluids migrated. This stratigraphic and structural control is speculative, but detailed analysis of rocks surrounding the mineralized area might be a fruitful area of investigation.

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