Onesquethawan Stratigraphy (Lower and Middle Devonian) of Northeastern Pennsylvania

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By Jack B. Epstein

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CONTENTS

ILLUSTRATIONS

ONESQUETHAWAN STRATIGRAPHY (LOWER AND MIDDLE DEVONIAN) OF NORTHEASTERN PENNSYLVANIA

By JACK B. EPSTEIN

ABSTRACT

Lower and Middle Devonian clastic rocks and limestones of the Onesquethawan Stage in the Valley and Ridge province of the Lehigh and Delaware Valleys of eastern Pennsylvania include the Esopus and Schoharie Formations, the Buttermilk Falls Limestone, and the Palmerton Sandstone. The Buttermilk Falls Limestone in Godfrey Ridge in the eastern part of the area is divided into three new members, from oldest to youngest: the Foxtown, McMichael, and Stroudsburg Members. The Palmerton Sandstone is present only southwest of Godfrey Ridge where it replaces the upper part of the Schoharie Formation and the basal Buttermilk Falls beds. The entire Onesquethawan sequence thins from about 560 feet (171 m) near Stroudsburg to 195 feet (59 m) along the northeast extension of the Pennsylvania Turnpike near Bowmanstown, a distance of 37 miles (60 km). The Tioga Ash Bed, which marks the top of the Onesquethawan Stage, lies immediately above the Buttermilk Falls near the Lehigh River and 27 feet (8 m) below the top of the Buttermilk Falls at Stroudsburg. These rocks were extensively leached by pre-Wisconsinan weathering southwest of the Wisconsinan terminal moraine near Saylorsburg. Outcrops are sparse in this area of deep weathering. The members of the Buttermilk Falls Limestone cannot be distinguished, and the Esopus and Schoharie Formations cannot be separated regionally, although they can be differentiated at a few localities of good exposure.

INTRODUCTION

Onesquethawan rocks in eastern Pennsylvania consist of less than 200 to more than 550 feet (61–168 m) of shaly siltstone, sandstone, and limestone that lies between the Ridgeley Sandstone of the Oriskany Group below and the Marcellus Shale above. They have been mapped for more than 35 miles (56 km) in the Delaware River and Lehigh River area (fig. 1). Some of the resistant Onesquethawan rocks alternate with the Ridgeley Sandstone in holding up the crest of a line of ridges known by various names: Godfrey Ridge in the northeast and Cherry, Chestnut, Stony, and Stone Ridges, southwest of a 2-mile-wide fold near Bossardsville.

The sequence is thickest in Godfrey Ridge near Stroudsburg where it consists of silty shale and shaly siltstone of the Esopus Formation at the base and grades up into calcareous siltstone of the Schoharie Formation and younger argillaceous limestone and calcareous shale of the Buttermilk Falls Limestone. In passing southwest from Godfrey Ridge to the other ridges, the sequence thins, and the Palmerton Sandstone replaces parts of the Schoharie Formation and Buttermilk Falls Limestone. The Tioga Ash Bed, which defines the top of the Onesquethawan Stage, crops out at the base of the Marcellus Shale near the Lehigh River and 27 feet (8 m) below the top of the Buttermilk Falls Limestone near Stroudsburg.

The units in the southwestern part of the area lie beyond the limits of Wisconsinan glaciation and have been leached deeply by pre-Wisconsinan weathering. As a consequence, the sandstones are friable, and the shales and limestones have weathered to a deep clay saprolite. Outcrops are sparse, making stratigraphic comparisons with the fresh exposures on Godfrey Ridge somewhat difficult. Three newly named members of the Buttermilk Falls Limestone cannot be distinguished southwest of Godfrey Ridge. Also, the Esopus and Schoharie Formations are difficult to separate southwest of Godfrey Ridge, and they have been combined for purposes of mapping. In the past, the combined Esopus and Schoharie were called the "Bowmanstown Chert," but that name has been abandoned (Epstein and Epstein, 1967).

The sinuous outcrop pattern of Onesquethawan rocks in eastern Pennsylvania is due to complex folding. The folds are asymmetric and have wavelengths averaging between 1,000 and 1,500 feet (305–457 m). They are mostly upright with some overturned limbs in Godfrey Ridge (see Epstein, 1973); others are recumbent with some limbs that are rotated more than 180° in Cherry Ridge and ridges to the southwest (see Epstein and others, 1974). An overview of the structure of the entire area is given in Epstein and Epstein (1969). Moderate structural thinning and thickening of stratigraphic units has occurred, depending on the lithology of the units and position of the units in the folds. Consequently, some of the thickness variations (see fig. 3)

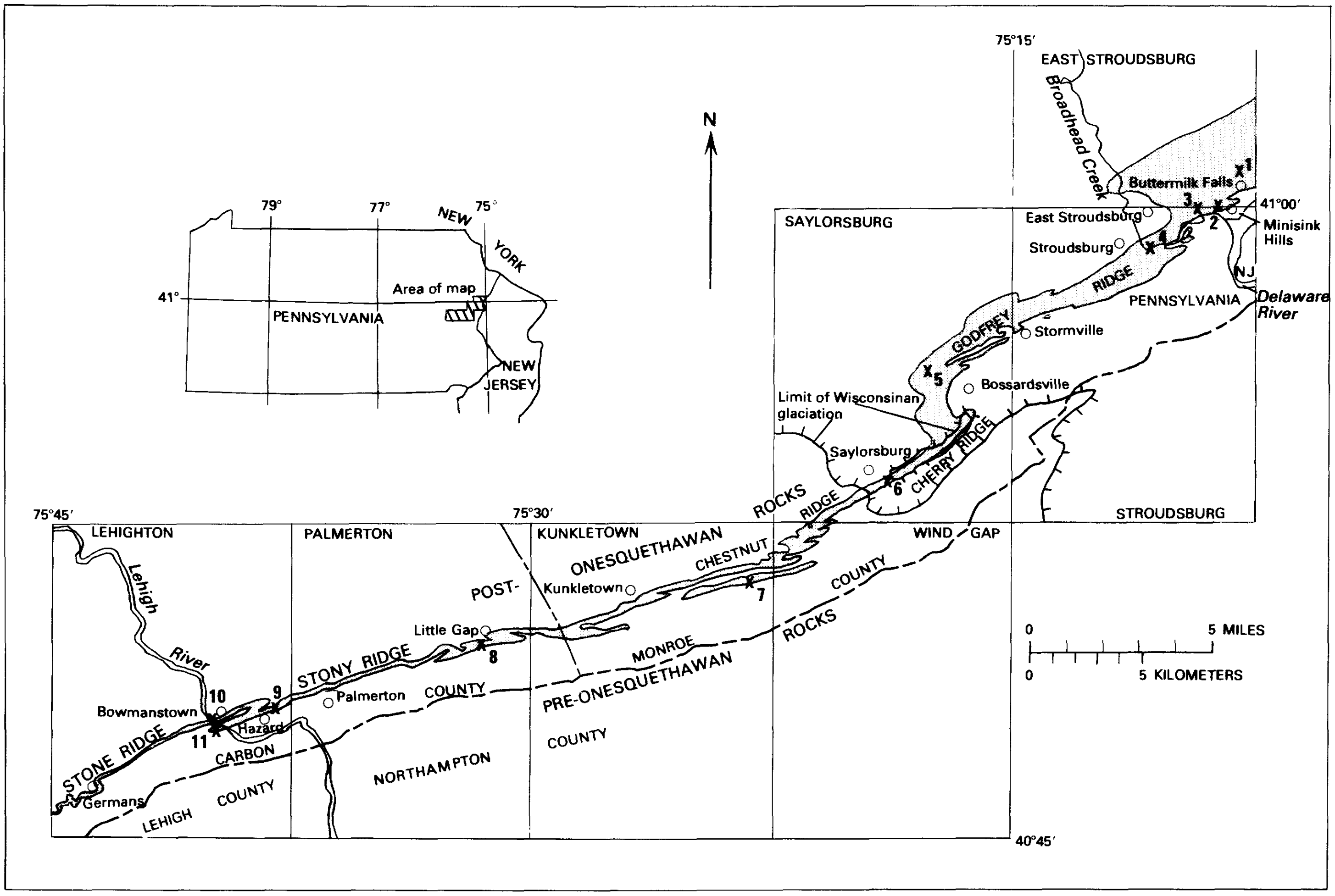

FIGURE 1.—Location of and 7½-minute quadrangle coverage of outcrop belt of Onesquethawan rocks between the Lehigh and Delaware Rivers in eastern Pennsylvania. Numbers refer to measured sections and other localities listed on p. 2–3.

may be structural. Detailed maps of most of the area are given in Epstein (1973, 1978), Epstein and Sevon (1978), and Epstein and others (1974). Localities of measured sections and some of the more important exposures in the area follow:

1. Schoharie Formation and parts of the Esopus Formation and Foxtown Member of the Buttermilk Falls Limestone (measured section 1) in roadcut along U.S. 209, 300 feet (91 m) northwest of Buttermilk Falls, type locality of the Buttermilk Falls Limestone, East Stroudsburg quadrangle.
2. Esopus Formation and part of the Schoharie Formation along abandoned railroad grade on north side of Brodhead Creek, 1,500 feet (457 m) west of Minisink Hills, Pa., Stroudsburg quadrangle.
3. Foxtown and McMichael Members of the Buttermilk Falls Limestone, Esopus Formation, and parts of the Schoharie Formation and Stroudsburg Member of the Buttermilk Falls Limestone (measured section 2) in abandoned quarry 100 feet (30 m) south of the intersection of U.S. 209 and I-80 and along bluffs north of the Erie-Lackawanna Railroad, 1,000 feet (305 m) southwest of the quarry, Stroudsburg quadrangle. The quarry is shown as a gravel pit on the Stroudsburg quadrangle.
4. Buttermilk Falls Limestone and part of the Schoharie Formation (measured section 3) along Erie-Lackawanna Railroad, 5,000 feet (1,524 m) south of the East Stroudsburg Post Office, type section of the three members of the Buttermilk Falls Limestone, Stroudsburg quadrangle.
5. Schoharie Formation and parts of the Esopus Formatoin and Foxtown Member of the Buttermilk Falls Limestone, Eureka Stone Co. quarry, 3.2 miles (5.1 km) northeast of Saylorsburg, Saylorsburg quadrangle.
6. Buttermilk Falls Limestone, Palmerton Sandstone, Schoharie Formation, and part of the Esopus Formation (measured section 4) along Pa. State Route 33 (also shown as Pa. State Route 115 on

some maps), 3,000 feet (914 m) east of Saylorsburg, Saylorsburg quadrangle.

7. Buttermilk Falls Limestone and part of the Palmerton Sandstone, clay pits of Universal Atlas Cement Co., 3.5 miles (5.6 km) east of Kunkletown, Pa., Kunkletown quadrangle.
8. Palmerton Sandstone and Schoharie and Esopus Formations, undivided, roadcut 1,600 feet (488 m) southwest of Little Gap, Pa., Palmerton quadrangle (Swartz and Swartz, 1941, p. 1153).
9. Buttermilk Falls Limestone, Palmerton Sandstone, and Schoharie and Esopus Formations, undivided, in abandoned mine tunnel at Hazard, Pa., Lehighton quadrangle (Swartz and Swartz, 1941, p. 1148).
10. Palmerton sandstone and Schoharie and Esopus Formations, undivided, in cuts along the Central Railroad of New Jersey and highway immediately above, 3,200 feet (975 m) southeast of Bowmanstown, Pa., Lehighton quadrangle (Swartz and Swartz, 1941, p. 1146–1147).
11. Buttermilk Falls Limestone, Palmerton Sandstone, Schoharie Formation, and Esopus Formation (measured section 5), Northeast Extension of the Pennsylvania Turnpike, 2,600 feet (792 m) southwest of Bowmanstown, Pa., Lehighton quadrangle (see also Willard, 1957, and Sevon, *in* Epstein and others, 1974, p. 400–406).

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HISTORY OF NOMENCLATURE

The naming of the Onesquethawan rocks in eastern Pennsylvania has had a long and complex history (fig. 2). Rogers (1858) developed a Latin nomenclature that describes the age of rocks in Pennsylvania by referring to divisions of the day, from dawn (Primal) to nightfall (Seral). Thus, he named the rocks herein described the Post-Meridian Series ("afternoon"). These names did not survive the First Pennsylvania Survey of Rogers, although many stratigraphic details are credible today. White (1882) and Chance (1882) first applied the New York names Caudi-galli grit and Corniferous limestone to the rocks of eastern Pennsylvania. The Caudi-galli was named for the trace fossil *Taonurus*, which resembles a rooster's tail. The New York name Onondaga was first applied by Kindle (1912) to rocks that were finally named the Buttermilk Falls Limestone by Willard (1938), although several later workers still used the name Onondaga, such as on the geologic map of Pennsylvania (Gray and others, 1960; and Inners, 1975, who examined these rocks in New York, New Jersey, and Pennsylvania). Kindle also substituted the name Esopus shale for the Caudi-galli. The petrology of the Esopus between New York and Pennsylvania is discussed by Rehmer (1976). Cooper and others (1942) first used the Schoharie shale in eastern Pennsylvania, although the earliest stratigraphic details were published by Herpers (1950a), Trexler (1953), Johnson (1957, 1959), and Johnson and Southard (1962).

In the Lehigh Valley, Swartz and Swartz (1938) first demonstrated that rocks that were previously considered to be the Oriskany sandstone of Early Devonian age also included a younger sandstone that is separated from the Oriskany by a "chert" of Middle Devonian age. These two younger units were named the Palmerton sandstone and Bowmanstown chert by Swartz (*in* Willard and others, 1939). The Bowmanstown was later dropped by Epstein and Epstein (1967) who showed that it was similar to the Esopus and the Schoharie farther to the northeast, except that it was generally more deeply weathered. The Buttermilk Falls was informally subdivided into three mappable members in Godfrey Ridge by Epstein (1971). These are, from oldest to youngest, the Foxtown, McMichael, and Stroudsburg Members. The Palmerton Sandstone and the members of the Buttermilk Falls Limestone are herein adopted for use by the U.S. Geological Survey.

Onesquethawan rocks were placed in the Onondaga formation of the Hamilton group by Willard (1936) because of faunal and lithologic similarities to the Hamilton. Willard later abandoned this designation and raised the Onondaga to group rank (Willard and others, 1939, 1947; Willard, 1938, 1957), as did Dyson (1956).

Minor units that have been recognized in this group of rocks include the Tioga Ash Bed (Roen and Hosterman, 1981), which marks the top of the Onesquethawan Stage (Dennison and Textoris, 1966), and the Hazard paint ore, first called the Schoharie(?) paint ore by Chance (1882).

Willard, who worked prolifically on the Devonian of Pennsylvania and who contributed enormously to our understanding of these rocks, nevertheless made a number of nomenclatural designations that simply added confusion (see fig. 2). For example, he (Willard, 1936, p. 583) discarded the name Selinsgrove that was applied by White (1882) to the upper noncherty

Rogers, 1858	White, 1882; Chance, 1882	Prosser, 1892, 1894	Kindle, 1912; Swartz and Swartz, 1941	Willard, 1936	Willard, 1938; Willard and others, 1939	Cooper and others, 1942
Post-Meridian Series: Post-Meridian limestone	Corniferous limestone	Upper Helderberg (Corniferous limestone)	Onondaga limestone	Onondaga formation of Hamilton Group: Upper member: Cherty limestone	Onondaga group: Buttermilk Falls Limestone	Buttermilk Falls Limestone
Post-Meridian Series: Post-Meridian grits or shale	Caudi-galli(?) grit	Caudi-galli grit	Esopus shale	Onondaga formation of Hamilton Group: Lower member: Esopus shale	Onondaga group: Esopus shale	Schoharie and Esopus shale

Willard and others, 1947	Willard, 1957	Johnson, 1957	Johnson and Southard, 1962	Epstein and Epstein, 1967, 1969; Epstein, 1973	Inners, 1975	Epstein, 1971; this report	Series
Onondaga group: Buttermilk Falls cherty limestone	Onondaga group: Buttermilk Falls limestone	Buttermilk Falls limestone (after Willard, 1938)	Onondaga limestone	Buttermilk Falls Limestone of Willard (1938): Upper member	Onondaga Limestone: Echo Lake Member (D); Member C	Buttermilk Falls Limestone: Stroudsburg Member	Middle Devonian
				Middle member	Member B	McMichael Member	
				Lower member	Member A	Foxtown Member	
Onondaga group: Esopus shale	Onondaga group: Schoharie formation	Schoharie formation	Schoharie formation (Carlisle Center member)	Schoharie formation	Schoharie Formation: Saugerties-Aquetuck Members, undivided; Carlisle Center Member	Schoharie Formation	Lower Devonian
	Esopus shale	Esopus formation	Esopus formation	Esopus Formation	Esopus Formation	Esopus Formation	

A—IN GODFREY RIDGE

Rogers, 1958	White, 1882; Chance, 1882	Agthe and Dynan, 1910	Kindle, 1912	Miller, 1934	Willard, 1936
Post-Meridian Series Post-Meridian limestone	Upper Helderberg Corniferous limestone Schoharie(?) paint ore Caudi-galli(?) clay ?	"Paint beds" Cement Rock Paint ore Clay (Esopus?)	Onondaga formation	Onondaga group	Onondaga Formation of Hamilton group Upper member Cherty limestone Noncherty limestone
Post-Meridian grits or shale	Oriskany Sandstone Oriskany shales	Oriskany Sandstone Helderberg Limestone Shales Yellow clay	Oriskany sandstone Lower Oriskany	Oriskany group	Lower member Paint ore Esopus shale

Willard and others, 1939	Swartz and Swartz, 1941	Cooper and others, 1942	Willard and others, 1947	Dyson, 1956	Willard, 1957
Onondaga group Buttermilk Falls limestone Selinsgrove limestone ? Hazard paint ore ? Esopus shale	Onondaga Limestone Paint ore	Selinsgrove limestone "Hazard"	Onondaga group Limestone paint ore	Onondaga Group Limestone (Hazard)	Onondaga Group Selinsgrove formation Hazard member
Esopus shale Palmerton sandstone	Palmerton sandstone	Palmerton sandstone	Palmerton sandstone	Palmerton sandstone	Palmerton sandstone
Bowmanstown chert	Bowmanstown chert	Bowmanstown chert	Bowmanstown chert	Bowmanstown chert and Esopus siltstone	Bowmanstown chert Esopus shale

Johnson, 1957	Oliver and others, 1967, 1969	Sevon, 1968	Epstein and Epstein, 1967, 1969, Epstein and Hosterman, 1969	Epstein and others, 1974	This report	Series
Onondaga formation Hazard paint ore	Tioga Ash Bed Buttermilk Falls Limestone	Onondaga Formation	Buttermilk Falls Limestone of Willard (1938)	Buttermilk Falls Limestone	Buttermilk Falls Limestone	Middle Devonian
Palmerton sandstone	Palmerton Sandstone	Palmerton Formation	Palmerton Sandstone of Swartz (1939)	Palmerton Formation	Palmerton Sandstone	?
Bowmanstown chert Esopus formation	Schoharie-Esopus Formations	Schoharie-Esopus Formation	Schoharie Formation Esopus Formation	Schoharie and Esopus Formations, undifferentiated	Schoharie and Esopus Formations, undivided	Lower Devonian

B—BETWEEN STONE AND CHERRY RIDGES

FIGURE 2.—Development of Onesquethawan nomenclature in northeastern Pennsylvania.

limestone in central Pennsylvania, but later Willard and others (1939) reinstated the name for noncherty beds near Bowmanstown. Because of the uncertainty of continuity of these beds with the type Selinsgrove in central Pennsylvania and because the weathered rocks at Bowmanstown contain some chert, they are herein referred to as the Buttermilk Falls Limestone. Willard also recognized the Palmerton and the Bowmanstown but apparently included them in his Esopus (Willard and others, 1939, p. 145, 151, 154, and 333). Willard's statements and diagrams indicate that he placed 87 feet (27 m) of Esopus above the Palmerton and below the Hazard paint ore. His conclusions create three inconsistencies. (1) One definition of Willard's Esopus ranks the Esopus as a separate unit above the Palmerton; another places the Palmerton and the Bowmanstown as members of the Esopus. This inconsistency is shown diagrammatically in figure 2 of this report. (2) Only 5 feet (1.5 m) of rock, not 87 feet (27 m) is present between the Palmerton and Hazard along the Pennsylvania Turnpike (see measured section 5). Willard's error was noted also by Swartz and Swartz (1941, p. 1180). (3) Whether Willard meant the Hazard to be a member of the Esopus (Willard and others, 1939, p. 154, table 21) or a part of the Selinsgrove (Willard and others, 1939, p. 151) is not clear.

ONESQUETHAWAN ROCKS

The rocks described in this report are the correlatives of the Esopus, Schoharie, and Onondaga of New York that comprise the Onesquethawan Stage. Their type section is west of Clarksville, Albany County, N.Y., near Onesquethaw Creek in the Helderberg Mountains (Cooper and others, 1942). Onesquethawan rocks in eastern Pennsylvania lie between the Ridgeley Sandstone of the Oriskany Group below and the Marcellus Shale of the Hamilton Group above. Willard (*in* Willard and others, 1939) proposed the Stroudsburgian Stage for these rocks; he did not recognize the Schoharie. His stage name has not been used by subsequent workers. The latest correlations (Oliver and others, 1969) place the Esopus, Schoharie, and Palmerton in the Lower Devonian and the Buttermilk Falls in the Middle Devonian, although other workers have placed all the units in the Middle Devonian (Willard, *in* Willard and others, 1939; Jones and Cate, 1957; Sevon, 1970). These age assignments may not be entirely accurate because field relations suggest that part of the Palmerton Sandstone may be laterally equivalent to the basal part of the Buttermilk Falls. Faunal lists for Onesquethawan rocks in eastern Pennsylvania are given by White (1882), Prosser (1892), Kindle (1911, 1912), Swartz and Swartz (1941), Willard (1936, 1938), Willard and others (1939), Willard and Whitcomb (1938), and Inners (1975). Figure 3 shows the stratigraphic relations of these rocks in the report area.

ONESQUETHAWAN ROCKS IN GODFREY RIDGE

ESOPUS FORMATION

Darton (1894) named the Esopus shale for exposures along Esopus Creek, near Esopus, N.Y. In the Stroudsburg area, White (1882) measured 250 feet (76 m) of his Caudi-galli grit. Willard (1936, 1938) reported more than 250 feet (76 m) of the Esopus and later (Willard and others, 1939) revised the figure to more than 300 feet (91 m). Swartz and Swartz (1941) measured 275 feet (84 m) of Esopus at Experiment Mills in Godfrey Ridge along Brodhead Creek (fig. 1, loc. 2). In their measurements, these workers included rocks herein assigned to the Schoharie Formation. Johnson (1957) and Johnson and Southard (1962), who recognized the Schoharie Formation, believed the Esopus to be more than 200 feet (61 m) thick in the Stroudsburg area.

The Esopus is 181 feet (55 m) thick in bluffs north of the Erie-Lackawanna Railroad, 1 mile (1.6 km) east of East Stroudsburg (fig. 1, loc. 3). On the basis of a series of cross sections, the Esopus appears to maintain this approximate thickness to the southwest termination of Godfrey Ridge. The Esopus is a medium-gray (*N*5) to dark-gray (*N*3), medium-gray- (*N*5) weathering, shaly to finely arenaceous siltstone with lesser silty shale and minor calcareous siltstone. Cleavage is very well developed, masking sedimentary features to some degree (fig. 4). The rock is laminated, but bedding is indistinct in many places. It generally is burrowed extensively with the trace fossil *Taonurus*, which is also common in the basal part of the Schoharie (see figs. 6 and 16). Brachiopods are present but are not abundant. Moderate-yellowish-brown (10*YR* 5/4) to dark-yellowish-orange (10*YR* 6/6) iron staining is distinctive. For practical separation from the overlying Schoharie into which it grades, the Esopus is decidedly less calcareous or noncalcareous, it has better developed cleavage, it has characteristic iron staining, and, when hit with a hammer, it emits a dull thud as compared to the more resonant ring of the more massive Schoharie. Rare beds of calcareous siltstone, similar to those of the Schoharie, were seen in the lowerpart of the Esopus in Godfrey Ridge north of Bossardsville.

In thin section, the Esopus is composed mainly of shaly graywacke siltstone and consists of medium- to coarse-silt-sized quartz grains (about 40–50 percent),

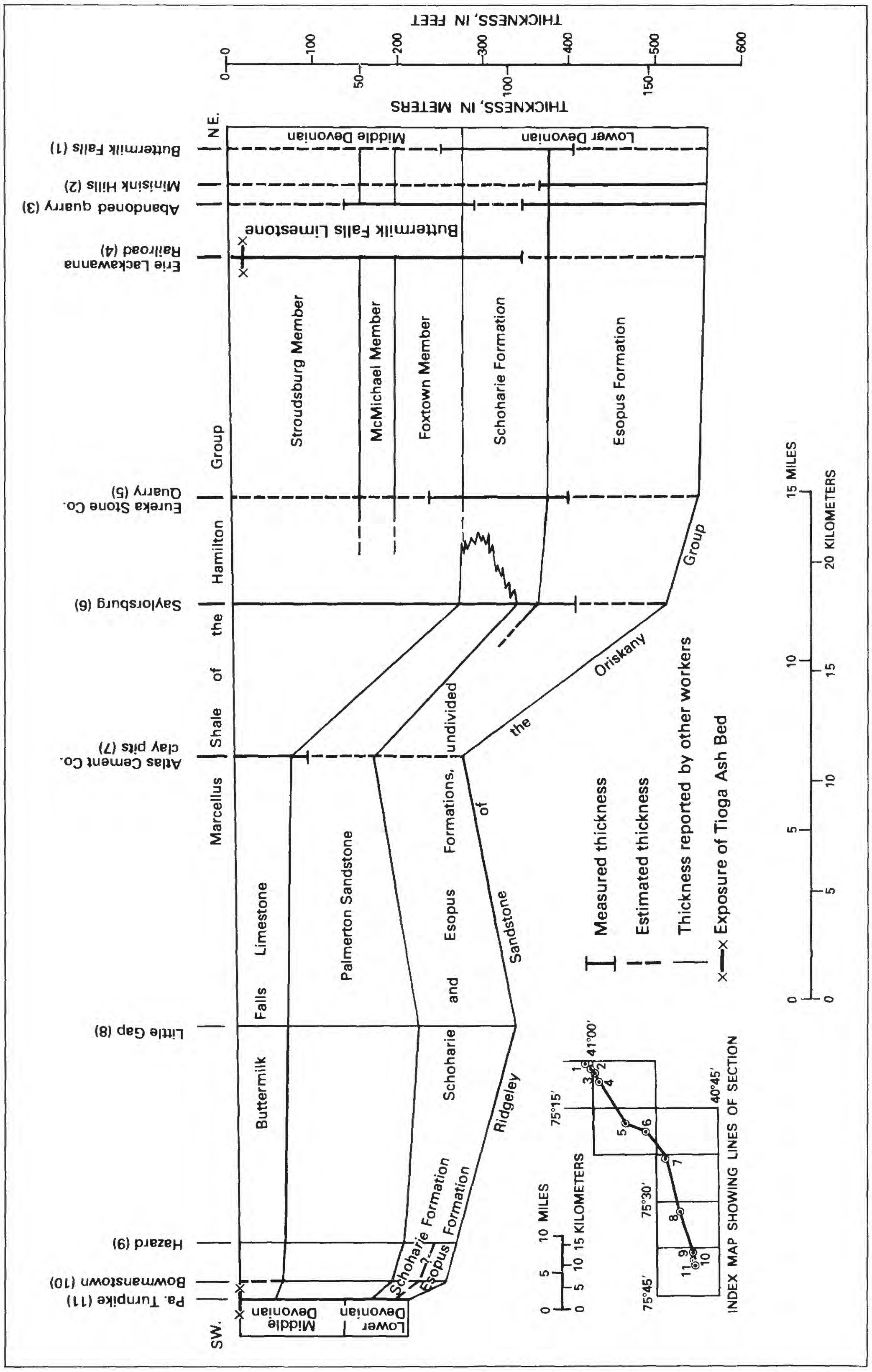

FIGURE 3.—Correlation chart of Onesquethawan rocks in northeastern Pennsylvania.

FIGURE 4.—Well-developed slaty cleavage in the Esopus Formation along U.S. 611 on the north slope of Godfrey Ridge immediately south of Stroudsburg. Cleavage (cl) dips about 75° to the southeast (to the left), and bedding (b) dips about 30° in the same direction.

muscovite and chlorite (15–30 percent), calcite (probably averaging less than 3 percent), plagioclase, chert, and angular to rounded tourmaline and zircon (rare) in a fine-silt to clay matrix consisting mostly of quartz, muscovite, and chlorite. Opaque minerals, including pyrite and leucoxene, comprise about 1 percent. The quartz is ragged and replaced with muscovite and chlorite in pressure-shadow areas of cleavage. Many of the muscovite, chlorite, and some quartz grains are oriented parallel to cleavage.

The Esopus underlies some of the highest parts of Godfrey Ridge. Good exposures are numerous, such as those along U.S. 209 (fig. 1, loc. 1), along the abandoned railroad grade west of Minisink Hills (fig. 1, loc. 2), at Foxtown Gap and on the north slope of Godfrey Ridge along U.S. 611 south of Stroudsburg, along the road east of Pine Grove Lake north of Stormville, and in the Eureka Stone Co. quarry (fig. 1, loc. 5).

The base of the Esopus is in sharp contact with the underlying Ridgeley Sandstone of the Oriskany Group and is unconformable (Willard, 1936; Cleaves, 1937; Cooper and others, 1942; Jones and Cate, 1957; Epstein and Epstein, 1969). This interpretation is supported by the faunal break, abrupt lithic changes, and inferred different environments of deposition discussed in the section "Environments of Deposition."

SCHOHARIE FORMATION

Vanuxem (1840) named the Schoharie for exposures in Schoharie County, N.Y. At Buttermilk Falls (fig. 1, loc. 1), Herpers (1950a) described 72 feet (22 m) of calcareous siltstone at the top of his Esopus Formation and placed them in his "X-beds," a transitional interval between the Esopus and Buttermilk Falls Limestone. These beds were later assigned to the Schoharie Formation by Johnson (1957), although the name Schoharie was first used by Cooper and others (1942) in eastern Pennsylvania. The base of the Schoharie, as recognized by Johnson (1957) and Johnson and Southard (1962), is placed at the lowest conspicuous calcareous siltstone or mudstone overlying the Esopus. Accepting this contact, which also coincides with the base of the lowest massive siltstone, I measured 103 feet (31 m) of Schoharie near Buttermik Falls (fig. 1, loc. 1; measured section 1). It thins at a rate of approximately 2 feet per mile to the Eureka Stone Co. quarry (fig. 1, loc. 5) where it is 97 feet (30 m) thick. Johnson (1957) noted a rate of thinning of 4 feet per mile from Port Jervis, N.Y., where the Schoharie is 271 feet (83 m) thick, to Buttermilk Falls, where he measured 102 feet (31 m).

The Schoharie in Godfrey Ridge is predominantly a medium-gray (*N*5) to grayish-black (*N*2), thin-bedded to very thick bedded, laminated and massive, fairly evenly bedded, calcareous siltstone with lesser amounts of fine-grained sandy siltstone. It weathers medium gray (*N*5) to medium dark gray (*N*4) and light olive gray (5*Y* 6/1). The more calcareous beds weather lighter than the silty beds. Beds range from a few inches to as much as 6 feet (2 m) thick (fig. 5). Dark-gray (*N*3) chert, which weathers light gray (*N*7), is scattered throughout as rounded and irregular nodules and lenses as much as 2 inches (5 cm) thick. The chert is more abundant toward the top of the unit. The upper beds in the Schoharie appear to become more cherty and limy toward the southwest termination of Godfrey Ridge; therefore, the Schoharie is gradational into the overlying Buttermilk Falls Limestone. Horizontal burrows (*Taonurus*) are abundant in the lower half (fig. 6). Brachiopods are common. The base of the formation, according to Johnson (1957), is marked by a zone of *Pacificocoelia acutiplicata* (Conrad), a fossil that is typically found in his "Carlisle Center" facies. Inners (1975) subdivided the Schoharie Formation in Godfrey Ridge into the Carlisle Center Member (containing abundant *Taonurus*), below, and the Aquetuck-Saugerties Members, undivided (with vertical burrows), above. These subdivisions could not be used in field mapping. The Schoharie is transitional into the Esopus. The boundary locally is placed within a 10- to 20-foot interval with difficulty, especially in the fresh rocks exposed in the Eureka Stone Co. quarry. Slaty cleavage is locally conspicuous in the Schoharie but is generally not as well developed as in the underlying Esopus.

In thin section (fig. 7), calcite as microspar and as sparry rhombs comprises 25 to 60 percent of most of the rock in the Schoharie. Quartz (35–65 percent) is etched and generally occurs as single grains, but a few composite grains of quartz and grains of chert were noted. Muscovite and chlorite make up less than 5 percent of the rock. Plagioclase feldspar (less than 1 percent) and rare tourmaline, zircon, and opaque minerals, including pyrite and leucoxene, are accessory minerals. Rare phosphatic shell material was seen in one section.

The Schoharie is fairly well exposed in Godfrey Ridge. It generally underlies high parts of the ridge. In addition to the locality near Buttermilk Falls, good exposures are found in an abandoned quarry 0.9 mile (1.4 km) west of Minisink Hills (fig. 1, loc. 2), along U.S. Highway 611 south of Stroudsburg, in the Erie-Lackawanna railroad cut nearly 1 mile (1.6 km) south of the East Stroudsburg Post Office (fig. 1, loc. 4), along the north slope of Godfrey Ridge throughout the area, and along Pa. Highway 33 1.4 miles (2.3 km) west of Bossardsville. It is completely exposed in the quarry of the Eureka Stone Co. (fig. 1, loc. 5), where it is processed for crushed stone.

BUTTERMILK FALLS LIMESTONE

The type locality of the Buttermilk Falls Limestone is at Buttermilk Falls on Marshall Creek (fig. 1, loc. 1). Willard (*in* Willard and others, 1939) named the unit and believed it to be about 200 feet (61 m) thick. At the type locality (measured section 1), only the lower 25 feet (8 m) are exposed. Elsewhere, as in the railroad cut of the Erie-Lackawanna Railroad (fig. 1, loc. 4), the Buttermilk Falls is 272 feet (83 m) thick and consists of three mappable members—a medial calcareous silty shale separating two cherty limestones. These members are herein named, in ascending order, the Foxtown, McMichael, and Stroudsburg Members. Inners (1975) recognized a similar subdivision but added an additional member to the top of the sequence (see fig. 2).

Foxtown Member

The type section of the Foxtown and of the other two members of the Buttermilk Falls Limestone is in the railroad cut of the Erie-Lackawanna Railroad, nearly 1 mile (1.6 km) south of the East Stroudsburg Post Office (fig. 1, loc. 4; measured section 3). The name is taken from Foxtown Hill on Godfrey Ridge where the member is exposed in nearly vertical beds along U.S. 611.

The Foxtown consists of wavy irregularly bedded and lenticular, medium-gray (*N*5) weathering to medium-dark-gray (*N*6), cherty limestone in beds 1 inch (3 cm) to 2 feet (0.6 m) thick (fig. 8). Grain size is generally fine (fig. 9), although very coarse grains are not uncommon. The limestone is interbedded with medium-dark-gray (*N*4), calcareous, evenly bedded shale and siltstone in beds 1 inch (3 cm) to 1 foot (0.3 m) thick and contains dark-gray (*N*3) to grayish-black (*N*2) chert. The chert in the lower half is in irregular nodules 0.5 to 6 inches (1–5 cm) in diameter. Chert is more abundant in the upper half where it makes up more than 50 percent of the

FIGURE 5.—Evenly bedded siltstone in the upper half of the Schoharie Formation in roadcut along U.S. 209 near Buttermilk Falls (fig. 1, loc. 1). More massive beds are seen at the top of the section. Lighter weathering beds are more calcareous.

unit. It is interbedded with calcareous argillite 1 to 2 inches (2.5–5 cm) thick and limestone pods 2 to 6 inches (5–15 cm) in diameter. The chert contains varying amounts of calcite and mica (fig. 9).

Large crinoid columnals (fig. 8), as much as 1 inch (2.5 cm) in diameter and 4 inches (10 cm) long, are conspicuous in the lower half of the Foxtown Member. Oliver (1962; written commun., 1962) traced zones of large crinoid columnals in the base of his Edgecliff Member at the bottom of the Onondaga Limestone from Onondaga, N.Y., to Port Jervis, N.Y. The similar crinoid marker bed at the bottom of the Buttermilk Falls of eastern Pennsylvania is the equivalent of the basal part of the Onondaga of southeastern New York. Although stratigraphic relations have not been worked out between Monroe County, Pa., and southeastern New York, the facies changes alone are sufficient to justify the new member names in the Stroudsburg quadrangle.

At the type section, the base of the Foxtown Member is marked by a 1-foot- (0.3-m-) thick bed of medium-gray (*N*5), medium- to very coarse grained limestone in abrupt contact with the underlying Schoharie Formation. In the western part of Godfrey Ridge, the boundary between the Foxtown and the Schoharie is transitional through about 6 feet (1.8 m) of cherty calcareous siltstone and silty limestone. In this area, coarse sand grains more than 3 mm (0.1 in.) in diameter are present in basal Foxtown beds, apparently heralding proximity to the Palmerton Sandstone in Cherry Ridge 1.3 miles (2 km) to the southeast. I believe that the basal part of the Foxtown and the upper part of the Schoharie are lateral equivalents of the Palmerton. Also in the western part of Godfrey Ridge, crinoid columnals are not as abundant as they are to the northeast along the ridge. The columnals are especially scarce in the southwesternmost exposures of the Foxtown 2,000 feet (610 m) south of Hamilton Square and 1.35 miles (2.2 km) southwest of Bossardsville in the Saylorsburg quadrangle.

The Foxtown Member is 82 feet (25 m) thick at the type section. In the abandoned quarry south of I–80 and 1,200 feet (366 m) west of where the highway

FIGURE 6.—Cross section of the trace fossil *Taonurus*, believed to be a horizontal feeding burrow, in the lower half of the Schoharie Formation, in roadcut along U.S. 209 near Buttermilk Falls (fig. 1, loc. 1).

crosses Brodhead Creek (fig. 1, loc. 3, the Slater-Canfield quarry, according to Johnson (1957) who assigned these beds to the Schoharie Formation), the Foxtown is 80 feet (24 m) thick, and the lower 45 feet contains the large crinoid columnals.

The Foxtown Member is fossiliferous. Brachiopods are common, and a large silicified ostracode faunule was recovered by dissolving the rock in dilute acetic acid. The following ostracodes were identified by J. M. Berdan and A. G. Harris (U.S. Geological Survey):

Acathoscapha navicula (Ulrich)
Aechmina sp.
Amphizona sp.
Bairdites? sp.
Beecherella sp. cf. *B. carinata* Ulrich
Bufina sp.
Camdenidea
Hollinella sp.
Kirkbyella (*Berdanella*) sp. cf. *K.* (*B.*) *unicornis* (Coryell and Malkin)
Kirkbyella sp.
Menoeidina sp.
New genus aff. *Pachydomella thlipsuroidea* Swain
Parabolbina sp.
Ranapeltis trilateralis Swartz and Swain
Ranapeltis sp. cf. *R. unicarinata*
Ranapeltis sp.
Richina? sp.
Rudderina sp.
Strepulites bifurcatus (Bassler)
Tricornina? sp.
Tubulibairdia sp.
Tubulibairdia? sp.
Ulrichia pluripuncta Swartz and Swain (Coryell and Malkin)

According to Berdan (written commun., 1963), these have affinities with forms described from the Hamilton Group and the Onondaga Limestone. Thus, it is probable that the collection represents beds of Onondaga age (Middle Devonian) rather than of Schoharie age (Early Devonian).

The Foxtown Member generally forms slight topographic rises on the north slope of Godfrey Ridge. It is coarsely jointed and has supplied large boulders, some of which exceed 30 feet (9 m) in length, to glacial drift to the south. In addition to the localities mentioned, good exposures are found at the foot of Godfrey Ridge along the junction of U.S. 611 and Pa. State Route 191, at the west edge of the Stroudsburg quadrangle near McMichael Creek, and along Pa. State Route 33 at the southwest end of Godfrey Ridge where about 15 to 40 feet (4.6–12 m) of the Foxtown forms a resistant cap on the Schoharie Formation.

McMichael Member

The member is named for McMichael Creek north of Godfrey Ridge. At the type section, along Erie-Lackawanna Railroad (fig. 10, it is 41 feet (12.5 m) thick, and at the abandoned quarry at locality 3 of figure 1 it is 42 feet (13 m) thick. It consists of evenly bedded to lenticular, medium-gray (*N*5) to medium-dark-gray (*N*4), weathering medium-gray (*N*5), calcareous, partly silty, fossiliferous shale in beds 2 inches (5 cm) to 1 foot (0.3 m) thick, and interbedded medium-gray (*N*5), fine-grained fossiliferous biomicrite and biomicrudite in beds, lenses, and nodules 1 to 3 inches (2.5–8 cm) thick. Fossils are abundant and include crinoid, trilobite, bryozoan, and brachiopod debris and ostracodes. Silicified ostracodes were recovered at the type section and were identified by J. M. Berdan and A. G. Harris (U.S. Geological Survey). They are of probable Onondaga age and include:

Aechmina sp.
Amphizona sp. cf. *A. asceta* Kesling and Copeland
Bairdiocypris? sp.
Bairdites? sp.
Bollia disceratina Swartz and Swain

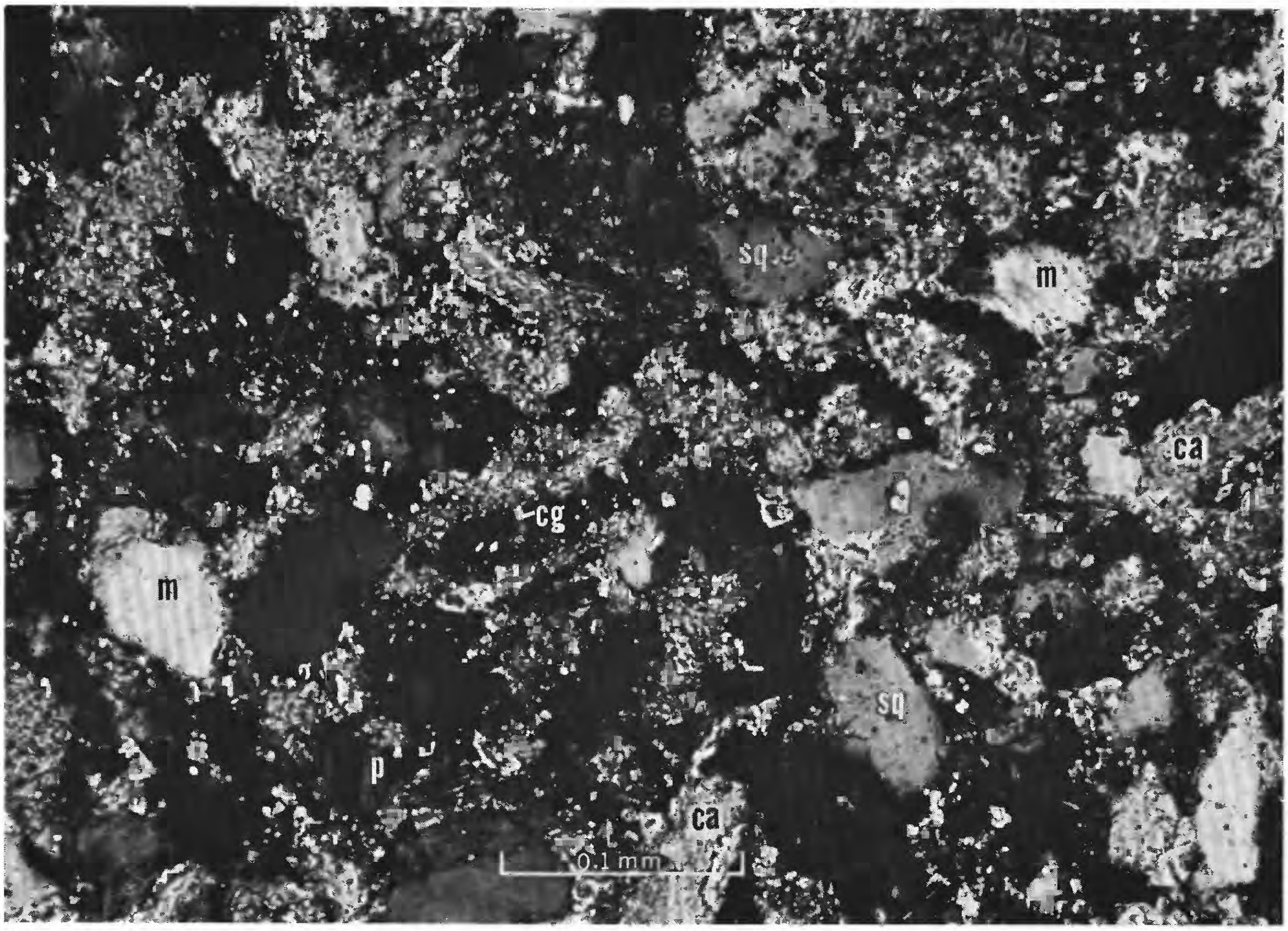

FIGURE 7.—Photomicrograph (crossed polarizers) of very coarse grained quartzose calcisiltite in the Schoharie Formation, 50 feet (15 m) below the contact with the overlying Buttermilk Falls Limestone, from roadcut along U.S. 209 near Buttermilk Falls, unit 4 of meaured section 1 (fig. 1, loc. 1). The rock contains about 50 percent calcite (ca) as microspar and recrystallized rhombs; etched, predominantly simple quartz (sq) (about 45 percent) with a few composite grains (cg); and minor muscovite (m), chlorite, and plagioclase feldspar (p).

B. planojugosa Swartz and Swain
Bufina sp.
Euglyphella? sp.
Eukloedenella? sp.
Favulella dicarinella Swartz and Swain
F. favulosa (Jones)
Hollinella sp. aff. *H. antespinosa* (Ulrich)
Kirkbyella (*Berdanella*) sp. cf. *K.* (*B.*) *unicornis* (Coryell and Malkin)
Pachydomella sp.
Parabolbina parvinoda Swartz and Swain
Parabolbina sp.
Ranapeltis trilateralis Swartz and Swain
Reversocypris? sp.
Rhopalonellus sp.
Richina sp.
Rishona? sp.
Rudderina sp.
Strepulites bifurcatus (Bassler)
Tricornina sp.?
Tubulibairdia sp.
Tubulibairdia? sp.
Ulrichia elongata Swartz and Swain
?*Ulrichia pluripuncta* Swartz and Swain

The McMichael Member is poorly exposed except for the localities mentioned. It is not exposed for 7.6 miles (12.2 km) southwest of the type section until 2,000 feet (610 m) south of Hamilton Square in the Saylorsburg quadrangle where it is identified with some uncertainty. The McMichael generally forms a topographic swale between the cherty limestones above and below. The lower boundary is gradational.

FIGURE 8.—Irregularly bedded cherty limestone in the upper half of the Foxtown Member of the Buttermilk Falls Limestone, in roadcut along Brown Street, 5,000 feet (1,524 m) northeast of the hospital in East Stroudsburg. Inset shows 1-inch-diameter crinoid columnal from the lower part of the Foxtown Member at the type section on the Erie-Lackawanna Railroad (fig. 1, loc. 4).

Stroudsburg Member

This member is named for Stroudsburg, Pa., where excellent exposures are seen along I–80 (see Epstein and Epstein, 1969, fig. 23*B*). In the abandoned quarry at locality 3 of figure 1, the lower 15 feet (4.6 m) are exposed, and, at the type section (fig. 11; measured section 3) 149 feet (45.4 m), probably the entire thickness of the member, is exposed. The Stroudsburg consists of irregularly bedded, medium-gray (*N*5) to medium-dark-gray (*N*4), weathering light-gray (*N*7) to medium-light-gray (*N*6), fossiliferous, fine- to medium-grained, locally argillaceous limestone in beds and lenses 1 inch (2.5 cm) to 1 foot (0.3 m) thick and dark-gray (*N*3) to grayish-black (*N*2) chert in irregular beds, lenses, and pods 0.25 inch (6.4 mm) to 1 foot (30 cm) thick. The upper 15 feet (4.6 m) at the type section and near Stroudsburg contains several beds, which are 3 to 6 inches (8–15 cm) thick, of medium-gray (*N*5) to medium-light-gray (*N*6), weathering light-gray (*N*7), medium to very coarse grained limestone (mostly biosparrudite). These coarser limestones were named the Echo Lake Member by Inners (1975). This name has not been used because the rocks are not mappable due to poor exposure. They contain abundant brachipod, coral, and crinoid debris and some conodonts. The conodonts were identified by A. G. Harris and J. W. Huddle (U.S. Geological Survey) and include *Icriodus expansus* Branson and Mehl and a new subspecies of *Icriodus latericrescens* Branson and Mehl. These indicate that the Stroudsburg Member is no older than the upper part of the Moorehouse Member of the Onondaga Limestone of New York.

The Tioga Ash Bed, first recognized by Inners (1975) in the Stroudsburg area, crops out about 27 feet (8.2 m) below the top of the Buttermilk Falls Limestone along the Erie-Lackawanna Railroad south of East Stroudsburg (measured section 3) and along I–80 just east of the Pa. State Route 191 overpass. The bed ranges between 10 inches (.25 m) and 1.3 feet (0.4 m) in thickness and is similar in general appearance to calcareous shales

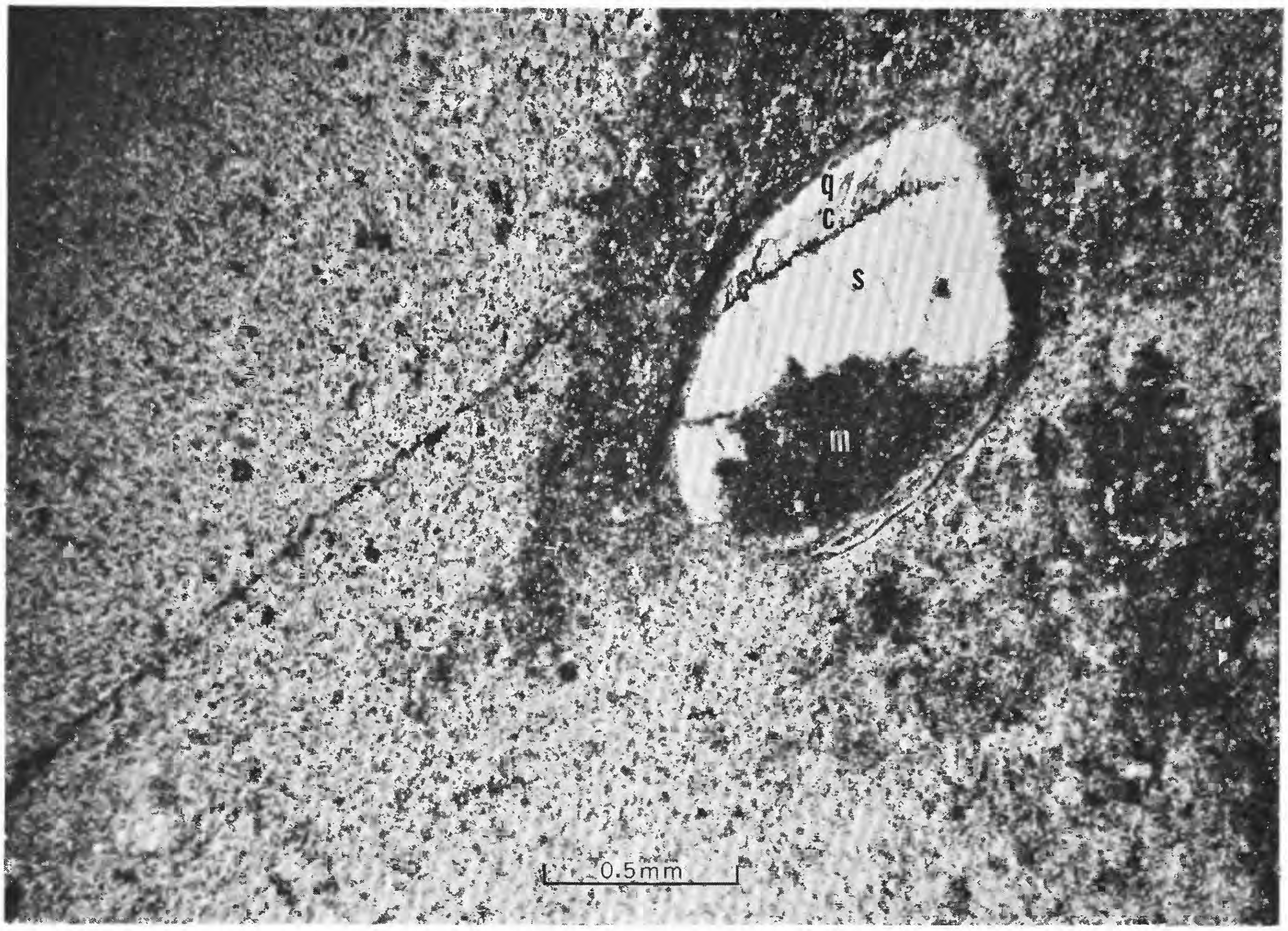

FIGURE 9.—Photomicrograph (plane-polarized light) of cherty biomicrite (light areas) and biomicrite (dark areas) in the Foxtown Member of the Buttermilk Falls Limestone, near Buttermilk Falls, unit 5 of measured section 1, 15 feet (4.6 m) above the contact with the Schoharie Formation. Ostracode is partly filled with micrite (m), a probable geopetal structure, and sparry calcite (s). Shell is also partly filled with quartz (q) and calcite (c) that are alined parallel to rock cleavage. Other samples of the Foxtown are biomicrudites, partly neocrystallized to microspar and pseudospar.

lower in the section. The Tioga is a light-olive-gray (5*Y* 6/1) to medium-olive-gray (5*Y* 5/1) and medium-gray (*N*5) to medium-dark-gray (*N*4), generally noncalcareous, tuffaceous siltstone to very fine grained sandstone and crystal tuff that weathers medium light gray (*N*6) and grayish orange (10*YR* 7/4) to moderate yellowish brown (10*YR* 5/4). It contains rare brachipods. The bed is characterized by abundant bleached mica flakes that are visible to the naked eye. These are normally biotite elsewhere (Dennison and Textoris, 1971; Roen and Hosterman, 1982), but in the Stroudsburg area, X-ray and thin-section analyses show that the biotite has been altered to ripidolite.

As seen in thin section, the biotite is the most abundant crystal in the tuffaceous sediment. It is subhedral to euhedral, lath shaped, and altered to limonite and chlorite. Less common single crystal quartz grains are euhedral to subhedral, and many have corroded edges. They are as much as 0.3 mm long. Elongate and curved grains of microcrystalline quartz are probably altered glass shards. Subsidiary equant grains of aggregate muscovite, as much as 0.2 mm long, are partial replacements of feldspar. Uncommon calcite grains, slightly longer than 0.1 mm, are partly replaced and rimmed by quartz. Minor minerals include euhedral apatite and zircon, as much as 0.2 mm long. Opaque minerals include pyrite and probably magnetite in irregular, framboidal, and euhedral grains as much as 0.06 mm long. The matrix makes up more than 50 percent of the rock and consists of chert and microcrystalline muscovite that may be alteration products of volcanic glass. The rock is laminated and irregularly laminated; this suggests some reworking by currents after deposition.

Because the Tioga Ash Bed marks the top of the Onesquethawan Stage, the uppermost 27 feet (8.2 m) of the Buttermilk Falls is Cazenovian in age and correlates

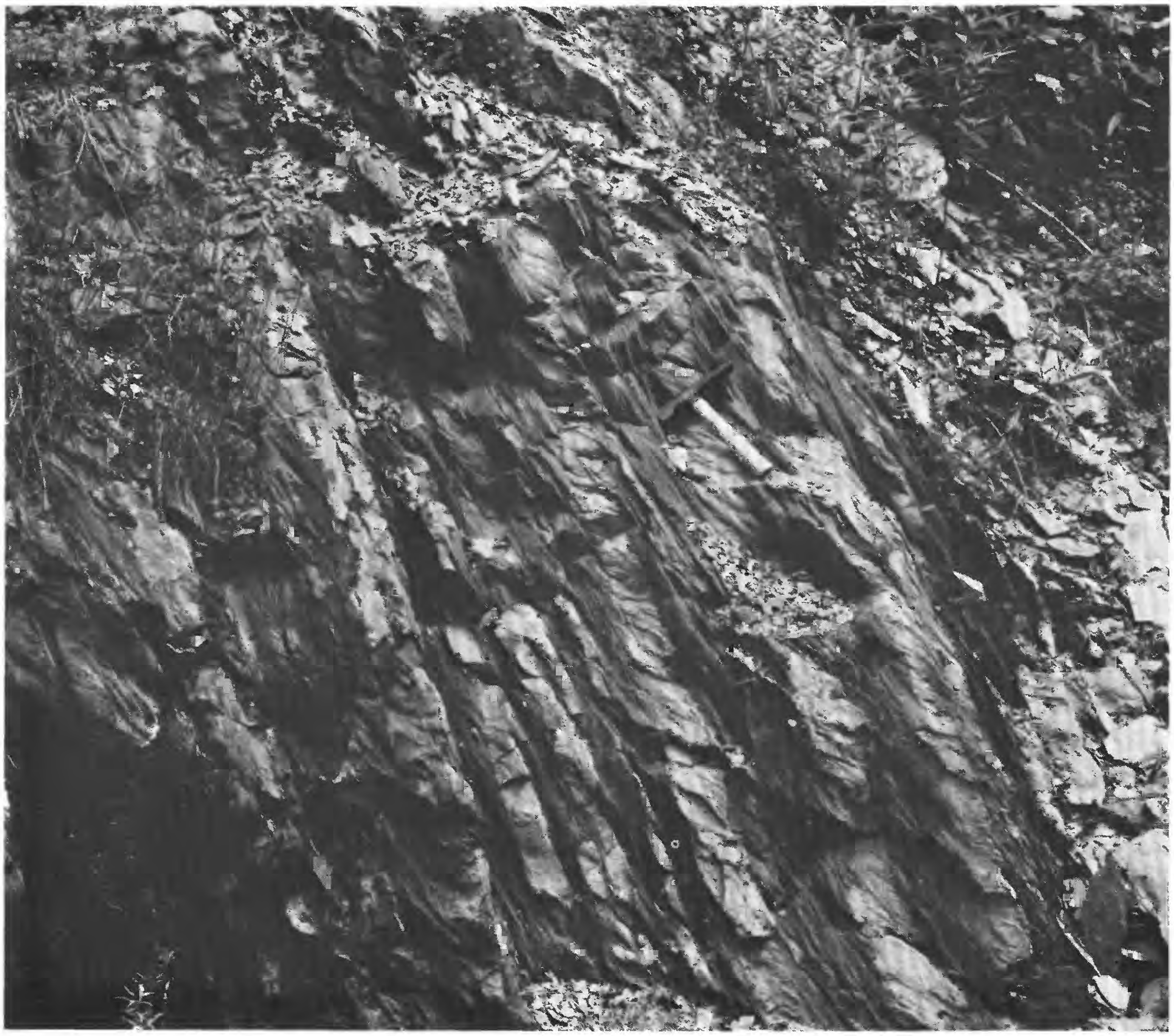

FIGURE 10.—Evenly bedded and lenticular limestone (light) and calcareous shale (dark) in the McMichael Member of the Buttermilk Falls Limestone at the type locality along the Erie-Lackawanna Railroad, nearly 1 mile (1.6 km) south of the East Stroudsburg Post Office (fig. 1, loc. 3). The beds are overturned and dip to the southeast (to the right) more steeply than the conspicuous cleavage in the shale. Note refraction of the cleavage in the limestone.

with the Seneca Member of the Onondaga Limestone of New York (the Tioga is found between the Seneca and underlying Moorehouse Member there). This corroborates the age of the uppermost part of the Buttermilk Falls in the Stroudsburg area suggested by the conodonts. As will be noted later (see p. 23), the Tioga is found at the base of the Marcellus Shale and just above the Buttermilk Falls along the northeast extension of the Pennsylvania Turnpike (see fig. 3). Therefore, the top of the Buttermilk Falls becomes younger to the northeast in the area of this report.

The McMichael and Stroudsburg Members have a gradational boundary. The upper boundary of the Stroudsburg Member is nowhere exposed in Godfrey Ridge but is probably in abrupt contact with shales and calcareous shales and siltstones of the Union Springs Shale and Stony Hollow Members of the Marcellus Shale.

The Stroudsburg Member is well exposed at the localities mentioned above, as well as in several small hills that rise above the valleys of McMichael and Brodhead Creeks and south of Hamilton Square near the southwest end of Godfrey Ridge.

FIGURE 11.—Unevenly but distinctly bedded chert (dark) and limestone (light) in the Stroudsburg Member of the Buttermilk Falls Limestone at the type section along the Erie-Lackawanna Railroad south of East Stroudsburg (fig. 1, loc. 4). Beds are overturned and dip to the southeast (to the left). Poorly developed cleavage dips gently to the southeast.

ONESQUETHAWAN ROCKS IN CHERRY TO STONE RIDGES

Several important changes occur in Onesquethawan rocks in passing from Godfrey Ridge to Cherry Ridge and the ridges to the southwest. The units become thinner, and the Palmerton sandstone appears and thickens to the southwest (fig. 3). Southwest of the Wisconsinan terminal moraine, which crosses Cherry Ridge near Saylorsburg (fig. 1), the rocks have been weathered to depths greater than 150 feet (46 m) in places, forming sedimentary-rock saprolites. Southwest of Bossardsville, exposures become scarcer, and the members of the Buttermilk Falls cannot be distinguished. Some of these changes have been noted by Swartz and Swartz (1941), although some of their interpretations differ in detail from the results presented here.

SCHOHARIE AND ESOPUS FORMATIONS, UNDIVIDED

Swartz (*in* Willard and others, 1939) named the Bowmanstown chert for about 67 feet (20 m) of chert and fossiliferous argillaceous sandstone above the Oriskany and below the Palmerton exposed along the State highway 0.5 mile (0.8 km) east of Bowmanstown. Prior to this identification, both the Bowmanstown and Palmerton were thought to be part of the Oriskany. Swartz and Swartz (1941) recognized that the Bowmanstown correlated with the lower half of their Esopus in Godfrey Ridge. Willard (1957) recognized that Swartz's Bowmanstown could be divided into a lower shale and siltstone, which he called the Esopus, and an overlying blocky chert, which he called the Bowmanstown. Epstein and Epstein (1967) noted that these rocks are similar to the Esopus and Schoharie in the Stroudsburg area and could be mapped into each other. Therefore, they discarded the name "Bowmanstown" and termed the rocks Schoharie and Esopus Formations, undivided, a designation also followed by Epstein and Epstein (1969), Epstein and others (1974), Epstein and Sevon (1978), and Berg and others (1983).

The Schoharie and Esopus Formations generally become thinner west of Saylorsburg (fig. 3). Thicknesses reported by different workers at any single locality vary considerably, no doubt because of differing stratigraphic boundary interpretations and complex folding and some faulting that make measurements somewhat inaccurate. For example, along the Northeast Extension of the Pennsylvania Turnpike and near Bowmanstown (fig. 1, locs. 10 and 11), where I measured nearly 48 feet (15 m) of these rocks (measured section 5), Willard (1936) measured 4 to 10 feet (1–3 m), and Swartz and Swartz (1941) reported 67 feet (20 m). At Little Gap, where folding is complex, Cleaves (*in* Willard and others, 1939) reported 54 feet (16 m), whereas Swartz and Swartz (1941) measured 111 feet (34 m). At Saylorsburg, 68 feet (21 m) of the Schoharie-Esopus are exposed (measured section 4), and the unit is probably about 175 feet (53 m) thick, on the basis of construction of cross sections. Near Stroudsburg, the combined Esopus and Schoharie Formation are about 285 feet (87 m) thick.

Because of poor exposures, the Schoharie and Esopus cannot be mapped separately west of Bossardsville. The two formations are distinguishable, however, in deep roadcuts (fig. 1, locs. 6, 10, and 11) and at a few places in between. The Esopus is dark, finer bedded, and shalier than the overlying Schoharie, which is more massive (fig. 12) and lighter in color, apparently due to weathering of more abundant calcium carbonate (calcium carbonate is much more abundant in the Schoharie than in the Esopus in the unweathered sections on Godfrey Ridge).

The Esopus is at least 35 feet (11 m) thick at Saylorsburg and thins to 11 feet (3 m) along the Pennsylvania Turnpike. Silty shale and shaly siltstone are the dominant lithic types. They are dark gray (*N*3) on fresher surfaces and are weathered to many colors at most localities, including very light gray (*N*8), light greenish gray (5*GY* 7/1), grayish red (5*R* 4/2), and dark yellowish orange (10*YR* 6/6). The Esopus is laminated to fine bedded (beds average 2 to 3 inches (5–8 cm) in thickness, but some are 1 foot (30 cm) thick). The trace fossil *Taonurus* is abundant. The contact with the underlying Ridgeley Sandstone of the Oriskany Group is abrupt, whereas the boundary with the overlying Schoharie is gradational through interbedded shaly siltstone and blocky siltstone. The boundary with the Schoharie is placed at the base of a prominent blocky siltstone that weathers lighter than the siltstones in the Esopus.

The Schoharie Formation is thinner than in Godfrey Ridge. It is 33 feet (10 m) thick at Saylorsburg and 37 feet (11 m) thick along the Pennsylvania Turnpike. It consists of evenly bedded siltstone to very fine grained sandstone with rare medium-grained sandstone. At Saylorsburg (loc. 6, fig. 1), a 3-inch- (8-cm-) thick very coarse grained sandstone bed is included in the Schoharie near the disconformable contact with the overlying Palmerton Sandstone (fig. 12; measured section 4). A somewhat similar unit with more sandstone along the Pennsylvania Turnpike (fig. 1, loc. 1) is placed in the Palmerton (measured section 5).

The Schoharie is medium light gray (*N*6) to dark gray (*N*3) on fresher surfaces and weathers white (*N*9) to light gray (*N*7) and very pale orange (10*YR* 8/2), pale yellowish orange (10*YR* 8/6) to dark yellowish orange (10*YR* 6/6), light brown (5*YR* 5/6) to grayish brown (5*YR* 3/2), and pale red (10*R* 6/2) to moderate reddish brown (10*R* 4/6). Chert nodules that are 1 to 3 inches (3–8 cm) in diameter and irregular chert beds and lentils as much as 3 inches (8 cm) thick are common. These are dark gray (*N*3) and weather very light gray (*N*8) to medium gray (*N*5). The Schoharie contains numerous brachiopod fragments and hexactinellid sponge spicules (fig. 13). Most of the spicules are multirayed and contain axial canals (identification by J. Keith Rigby, Jr., Brigham Young University, written commun. to W. A. Oliver, Jr., U.S. Geological Survey, January 1981). The horizontal trace fossil *Taonurus* is abundant, especially in the lower part. Scattered quartz grains, 0.1 to 0.4 inches (3–10 mm) in diameter, are found in some beds. Fresher rocks are not calcareous but are siliceous and have not been leached as have adjacent rocks that presumably contains appreciable calcium carbonate. The Schoharie appears to be more siliceous and blocky to the southwest (see fig. 84 of Sevon, *in* Epstein and others, 1974), but this trend is masked by the extensive weathering of the rocks throughout the area. The Schoharie also contains some shaly siltstone in beds 1 to 6 inches (3–15 cm) thick, which are similar to beds in the underlying Esopus. Dark-yellowish-brown (10*YR* 5/2) ironstone concretions, which are as much as 5 inches (13 cm) in diameter, are abundant at the top of the Schoharie near Saylorsburg. An 8-inch- (20-cm-) thick grayish-red (5*R* 4/2) siltstone bed lies 21 feet (6 m) above the base of the Schoharie along the Pennsylvania Turnpike.

Swartz's Bowmanstown chert was named for beds southwest of Godfrey Ridge that were later equated with the Esopus and Schoharie in Godfrey Ridge by Epstein and Epstein (1967). The units in both areas are dissimilar mainly because of the more extensive and deep weathering southwest of the Wisconsinan terminal moraine. However, similar lithic types and sedimentary features may be traced between the two areas. Moreover, there are a few localities on Godfrey Ridge where

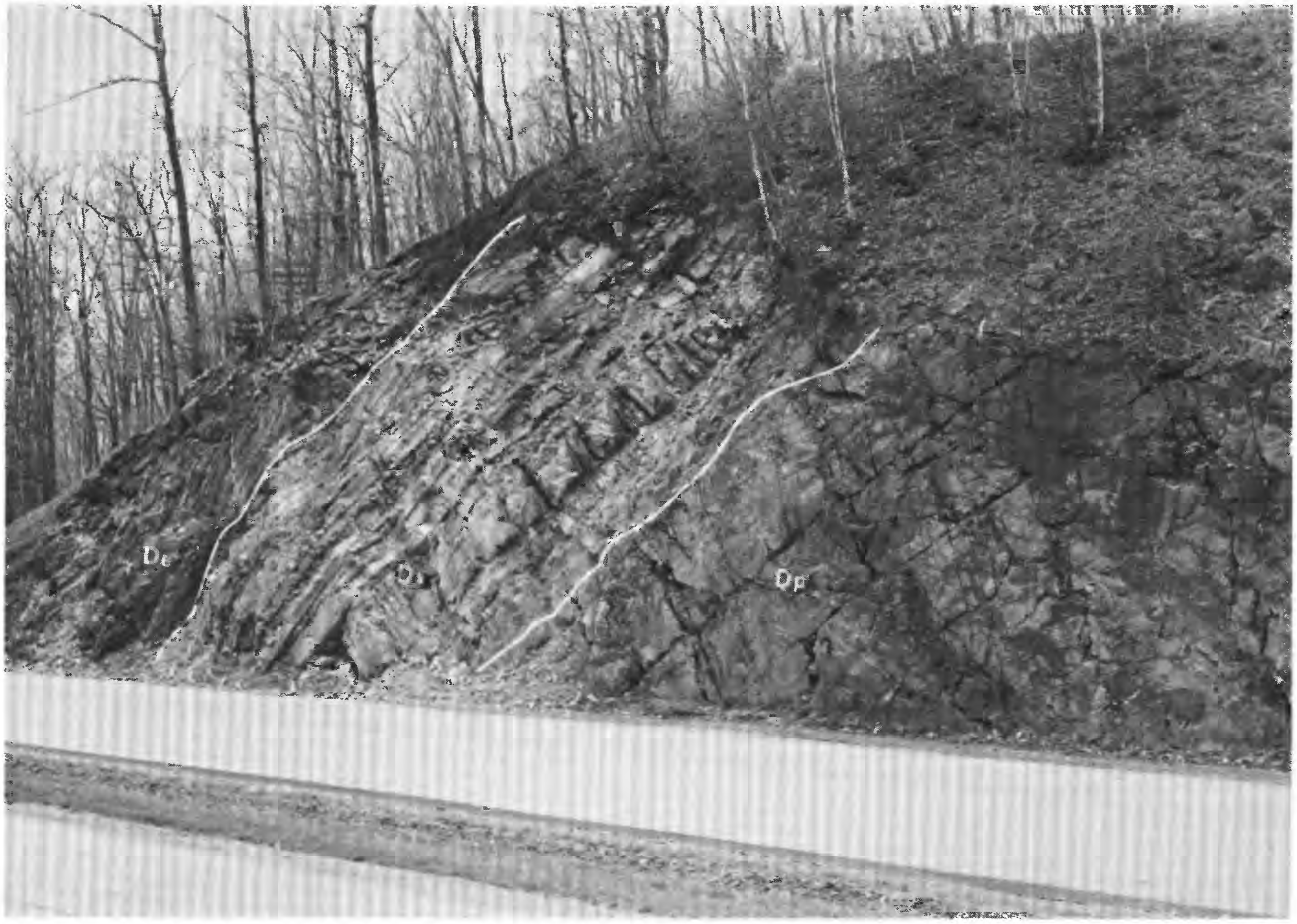

Figure 12.—Roadcut along Pa. State Route 33 at Saylorsburg (fig. 1, loc 6; measured section 4) showing dark thin-bedded siltstone of the Schoharie Formation (Ds), which overlies the massive Palmerton Sandstone (Dp). The contact between the Esopus (De) and Schoharie is abrupt but appears uneven due to irregularities in the exposure. The Schoharie-Palmerton contact is unconformable with a relief of about 2.7 feet (0.8 m). The beds dip about 50° to the southeast and are overturned.

the Esopus and the Schoharie are weathered deeply and resemble the equivalent rocks to the southwest. For example, on the road crossing Godfrey Ridge 1.2 miles (1.9 km) northeast of Bossardsville, the Esopus is weathered to light shades of gray and is varicolored. Also, chert float from the nearby Schoharie Formation has white weathering rinds similar to weathered chert in ridges southwest of the Wisconsinan terminal moraine.

Thin sections show that lath-shaped sponge spicules made of microcrystalline quartz, as much as 0.3 mm long, are fairly common in the Schoharie (fig. 13). Angular quartz and chert grains make up most of the rocks examined. Muscovite and lesser chlorite grains as much as 0.2 mm long comprise 20 percent of some rocks. Limonite and hematite are common products of weathering. Rare collophane fragments and idiomorphic tourmaline and zircon make up the heavy mineral fraction. Sevon (*in* Epstein and others, 1974) also noted epidote and garnet. A few shale fragments were seen. All of the brachiopod fragments are replaced by silica, and chert has replaced much of the quartz. This silicification gives many outcrops their blocky resistant character.

In addition to the good exposures mentioned above, there are only a few other scattered outcrops of the Schoharie and Esopus. These are generally near the crest or on the steep south slopes of the ridges, in the clay and sand pits south and east of Kunkletown, and in the sand pits near Palmerton and Germans. Elsewhere, these rocks were mapped by tracing siltstone and shale float between the sandstone of the Ridgeley and Palmerton (see Epstein and others, 1974; Epstein, 1978; and Epstein and Sevon, 1978).

PALMERTON SANDSTONE

The Palmerton Sandstone was named by Swartz and Swartz (1941) after it was first determined (Swartz and

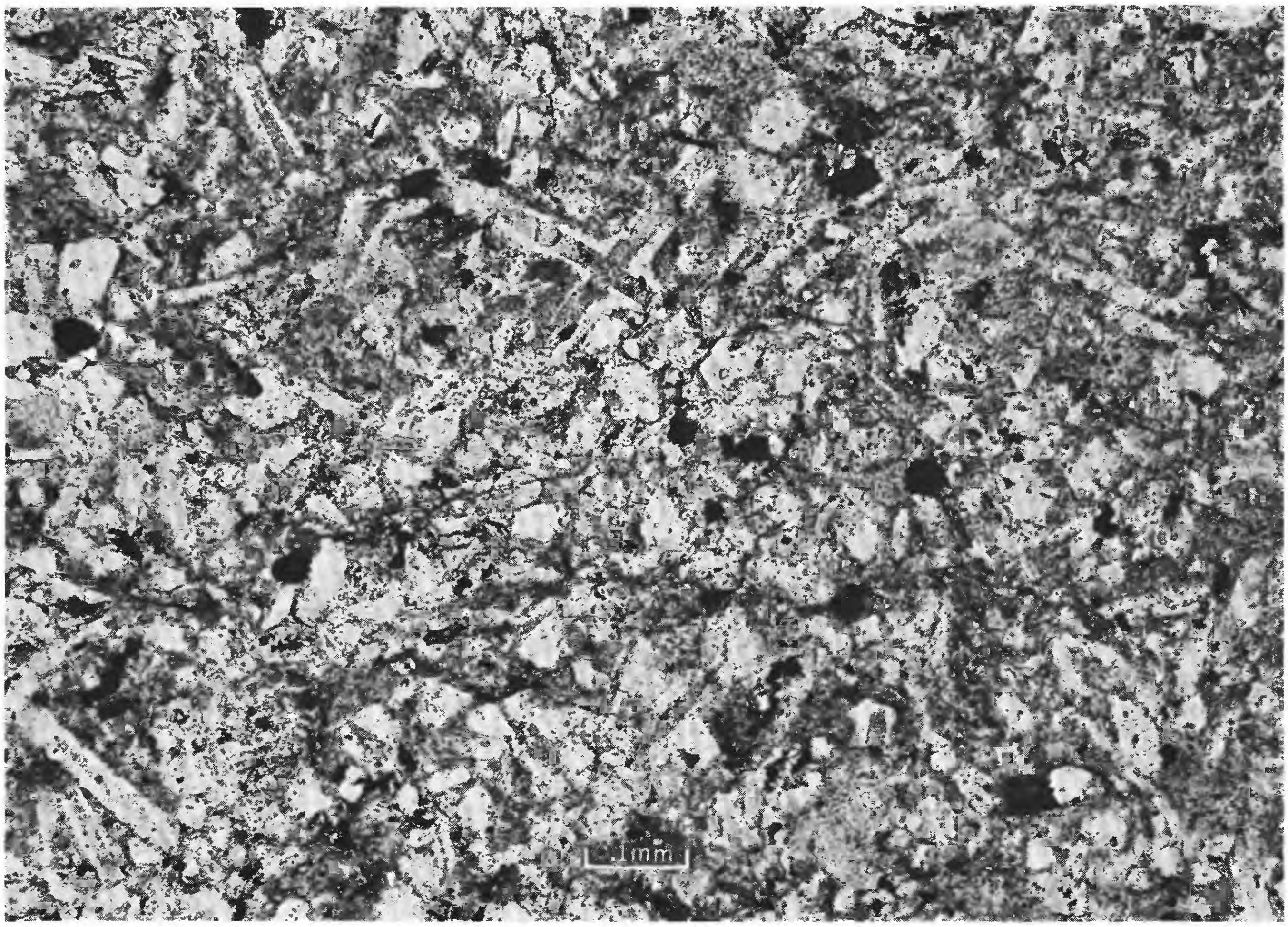

FIGURE 13.—Photomicrograph (plane-polarized light) of spicularite or very fine grained sandstone made up predominantly of angular quartz and chert grains and abundant hexactinellid sponge spicules of monocrystaline quartz. From a small quarry in massive Schoharie Formation (beds are as much as 4 feet (1.2 m) thick), in Stony Ridge just west of Mill Creek in Aquashicola, Palmerton quadrangle.

Swartz, 1938; Swartz *in* Willard and others, 1939) to be a unit that is separable from underlying sandstones of the Oriskany Group, with which it was previously confused. The name was derived from exposures near Palmerton, but a type section was not designated. The best exposure, one that could serve as a reference section, is along the Pennsylvania Turnpike through Stone Ridge (fig. 1, loc. 10; measured section 5). A more detailed measured section is given by Sevon (*in* Epstein and others, 1974). The Palmerton Sandstone is thickest in Stony Ridge (fig. 1) and thins in both directions along strike (fig. 3). It is 108 feet (33 m) thick along the Pennsylvania Turnpike, although slightly greater thicknesses were reported by several workers, including 120 feet (37 m) by Cleaves and Willard (*in* Willard and others, 1939), 126 feet (38 m) by Swartz and Swartz (1941), and 125 feet (39 m) by Dyson (1956). It thickens to 140 feet (43 m) in a mine tunnel at Hazard, according to Swartz and Swartz (1941). Northeastward, it thins to 66 feet (20 m) along Pa. State Route 33 at Saylorsburg and to about 40 feet (12 m), 1.6 miles (2.6 km) northeast of Pa. State Route 33. The Palmerton thins to a feather edge along the northeast end of Cherry Ridge and is absent in Godfrey Ridge.

The Palmerton Sandstone is fairly uniform in its petrographic characteristics throughout its area of outcrop. It is generally a medium-dark-gray (*N*4) to very light gray (*N*8), medium- to very coarse grained sandstone and conglomeratic sandstone with rounded quartz pebbles as much as 0.75 inch (19 mm) long. A few fine- to very fine grained sandstone and siltstone beds are in the basal few feet. These rocks weather pale yellowish orange (10*YR* 8/6) to dark yellowish orange (10*YR* 6/6) and very pale orange (10*YR* 8/2) to grayish orange (10*YR* 7/4). Bedding is generally poorly developed and massive. Beds range up to 8 feet (24 m) thick at Saylorsburg and to more than 20 feet (6.1 m) thick along the Pennsylvania Turnpike; however, some parts of the Palmerton are thin bedded and partly laminated.

The Palmerton is quartz rich. The sand grains are well rounded to subangular. Silica cement in places creates a dense vitreous quartzite, and limonite is a common but minor cement. Cementation is variable in outcrops so that the Palmerton forms resistant ledges in places, whereas elsewhere it deteriorates into a loose sand.

The basal few feet are generally iron stained and locally contain moderate-brown (5*YR* 4/4) ironstone concretions 1 to 2 inches (3–5 cm) in diameter. The contact with the underlying Schoharie Formation is sharp, and at Saylorsburg it is irregular and disconformable, with a relief of about 2.7 feet (0.8 m). The contact generally is placed at the base of the lowest sandstone above the siltstones of the Schoharie, whereas at Saylorsburg, predominant siltstone and lesser sandstone in the lower 2.8 feet (0.9 m) are placed in the upper part of the Schoharie.

The Palmerton is the best and most continuously exposed stratigraphic unit in Cherry, Chestnut, Stony, and Stone Ridges. It underlies the crests of these ridges in most places and also is well exposed in several sand quarries between Germans and the area east of Kunkletown (fig. 14). Sevon (1970) discussed the geology and economics of this sand resource. The Palmerton generally crops out as a rib several tens of feet high. In many places, it is characterized by bare loose blocks that are so jumbled by frost heaving that obtaining structural attitudes is difficult or impossible. It is everywhere prominently jointed, and, locally, weathering has produced spheriodal masses (fig. 14).

As seen in thin section, quartz makes up more than 95 percent of all rocks examined. The quartz occurs mainly as single grains with slightly to strongly undulose extinction due to postdepositional deformation. Many grains are composite vein quartz with comb structure and abundant vacuoles. Vermicular chlorite is found in a few. Recrystallized composite grains (probably from a quartzite source) and chert are minor components. Many of the grains have original rounded to subrounded outlines, but most are angular due to interpenetration of the contacts (fig. 15). Interstitial quartz forms a cement, commonly in optical continuity with the enclosing grains. Limonite cement is minor, and no

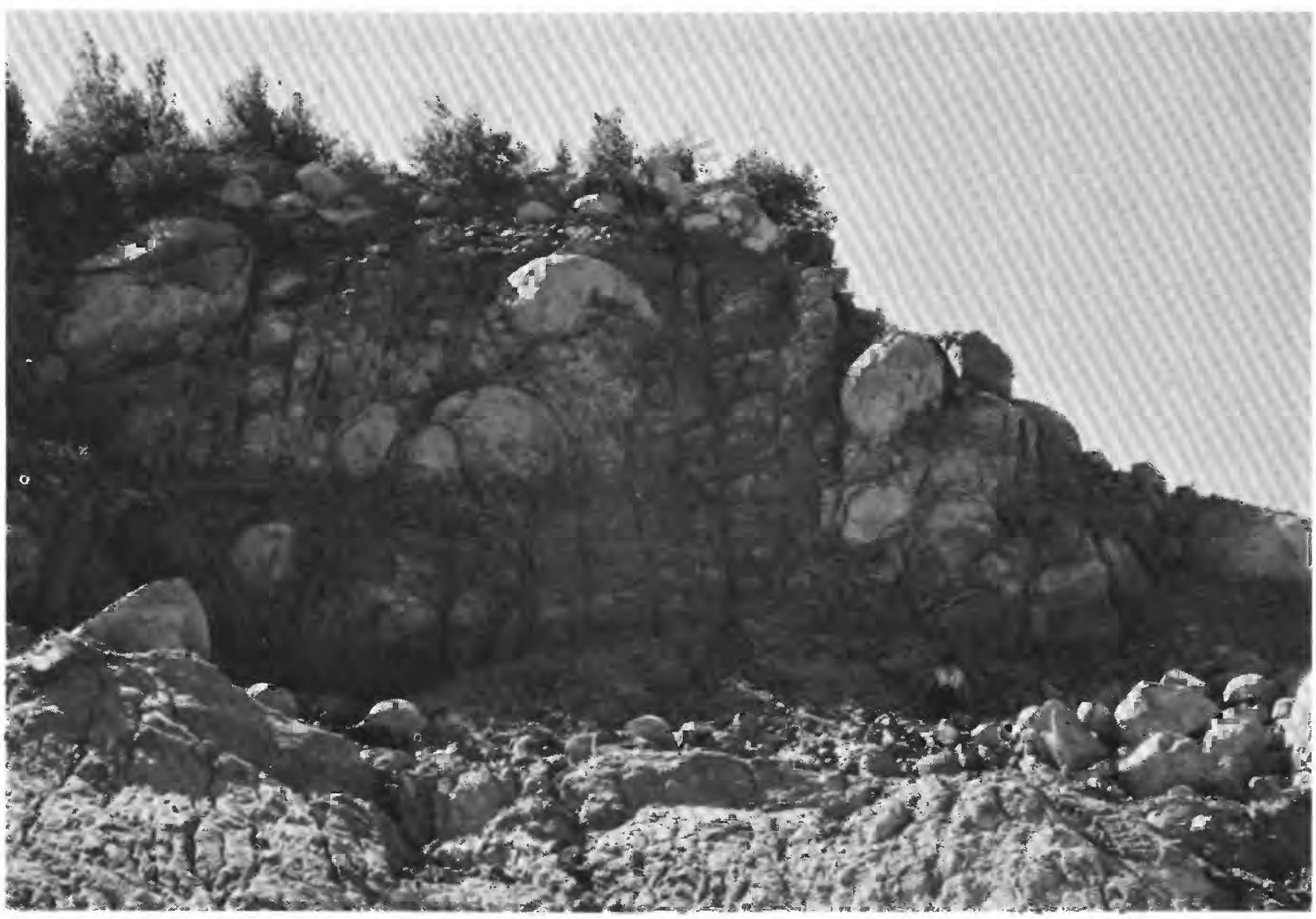

FIGURE 14.—Spheroidal weathering in massive Palmerton Sandstone in pits of the Universal Atlas Cement Co., 3.5 miles (5.6 km) east of Kunkletown (fig. 1, loc. 7). Prominent vertical and more poorly defined horizontal joints control the shape of the large weathered spheroids.

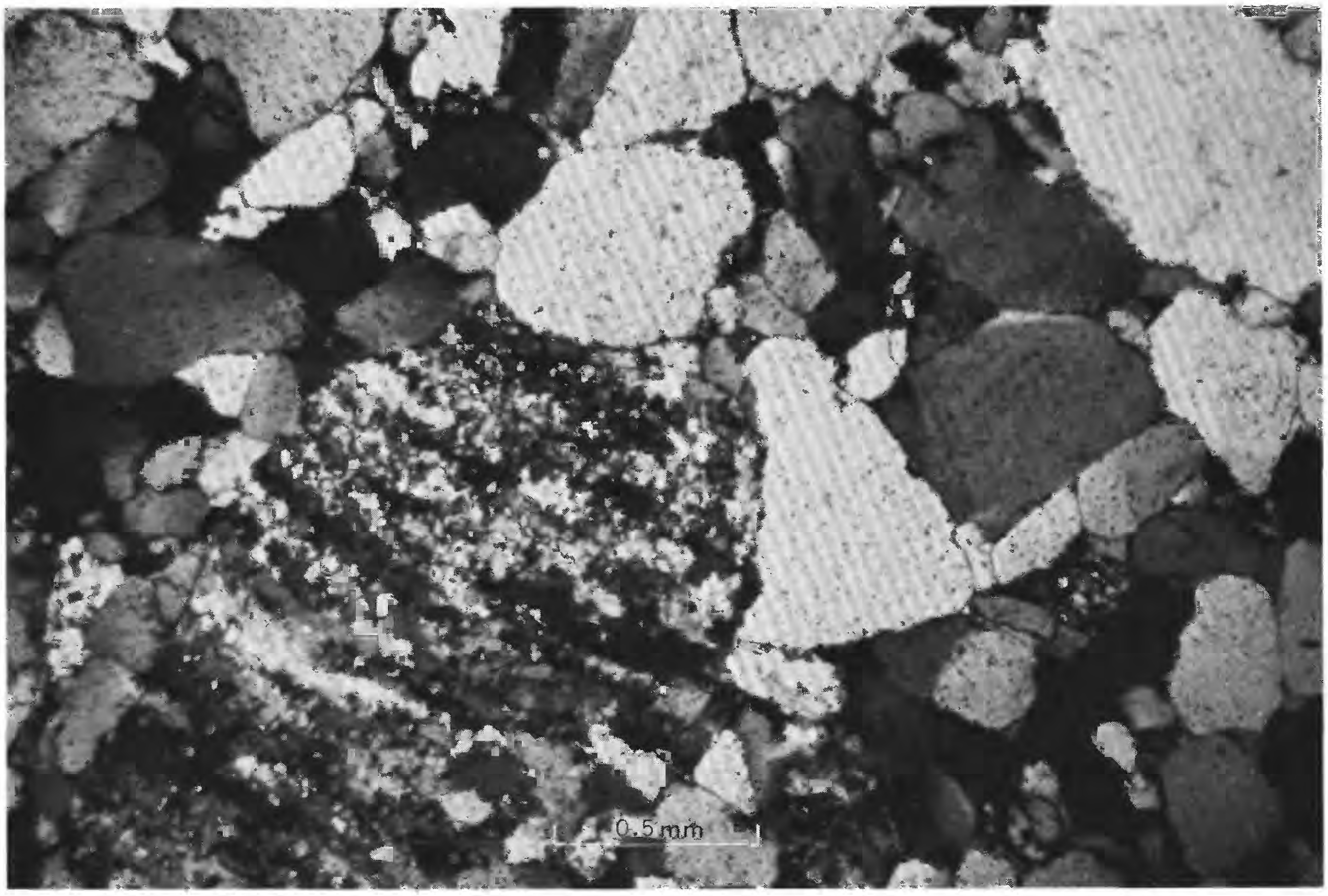

FIGURE 15.—Photomicrograph (crossed polarizers) of poorly sorted very coarse grained conglomeratic orthoquartzite in the Palmerton Sandstone, roadcut along Pa. State Route 33 near Saylorsburg (fig. 1, loc. 6). Rounded to subangular grains are mostly single-grained quartz. The large composite vein-quartz grain is more than 3 mm (0.1 in.) long. Many of the grain boundaries are indented, but quartz overgrowths cement some grains. Quartz makes up more than 99 percent of the rock.

samples studied contain more than 4 percent. Rare heavy minerals include zircon, hornblende, and pyrite.

In the past the Palmerton sandstone has been confused with the Ridgeley Sandstone of the Oriskany Group. It differs from the Ridgeley by being more poorly bedded, and it lacks the abundant spiriferid molds that are so characteristic of the Ridgeley. The Palmerton, however, does contain rare favositid coral and crinoid columnals molds as much as 4 inches (10 cm) long and rarer brachiopod molds. Sevon (1970, and *in* Epstein and others, 1974) also noted that the Palmerton has a unimodal grain-size distribution and is generally well sorted (although some samples are poorly sorted as shown in fig. 15), whereas the Oriskany is mostly bimodal, with modes of coarse sand and pebble-sized grains. The Palmerton is readily separated from the Oriskany where the intervening Esopus and Schoharie are exposed or distinguishable by float.

The latest correlations (Oliver and others, 1967, 1969) place the Palmerton at the top of the Lower Devonian, with the overlying Buttermilk Falls Limestone in the Middle Devonian. However, the Palmerton does not contain diagnostic fossils, and, as discussed below and as shown in figure 3, the upper part of the Palmerton probably grades laterally into the lowermost part of the Buttermilk Falls. Thus, the Palmerton probably spans the Lower-Middle Devonian boundary.

The Palmerton is everywhere sandwiched between the Buttermilk Falls Limestone above and Schoharie Formation below. In Godfrey Ridge, where the Palmerton is absent, the Buttermilk Falls immediately overlies the Schoharie. The only evidence in Godfrey Ridge that may herald the lateral presence of the Palmerton to the southwest is the occurrence of isolated coarse quartz grains in the lowermost beds of the Foxtown Member of the Buttermilk Falls. These quartz grains disappear along strike to the northeast. Crinoid columnals are common in the lower half of the Foxtown Member and become scarcer to the southwest along Godfrey Ridge as the outcrop area of the Palmerton is approached. The

Palmerton contains scarce comminuted crinoid columnals that, together with the presence of quartz grains in the Foxtown, suggest that the upper part of the Palmerton and basal part of the Buttermilk Falls are laterally continuous.

At Saylorsburg, basal Palmerton beds unconformably cut into the Schoharie, and the uppermost part of the Schoharie contains interbedded sandstone of Palmerton type. This vertical relation suggests lateral equivalence of the basal Palmerton and uppermost Schoharie.

Along the Pennsylvania Turnpike (loc. 11), the basal 5 feet (1.5 m) of the overlying Buttermilk Falls Limestone contains conodonts of early Middle Devonian age. These rocks underlie the Tioga Ash Bed and correlate with the upper half of the Moorehouse Member of the Onondaga Limestone of New York. Thus, the Palmerton in the western area of this report may range from Schoharie, through Edgecliff and Nedrow, to Moorehouse in age. In the eastern end of Cherry Ridge, the Palmerton is thinner and may have a much narrower age range, since it replaces upper Schoharie and lower Foxtown rocks. If the lower part of the Foxtown Member of the Buttermilk Falls is continuous with the Edgecliff Member of the Onondaga Limestone of New York, on the basis of the lateral continuity of the distinctive crinoid-bearing beds (Oliver, 1962), then the Palmerton may range from Schoharie to Edgecliff in age in the eastern part of the report area.

The area where the Palmerton disappears and is replaced by other Onesquethawan rocks is about 1 mile (1.6 km) southwest of Bossardsville. As mentioned, the Palmerton is about 40 feet (12 m) thick in Cherry Ridge, 1.6 miles (2.6 km) northeast of the roadcut along Pa. State Route 33 in Saylorsburg. It crops out for an additional 0.9 mile (1.4 km) to the northeast along the ridge crest, to a point that is 0.9 mile (1.4 km) S. 10° W. from Bossardsville. There the Palmerton apparently is folded to the northwest for about 1 mile (1.6 km), as indicated by a topographic high in that direction, but this area is covered by thick glacial drift. In the next exposure of Onesquethawan rocks, 0.3 mile (0.5 km) to the north, the Palmerton is missing, and the Buttermilk Falls is in contact with the Schoharie. The possibility that the Palmerton-bearing sequence in Cherry Ridge has been telescoped structurally onto the Palmerton-absent sequence in Godfrey Ridge is discounted because there is no evidence for faulting along strike in the Bossardsville area. Abundant exposures are in many quarries of the Bossardsville Limestone of Silurian age, demonstrating that a major dislocation does not exist (see Epstein, 1980, fig. 8). Thus, the lateral change from the Palmerton Sandstone in Cherry Ridge to equivalent rocks in Godfrey Ridge occurs within a distance of 1 mile (1.6 km) in an area of no exposures.

BUTTERMILK FALLS LIMESTONE

The three members of the Buttermilk Falls Limestone that are mappable in Godfrey Ridge cannot be distinguished to the southwest because of poor exposure and extensive leaching of the original cherty limestone and calcareous shale. This leaching has produced deep residual clay (sedimentary rock saprolite) because of pre-Wisconsinan weathering (Epstein and Hosterman, 1969). The clay is found only southwest of the Wisconsinan terminal moraine (fig. 1). Presumably, the clay extended farther to the northeast but was stripped by the advancing Wisconsinan glacier, exposing the fresh bedrock that is now present in Godfrey Ridge.

The Buttermilk Falls is 263 feet (80 m) thick at Saylorsburg (measured section 4; fig. 1, loc. 6), similar to the thickness at the southwest end of Godfrey Ridge (fig. 3). It thins rapidly to 63 feet (19 m) at the pits of the Universal Atlas Cement Co., east of Kunkletown (fig. 1, loc. 7), and to 40 feet (12 m) along the Pennsylvania Turnpike (measured section 5; fig. 1, loc. 10). At the latter locality, previous workers reported 27 to 29 feet (8.2–8.8 m) (Chance, 1882; White, 1882; and Willard, *in* Willard and others, 1939), whereas Willard (1957) reported slightly more than 50 feet (15 m).

At most exposures, the Buttermilk Falls is a deeply weathered silty and shaly clay with rare fine-grained sand and minor clayey, shaly siltstone. Much of the clay is iron stained with limonite and hematite. Nodular and irregularly bedded chert is common. The nodules are as much as 3 inches (8 cm) in diameter, and some pods are up to 1 foot (30 cm) long. The chert beds are as much as 3 inches (8 cm) thick. The chert weathers to mottled very dusky red (5*R* 2/6) and very light gray (*N*8) to medium gray (*N*5). Fresher chert is dark gray (*N*3) to grayish black (*N*2).

The clays of the Buttermilk Falls Limestone weather light gray (*N*7) to white (*N*9), yellowish gray (5*Y* 8/1) to grayish yellow (5*Y* 8/4), and many shades of orange, red, and purple, including very pale orange (10*YR* 8/2) to moderate yellowish brown (10*YR* 5/4), pale yellowish orange (10*YR* 8/6) to dark yellowish orange (10*YR* 5/6), pale brown (5*YR* 5/2), pale red (10*R* 6/2) to pale red purple (5*RP* 6/2), and moderate orange pink (10*R* 7/4) to moderate reddish brown (10*R* 4/6). Less weathered rocks are medium gray (*N*5) to medium dark gray (*N*4).

The Buttermilk Falls southwest of Godfrey Ridge is fossiliferous, containing brachiopods, crinoid columnals, ostracodes, bryozoans, trilobites, conodonts, and corals.

About 25 feet (8 m) of fresh Buttermilk Falls Limestone is exposed in a 40-foot- (12-m-) long overgrown pit cut into the side of Stony Ridge behind a red garage, about 1,000 feet (305 m) southwest of the road intersection in Little Gap and on the west side of Buchwha

Creek (fig. 1, loc. 8). The rocks here consist of flaggy to thin-bedded (beds 1 inch to 2 feet (2.5 m–0.6 m) thick) and unevenly bedded, medium-light-gray (*N*6) to medium-dark-gray (*N*4), fine-grained limestone with nodules of grayish-black (*N*2) chert several inches long. Brachiopods are common. A channel sample of about 9 pounds (4 kg) of rock was digested in dilute acetic acid, but no conodonts or ostracodes were found; only minor silicified brachiopod fragments were recovered.

At the pits of the Universal Atlas Cement Co., east of Kunkletown (fig. 1, loc. 7), the varicolored clay becomes white (*N*9) at depth. In these pits, the saprolite is deeper than 180 feet (55 m) in places. X-ray diffraction studies show that leaching of the Buttermilk Falls Limestone has removed calcite and chlorite from the fresh rock and altered 2M muscovite to Md polymorph (Epstein and Hosterman, 1969). A few thin bands of moderate-red (5*R* 4/6) to dusky-red (5*R* 3/4) hematitic shale about 2 inches (5 cm) thick are found in the clay near the top.

At Saylorsburg, the contact with the underlying Palmerton Sandstone is covered, but it is probably sharp, as it is in the pits of the Universal Atlas Cement Co., east of Kunkletown, and along the Pennsylvania Turnpike. Both the Buttermilk Falls and the overlying Marcellus are deeply weathered at Saylorsburg, and the upper contact is placed at the top of the bed containing the last chert going upsection (measured section 4). At the pits near Kunkletown, the Buttermilk Falls clays are in sharp contact with at least 5 feet (1.5 m) of grayish-black (*N*2) carbonaceous fissile shale of the overlying Union Springs Shale Member of the Marcellus Shale (Epstein and Hosterman, 1969, fig. 6). A similar sharp contact is exposed along the Pennsylvania Turnpike where the basal 1.5 feet (0.5 m) of dark-gray (*N*3) to medium-dark-gray (*N*4) shale of the Marcellus contains abundant coarse mica and pyrite grains of its Tioga Ash Bed (see Sevon, *in* Epstein and others, 1974, p. 132), marking the top of the Onesquethawan Stage (Dennison and Textoris, 1966). Three to five beds within the Buttermilk Falls contain similar mica flakes. These may be volcanic ash similar to the Tioga. These pale-yellowish-orange (10*YR* 8/6) to grayish-orange (10*YR* 7/4) shale beds are 1 inch (2.5 cm) to 1.1 feet (34 cm) thick and lie 16 to 28 feet (5–8.5 m) above the base of the Buttermilk Falls along the Turnpike exposure.

In the clay pits near Kunkletown, no ash bed was seen in the 10-foot (3-m) interval straddling the Marcellus-Buttermilk Falls contact. The rocks at the contact are replete with slickensides, so it is probable that the Tioga here is absent due to faulting.

About 5 feet (1.5 m) above the base of the Buttermilk Falls in the Turnpike roadcut are two beds of brownish-gray (5*YR* 4/1) to dusky-red (5*R* 3/2) siderite separated by a dark-gray (*N*3) hematitic siltstone. This is the Hazard paint ore that has been described by many workers, including Agthe and Dyan (1910), who traced it from Little Gap to Germans, a distance of more than 12 miles (19 km). The Hazard "ironstone" is 1.6 feet (0.5 m) thick along the Pennsylvania Turnpike (measured section 5), a figure in agreement with all previous workers, except Willard (1967) who reported 6 to 7 feet (2 m). It was reportedly 3.7 feet (1.1 m) thick in the abandoned mine at Hazard (Hill, 1887), but Miller (1911, p. 57) was unable to verify this figure. Sevon (1970, *in* Epstein and others, 1974) believed that the distribution of the Hazard could be determined by the extent of iron staining in the underlying Palmerton Sandstone. The iron was leached from the Hazard and precipitated in the Palmerton. However, hematite staining is also common beyond the limits of the Hazard, such as at Saylorsburg. The iron probably was leached from the overlying Buttermilk Falls at this locality.

The Hazard contains abundant brachiopods, trilobites, crinoids, and bryozoa and less common corals, ostracodes, and mollusks (Willard and Whitcomb, 1938).

Below the Hazard paint ore along the east side of the Pennsylvania Turnpike, is about 5 feet (1.5 m) of weathered light-gray (*N*7) to medium-dark-gray (*N*4), grayish-orange (10*YR* 7/4) to moderate-yellowish-brown (10*YR* 5/4) clay, shale, and minor siltstone containing scattered coarse and medium sand grains similar to the sand grains in the basal part of the Foxtown Member of the Buttermilk Falls Limestone at the southwest end of the Godfrey Ridge. Lithologic details of this unit and the others in the Buttermilk Falls are given by Sevon (*in* Epstein and others, 1974, p. 403–405).

On the west side of the turnpike at road level, there are several fresh limestone beds below the Hazard that contain the following conodonts (identified by A. G. Epstein, U.S. Geological Survey): (1) *Icriodus* cf. *I. struvei* Weddige, (2) *I.* sp. indet., (3) *Polygnathus angusticostatus* Wittekindt, and (4) *P. angusticostatus* trans. to *P. robusticostatus* Bischoff and Ziegler. Because these rocks lie below the Tioga Ash Bed, the age can be narrowed to the *Polygnathus costatus costatus* zone (early Middle Devonian), and the rocks correlated with the upper half of the Moorehouse Member of the Onondaga Limestone of New York.

There are no natural outcrops of the Buttermilk Falls Limestone southwest of the Wisconsinan terminal moraine. It is exposed only in several clay and sand pits and highway cuts. In the Saylorsburg area, the position of the Buttermilk Falls is marked by many collapsed drifts that were sites for underground access to the clays (Peck, 1922). Elsewhere, it generally lies on the northern slopes of the ridges buried by debris shed from units higher up, generally from the Palmerton Sandstone.

REGIONAL CORRELATIONS

Rocks of Onesquethawan age extend northeast through New Jersey into southeastern New York with the same general lithologic characteristics as those in Godfrey Ridge (for example, Herpers, 1950b; Johnson and Southard, 1962; Oliver, 1962, Rickard, 1964; and Oliver and others, 1967). However, stratigraphic details have not been determined, and the three members of the Buttermilk Falls Limestone have not been mapped beyond Buttermilk Falls, Pa. Oliver (1962) and Inners (1975) recognized that the crinoid columnals in the lower half of the Foxtown Member are similar and probably are part of a zone continuous with those in the basal part of the Edgecliff Member of the Onondaga Limestone of New York.

Equivalents of the Palmerton Sandstone are not found in the main outcrop belt between Godfrey Ridge and Port Jervis, N.Y. However, a similar sandstone is found in the Green Pond Mountain area of northern New Jersey and southeastern New York, about 40 miles (64 km) northeast of Buttermilk Falls and about 22 miles (35 km) southeast of the main outcrop belt. It was named the Kanouse Sandstone by Spencer and others (1908), who believed that it is a shoreward equivalent of the Onondaga Limestone in the main outcrop belt, a fact corroborated by Kindle and Eidman (1955), although Willard (1937) thought that it correlated with the Esopus of the Delaware Valley. In central New York, much thinner sandstone is found at the base of the Edgecliff Member of the Onondaga Limestone (Oliver, 1954).

The Palmerton Sandstone does not appear to extend very far northward in the subsurface from its type area. The Phillips Petroleum No. 1 Graver Estate well was drilled 3.5 miles (5.6 km) north of Palmerton in an apparently faulted sequence of rock. It did not penetrate any rocks that could be interpreted to be the Palmerton Sandstone (Epstein and others, 1974, p. 459). The absence of the Palmerton is similar to the rapid disappearance of the sandstone between the northeast end of Cherry Ridge and Godfrey Ridge near Saylorsburg. The Palmerton, therefore, may be interpreted as a linear sand body that was probably never more than a few miles wide.

Stratigraphic relations of Upper Silurian through lower Middle Devonian rocks southwest of the Lehighton quadrangle are not well known because of very poor exposures, limited paleontologic data, and abrupt lithic changes. The entire sequence becomes thinner and more clastic as an ancient low-lying positive area is approached about 35 miles (56 km) southwest of the Lehighton quadrangle (Epstein and others, 1974, p. 111). The area was named the "Harrisburg axis" by Ulrich (1911) and Willard (1941) and termed the "Auburn Promontory" by Swartz (*in* Willard and others, 1939). Wood and others (1969) delineated this area of stratigraphic thinning in several isopach maps. Rocks of Onesquethawan age thin to about 100 feet (30 m) at Andreas, Pa., 7 miles (11 km) southwest of the Lehigh River, and are absent about 46 miles (74 km) farther southwest (Berg and others, 1980).

The continuation and identity of Onesquethawan rocks southwest of the Lehigh River is uncertain. For example, along the Pennsylvania Turnpike, Willard (*in* Willard and others, 1939) subdivided the rocks above the Hazard paint ore and below the Marcellus into the Buttermilk Falls Limestone and the underlying Selinsgrove Limestone. The Buttermilk Falls disappears westward with the loss of chert and was included in the Selinsgrove of central Pennsylvania. Willard equated the Hazard and the underlying Esopus (Schoharie-Esopus of this report) with the Needmore Shale of central Pennsylvania. Willard (1957) later placed all the rocks above the Hazard along the Turnpike in the Selinsgrove Limestone (see fig. 2). Sevon (*in* Epstein and others, 1974) believed that the 5 feet (1.5 m) of shaly beds below the Hazard may correspond to the Needmore Shale of the Susquehanna River area. Thus, correlation of Onesquethawan rocks west of the area of this report has been quite speculative.

There are only two good exposures of these rocks between the Lehigh and Schuylkill Rivers. One is in an active quarry 0.5 mile (0.8 km) southeast of Andreas, Pa., 2.3 miles (3.7 km) southwest of the southwest corner of the Lehighton quadrangle. The other is 20 miles (32 km) southwest of Andreas in an abandoned quarry about 1 mile (1.6 km) northeast of Schuylkill Haven, Pa.

At Andreas, weathered limestone, called Onondaga by Swartz and Swartz (1941) and by Sevon (1968), and the Palmerton Sandstone are exposed. Near the bottom of the quarry, the Bossardville Limestone, which is about 70 feet (21 m) thick, underlies about 60 feet (18 m) of argillaceous and sandy limestone and calcareous shale and sandstone of the Decker Formation. Both of these units are Late Silurian in age (Swartz and Swartz, 1941; Epstein and Epstein, 1967, 1969). These are overlain by 86 feet (26 m) of red shale (termed the Andreas red beds by Swartz and Swartz (1941) and tentatively assigned a Keyser (Decker) age) and sandstone. These red beds are interbedded with light-gray (*N*7) crossbedded sandstone that weathers grayish orange (10*YR* 7/4). The age of the red beds and gray sandstones remains speculative. They may be Decker equivalents (uppermost Silurian) or facies of the Stormville Member of the Coeymans Formation (Lower Devonian, on the basis of inferred stratigraphic position as determined by mapping (Epstein and Epstein, 1967, p. 16, 17; Epstein and others, 1974, p. 84–87). Sevon (1968, p. 191) believed that the Oriskany is represented by nonred sandstones interbedded with the red beds that he called New Scotland. These uncertainties as to the age of these sandstones have an important bearing on identifications at Schuylkill Haven.

About 1 mile (1.6 km) southwest of Andreas, Swartz and Swartz (1941, p. 1145) and Sevon (1968) reported that the Oriskany is missing, on the basis of interpretation of float. The only difference is that Sevon (1968, and oral commun., 1981) noted that 27 feet (8 m) of Esopus and Schoharie intervened between cherts of the New Scotland Formation and the Palmerton Sandstone and Swartz and Swartz (1941) did not recognize any Esopus and Schoharie (their Bowmanstown Chert).

At Schuylkill Haven, the section consists of 44 feet (13 m) of nodular limestone and calcareous shale, siltstone, and sandstone, referred to as the Keyser Limestone by Swartz and Swartz (1941, p. 1134) and equivalent to the Decker Formation to the northeast. Most of these beds contain typical Late Silurian fossils. At the top of this sequence are about 13 feet (4 m) of interbedded, laminated to slabby (beds up to about 10 inches (25 cm) thick), pale-olive (10*Y* 6/2) to light-olive-gray (5*Y* 6/1) and greenish-gray (5*GY* 6/1) fissile shale and shaly siltstone and quartzose blocky medium-light-gray (*N*6) and light-olive-gray (5*Y* 6/1) very fine grained sandstone. No fossils were seen in these upper beds. Sevon (1968) tentatively assigned the lower rocks to the Schoharie and Esopus Formations and the upper 13 feet (4 m) to the New Scotland Formation, but this assignment is doubtful. The uppermost sandstones and shales may correlate with the Stormville Member of the Coeymans or the Decker Formation.

Next in succession at Schuykill Haven is a 4- to 5-foot- (1.2- to 1.5-m-) thick bed of quartz-pebble conglomerate with pebbles 0.25 inch to 1 inch (0.6–2.5 cm) long. This bed lies abruptly on the green and gray beds, possibly unconformably or in fault contact. No fossils were seen. Cleaves (*in* Willard and others, 1939, p. 129), however, reported an Oriskany fauna from an outcrop on the east side of the quarry, presently not exposed, and in loose blocks. He believed that the Palmerton Sandstone is absent in the quarry, as did Willard (*in* Willard and others, 1939, p. 153). Swartz and Swartz (1941, p. 1134) also identified these rocks as the Oriskany Sandstone. Sevon (1968), on the other hand, identified the sandstone as the Palmerton, on the basis of textural comparisons of the Palmerton with the Oriskany. Wood (1973) mapped a conglomeratic sandstone in the bottom of the Selinsgrove Limestone, suggesting that it is the Palmerton Sandstone.

Thus, the identification of this sandstone bed at Schuylkill Haven is open to considerable question. Unless the Oriskany fauna can be confirmed, this bed could be Palmerton, Oriskany, or even Stormville. An added complication is that Cleaves (*in* Willard and others, 1939) thought that the Oriskany is more than 40 feet (12 m) thick here. Faulting in the area, cutting out the Oriskany in the quarry, is quite possible.

The conglomeratic sandstone is overlain next by noncherty medium-gray (*N*5) and medium-dark-gray (*N*4) fossiliferous shale and limestone. This was named the Needmore Shale by Cleaves (*in* Willard and others, 1939, p. 129), the Selinsgrove Limestone by Willard (*in* Willard and others, 1939, p. 153) and Wood (1973), and the Onondaga Limestone or Formation by Swartz and Swartz (1941), Sevon (1968), and Inners (1975).

The discussion above demonstrates the need for further study of stratigraphic details between the Lehigh River and the well-known Onesquethawan interval in central Pennsylvania in the Susquehanna River area.

ENVIRONMENTS OF DEPOSITION

The abrupt contact between the Esopus Formation at the base of Onesquethawan rocks and the underlying Ridgeley Sandstone of the Oriskany Group is believed to be an unconformity (Willard, *in* Willard and others, 1939, p. 154; Epstein and Epstein, 1967, p. 18), reflecting a period of regional emergence. The locus of subsequent Onesquethawan deposition was in northeasternmost Pennsylvania and southeastern New York, where more than 800 feet (240 m) of sediments was deposited. Nearly pure carbonate rocks are in the north, and they become more clastic southwards (Oliver and others, 1967, p. 1012–1013). In the area of this report, the units thin and become more clastic to the southwest along strike (fig. 3).

Onesquethawan rocks are believed to represent a deep- to shallow-neritic regressive sequence that followed shallow marine (beach or bar) deposition of the underlying Ridgeley Sandstone. The Esopus Formation is interpreted to be a deep neritic deposit because it is widespread and fairly uniform in its lithic characteristics, it does not contain abundant shell debris, and it contains the trace fossil *Taonurus* (fig. 6), which represents the sublittoral to bathyal *Zoophycus* facies of Seilacher (1967). Lower Schoharie beds also contain *Taonurus*, as well as hexactinellid sponge spicules, which also suggests a deepwater environment (Prof. J. Keith Rigby, Jr., written commun., 1981). According to Shrock and Twenhofel (1957, p. 83), the Hexactinellida lived at depths between 300 to 16,000 feet (100–>5,000 m). Reid (1968) similarly indicated that Hexactinellida are rare above 660 feet (200 m). *Taonurus* disappears upwards, and vertical burrows become dominant in the middle part of the Schoharie Formation.

Seilacher (1967, p. 421) noted that the transition from horizontal to vertical burrows reflects transition from sediment feeding in the deeper zone, where food settles in quieter water, to suspension feeding in the shallower, more agitated zone. This indicates that gradual transition from deep-neritic to shallower deposits proceeded through Schoharie time. Basin shallowing continued from late Schoharie into Buttermilk Falls time and produced depths within the photic zone that contained warm, well-oxygenated, and gently circulating water. These neritic conditions are indicated by the upward increase in diverse marine fauna (including corals), vertical burrows, and abundance of limestone in the upper part of the Schoharie and the Buttermilk Falls Limestone.

Interpretation of the bathymetry of the Esopus and Schoharie Formations rests to a large part on inferences drawn from the occurrence of *Taonurus*. A short discussion of this trace fossil therefore is appropriate.

In cross section, *Taonurus* consists of alternating light and dark meniscate bands in laminae 0.1 to 0.3 inch (2–8 mm) thick (fig. 16*A*, *B*). The laminae generally parallel bedding, but some are crosscutting and may be inclined nearly 30° (fig. 16*C*). The sediments in which *Taonurus* is found are mostly fine to coarse siltstone. The darker bands contain more muscovite and chlorite and less quartz than the lighter bands and may contain slightly more carbonaceous matter. There does not appear to be differential sorting of the quartz in the two types of bands.

A large literature on ichnology (the study of trace fossils) exists, but total agreement on the interpretation of *Zoophycus*, the general group to which *Taonurus* belongs, is lacking. Most investigators have concluded that ichnofossils are sedimentary structures resulting from organic activity and reflect the ecological environment of the producing animals regardless of the animals' morphology or geologic age. The structures in the *Zoophycus* facies were produced by hemisessile deposit feeders, generally below wave base in areas free of turbidite sedimentation (that is, quiet offshore waters in deep-shelf and bathyal areas), although the facies is gradational into shallower and deeper zones (Crimes, 1973; Frey, 1975; Seilacher, 1964, 1967, 1978). Some workers have noted that *Taonurus* occurs in sediments deposited above wave base in protected areas (Crimes, 1973; Hallam, 1975; Kennedy, 1975; Osgood and Szmuc, 1972). As noted by Seilacher (1978), the examples of *Taonurus* in shallower deposits do not invalidate the use of trace fossil assemblages in environmental analysis, especially when other paleontological and sedimentological criteria are used.

At the other end of the interpretive spectrum, Plicka (1968) believed that *Zoophycus* are prostomia of marine worms. Osgood (1975) disagreed, partly because of the interpenetration of the structures (see fig. 16*C*). Similarly, Sarle (1906) believed that *Taonurus* could not be a body fossil. Osgood also disagreed with the interpretation of Loring and Wang (1971) that *Taonurus* is a marine plant.

Goldring and Flower (1942) suggested that *Taonurus* represents deposition in mud flats "in which sandy sediments were subject to constant reworking by organisms during their extremely slow accumulation." However, I know of no reports of *Taonurus* forming in recent tidal-flat sediments or formed in proven ancient tidal-flat sediments.

Another dissenting opinion is given by Sevon (*in* Epstein and others, 1974, p. 118–119) who believed that these structures are overturned ripples formed by currents that alternated in direction on a tidal flat. However, if these structures are indeed ripples, most overlying laminae would indicate a direction of current flow that is opposite to the direction that would be necessary to overturn the underlying ripple (see fig. 16*A*, *B*). In plan view, as seen on bedding surfaces, which are rarely exposed in eastern Pennsylvania because of the intense development of rock cleavage, *Taonurus* appears as curved alternating light and dark bands in masses up to a few feet in diameter (see Chamberlain, 1978, p. 159, fig. 115) with tiny appendages (fig. 16*D*), quite unlike ripple marks generated on a tidal flat. Moreover, there are many published photographs of *Zoophycus* from a wide range of geologic ages that are similar to *Taonurus* seen in the Esopus and Schoharie of eastern Pennsylvania (Chamberlain, 1978, p. 158; Ekdale, 1977, p. 171, 173; Kennedy, 1975, p. 386; Seilacher, 1967, p. 423).

In summary, the available evidence and comparisons with published data suggest that the trace fossil *Taonurus* is a feeding burrow of an animal that lived in a marine environment below wave base.

The Palmerton Sandstone, which is the southwestward lateral equivalent of the upper part of the Schoharie Formation and the lower part of the Buttermilk Falls Limestone (fig. 3), probably accumulated at depths similar to or somewhat shallower than those of its correlatives but was close to a source of coarse clastic supply. The formation is massive and generally lacks sedimentary structures except for channeled lower contacts in basal beds. This does not help in interpretation of the environment of deposition. The Palmerton is definitely marine, as indicated by minor crinoid and coral debris (probably derived from the nearby Buttermilk Falls carbonate terrane). It may be a beach or barrier-bar nearshore deposit. The quartz types in the Palmerton suggest a source area consisting of sandstone and quartzite, quartz veins, chert-bearing sediments, and possibly granitic rocks.

The unique iron-rich rocks of the Hazard paint ore

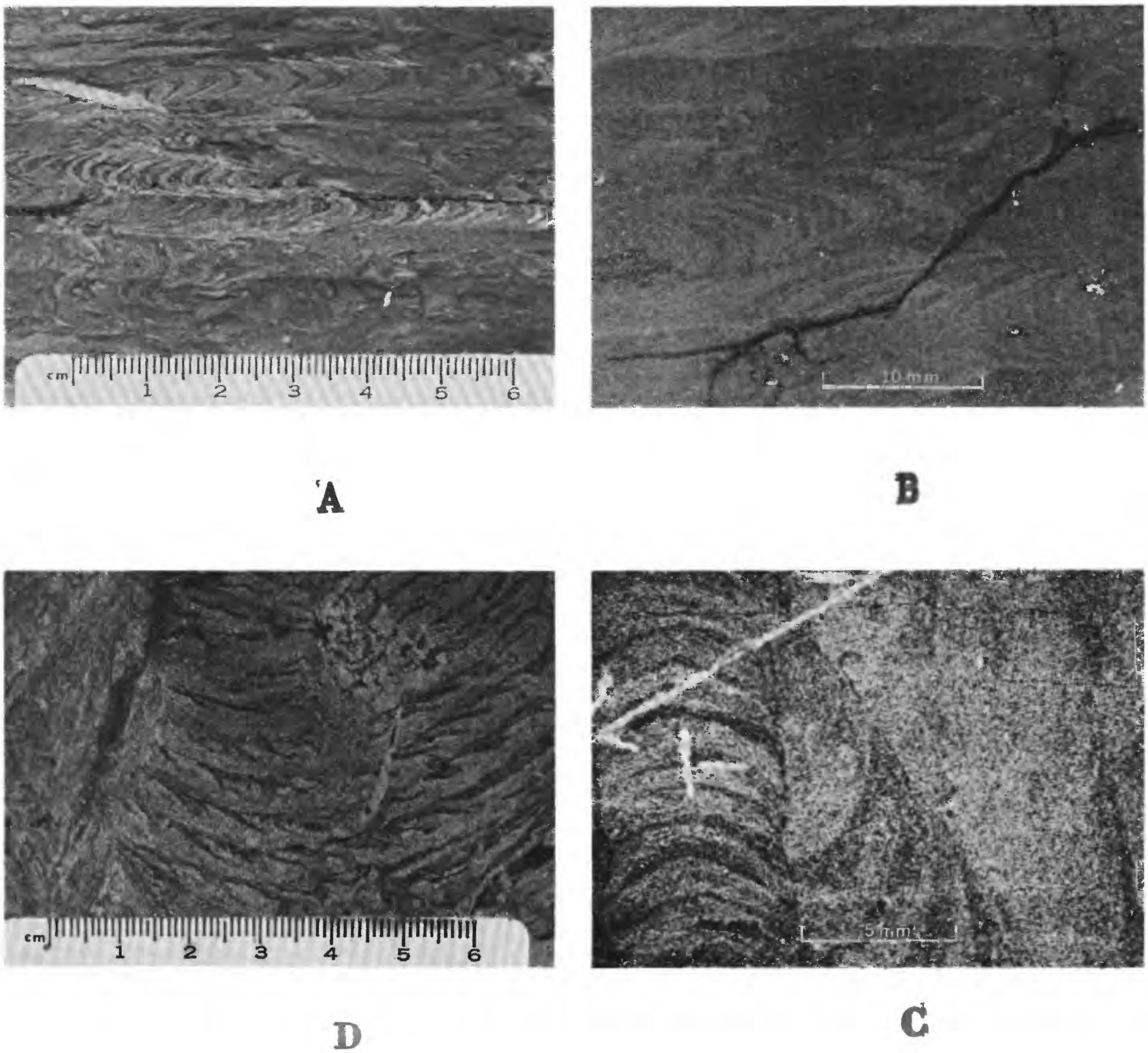

FIGURE 16.—The trace fossil *Taonurus* in the Esopus and Schoharie Formations, northeastern Pennsylvania. *A*, Polished slab showing cross section of completely bioturbated siltstone, from roadcut southeast of Bowmanstown (fig. 1, loc. 10). Direction of meniscate light and dark bands alternates in each overlying laminae. *B*, Negative print of acetate peel showing rapid lateral termination of meniscate laminae. Stratigraphic top is up. Lower half of Schoharie Formation from roadcut along U.S. 209 near Buttermilk Falls (fig. 1, loc. 1). *C*, Negative print of thin section showing crosscutting burrows in coarse quartz-muscovite-chlorite siltstone of the Esopus Formation in Godfrey Ridge, 650 feet (198 m) southwest of the WVPO radio tower, near Stroudsburg. Stratigraphic top is to the left. Horizontal lines are rock cleavage. White markings are orientation scratches on thin section. *D*, Polished slab cut parallel to bedding from same locality as figure 16*A*. The burrows are curved, and the bands are digitated. Later burrowing has altered earlier structures in several places.

suggested unusual conditions for iron accumulation to Sevon (*in* Epstein and others, 1974, p. 119, 130–131).

Onesquethawan time ended with the regional deposition of a volcanic ash, the Tioga Ash Bed. The volcanic center was in the Piedmont of central Virginia (Dennison, 1969). This was followed by sublittoral deposition below wave base in a reducing environment represented by the carbonaceous, pyritic, sparsely fossiliferous laminated shales of the Marcellus Shale.

MEASURED SECTIONS

Section 1

Esopus and Schoharie Formations and Foxtown Member of the Buttermilk Falls Limestone in roadcut along U.S. Route 209 near Buttermilk Falls, East Stroudsburg quadrangle, Pennsylvania. Beds dip gently to the southwest. Type locality of the Buttermilk Falls Limestone. Locality 1, figure 1.

	Thickness (Feet)	Thickness (Meters)
Buttermilk Falls Limestone (part):		
Foxtown Member (part):		
7. Limestone, silty; medium-gray (*N*5); weathers medium light gray (*N*6) to light gray (*N*7) and olive gray (5*Y* 5/1) to yellowish gray (5*Y* 8/1); fine- to medium-grained, with some coarser grains as much as 2 mm long; evenly to unevenly bedded; thin-bedded (beds range from 1 in. to 1 ft in thickness), with brachiopods and crinoid columnals that are as much as 1 in. in diameter. Lesser interbedded calcareous shale is medium dark gray (*N*4); weathers medium gray (*N*5); and is in thin lenses, laminae, and beds as much as 2 in. thick; burrow mottled. Irregular dark-gray (*N*3) chert lenses and pods as much as 5 in. long are throughout and make up about 5 percent of unit near base. Chert replaces limestone and also forms a halo around more calcareous segregations. Some chert contains fossils and burrows. Basal contact abrupt	25.0	7.6
Incomplete thickness of Foxtown Member of the Buttermilk Falls Limestone	25.0	7.6
Schoharie Formation:		
6. Siltstone, dark-gray (*N*3) to medium-dark-gray (*N*4); weathers medium dark gray (*N*4) to medium gray (*N*5) and light olive gray (5*Y* 6/1); calcareous; massive; evenly bedded; laminated. Contains scattered dark-gray (*N*3) chert nodules and lenses as much as 2 in. thick in lower half and more abundant chert and limestone in upper half of unit. Chert makes up less than 5 percent of basal part of unit. Upper 15 ft contains as much as 40 percent chert, enclosing irregular lenses of dark-gray (*N*3) to grayish-black (*N*2) fossiliferous (brachiopods), irregularly bedded, shaly siltstone. Lowest bed contains a 2-in.-thick grayish black chert lens that is about 3 ft long and about 4 in. above base; chert is more abundant above 31 ft above base. Above 51 ft above base, beds become sandy (fine-grained sandy siltstone), more massive and blocky (beds as much as 6 ft thick), and cleavage is poorly developed. More calcareous beds weather lighter gray than silty beds. Irregular lenses, beds, and pods of more calcareous siltstone slightly burrow mottled with vertical shale-filled burrows approximately 0.5 in. in diameter and 1 to 2 in. long. More extensively burrowed and less laminated toward top of unit. Contains scattered shale chips that are inclined about 45° and are as much as 2 in. long	66.0	20.1
5. Siltstone, medium-dark-gray (*N*4); weathers medium dark gray (*N*4) to medium gray (*N*5); calcareous; evenly bedded; thin-bedded; beds range from about 4 to 16 in. thick; fossiliferous; moderate cleavage development	7.0	2.1
4. Siltstone, calcareous; dark-gray (*N*3) to medium-dark-gray (*N*4); weathers medium dark gray (*N*4) to medium gray (*N*5) and light olive gray (5*Y* 6/1) and grayish orange (10*YR* 7/4); thin- to thick-bedded (beds range from a few in. to as much as 3 ft thick); laminated, with minor interbedded calcareous shaly siltstone; fossiliferous; more evenly bedded and laminated and more calcareous toward top where unit contains coarser grained siltstone. Slightly burrow mottled toward top; most burrows are horizontal. Slightly pyritic toward base. No chert. Abundant *Taonurus caudigalli*. Slightly pyritic toward base. Cleavage not well developed, except in basal 20 ft. Contact with Esopus is gradational and placed with some question at the base of the first massive siltstone going upsection. Schoharie more resonant when hit with a hammer as compared to the muted sound of the Esopus	30.0	9.2
Thickness of Schoharie Formation	103.0	31.4
Esopus Formation (part):		
3. Siltstone, shaly; dark-gray (*N*3); weathers medium gray (*N*4) to dark gray (*N*3) and light olive gray (5*Y* 6/1); iron stained dark yellowish orange (10*YR* 6/6) to moderate yellowish brown (10*YR* 5/4); pyritic; laminated; thin- to very thick bedded (beds range from 4 in. to 7 ft thick); locally calcareous; abundant *Taonurus caudigalli*. Weathers into platy fragments more readily than Schoharie	11.0	3.4
2. Covered	26.0	7.9
1. Siltstone, similar to unit 3	40.0	12.2
Incomplete thickness of Esopus Formation	77.0	23.5

Section 2

Generalized description of the Foxtown and McMichael Members of the Buttermilk Falls Limestone, Esopus Formation, and parts of the Schoharie Formation and Stroudsburg Member of the Buttermilk Falls Limestone in abandoned quarry 100 ft (30 m) south of the intersection of U.S. 209 and Interstate 80, 1.5 mi (2.4 km) east of East Stroudsburg, and 1,000 ft (305 m) southwest of the quarry along bluffs near the Lackawanna and Western Railroad, Stroudsburg quadrangle. The Buttermilk Falls is exposed in the quarry in an overturned syncline, and the Esopus and Schoharie are exposed in the overturned limb of that fold in the bluffs. Locality 3, figure 1.

	Thickness (Feet)	Thickness (Meters)
Buttermilk Falls Limestone (part):		
Stroudsburg Member (part):		
5. Limestone, argillaceous, medium-gray (*N*5) to medium-dark-gray (*N*4); weathers medium gray (*N*5) to light olive gray (5*Y* 6/1); fossiliferous; thin-bedded (beds range from 4 in. to 1 ft in thickness); with dark-gray (*N*3) chert nodules several in. long	15.0	4.6
Incomplete thickness of the Stroudsburg Member of the Buttermilk Falls Limestone	15.0	4.6
McMichael Member:		
4. Shale, calcareous; medium-gray (*N*5); weathers light olive gray (5*Y* 6/1) to medium gray (*N*5) and grayish orange (10*YR* 7/4); thin-bedded (beds 2 to 8 in. thick); with lenses of medium-light-gray (*N*6) fossiliferous limestone	41.7	12.7
Thickness of McMichael Member of the Buttermilk Falls Limestone	41.7	12.7
Foxtown Member:		
3. Siltstone, calcareous; medium-dark-gray (*N*4) alternating with medium-gray (*N*5) argillaceous limestone; weathers medium gray (*N*5) to light olive gray (5*Y* 6/1) and grayish orange (10*YR* 7/4); irregularly bedded; thin-bedded (beds range between 2 and 10 in. in thickness); fossiliferous (brachiopods and abundant crinoid columnals up to 1 in. in diameter in lower 45 ft)	80.0	24.4
Thickness of Foxtown Member of the Buttermilk Falls Limestone	80.0	24.4
Incomplete thickness of Buttermilk Falls Limestone	136.7	41.7
Schoharie Formation:		
2. Siltstone, partly calcareous; dark-gray (*N*3); generally massive; prominent cleavage not as well developed as in underlying Esopus Formation. Contact with Esopus gradational through about 20 ft of interbedded siltstone and silty shale. Contact placed at first massive siltstone bed going upsection.		
Thickness from construction of cross section	100.0	30.5
Approximate thickness of Schoharie Formation	100.0	30.5
Esopus Formation:		
1. Siltstone, generally noncalcareous except for beds between 7 to 9 ft above base and some beds between 104 to 181 ft above base; dark-gray (*N*3); weathers medium dark gray (*N*4) and is iron stained grayish orange (10*YR* 7/4) to moderate brown (10*YR* 5/4); laminated; generally massive (beds range from 2 in. to more than 6 ft thick); bedding generally not distinct below 104 ft; abundant *Taonurus caudagalli*; lower 7 ft covered; contact with underlying Ridgeley Sandstone of the Oriskany Group covered	181.0	55.2
Thickness of Esopus Formation	181.0	55.2

Section 3

Buttermilk Falls Limestone and part of the Schoharie Formation in railroad cut of the Erie-Lackawanna Railroad, 1 mi south of the East Stroudsburg Post Office, Stroudsburg quadrangle. The center of the cut is in the Schoharie Formation and in the crest of an overturned anticline. The Buttermilk Falls Limestone is in overturned beds to the north that dip as much as 55° to the southeast. Locality 4, figure 1.

	Thickness (Feet)	Thickness (Meters)
Buttermilk Falls Limestone:		
Stroudsburg Member:		
6. Limestone, medium-dark-gray (*N*4); weathers medium light gray (*N*6) to light gray (*N*7); fine- to medium-grained; fossiliferous; lenticular and irregularly interbedded with about equal amounts of grayish-black (*N*2) to dark-gray (*N*3) chert. Generally thin bedded (beds between 2 in. and 1 ft thick). The top of the Tioga Ash Bed is 27 ft below the top of the unit. It is 10 in. to 1 ft thick and consists of light-olive-gray (5*Y* 6/1) to dark-gray (*N*4) tuffaceous siltstone to very fine grained sandstone that weathers medium light gray (*N*6) and moderate yellowish brown (10*YR* 5/4). Upper 15 ft contains three beds that are 3 to 6 in. thick of medium-gray (*N*5) to medium-light-gray (*N*6), light-gray- (*N*7) weathering, medium- to very coarse grained limestone with abundant brachiopod debris. Contact with overlying Union Springs Shale Member of the Marcellus Shale not exposed but probably near top of measured unit	90.0	27.4
5. Shale, calcareous; silty; medium-gray (*N*5); with some medium-gray (*N*5) to medium-light-gray (*N*6), fine- to medium-grained limestone pods as much as 2 in. in diameter that weather light gray (*N*7)	3.0	0.9
4. Limestone, locally argillaceous and fossiliferous; medium-gray (*N*5) to medium-dark-gray (*N*4), weathers light gray (*N*7) to medium light gray (*N*6); fine- to medium-grained; thin bedded with irregular beds; lenses and pods 1 in. to 1 ft thick; and dark-gray (*N*3) to grayish-black (*N*2) chert in irregular pods, lenses, and discontinuous beds 0.25 to 8 in. thick	56.0	17.1

	Thickness (Feet)	Thickness (Meters)
Thickness of Stroudsburg Member of the Buttermilk Falls Limestone	149.0	45.4
McMichael Member:		
3. Shale, calcareous; partly silty; medium-gray (N5) to medium-dark-gray (N4); weathers medium gray (N5); evenly bedded to lenticular; fossiliferous; thin-bedded (beds 2 in. to 1 ft thick); interbedded with medium-gray (N5), fine-grained limestone in beds, lenses, and nodules 1 to 3 in. thick. Limestone contains ostracodes and brachiopod and crinoid debris. Contact with overlying Stroudsburg Member gradational and marked by upward appearance of chert and disappearance of argillaceous beds	41.0	12.5
Thickness of McMichael Member	41.0	12.5
Foxtown Member:		
2. Limestone, medium-gray (N5) to medium-dark-gray (N4); weathers light gray (N7) to medium light gray (N6); fine- to very coarse grained; irregularly bedded to lenticular; generally thin-bedded (beds 1 in. to 2 ft thick); interbedded with medium-dark-gray (N4), calcareous, evenly bedded shale and siltstone in beds 1 in. to 1 ft thick and grayish-black (N2) to dark-gray (N3) chert. Chert in lower half in irregular nodules 0.5 to 6 in. long. Chert becomes more abundant in upper half where it makes up more than 50 percent of unit and is interbedded with calcareous shale and siltstone 1 to 2 in. thick and limestone pods 2 to 6 in. in diameter. Large crinoid columnals with cross section diameters to 1 in. are conspicuous in lower half. Abundant ostracodes. Base marked by 1-ft-thick, medium-gray (N5), light-gray- (N7) weathering, medium- to very coarse grained limestone in abrupt contact with underlying Schoharie Formation. Contact with overlying McMichael Member transitional through 4-ft interval	82.0	25.0
Thickness of Foxtown Member	82.0	25.0
Thickness of Buttermilk Falls Limestone	272.0	82.9
Schoharie Formation (part):		
1. Siltstone, sandy to argillaceous; calcareous to noncalcareous; medium-gray (N5) to medium-dark-gray (N4); in beds as much as 5 ft thick. Becomes sandier towards top. Base not exposed	58.0	17.7
Incomplete thickness of Schoharie Formation	58.0	17.7

Section 4

Schoharie Formation, Palmerton Sandstone, and parts of the Esopus and Schoharie Formations and Marcellus Shale in roadcut through Cherry Ridge along Pa. State Route 33 near Saylorsburg, Saylorsburg quadrangle. Beds are overturned and dip as much as 30° to the southeast. Many units are deeply weathered to saprolite. Measured during road construction in 1962. Locality 6, figure 1.

	Thickness (Feet)	Thickness (Meters)
Marcellus Shale (part):		
27. Shale, medium-gray (N5); weathers dark yellowish gray (5Y 6/2) to grayish orange (10YR 7/4). Upper contact covered	10.0	3.1
26. Shale, medium-gray (N5); weathered partly to clay; weathers pale yellowish orange (10YR 8/6) to dark yellowish orange (10YR 6/6), pale red purple (5RP 6/2), moderate reddish brown (10R 4/6), and light gray (N7). Thickness approximate	50.0	15.2
25. Shale, silty, and clay; weathers grayish orange (10YR 7/4) to moderate reddish brown (10R 4/6); trilobite fragments	45.0	13.7
Incomplete thickness of Marcellus Shale	105.0	32.0
Buttermilk Falls Limestone:		
24. Clay, silty, with some fine-grained sand; pale-red-purple (5RP 6/2) and very light gray (N8), with light-gray (N7) and mottled reddish chert; few crinoid columnals; last chert going upsection	17.0	5.2
23. Clay, argillaceous; limonitic and hematitic; very dark yellowish-orange (10YR 5/6) to dark-yellowish-orange (10YR 6/6) and moderate-reddish-brown (10R 4/6) to pale-brown (5YR 5/2); with iron-stained light-gray (N7) to medium-gray (N5) chert; scattered brachiopods. Lower half covered by concrete abutment at overpass of Saylorsburg-Bossardsville road	35.0	10.7
22. Clay, silty; moderate-pinkish-red (5R 6/4), light-gray (N7), and dark-yellowish-orange (10YR 6/6); with minor chert that weathers very dusky red (5R 2/6) and very light gray (N8) to medium gray (N5). Some brachiopods	25.0	7.6
21. Siltstone, shaly; clayey; mottled yellowish-orange (10YR 7/6) and pale-red-purple (5RP 6/2); fossiliferous	3.0	0.9
20. Clay, white (N9) to light-gray (N7) and very pale orange (10YR 8/2), with light-gray (N7) to medium-gray (N5) chert	28.0	8.5
19. Clay, medium-light-gray (N6) and yellowish-orange (10YR 7/6), with very light gray (N8) to medium-gray (N5) chert. Chert more abundant than in underlying unit	32.0	9.8
18. Clay, light-gray (N7), yellowish-gray (5Y 8/1), yellowish-orange (10YR 7/6), and pale-red (5R 6/2). Few beds 1 to 3 in. thick of nodular chert 25 to 45 ft above base. Fossiliferous (bryozoans)	58.0	17.7
17. Chert, white (N9) to light-gray (N7); and silty to medium- to coarse-grained sandy white (N9) to very light gray (N8) clay. Very fossiliferous in places (crinoid columnals, favositiid corals, ostracodes, and bryozoans). Contact with underlying Pal-		

	Thickness (Feet)	Thickness (Meters)
merton Sandstone covered but probably sharp	65.0	19.8
Thickness of Buttermilk Falls Limestone	263.0	80.2

Palmerton Sandstone

	Thickness (Feet)	Thickness (Meters)
16. Sandstone, slightly limonitic; medium-gray (*N*5) to very light gray (*N*8) and dark-yellowish-orange (10*YR* 6/6); medium- to very coarse grained; with some quartz grains as much as 3 mm long; silica cement; thin- to thick-bedded	13.0	4.0
15. Sandstone, coarse- to very coarse grained and conglomeratic; quartz pebbles are subrounded to well rounded and as much as 5 mm long with rare grains as much as 10 mm long; very light gray (*N*8) to light-gray (*N*7), pale-yellowish-orange (10*YR* 8/6) to dark-yellowish-orange (10*YR* 6/6); partly laminated; generally very thick bedded (some beds are more than 8 ft thick); a few beds of fine-grained sandstone near base	48.0	14.6
14. Sandstone, very fine to fine-grained; with scattered coarse sand grains; dark-yellowish-orange (10*YR* 6/6); with moderate-brown (5*YR* 4/4) ironstone concretions that are 1 to 2 in. in diameter	0.6	0.2
13. Sandstone, very coarse grained; iron-stained; very dark reddish-brown (10*R* 2/4) to dark-yellowish-brown (10*YR* 4/2); with lesser yellowish orange (10*YR* 7/6) and very pale orange (10*YR* 8/2) siltstone and very fine grained sandstone. Many channeled upward-fining subunits; base irregular and disconformable; relief about 2.7 ft	4.2	1.3
Thickness of Palmerton Sandstone	65.8	20.1

Schoharie and Esopus Formations, undivided:

Schoharie Formation:

	Thickness (Feet)	Thickness (Meters)
12. Siltstone and very fine grained sandstone with scattered quartz grains as much as 3 mm long; dark-yellowish-orange (10*YR* 6/6) and very light gray (*N*8); with dark-yellowish-brown (10*YR* 5/2) ironstone concretions as much as 5 in. in diameter and ironstone beds about 0.5 in. thick. Near top of unit, 3-in.-thick, pale-yellowish-orange (10*YR* 8/6) to dark-yellowish-orange (10*YR* 6/6), very coarse grained sandstone bed is cut out by channeling of overlying unit about 10 ft above road level. Lower contact irregular and disconformable	2.2	0.7
11. Siltstone and medium-grained sandstone with scattered quartz grains as much as 1 mm long; very light gray (*N*8) to light-brown (5*YR* 5/6); with light-gray (*N*7) to medium-gray (*N*5) chert; sparingly fossiliferous (brachiopods)	0.6	0.2
10. Siltstone, sandy; with scattered quartz grains as much as 3 mm long; very light gray (*N*8) and dark-yellowish-orange (10*YR* 6/6), with light-gray (*N*7) to medium-gray (*N*5) chert nodules averaging about 1 in. in diameter	2.0	0.6
9. Siltstone, silicified, and very fine grained sandstone with scattered quartz grains as much as 2 mm long; light-gray (*N*7) and dark-yellowish-orange (10*YR* 6/6); with light-gray (*N*7) to very light gray (*N*8) chert nodules as much as 2 in. long; scattered brachiopods	1.1	0.3
8. Siltstone, sandy, shaly, silicified, to very fine grained sandstone with scattered quartz grains as much as 2 mm long and a few grains as much as 5 mm long; pale-yellowish-orange (10*YR* 8/6) to dark-yellowish-orange (10*YR* 6/6); massive (beds as much as 3.5 ft thick), with a few shale and shaly siltstone beds 1 to 2 in. thick; scattered brachiopods	10.7	3.2
7. Siltstone, silicified, to very fine grained sandstone with scattered quartz grains as much as 1 mm long; very light gray (*N*8) and pale-yellowish-orange (10*YR* 8/6) to dark-yellowish-orange (10*YR* 6/6); burrowed	0.9	0.3
6. Siltstone, shaly; yellowish-orange (10*YR* 7/6)	0.6	0.2
5. Siltstone, shaly; very pale orange (10*YR* 8/2) to yellowish-orange (10*YR* 6/6) in two beds 14 and 12 in. thick; fossiliferous; burrowed; with very light gray (*N*8) to light-gray (*N*7) chert	2.2	0.7
4. Siltstone, shaly; grayish-orange (10*YR* 7/4) to yellowish-orange (10*YR* 7/6); thin-bedded (beds 2 in. to 1.2 ft thick); fossiliferous; with a few shale beds about 1 in. thick; and very light gray (*N*8) to medium-gray (*N*5) and grayish-orange (10*YR* 7/4) chert pods, lentils, and irregular beds as much as 3 in. thick	8.2	2.5
3. Chert, medium-gray (*N*5) to very light gray (*N*8) and grayish-orange (10*YR* 7/4) to dark-yellowish-orange (10*YR* 6/6) burrowed siltstone	0.3	0.1
2. Siltstone, shaly; very light gray (*N*8), yellowish-gray (5*Y* 8/1), yellowish-orange (10*YR* 7/6), and grayish-yellow (5*Y* 8/4), evenly bedded; thin-bedded (beds 2 in. to as much as 1 ft thick); fossiliferous; burrowed; with small (less than 1 in. long) lenticular chert pods parallel to bedding	4.3	1.3
Thickness of Schoharie Formation	33.1	10.1

Esopus Formation:

1. Siltstone and shaly siltstone, light-gray (*N*7) to medium-dark-gray (*N*4) on fresher surfaces; weathers shades of gray, purple, orange, red, and brown (light gray (*N*7), light greenish gray (5*GY* 7/1), grayish red (5*R* 4/2) to blackish red (5*R* 2/2), and dark

	Thickness (Feet)	Thickness (Meters)
yellowish orange (10*YR* 6/6)); mottled in places; iron-stained; color bands transect bedding and well-developed cleavage; evenly bedded; laminated and thin-bedded (beds range from 1 in. to 1 ft in thickness); lower half of unit partly slumped; lower contact concealed; weathers darker than overlying Schoharie Formation	35.0	10.7
Incomplete thickness of Esopus Formation	35.0	10.7
Incomplete thickness of Schoharie and Esopus Formations, undivided	68.1	20.8

Section 5

Generalized description of the Ridgeley Sandstone and part of the Shriver Chert of the Oriskany Group, Esopus and Schoharie Formations, Palmerton Sandstone, Buttermilk Falls Limestone (including the Hazard paint ore), and lower part of the Marcellus Shale (Union Springs Shale Member, including the Tioga Ash Bed, and part of the Stony Hollow Member) along the east bench in highway cut through Stone Ridge about 20 ft above the Northeast Extension of the Pennsylvania Turnpike, Lehighton quadrangle. Beds are overturned and dip 67° to 80° SE. A more detailed description of the units is given by Sevon (*in* Epstein and others, 1974, p. 400–406). The rocks are faulted, particularly the Marcellus Shale (see Glaesser, *in* Epstein and others, 1974, p. 288), so that the units have different thicknesses in different parts of the cut. The rocks are generally deeply weathered but are fresher at lower levels of the cut. Locality 11, figure 1.

	Thickness (Feet)	Thickness (Meters)
Marcellus Shale (part):		
Stony Hollow Member (part):		
13. Shale, calcareous; medium-dark-gray (*N*4) to dark-gray (*N*3); interbedded with evenly bedded dark-gray (*N*3) shaly fine-grained limestone in beds between 4 in. and 1 ft in thickness and aggregating about 5 ft of unit; with scattered shaly limestone pods about 1 ft long and 4 in. thick. Upper contact at top of last limestone encountered going upsection and gradational into calcareous shales that are in turn gradational into noncalcareous shales of the overlying Brodhead Creek Member of the Marcellus Shale. Lower contact placed at base of lowest limestone bed. Unit highly faulted	41.7	12.7
Incomplete thickness of Stony Hollow Member of the Marcellus Shale	41.7	12.7
Union Springs Shale Member:		
12. Shale, noncalcareous; dark-gray (*N*3) to medium-dark-gray (*N*4); sheared, well-developed slaty cleavage; basal 1.5 ft contains three layers 1 to 2 in. thick with abundant mica and pyrite grains as much as 1 mm long (Tioga Ash Bed). Lower contact abrupt	29.2	8.9
Thickness of Union Springs Shale Member of the Marcellus Shale	29.2	8.9
Incomplete thickness of Marcellus Shale	70.9	21.6
Buttermilk Falls Limestone:		
11. Shale, siltstone, very fine grained sandstone, and clay; deeply leached residue from limestone; varicolored, including light-gray (*N*7) to medium-dark-gray (*N*4), dark-yellowish-orange (10*YR* 6/6) to pale-yellowish-orange (10*YR* 8/6) to moderate-grayish-red (10*R* 5/2); partly hematitic and fossiliferous; with about five intervals of dark-gray (*N*3) to grayish-black (*N*2) chert nodules and irregular beds between 7 and 25 ft above base above base of unit; with at least three beds and possibly five beds of grayish-orange (10*YR* 7/4) to pale-yellowish-orange (10*YR* 8/6) shale that are 1 in. to 1.1 ft thick and 9 to 21 ft above base of unit, containing abundant biotite flakes (Tioga Ash?). Lower contact abrupt	33.7	10.3
10. Siderite and hematitic siltstone; brownish-gray (5*YR* 4/1) to dusky-red (5*R* 3/2) and dark-gray (*N*3) siltstone; in beds 0.5 to 0.6 ft thick (Hazard paint ore). Lower contact abrupt	1.6	0.5
9. Clay, shale, and minor siltstone, leached from limestone, with floating medium and coarse sand grains; light-gray (*N*7) to medium-dark-gray (*N*4), grayish-orange (10*YR* 7/4) to moderate-yellowish-brown (10*YR* 5/4). Lower contact abrupt. On west side of the cut at road level, this interval contains nodular beds, 1 to 6.5 in. thick, of dark-gray (*N*3) to medium-dark-gray (*N*4) fine-grained fossiliferous limestone that weathers medium light gray (*N*6) to light gray (*N*7) and light olive gray (5*Y* 6/1) and contains conodonts of early Middle Devonian age	4.9	1.5
Thickness of Buttermilk Falls Limestone	40.2	12.3
Palmerton Sandstone:		
8. Sandstone, generally very coarse grained; conglomeratic; with pebbles that are generally rounded and as much as 0.5 in. long; very light gray (*N*8) to medium-light-gray (*N*6) and dark-yellowish-orange (10*YR* 6/6) to grayish-orange (10*YR* 7/4); partly iron stained; thick bedded (beds about 2 to 25 ft thick). Lower contact abrupt	104.0	31.7
7. Siltstone, light-gray (*N*7), and lenticular very coarse grained sandstone in beds 0.4 to 1.6 ft thick. Lower contact abrupt	3.5	1.1
Thickness of Palmerton Sandstone	107.5	32.8
Schoharie and Esopus Formations, undivided:		
Schoharie Formation:		
6. Siltstone to minor very fine grained sandstone; partly shaly; very pale orange (10*YR* 8/6); fossiliferous; with medium-light-gray (*N*6) nodular chert. Lower contact abrupt	13.5	4.1

	Thickness (Feet)	(Meters)
5. Siltstone, siliceous; dark-gray (*N*3) to medium-dark-gray (*N*4); with minor very fine grained sandstone; generally weathers from pale brown (5*YR* 5/2) to light brown (5*YR* 5/6); lower part contains silty shale in beds 2 to 5 in. thick and more massive siltstone to very fine grained sandstone in beds 3 to 9 in. in thickness; upper part is mostly siltstone to very fine grained sandstone in massive even beds as much as 3 ft thick; grayish-red (5*R* 4/2) siltstone, 8 in. thick, is 2.2 ft below top of unit. Abundant *Taonurus*. Lower contact abrupt	23.2	7.1
Thickness of Schoharie Formation	36.7	11.2
Esopus Formation:		
4. Siltstone, very shaly; medium-gray (*N*5); fissile; thin-bedded (beds as much as 3 in. thick); *Taonurus*. Upper contact transitional through interbedded shaly siltstone and siltstone	3.0	0.9
3. Shale, silty; fissile; very light gray (*N*8) to olive-gray (5*Y* 4/1). Lower contact abrupt	8.0	2.4
Thickness of Esopus Formation	11.0	3.3
Thickness of undivided Schoharie and Esopus Formations	47.7	14.5
Oriskany Group (part):		
Ridgeley Sandstone:		
2. Sandstone, generally medium- to very coarse grained; conglomeratic; with rounded quartz grains as much as 0.5 in. long; pale-yellowish-orange (10*YR* 8/6); thin- to thick-bedded (beds range from 0.5 to 3 ft in thickness); upper 8 in. hematitic; base partly covered by rubble; probably transitional into underlying Shriver Chert; fault contact with overlying Esopus Formation so that unit is 5.6 ft thinner at road level below	26.9	8.2
Thickness of Ridgeley Sandstone of the Oriskany Group	26.9	8.2
Shriver Chert (part):		
1. Chert, white (*N*9) to very light gray (*N*8); fossiliferous; thin-bedded (beds as much as 1 ft thick); interbedded with very pale yellowish-orange (10*YR* 9/6) coarse- to very coarse grained conglomeratic sandstone with quartz grains as much as 0.4 in. long. Base covered	6.0	1.8
Incomplete thickness of Shriver Chert	6.0	1.8
Incomplete thickness of Oriskany Group	32.9	10.0

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