GEOLOGY OF THE STROUDSBURG QUADRANGLE AND ADJACENT AREAS, PENNSYLVANIA--NEW JERSEY

By

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U.S. Geological Survey

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ABSTRACT

The Stroudsburg area is within the Valley and Ridge and Great Valley physiographic provinces, Northampton and Monroe Counties, Pennsylvania, and Warren County, New Jersey. The northeast-trending subparallel valleys and ridges resulted from erosion of folded heterogeneous sedimentary rocks. These are Middle Ordovician to Middle Devonian in age and are more than 17,000 feet thick.

Deposition of a thick flysch sequence (Martinsburg Formation of Ordovician age) accompanied onset of Taconic orogenesis. It was followed by deposition of a thick molasse sequence of Silurian and Early Devonian age (continental and marginal-marine clastics--Shawangunk Formation and Bloomsburg Red Beds--overlain by predominantly marginal-marine and subtidal limestone, dolomite, shale, and sandstone--Poxono Island Formation through Oriskany Group). Basin deepening and gradual shallowing occurred during Esopus through Mahantango deposition, heralding the Acadian clastic wedge exposed north of the Stroudsburg area. Interpretation of sedimentary structures and regional stratigraphic relations suggest that the Silurian and Devonian rocks were deposited in the following environments: Alluviated coastal plain (meandering and braided streams), tidal flats

(supratidal and intertidal), barrier zone, and neritic zone (upper and lower).

The rock stratigraphic units have been grouped into four lithotectonic units, each having a different style of deformation. Folds produced in these rocks are disharmonic, and it is believed that each rock sequence is set off from units above and below by décollements, or zones of detachment. Movement was northwest into the Appalachian basin, primarily by gravitational sliding. The contact between the Shawangunk Formation of Silurian age and Martinsburg Formation of Ordovician age, is one zone of detachment as well as an angular unconformity.

Deformational effects of the Middle to Late Ordovician Taconic orogeny are elusive, but it appears that the folds and most minor structures, including the prominent regional cleavage, were produced during the late Paleozoic Appalachian orogeny and are superimposed upon larger Taconic folds and faults.

Field relations and microscopic study suggest that the regional cleavage in the Stroudsburg area is due to laminar flow of pelitic material along cleavage folia accompanied by mechanical reorientation of platy and elongate minerals and neocrystallization of mica, quartz, chlorite, and probably albite. Numerous lines of evidence point to the conclusion that cleavage developed after the rock was indurated and formed at, and just below, conditions of low-grade metamorphism. Intensity of cleavage development increases to the southeast across the area. Second-generation slip cleavage, also believed to be Appalachian in age, formed by mechanical reorientation of minerals as well as by limited new mineral growth.

The topography had a profound effect on the direction of movement of the Wisconsin glacier, as well as the manner of its retreat and the deposits that were formed. Till and stratified drift of Wisconsin age and till of Illinoian(?) age are common in the area. Wisconsin deglaciation occurred by northeastward retreat and by stagnation. A conspicuous terminal moraine marks the limit of Wisconsin ice movement. Lake Sciota was dammed between the retreating ice, the moraine, and the surrounding ridges north of Godfrey Ridge. Several deltas mark ice stand positions during the retreat of the ice. Lake-bottom and kame deposits are locally common in Cherry Valley. South of Kittatinny Mountain, on the other hand, melt water was freely discharged to the south.

The wind and water gaps in the Stroudsburg area (including Delaware Water Gap and Wind Gap) are structurally controlled; specifically they are located where folds die out in short distances, where folding is locally more intense, or where resistant rocks dip steeply and have a narrow width of outcrop. This conclusion is contrary to the concept of regional superposition.

ACKNOWLEDGMENTS

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INTRODUCTION

The Stroudsburg quadrangle and surrounding areas discussed in this report lie within the Valley and Ridge and Great Valley physiographic provinces in Northampton and Monroe Counties, Pennsylvania, and Warren County, New Jersey (fig. 1). The northeast-trending subparallel valleys and ridges are the result of erosion of folded heterogeneous sedimentary rocks (fig. 2) aggregating more than 17,000 feet in thickness and ranging in age from Middle Ordovician to Middle Devonian. The rock stratigraphic units have been grouped into four successive lithotectonic units, each of which has a different style of deformation. Folds produced in these rocks are disharmonic, and it is believed that each rock sequence is set off from sequences above and below by a décollement, or zone of detachment. Movement was northwest into the Appalachian basin, primarily by gravitational sliding, aided by directed tectonic forces. The contact between the Shawangunk Formation of Silurian age and Martinsburg Formation of Ordovician age, believed by most workers to be an angular unconformity, may also be one zone of detachment. Deformational effects of the Middle to Late Ordovician Taconic orogeny in pre-Silurian rocks are elusive, and it appears that the folds and most minor structures, including the prominent regional cleavage, were produced during the late Paleozoic Appalachian orogeny and are superimposed upon larger Taconic folds and faults. Sedimentalogically, uplift during the Taconic orogeny resulted in the

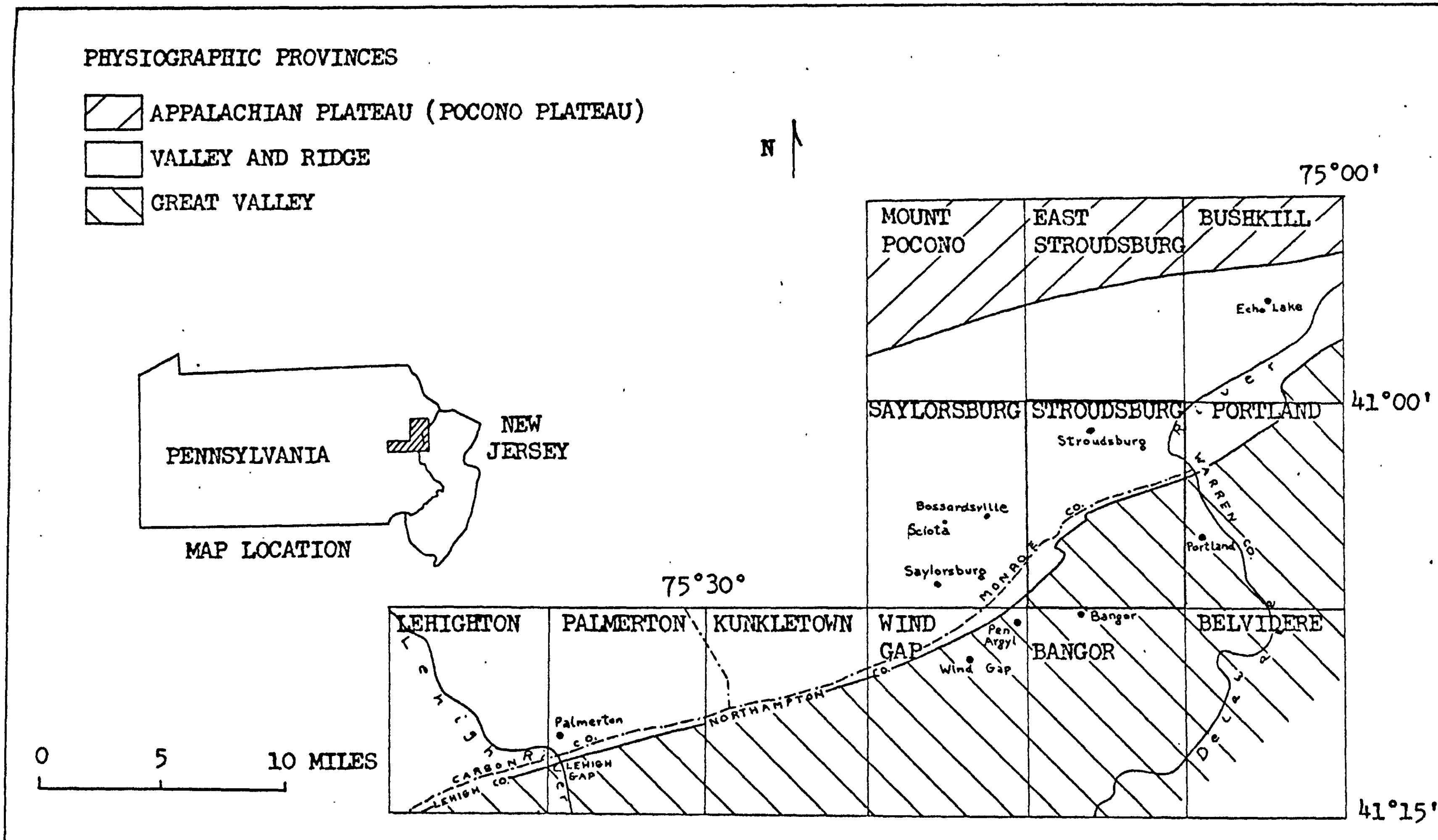

Figure 1. Index map of parts of eastern Pennsylvania and northwestern New Jersey showing location of the Stroudsburg and surrounding quadrangles and physiographic provinces.

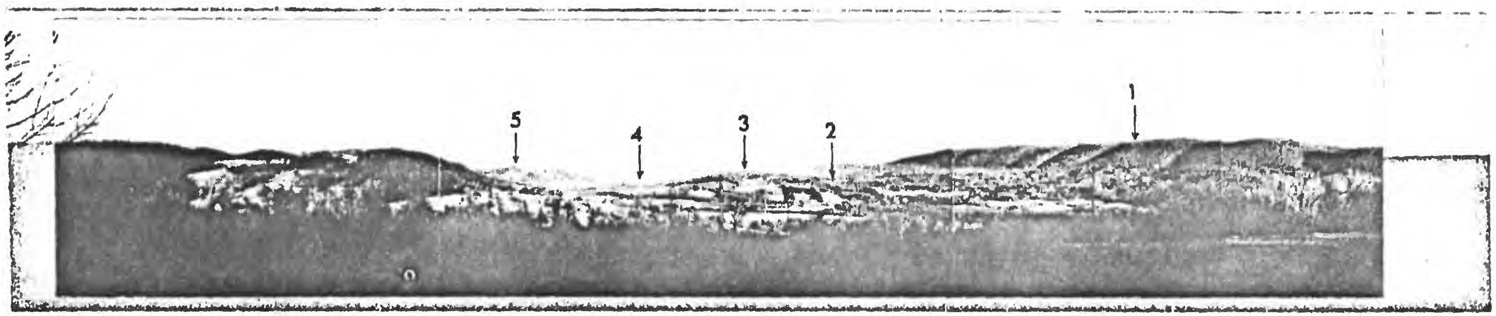

Figure 2. Panoramic view from Cherry Ridge, Bossardsville, Pa., showing some of the variety of geologic features in the Stroudsburg quadrangle. View from southeast (right) to northwest (left). 1, Blue Mountain underlain by moderately to steeply northwest-dipping Silurian clastic rocks of the Shawangunk Formation and Bloomsburg Red Beds. The Bloomsburg forms a synclinal valley (Poplar Valley, 2) and an anticlinal ridge (Kemmererville anticline, 3). The scenic Cherry Valley is choked with Wisconsin kame deposits, 4. The irregular serrated crest of Godfrey Ridge, 5, reflects complex folding of heterogeneous Upper Silurian through Middle Devonian rocks. The folds in Godfrey Ridge (lithotectonic unit 3) are of a smaller scale than those in the underlying Shawangunk and Bloomsburg (lithotectonic unit 2).

deposition of a thick synorogenic flysch sequence (Martinsburg Formation) followed by a thick molasse during Silurian and Early Devonian time (predominantly continental clastic wedge overlain by shallow-marine sediments). Basin deepening began again in later Early Devonian time culminating with another thick clastic wedge (Catskill Formation north of the quadrangle).

The topography had a profound effect on the direction of movement of the Wisconsin glacier, as well as the manner of its retreat and the deposits that were formed. Till and stratified drift of Wisconsin age and till of possible Illinoian age are common in the quadrangle. Wisconsin deglaciation occurred by northeastward retreat and by stagnation. A conspicuousterminal moraine marks the limit of Wisconsin ice movement. Lake Sciota was dammed between the retreating ice, the moraine, and the surrounding ridges north of Godfrey Ridge. Several deltas mark ice stand positions during the retreat of the ice. Lake-bottom and kame deposits are locally common in Cherry Valley. South of Kittatinny Mountain, on the other hand, melt water was freely discharged to the south.

It is concluded that the wind and water gaps in the Stroudsburg quadrangle and surrounding areas are structurally controlled; specifically, they are located where folds die out in short distances, where folding is locally more intense, or where resistant rocks dip steeply and have a narrow width of outcrop. This conclusion is contrary to the concept of regional superposition.

Field work in the Stroudsburg quadrangle was done in 1961 to 1963 and was field checked in 1968. It is part of a larger bedrock and surficial mapping study by the U.S. Geological Survey involving all or parts of eight $7\frac{1}{2}$-minute quadrangles (Stroudsburg, East Stroudsburg, Portland, Saylorsburg, Wind Gap, Kunkletown, Palmerton, and Lehighton--the last five done in cooperation with the Pennsylvania Geological Survey), and also includes stratigraphic studies of Upper Silurian and Lower Devonian rocks of northeastern Pennsylvania, New Jersey, and southeasternmost New York in association with A. G. Epstein and members of the New Jersey Geological Survey. Some data included herein are derived from those areas outside the Stroudsburg quadrangle. Much of these data are published, including discussion of the geologic relations in eastern Pennsylvania between Delaware Water Gap and Lehigh Gap (Epstein and Epstein, 1967, 1969), the stratigraphy of the Martinsburg Formation (Drake and Epstein, 1967) and Upper Silurian and Lower Devonian rocks (Epstein and others, 1967), the origin of wind and water gaps in the Stroudsburg area (Epstein, 1966), the surficial geology of the Stroudsburg quadrangle (Epstein, 1969), and the bedrock geology of the Bangor quadrangle (Davis and others, 1967), and the Portland and Belvidere quadrangles (Drake and others, 1969).

BEDROCK STRATIGRAPHY

The stratigraphic sequence in the Stroudsburg quadrangle consists of more than 17,000 feet of shale, siltstone, sandstone, conglomerate, limestone, and dolomite ranging from Middle Ordovician to Middle Devonian in age (see pl. 1). Thick drift covers all the area underlain by the Poxono Island Formation and upper part of the Bloomsburg Red Beds, but their characteristics are known from exposures in the Saylorsburg quadrangle to the west and from drilling by the U.S. Army Corps of Engineers in the Bushkill quadrangle to the northeast. Large areas of the Martinsburg Formation as well as the lower part of the Brodhead Creek Member of the Marcellus Shale are similarly covered.

ORDOVICIAN

Martinsburg Formation

The name Martinsburg was first used by Geiger and Keith (1891), and the formation was first adequately described by Keith (1894) for partly calcareous shales exposed near Martinsburg, West Virginia. The belt of rock was traced by subsequent workers into the Delaware Valley where it consists of slate and graywacke between 9,800 and 12,800 feet thick, is generally considered to be Middle Ordovician (Trenton) to Late Ordovician (Maysville) in age, and was subdivided into three members (summarized by Drake and Epstein, 1967).

For nearly a century there has been disagreement on the internal subdivision of the Martinsburg Formation in eastern Pennsylvania and New

Jersey. The arguments have been based on faunal and structural evidence. Those workers who have investigated the area generally west of the Lehigh River believe that the Martinsburg is divisible into two parts: a lower shale unit and an upper sandstone unit (Stose, 1930; Ward, 1937; Willard and Cleaves, 1939; Miller and others, 1941; Willard, 1943; Moseley, 1950), In the Delaware Valley and New Jersey a twofold division was likewise interpreted by Sanders (in Lesley, 1883), Lesley (1892), and Lewis and Kümmel (1915). Investigations in the slate belt between Delaware and Lehigh Rivers in Pennsylvania have generally yielded a threefold breakdown: two slate belts separated by a middle sandstone-bearing unit (Merriman, 1898; Dale and others, 1906, 1914; Peck, 1908; Miller, 1925; Behre, 1924, 1933; and Miller and others, 1939). Behre's work is the most detailed in the slate belt, but his threefold interpretation was not accepted on the most recent State geologic map (Gray and others, 1960). Detailed stratigraphic and structural evidence presented later by Drake and Epstein (1967) showed that the Martinsburg of the slate belt can be divided into three mappable members in almost the same way as defined by Behre. These are, in ascending order, the Bushkill, Ramseyburg, and Pen Argyl Members.

Differences in stratigraphic interpretation have led to various thickness estimates. Those who believe in a twofold interpretation have estimated that the Martinsburg is as thin as 3,000 feet (Stose, 1930), whereas those who believe in three members have estimated thicknesses in excess of 10,000 feet (Behre, 1933; Drake and Epstein, 1967).

The differences in stratigraphic interpretation have generally been blamed on complicated structure and poor exposures in the slate belt. However, mapping in the Stroudsburg and adjoining quadrangles has shown conclusively that there are three members. All geologists agree that a basal slate member (Bushkill) is overlain by a sandy member (Ramseyburg). However, those who believe in two members maintain that the upper member (Pen Argyl) of the threefold school is actually the lower member repeated by folding in a large, upright regional syncline and that it dips underneath the middle member. Thus, the relationships between the middle and upper members is of initial importance.

Southwest of the Stroudsburg quadrangle, where the Pen Argyl dips south at its contact with the Ramseyburg, it is overturned, as indicated by numerous sedimentary structures (i.e., graded bedding and cross-bedding), bedding-cleavage relations, and geometry of folds. In the Stroudsburg quadrangle the contact dips to the north, the beds are upright as shown by sedimentary structures, and the Pen Argyl is clearly younger than the Ramseyburg.

In support of his twofold hypothesis, Stose (1930, p. 655) argued that in the ravine at Slateford, near Delaware River (Portland quadrangle, pl. 1), calcareous sandstones underlie slates that Behre (1933) placed in his upper member. Stose believed, on the contrary, that the sandstones are near the base of the lower shale member because fossils collected 20 miles to the southwest along strike were considered by Ulrich to be older than Pulaski (Maysvillian), hence older than Behre's middle sandy member which Stose identified as the upper sandy member. As added proof, Stose (1930) believed that a possible outcrop of limestone with "Canadian" fossils beneath the drift in New Jersey, across the river from Slateford, showed that the calcareous sandstones in the ravine are basal Martinsburg and immediately overlie the limestones brought up in an anticline.

Stose's reasoning is in error. Behre (1933, p. 142) maintained that the fossils identified by Ulrich are too poorly preserved to be of stratigraphic value. The sandstones in the ravine are basal Ramseyburg, not basal Bushkill, and there is no limestone outcrop immediately across the river. Behre (1933) had erred slightly by including the slate in the quarries in his upper slate member (Pen Argyl Member). Actually, the quarries are in a slate belt or "run" within the Ramseyburg Member. Behre had failed to recognize that the Pen Argyl-Ramseyburg contact trended more northerly than he believed and was overlapped by the Shawangunk Formation just west of Delaware Water Gap. As a consequence, he (1933, pl. 24) mapped a thinned middle member and was obliged to map an unnecessary fault within it.

Thus, mapped structural relations demonstrate that the Pen Argyl overlies the Ramseyburg. There is also added stratigraphic supporting evidence. If the upper member were the lower member repeated by folding, the two units should be lithically similar. Such is not the case, as will be discussed below. In addition, quarrymen in eastern Pennsylvania have long been aware of two distinctly different slate belts in eastern Pennsylvania: a "soft-vein" belt to the north and a "hard-vein" belt to the south. These are not belts repeated by folding; Stose's (1930) regional syncline does not exist in this area (Drake and Epstein, 1967).

It should be pointed out that the two-member interpretation in the Delaware Valley and New Jersey by Sanders (1883), Lesley (1892), and Lewis and Kümmel (1915) is partly correct because the Pen Argyl Member is neither exposed at nor for several miles east of Delaware

Water Gap. It is possible that the upper member does not reappear in New Jersey, although Offield (1967) reports a similar three-unit sequence in Ordovician clastic rocks in southeastern New York.

Bushkill Member

The Bushkill Member was named by Drake and Epstein (1967) for exposures along Bushkill and Little Bushkill Creeks in the Wind Gap quadrangle, Northampton County, Pennsylvania. It is exposed in a few localities in the southeast corner of the Stroudsburg quadrangle where it consists of dark- to medium-gray thin-bedded to laminated carbonaceous slate, claystone slate, and thin interbeds of graywacke siltstone in upward-fining cycles. Beds do not exceed 6 inches in thickness and rarely exceed 1 inch, in sharp contrast to the much thicker bedded Pen Argyl Member. No fossils have been found in the Bushkill Member. The base is not exposed in the Stroudsburg quadrangle, but to the south it is gradational into the Jacksonburg Limestone of Middle Ordovician age. It is about 4,000 feet thick.

Ramseyburg Member

The Ramseyburg Member is characterized by graywacke that makes up 20 to 25 percent of the unit. It was named for representative outcrops near Ramseyburg, Portland quadrangle, Warren County, New Jersey (Drake and Epstein, 1967). The graywacke occurs as siltstone to medium-grained sandstone in beds ranging from laminae to more than 4 feet thick. Typically, the graywacke beds have an erosional base and grade up into medium-gray slate which in turn passes into grayish-black carbonaceous slate. The slate makes up most of the Ramseyburg, occurs in beds less than 1 inch to more than 10 feet thick, and is well exposed in many slate quarries in the vicinity of East Bangor (fig. 3).

Those parts of the Martinsburg that have more than 30 percent graywacke are shown as "Omrg" in plate 1. They range from 250 to 900 feet thick and alternate with equally thick slate-dominated intervals or "runs," one of which, the Bangor beds of Behre (1933), is still actively quarried. Behre included the Bangor beds in his upper slate member, but a prominent interval of graywacke overlies the Bangor beds and forms the top of the Ramseyburg Member as defined in the Stroudsburg quadrangle.

Graywacke beds are generally poorly exposed because they are calcareous and readily leached. Characteristically, they hold up low hills and litter the ground with "tobacco brown" (light brown to moderate yellowish brown) angular fragments several inches long. Graded bedding, parallel and ripple laminations, and convoluted bedding is common in the graywacke. Rarely, comminuted fossil debris is found. These characteristics, along with sole marks, have led Van Houten (1954) and McBride (1962) to the conclusion that the graywacke was emplaced by turbidity currents in deep water where the "normal" sediment was pelagic mud.

The Ramseyburg Member is about 2,800 feet thick. Its gradational contact with the underlying Bushkill Member is placed at the lowest prominent graywacke bed, generally more than 1 foot thick, in the section.

Pen Argyl Member

The slate quarries near Pen Argyl, Wind Gap quadrangle, Northampton County, Pennsylvania, are tho type locality for the Pen Argyl Member

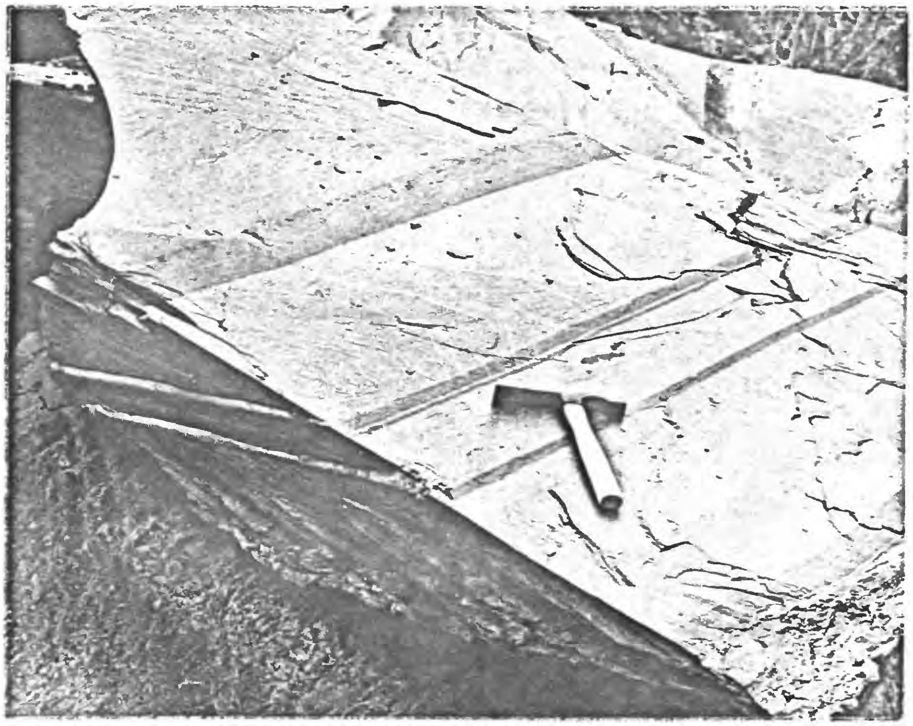

Figure 3. Gray slate beds, more than 1 foot thick, and thinner carbonaceous beds in slate block at Capitol Slate Co. quarry, East Bangor, Pa. Hammer rests on cleavage; bedding dips to left. Note white calcite and quartz in bedding-plane slickensides on underside of block. Cleavage deforms the slickensides, although this is not apparent in photograph.

(Drake and Epstein, 1967). The Pen Argyl Member consists of dark-gray, thick- to thin-bedded (beds more than 15 feet thick are common), evenly bedded claystone slate rhythmically interbedded with grayish-black carbonaceous slate. Occasional graywacke beds as much as 4 feet thick mark the base of fining-upward sequences as they do in the underlying Ramseyburg Member. The Pen Argyl is probably more than 5,000 feet thick in the Stroudsburg quadrangle and is unconformably overlain by the Shawangunk Formation. Its lower contact is the top of the uppermost prominent graywacke bed in the upper graywacke interval of the Ramseyburg Member. The Pen Argyl disappears under the Shawangunk just west of Delaware Water Gap and no exposures are known in the Portland quadrangle west of the gap.

Age of the Martinsburg Formation

The Martinsburg Formation has been regarded as Middle Ordovician (Trenton) to Late Ordovician (Maysville) in age (see summary by Drake and Epstein, 1967). The Bushkill Member rests conformably on the Jacksonburg Limestone). The upper Jacksonburg is early Barnveldian (= middle Trenton), based on conodont studies by Barnett (1965). In 1969, I discovered graptolites in the upper part of the Pen Argyl Member at Lehigh Gap, Palmerton quadrangle, Pennsylvania. These were identified by W. B. N. Berry of the University of California, Berkeley (written commun., 1969, 1970). The graptolites are indicative of the upper subzone (Climacograptus spiniferus subzone) of zone 13 (Orthograptus truncatus intermedius zone) which is probably early Edenian. Thus the Martinsburg ranges from late(?) Barnveldian to early Edenian and is more restricted than previously reported.

Petrography

Besides the gross lithic differences mentioned above, the slates and sandstones (graywackes) vary little throughout the Martinsburg Formation. Grain size ranges from less than .005 mm in clay slates to about 0.3 mm in medium-grained sandstones.

As determined by semiquantitative X-ray diffraction analyses, the dominant minerals in three random samples of slate in the Stroudsburg quadrangle are quartz (32-52 percent), muscovite (25-55 percent), chlorite (10-25 percent), and feldspar (1-3 percent). Calcite is variable as seen in thin section. Probably much of the calcite is ankeritic, judging from the brown stain that develops on weathering. Pyrite and black opaque minerals are commonly scattered throughout all samples. The grayish-black slates that form the top of upward-fining cycles are carbonaceous, less calcareous, and finer grained than the dark-gray slates.

Quartz grains in the slate are angular. They are stretched in the direction of cleavage and the sides that are perpendicular to cleavage are ragged, evidently due to pressure solution. Finer grained quartz, chlorite, muscovite, calcite, and iron-oxide dust have grown in the pressure-shadow areas (fig. 4).

Chlorite and muscovite form a large part of the groundmass of the slate. They are lath shaped and some of these grains lie parallel to the cleavage, although many grains do not. These groundmass minerals are difficult to examine optically because of their small size. Larger grains of intergrown chlorite and muscovite are as much as 50 times the average grain size of the groundmass minerals and are believed to be porphyroblasts (fig. 4). The chlorite has blue and reddish-brown

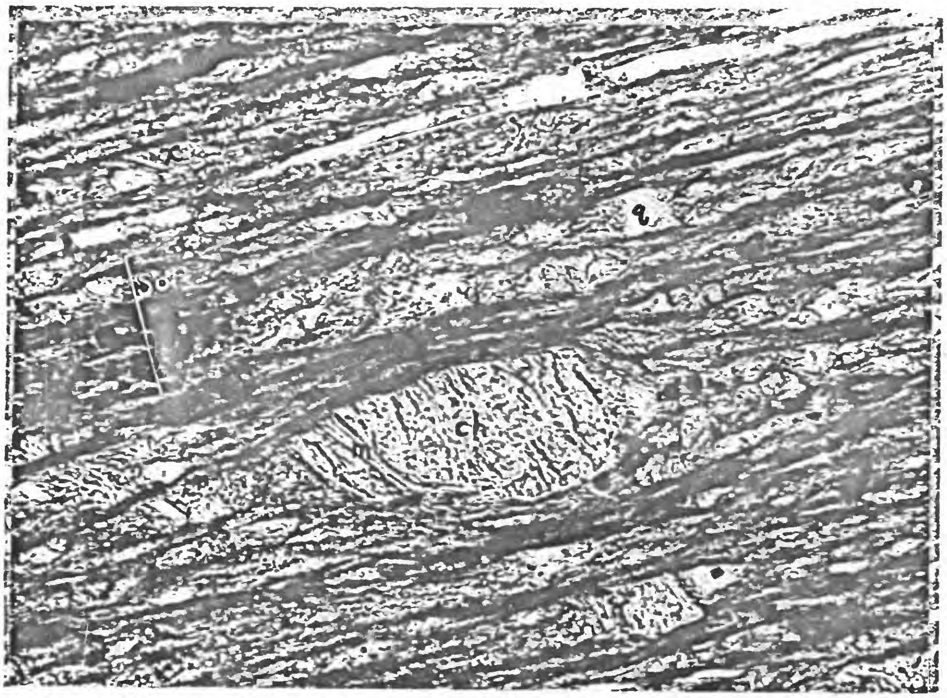

Figure 4. Photomicrograph (plane-polarized light, X 275) of dark-gray slate, Pen Argyl Member of the Martinsburg Formation, from dumps of inactive New Peerless slate quarry, 2,800 feet southeast of North Bangor, Pennsylvania. Bedding (S_0) lies at an angle of about 90° to slaty cleavage (S_1). Quartz (q) is angular with growths of smaller muscovite, quartz, chlorite, and calcite in pressure-shadow areas (arrow). Several porphyroblasts of intergrown chlorite (ch, penninite) and muscovite (m) are more than 10 times the average grain size of the groundmass. The porphyroblasts are elongated in the direction of cleavage, their mineral cleavage is at a high angle to the slaty cleavage, and the mineral cleavage lies at a slight angle to bedding. Many platy minerals are parallel to cleavage, but some (at x, for example), lie at appreciable angles to cleavage. Opaque minerals, mostly pyrite and probably magnetite, are scattered throughout.

interference colors and is identified as pennine.

Carbonaceous matter forms black streaks in cleavage planes. An occasional grain of microcline can be identified in thin section, but the dominant feldspar is albite, as indicated by X-ray analysis. Albite has not been definitely identified in thin section because of the fine grain size of the slates.

The slaty cleavage is believed to have developed under conditions of low-grade metamorphism. This has important regional structural significance and will be discussed under the section on structural geology.

Chemical analyses of typical slates and graywackes from the Martinsburg Formation are given in table 1. The relatively low silica content, low silica/alumina ratios, and low alumina/soda ratios as shown by the chemical analyses, as well as the textural and mineralogical characteristics of these rocks, particularly the sandstones, show that they are an immature suite (compare with more mature rocks of the Shawangunk Formation in table 2). Further details of mineralogy and chemical composition are given by Behre (1933). Megascopically, graywacke is hard, medium-gray to medium-dark-gray, micaceous, poorly sorted sandstone and siltstone. Both lithic and feldspathic graywackes are common (classification of Pettijohn, 1957). As shown in thin section (figs. 5-7), the matrix consists predominantly of silt- and clay-size muscovite, quartz, chlorite, and calcite, with minor opaque minerals and carbonaceous matter. Floating in the matrix, which ranges from about 25 to 50 percent of the rock, are angular grains of quartz (probably 30 to 40 percent), feldspar (1-10 percent, predominantly plagioclase and mostly albite-andesine), muscovite and chlorite

Table 1. Typical chemical analyses of slate (samples 1-3) and graywacke (samples 4 and 5) from the Martinsburg Formation. [Samples 1, 4, and 5 are rapid-rock analyses by P. Elmore, G. Chloe, J. Kelsey, S. Botts, H. Smith, J. Glenn, and L. Artis, U.S. Geological Survey. Samples 2 and 3 are analyses from Behre (1933, p. 174).]

	1	2	3	4	5
SiO_2	50.2	57.14	55.56	59.2	69.9
Al_2O_3	16.4	17.08	20.57	8.4	12.7
Fe_2O_3	2.0	5.76	6.18	1.5	2.0
FeO	4.4			3.2	4.1
MgO	2.8	3.29	2.76	2.6	2.4
CaO	7.6	3.95	3.27	9.6	.36
Na_2O	.63	1.05	1.12	1.5	1.3
K_2O	3.8	3.11	2.95	1.5	2.6
H_2O-	.19			.10	.29
H_2O+	3.8			1.6	3.0
TiO_2	.80	.53	.66	.48	.84
P_2O_5	.16			.12	.15
MnO	.10			.17	.05
CO_2	6.6	n.d.	n.d.	9.5	.05
Total	99.48			99.47	99.74

1. Slate, middle part of the Pen Argyl Member, abandoned Peters slate quarry, 5,000 feet north-northeast of Walnutport, Palmerton quadrangle, Northampton County, Pa.
2. Hard slate, Ramseyburg Member, Consolidated No. 1-Star quarry (now Capitol Slate Co.), East Bangor, Pa., Stroudsburg quadrangle. Note: n.d., not determined; loss on ignition 9.75 percent.
3. Soft slate, Ramseyburg Member, Consolidated No. 1-Star quarry (now Capitol Slate Co.), East Bangor, Pa., Stroudsburg quadrangle. Note: n.d., not determined; loss on ignition 9.50 percent; sulphur 0.76 percent.
4. Graywacke, Pen Argyl Member, abandoned Lehigh Gap slate quarry, 4,500 feet north of Slatington, Pa., Palmerton quadrangle. Figure 5 is photomicrograph of sample.
5. Graywacke, Pen Argyl Member, 150 feet below contact with Shawangunk Formation, Lehigh Gap, Pa., Palmerton quadrangle. Figure 6 is photomicrograph of sample.

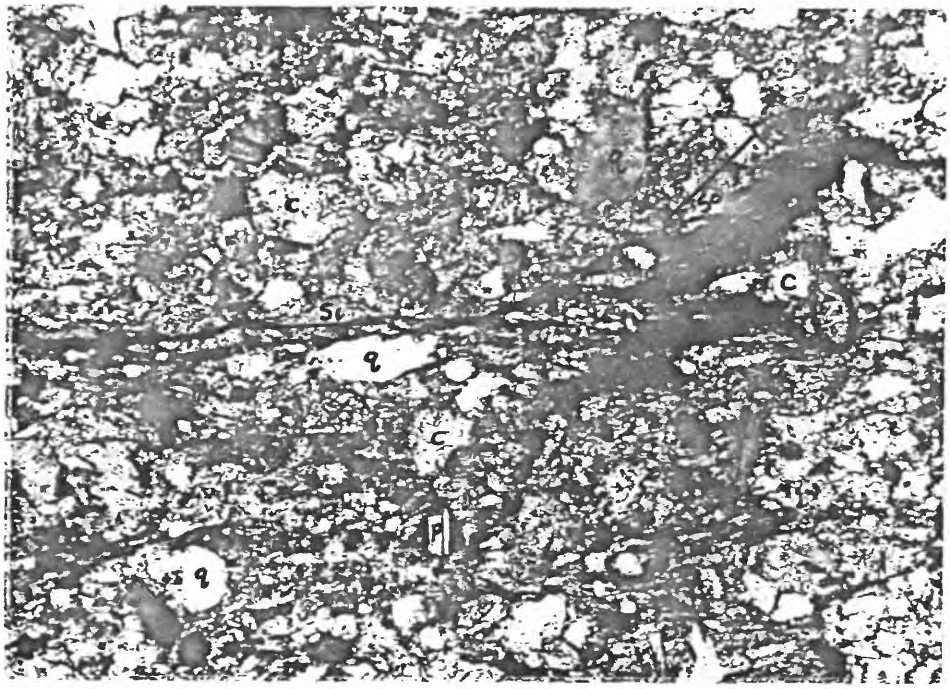

Figure 5. Photomicrograph (crossed polarizers, X 110) of medium-dark-gray, fine- to medium-grained lithic (calcitic) graywacke, Pen Argyl Member of the Martinsburg Formation, abandoned Lehigh Gap slate quarry, 4,500 feet north of Slatington, Pa., Palmerton quadrangle. The framework grains are as much as 0.2 mm long and consist of quartz (q, 35 percent); irregular discrete grains and lesser rhombs of calcite (c, 15 percent); plagioclase feldspar (p, 1 percent); muscovite (m) and chlorite (about 2 percent); and rare zircon (z). The groundmass is composed of finer grained muscovite, quartz, chlorite, and calcite, and lesser carbonaceous matter and opaque minerals. Note cleavage (S_1) which is at an angle of 25° to bedding (S_0). Chemical analysis of this sample is given in table 1, column 4.

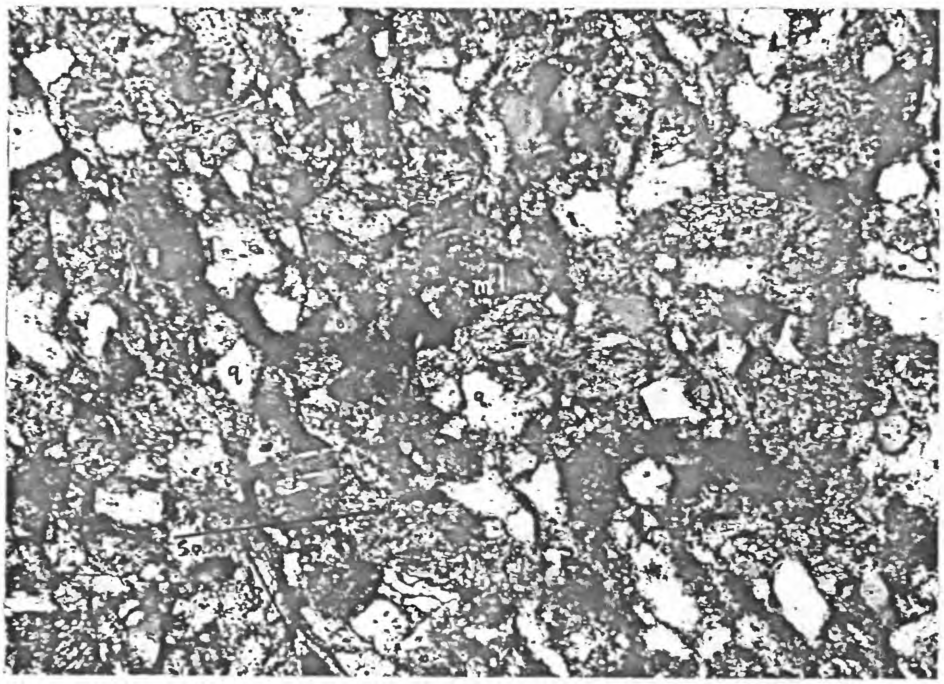

Figure 6. Photomicrograph (crossed polarizers, X 110) of lithic graywacke, Pen Argyl Member of the Martinsburg Formation, 150 feet below the contact with the Shawangunk Formation, Lehigh Gap, Palmerton quadrangle, Pennsylvania. The framework minerals are quartz (q, 34 percent), argillite rock fragments (r, 9 percent), plagioclase feldspar (p, 4 percent), and microcline (m) and orthoclase (2 percent), in a fine-grained matrix of muscovite, quartz, and chlorite (47 percent) with minor limonite and other opaque minerals. Detrital biotite (b), partly altered to chlorite, makes up less than 1 percent of the rock. Bedding (S_0) makes an angle of 60° to cleavage (S_1). Chemical analysis of this sample is given in table 1, column 5.

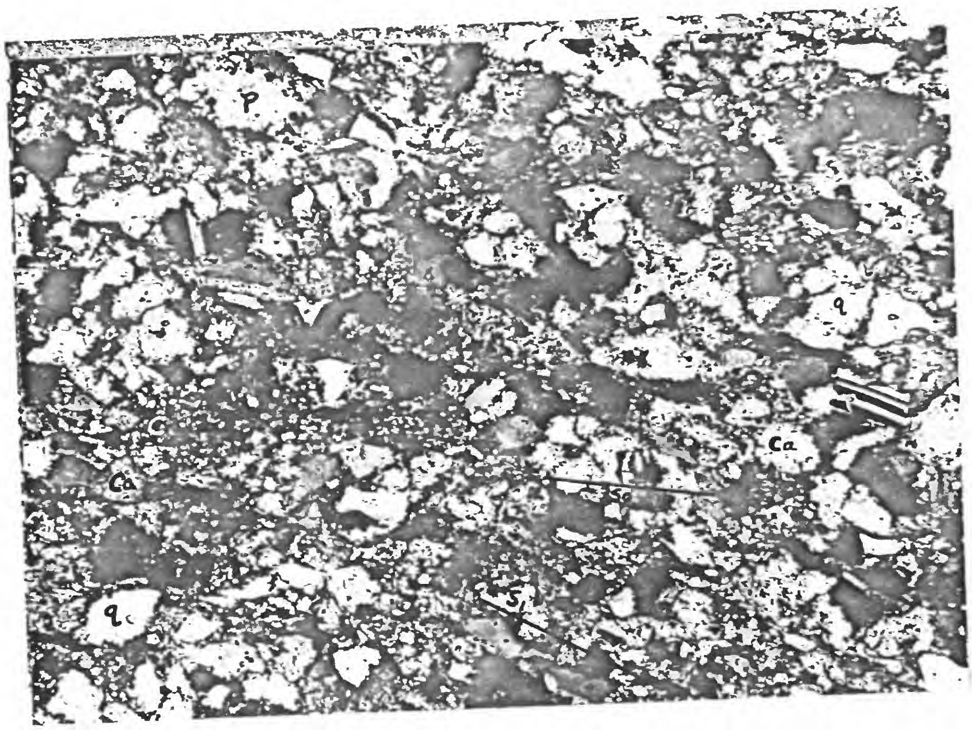

Figure 7. Photomicrograph (crossed polarizers) of fine-grained feldspathic graywacke, Ramseyburg Member, Slateford Creek, Portland quadrangle. Matrix (36 percent) consists of a paste of muscovite, chlorite, quartz, calcite, and opaque matter. The framework grains are quartz (q, 43 percent), feldspar (mostly plagioclase, p, 7 percent), rock fragments (shale, 2 percent), and less than 3 percent chert (c), zircon, chlorite, and muscovite. Very rare detrital biotite in the rock, partly altered to chlorite, is not present in this photograph. Carbonate minerals, probably sideritic calcite (Ca), make up about 9 percent of the rock. Some calcite appears as discrete grains, but much is recrystallized and envelops and replaces other grains. Bedding (S_0) is at an angle of 17° to cleavage (S_1).

(probably averaging about 5 percent), and calcite (probably 1 to 15 percent). The calcite in many thin sections appears to be detrital because it occurs as discrete irregular grains with the same range in grain size as detrital quartz and does not generally envelop and form a cement around other grains. Thus, if the calcite is considered as rock fragments, these sandstones are lithic graywackes (fig. 5). Rock fragments of other types, such as shale and siltstone, are rare in calcitic graywackes and common in some noncalcitic types (fig. 6). Feldspathic graywackes are also common (fig. 7). In outcrop, intraclasts of shale (now slate) are common. These are as much as several inches in length. Heavy minerals, such as zircon and rutile, were noted. No amphibole or pyroxene was seen. Many graywacke beds have framework minerals that are dominantly silt size. These are graywacke siltstones and generally overlie graywacke sandstones and grade up into slates.

SILURIAN

Shawangunk Formation

Sandstones and conglomerates in southeastern New York were first named the Shawangunk Conglomerate by Mather (1840). In eastern Pennsylvania, these rocks were called Levant by Rogers (1858), Oneida and Medina by White (1882), and first termed Shawangunk by Grabau (1909). Historical summaries are given by Schuchert (1916) and Swartz and Swartz (1931).

Swartz and Swartz (1931) traced the Tuscarora Sandstone and Clinton Formation eastward from central Pennsylvania to Delaware Water Gap where they lose their identity and merge into the Shawangunk Formation. Detailed mapping by Epstein and Epstein (1967, 1969) shows that the

Clinton Formation of Swartz and Swartz (1931) can be traced from the Lehigh Gap area eastward to Delaware Water Gap where it forms a tongue in the Shawangunk (fig. 8). Similarly, the Tuscarora of Swartz and Swartz (1931) can be traced beneath the Clinton. Because the name Shawangunk has priority over the Tuscarora (named by Darton in 1896) and Clinton (named by Conrad, 1842), the Shawangunk Formation is used in the area of this report for rocks above the Martinsburg Formation and below the Bloomsburg Red Beds. Three members are herein defined. They are, from bottom to top, the Minsi, Clinton, and Tammany Members.

The Shawangunk is about 1,390 feet thick along U.S. Interstate 80 in Delaware Water Gap. Because of the extremely irregular upper contact with the Bloomsburg Red Beds, to be discussed later, the thickness can be as great as 2,100 feet. This may account for the wide variation of reported thicknesses at the gap: Chance (1882), 1,565 feet; Grabau (1913), 1,900 feet; Swartz and Swartz (1931), 1,823 feet.

Minsi Member

The Minsi Member of the Shawangunk Formation is named for exposures in Delaware Water Gap, Warren County, N. J. (fig. 9), where it contains quartzite[1], conglomerate, and minor siltstone. It forms a cliff face along the south slope of Blue and Kittatinny Mountains. The Minsi Member is 303 feet thick at its type section (measured section 1) and consists of light-gray to medium-dark-gray, medium- to coarse-grained,

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[1] Quartzite is used in this report for a dense sandstone that is generally cemented by silica or which has interlocking quartz grains. The rock breaks across the grains. Quartzite does not necessarily imply metamorphism. "Sandstone" and "quartzite" are used interchangeably in this report, where applicable.

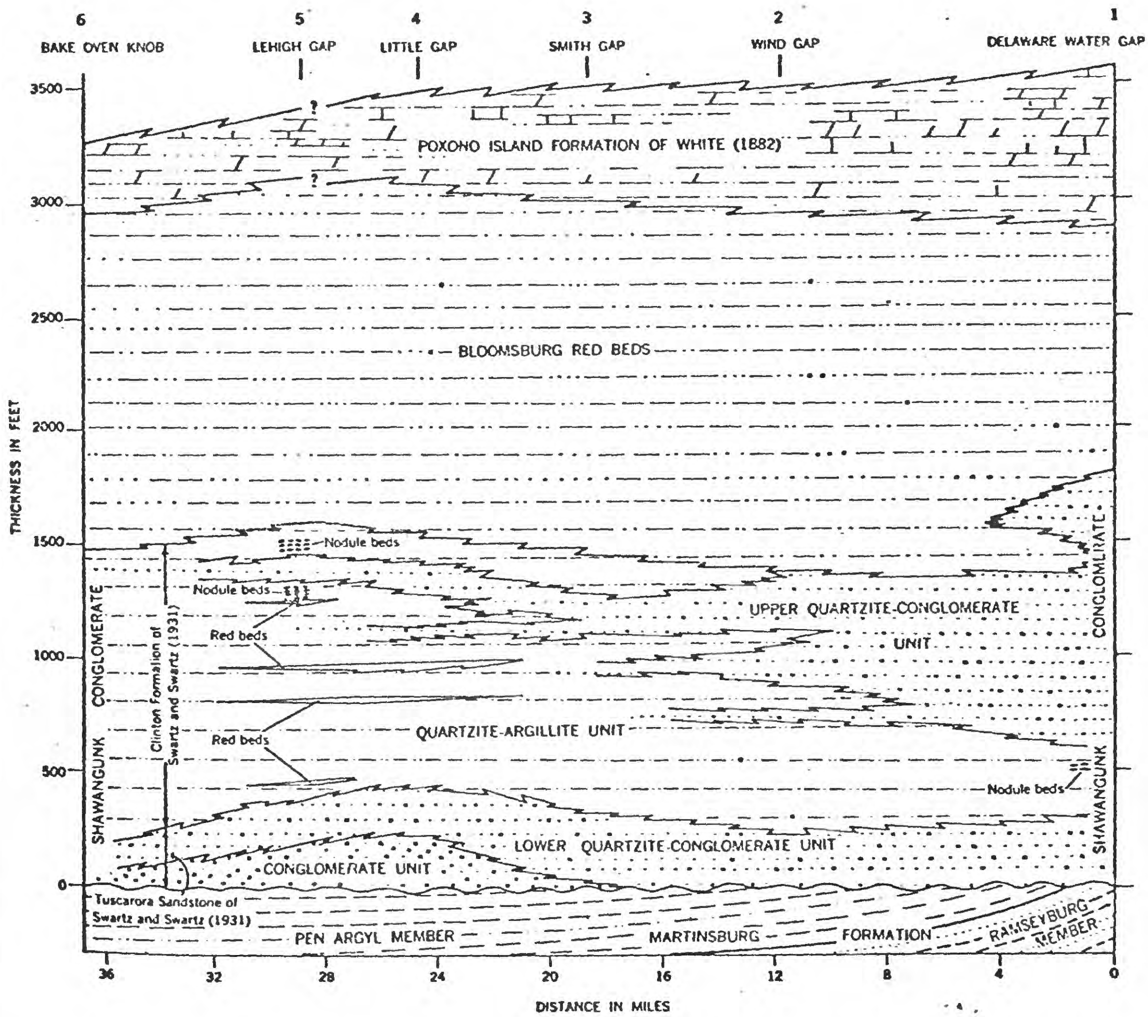

Figure 8. Stratigraphic section of the Shawangunk Conglomerate (Shawangunk Formation in this report), Bloomsburg Red Beds, and Poxono Island Formation from Delaware Water Gap in the Stroudsburg and Portland quadrangles, to Bake Oven Knob, just south of the Lehighton quadrangle. From Epstein and Epstein, 1969. The lower quartzite-conglomerate unit is herein named the Minsi Member, the quartzite-argillite unit is the Clinton Member, and the upper quartzite-conglomerate unit is the Tammany Member.

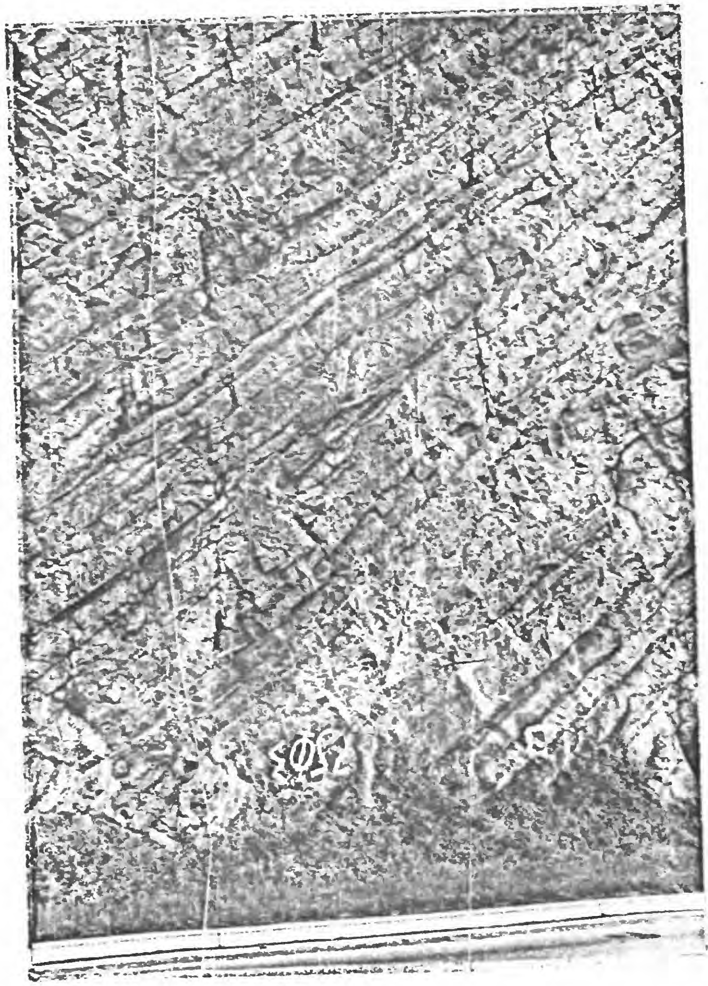

Figure 9. Interbedded quartzite and conglomerate in the Minsi Member of the Shawangunk Formation at the type section, Delaware Water Gap, Warren County, N. J. Note channeled bases of many of the beds.

crossbedded to planar-bedded, limonitic, pyritic, unevenly to moderately evenly bedded, thin- to thick-bedded quartzite, conglomeratic quartzite, and quartz-, chert-, and shale-pebble conglomerate (quartz pebbles are as much as 2 in. long).

About 7 percent of the member is made up of dark-gray irregularly bedded to evenly laminated siltstone that is locally shaly and mud-cracked (fig. 10). The lower contact is not presently exposed in the quadrangle, but Beerbower (1956) described it as abrupt and unconformable on the Martinsburg Formation. No fossils have been found in the Minsi Member, although Schuchert (1916, p. 546) reports Arthrophycus, probably a feeding burrow, 225 feet above the base in Delaware Water Gap, and I have observed the same trace fossil in a large block of rock in the retaining wall about 300 feet south of the Martinsburg-Shawangunk contact along U.S. Interstate 80 in New Jersey.

The sandstones or quartzites of the Minsi Member are submature (matrix averages about 12 percent of thin sections studied) and contain enough feldspar (about 3-5 percent, predominantly potash feldspar) and minor rock fragments (<1 percent, mostly shale and siltstone) to be classed as feldspathic sandstones (fig. 11). The chemical composition of a similar submature sandstone (protoquartzite, in this case) from basal beds of the Shawangunk Formation is given in Table 2, sample 1. The heavy-mineral suite in the quartzites is mature (mostly zircon and lesser rutile and tourmaline). These heavy minerals are well rounded to anhedral, and, together with quartz grains that contain minor inclusions of biotite and vermicular chlorite, as well as grains of orthoclase, suggest a reworked sedimentary source with possible minor contributions from a granitic terrane with quartz veins. On the other

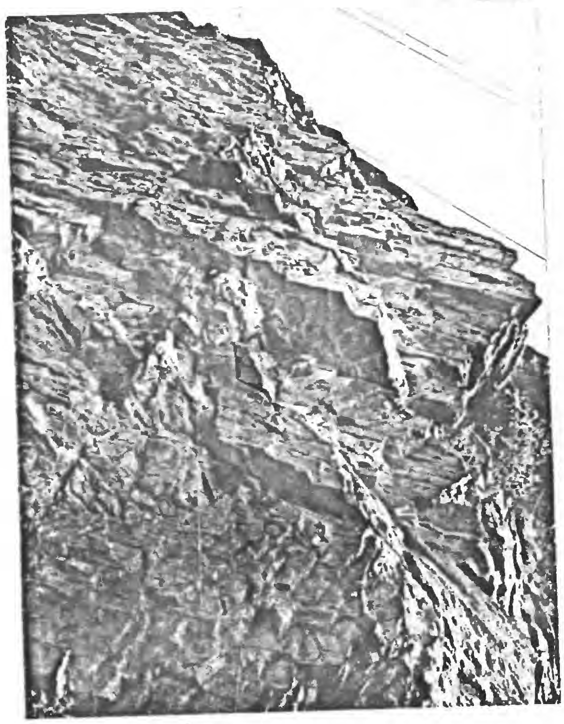

Figure 10. Mud-cracked shaly siltstone, Minsi Member of the Shawangunk Formation. Underside of bed exposed about 50 feet above U.S. Interstate 80 at south entrance of Delaware Water Gap, Portland quadrangle, Warren County, N. J.

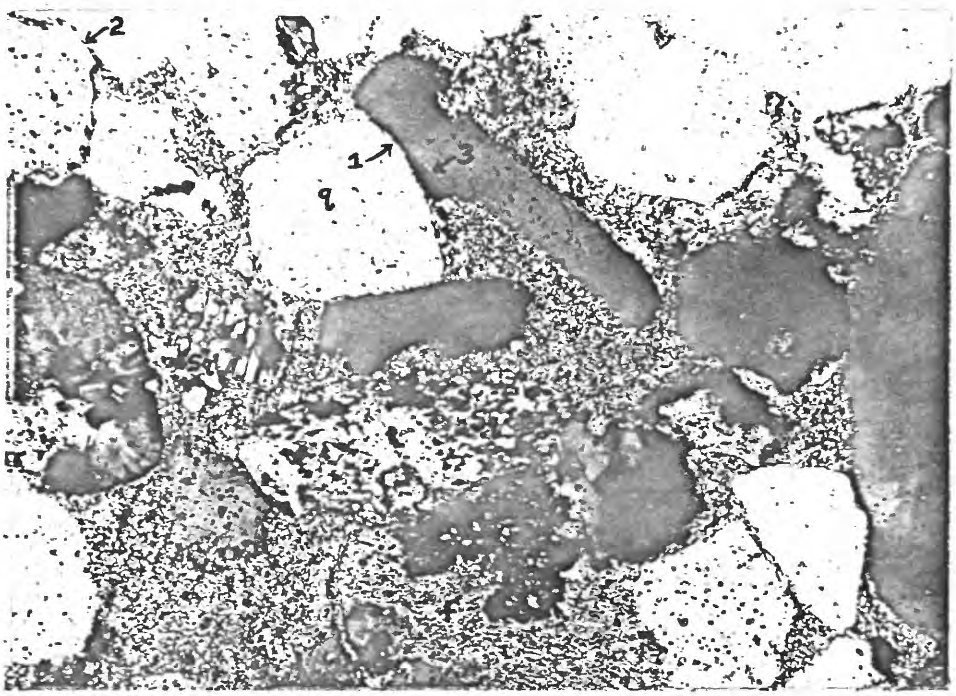

Figure 11. Photomicrograph (crossed polarizers, X 106) of poorly sorted, conglomeratic, fine- to medium-grained feldspathic sandstone from lowest exposed bed of the Minsi Member of the Shawangunk Formation, Delaware Water Gap, Portland quadrangle, New Jersey (unit 1 of measured section 1). Matrix minerals (13 percent) are not readily identified but appear to consist mainly of muscovite and quartz with minor chlorite, limonite, and hematite. Framework grains are quartz (q, 80 percent), as much as 5 mm long, sericitized potash feldspar (f, 5 percent), partly perthitic and as much as 0.1 mm long, and chert (2 percent). Many quartz grains are composite with sutured contacts (sq) and indicate a metamorphic or presolved sedimentary quartzite source. Grains are angular to subround. Quartz-grain contacts are straight or concave with (at 1) or without (at 2) a clay coating, or are overgrown with optically continuous quartz (at 3). Abundant vacuole inclusions are in the quartz. Accessory heavy minerals include a mature suite of subhedral to rounded zircon and lesser rutile and tourmaline. One grain tentatively identified as monazite is included in a quartz grain. Rock fragments (shale) are not common (<1 percent).

Table 2. Typical chemical analyses of rocks from the Shawangunk Formation. [Rapid-rock analyses by P. Elmore, G. Chloe, J. Kelsey, S. Botts, H. Smith, J. Glenn, and L. Artis, U.S. Geological Survey.]

	1	2	3	4
SiO_2	76.6	92.2	82.9	67.3
Al_2O_3	11.0	2.5	5.3	18.3
Fe_2O_3	.68	1.0	2.2	1.6
FeO	2.2	1.1	3.5	.76
MgO	1.7	.37	1.1	1.2
CaO	.24	.13	.81	.32
Na_2O	.03	.00	.12	.18
K_2O	3.2	.26	.98	5.7
H_2O-	.24	.09	.11	.38
H_2O+	2.3	1.2	1.6	2.5
TiO_2	.75	.28	.45	1.1
P_2O_5	.11	.00	.27	.04
MnO	.04	.04	.02	.02
CO_2	$<.05$	$<.05$	.05	.10
Total	99.09+	99.17+	99.41	99.50

1. Quartzite, probably protoquartzite, from lower 10 feet of Shawangunk Formation (conglomerate unit, fig. 8), Lehigh Gap, Palmerton quadrangle, Northampton County, Pa.
2. Orthoquartzite, Clinton Formation, Lehigh Gap, Palmerton quadrangle, Carbon County, Pa.
3. Phosphatic quartzite, Clinton Member of the Shawangunk Formation, Delaware Water Gap, Portland quadrangle, New Jersey; unit 46 of measured section 1.
4. Dark-gray siltstone, Minsi Member of the Shawangunk Formation, Delaware Water Gap, Portland quadrangle, New Jersey; unit 11 of measured section 1.

hand, composite quartz veins, made up of sutured and partly stretched smaller quartz grains, indicate a sedimentary (presolved) quartzite or low-grade metamorphic terrane. Conceivably, the total mineral assemblage could have been derived directly from a sedimentary source. Labile minerals, such as hornblende, are extremely rare.

The siltstones, as seen in thin section, consist predominantly of quartz in a muscovite-chlorite matrix. Figure 12 is a photomicrograph of a siltstone containing about 55 percent quartz, 25 percent muscovite, 15 percent chlorite, and less than 1 percent feldspar (determined by semiquantitative X-ray diffraction analyses).

Clinton Member

The name Clinton was first used by Conrad (1842) for exposures near Clinton, N. Y. The New York Geological Survey now uses the name as a group in central New York which includes conglomerate, shale, and sandstone (Fisher, 1960). The name has been used extensively throughout the Appalachians and was used by Chance (1882) at Delaware Water Gap for rocks that are herein called Bloomsburg. Interestingly, the Clinton was not used for rocks in southeastern New York (Fisher, 1960) that are part of the outcrop belt that extends into eastern Pennsylvania. However, the name is so ingrained in Pennsylvania literature (e.g., Swartz and Swartz, 1931; Wood and others, 1969) that the name is retained. As described above, the Clinton Member, in the area of this report, is a tongue of the Clinton Formation of Swartz and Swartz (1931). The reference section for the Clinton Member is in the exposures along U.S. Interstate 80 in Delaware Water Gap where the member consists of alternating shaly siltstone and quartzite (fig. 13).

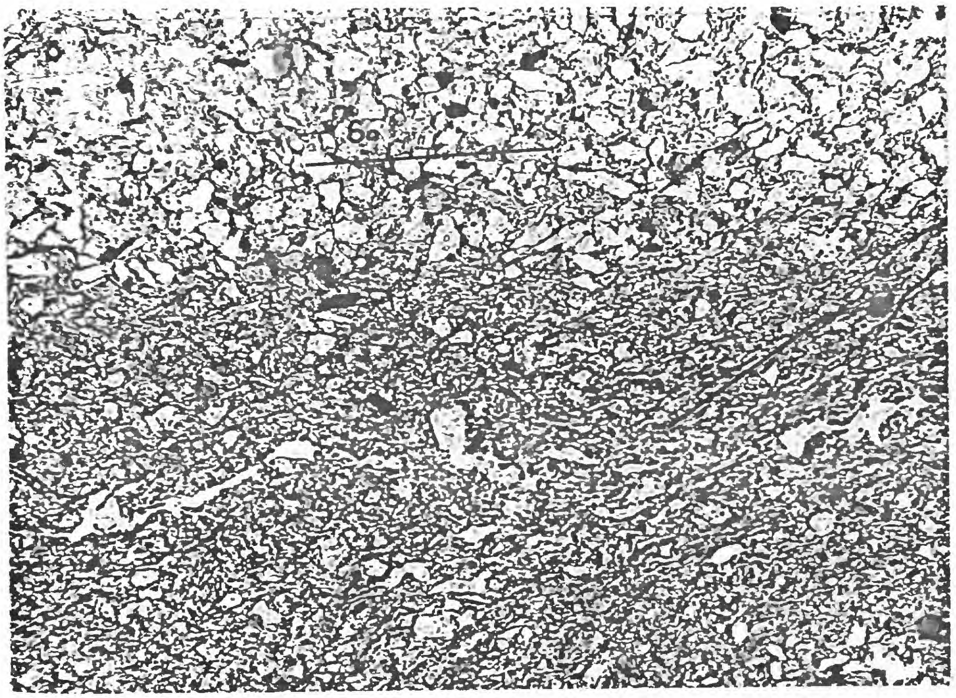

Figure 12. Photomicrograph (plane-polarized light, X 150) of siltstone, Minsi Member of the Shawangunk Formation, Delaware Water Gap, Portland quadrangle, New Jersey. Top of unit 9 of measured section 1. Coarse siltstone lamina channeled into fine siltstone. Coarser grains are mostly quartz and lesser muscovite. Finer matrix is composed of quartz, muscovite, and chlorite. Irregular cleavage (S_1) is at an angle of 50° to bedding (S_o).

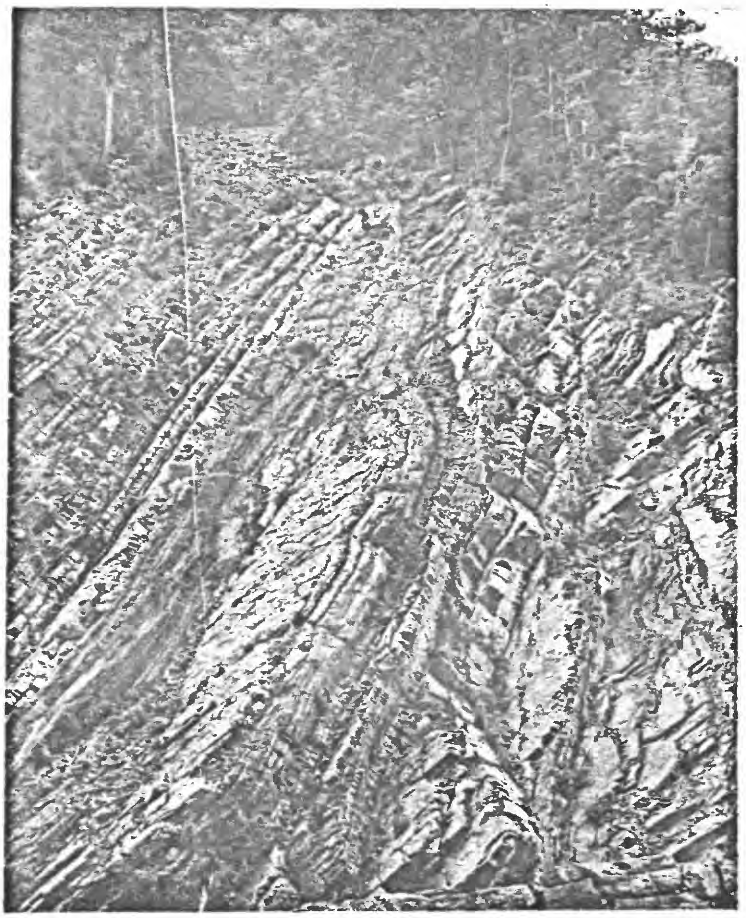

Figure 13. Reference section of the Clinton Member of the Shawangunk Formation along U.S. Interstate 80, Delaware Water Gap. The unit consists predominantly of evenly bedded alternating shaly siltstone and quartzite.

Stratigraphic details are given in measured section 1. The contact with the underlying Minsi Member is gradational.

The Clinton Member is 273 feet thick at Delaware Water Gap, and presumably thickens slightly westward in the Stroudsburg quadrangle as judged from regional relations (fig. 8). The quartzites are medium-light gray to medium-dark gray and light-olive gray, fine to coarse grained, laminated (fig. 14) to planar bedded, rippled (fig. 15), and flaser-bedded (fig. 16). Convolutions occur locally (fig. 17). Many quartzites are limonitic, calcitic, and pyritic; some contain rare flakes of graphite. White-weathering, black phosphatic nodules (fig. 16, 18) are common in some beds. The phosphatic mineral is carbonate fluorapatite (determined by X-ray diffraction methods).

The quartzites appear to lack the feldspar that is common in the underlying Minsi Member. They are mostly protoquartzites, although close to orthoquartzite in mineral composition (fig. 19).

The quartzites are interbedded with medium-dark-gray to dark-gray, laminated, flaser-bedded, evenly to unevenly bedded, and burrowed (fig. 20) siltstone and shaly siltstone.

The Clinton Member generally forms steep slopes on Blue and Kittatinny Mountains.

<u>Tammany Member</u>

The Tammany Member of the Shawangunk Formation is named for Mt. Tammany overlooking Delaware Water Gap, Warren County, N. J., Portland quadrangle. It forms the crest of most of Kittatinny and Blue Mountains. The type section is in Delaware Water Gap (fig. 21), where, along U.S. Interstate 80, it is 816 feet thick, but it thickens to about 1,500 feet to the northwest in the gap, at the expense of the overlying

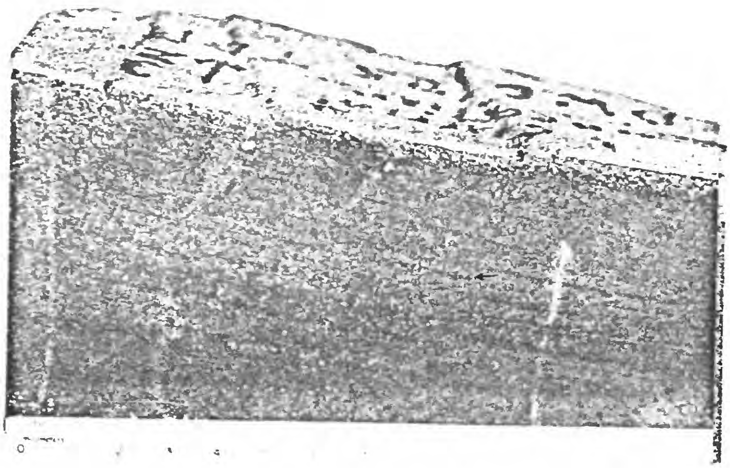

Figure 14. Laminated, well-sorted, fine-grained calcitic sandstone (protoquartzite, perhaps approaching orthoquartzite), believed to be a beach or barrier-bar deposit (see section on environments of deposition). Primary current lineation (not apparent in photograph) is present on the upper bedding surface and parallels the dip of the laminae. Small ridges on bedding surface are not ripples but offsets of small soft-rock faults (arrow) that paralleled the ancient strand line. Clinton Member of the Shawangunk Formation, Delaware Water Gap, N. J. Unit 25 of measured section 1.

Figure 15. Asymmetric ripples in fine-grained sandstone. Ripples have wavelengths of about 4 inches and amplitudes of about ½ inch. Clinton Member of the Shawangunk Formation, Delaware Water Gap, N. J. Unit 35 of measured section 1.

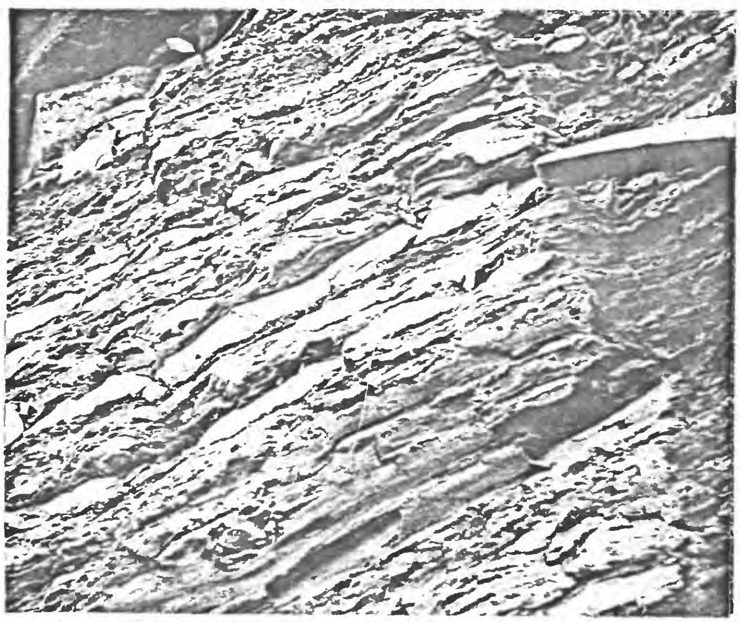

Figure 16. Flaser-bedded (ripple lenses), fine-grained sandstone irregularly interbedded with burrowed muddy siltstone. Many of the sandstones have load-cast sole markings. Black phosphate nodules that weather white, as much as $1\frac{1}{2}$ inches long, are scattered throughout. See figure 18 for photomicrograph of unit. Clinton Member of the Shawangunk Formation, Delaware Water Gap, N. J. Unit 46 of measured section 1.

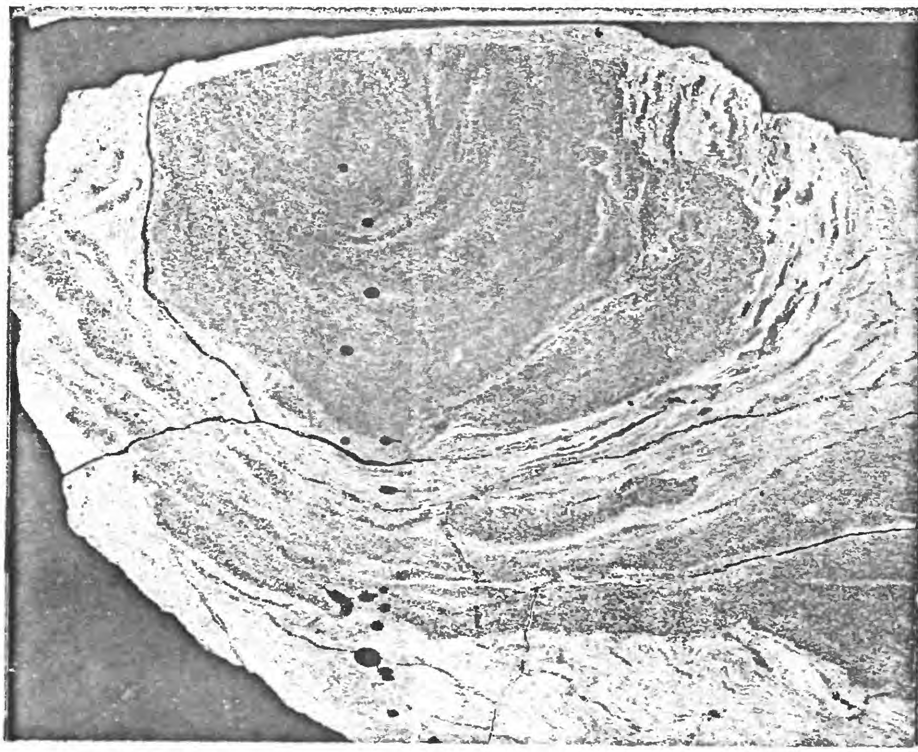

Figure 17. Convolutions (ball-and-pillow structure), due to soft-rock slumping, in very fine grained sandstone and siltstone. Note overturned and refolded flow fold at top. Negative print of acetate peel. Clinton Member of the Shawangunk Formation, Delaware Water Gap, N.J. Unit 43 of measured section 1.

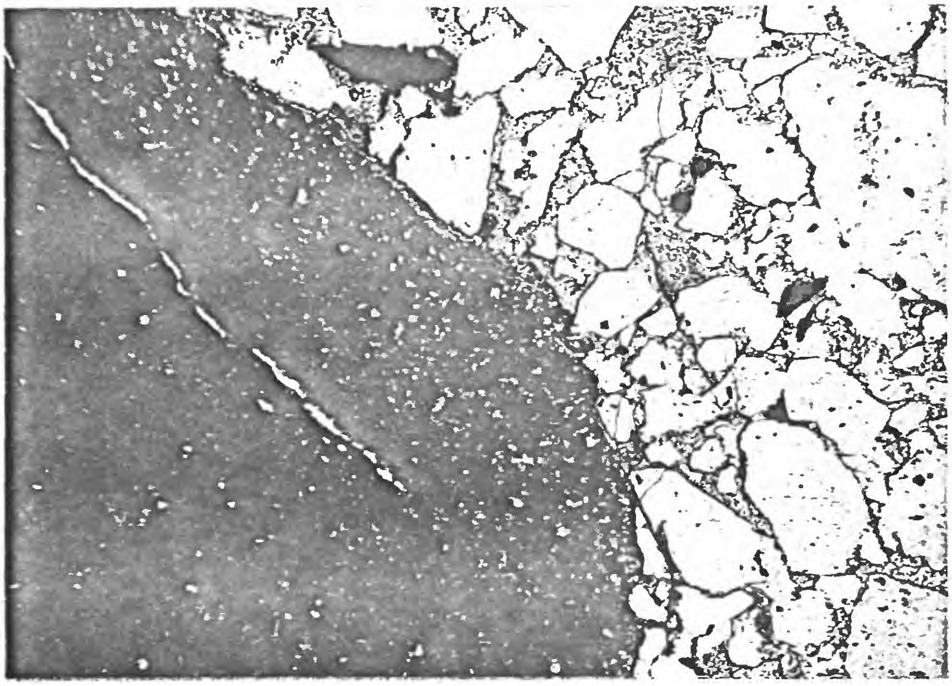

Figure 18. Photomicrograph (crossed polarizers, X 43) of phosphatic shale (large dark grain) in protoquartzite, Clinton Member of the Shawangunk Formation, Delaware Water Gap. Unit 46 of measured section 1. Figure 16 shows outcrop.

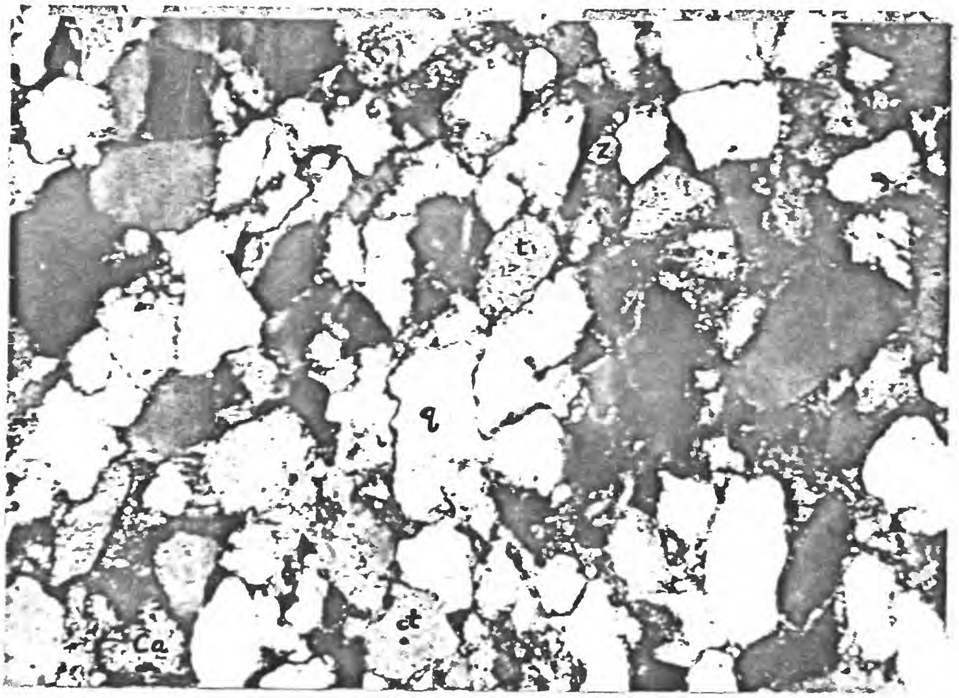

Figure 19. Photomicrograph (crossed polarizers, X110) of fine-grained quartzite, Clinton Member of the Shawangunk Formation, Delaware Water Gap, Portland quadrangle, N.J. Unit 25 of measured section 1. Quartz (q) and minor chert (86 percent) are the dominant minerals in a muscovite and chlorite matrix. Some matrix is entirely recrystallized to chlorite (pennine). Note the straight to interlocking contacts between quartz grains. Limonite-stained carbonate (probably calcite) (Ca) forms a cement in some areas and makes up about 4 percent of the rock. Minor potash feldspar (<1 percent) and rock fragments (shale, about 1 percent) were noted. Heavy minerals are not uncommon and include subrounded to rounded tourmaline (t), zircon (z), and rutile. The composition of the rock is on the borderline between that of a protoquartzite and orthoquartzite. Figure 14 is a photograph of the rock sample.

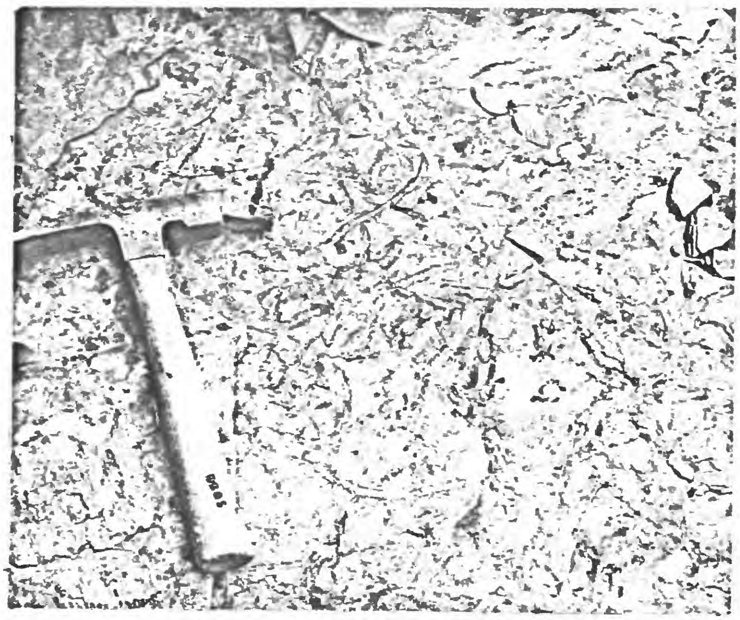

Figure 20. Feeding burrows on bedding plane of siltstone in Clinton Member of the Shawangunk Formation. Delaware Water Gap, N.J. Vertical burrows, more than 1 foot deep, are also common. Unit 31 of measured section 1.

Figure 21. Type section of Tammany Member (Sst) of the Shawangunk Formation overlying the Clinton Member (Ssc) at Delaware Water Gap, N. J.

Bloomsburg Red Beds.

The sandstones of the Tammany Member are similar to those of the Minsi Member, except that feldspar does not seem to be as abundant in the Tammany (<1 percent). The Tammany consists of medium-gray to medium-dark-gray, fine- to very coarse grained, planar-bedded to crossbedded, limonitic, pyritic, evenly to unevenly bedded quartzite and about 2 percent dark-gray shaly siltstone. Flattened shale pebbles are common. Quartz pebbles are as much as 2 inches long. The quartzites are predominantly protoquartzites (fig. 22).

Unique dolomite beds occur near the top of the Tammany Member about 400 feet south of the contact with the overlying Bloomsburg Red Beds and a few hundred feet north of the tollgate on U.S. Interstate 80 near the village of Delaware Water Gap, Pa. These beds are about 4 feet thick and consist of a medium-gray dolomite that weathers moderate brown and an upper greenish-gray dolomitic shale or shaly dolomite (fig. 23). The medium-gray dolomite is nearly pure ferroan dolomite (determined by X-ray diffraction and staining techniques). Minor calcite, quartz, muscovite, and a 14Å mineral, probably chlorite, were noted on the X-ray trace. The rock reacts slightly with cold dilute hydrochloric acid. The greenish-gray dolomitic shale or shaly dolomite consists of ferroan dolomite with about equal amounts of muscovite, quartz, and chlorite. No calcite was noted and the rock does not react with dilute HCl. Concretions of dolomite and calcite between $\frac{1}{2}$ and 3 inches in diameter, with concentric structure, are abundant. The dolomite beds are overlain and underlain by crossbedded and planar-bedded, predominantly medium grained, partly conglomeratic quartzites and siltstone. The lower bed contains irregular patches of rock similar to the upper bed. In thin

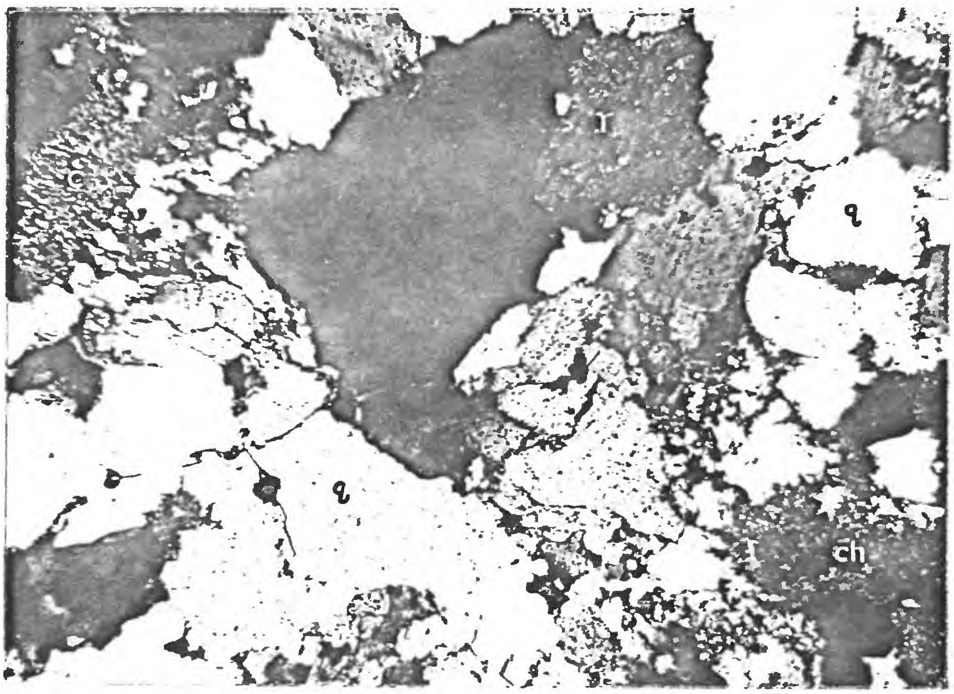

Figure 22. Photomicrograph (crossed polarizers, X 43) of conglomeratic coarse-grained protoquartzite, Tammany Member of the Shawangunk Formation, Delaware Water Gap (unit 58 of measured section 1). Framework minerals are quartz (q, 80 percent), chert (c, 1 percent), rock fragments (r, shale and siltstone, 1 percent), and minor muscovite and zircon. The quartz is rutilated and contains abundant vacuoles and minor vermicular chlorite inclusions. The quartz grains are angular to subrounded, simple to composite, and have straight to undulose extinction. Grain contacts are straight to concave. The matrix (18 percent) is composed of fine quartz, muscovite, and chlorite. Some areas are recrystallized to spherulitic chlorite (ch). Note peripheral growth of mica on some quartz grains.

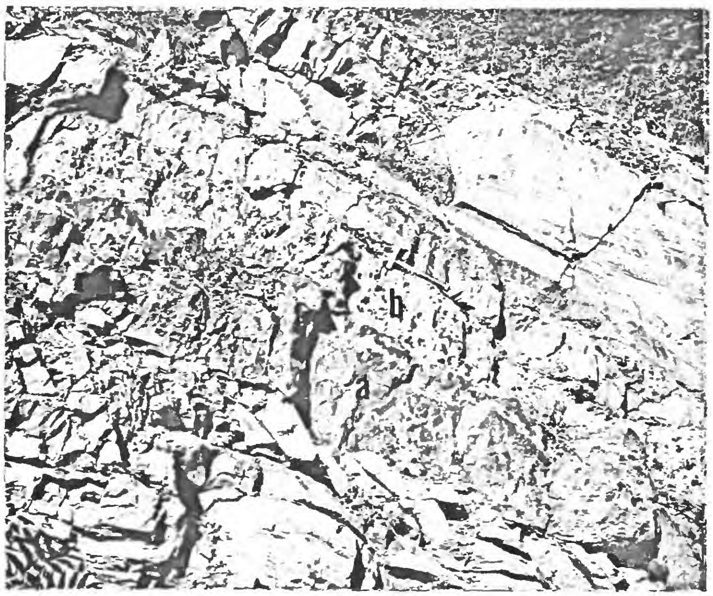

Figure 23. Medium-gray dolomite that weathers moderate brown (a, about 2 feet thick) overlain by greenish-gray dolomitic shale or shaly dolomite with nodules of calcite and dolomite with concentric structure (b, about 1.8 feet thick). Hammer is at contact with overlying fine- to medium-grained feldspathic sandstone. Tammany Member of the Shawangunk Formation, near tollgate on U.S. Interstate 80, at village of Delaware Water Gap, Pa.

section (fig. 24), the medium-gray dolomite consists of a mosaic of slightly clouded dolomite grains averaging about 0.04 mm in diameter that replace the dolomitic shale or shaly dolomite. A thin rim of a clearer carbonate mineral (calcite?) and minor quartz locally separates the two rock types. The calcite(?) and quartz are alined parallel to a poorly developed rock cleavage and are found in the pressure-shadow areas surrounding the shaly rock. It is, therefore, believed that the calcite(?) and quartz formed during development of rock cleavage and not during replacement by the medium-gray dolomite. The rock cleavage cuts both dolomite and shaly dolomite and postdates the original replacement. Ferroan dolomite nodules occur in scattered beds overlying and underlying this horizon, as well as in the overlying Bloomsburg Red Beds.

The lower boundary of the Tammany Member is transitional and is placed at the top of the last siltstone of the interbedded siltstone-quartzite sequence of the underlying Clinton Member. The upper contact is placed at the base of the first red bed. This color contact is extremely irregular, transects bedding, and rises about 700 feet within a horizontal distance of less than 1 mile in Delaware Water Gap (see cross section F-F', pl. II and measured section 2).

The lithologic contrast between the Bloomsburg and Shawangunk is likewise indistinct, so that lithologies could not be used conveniently for a mappable boundary. The color change was used because it has been the accepted method of separating the two formations (Willard, 1938, p. 10), and because it is the most satisfactory method when mapping float (the contact is covered in most areas beyond Delaware Water Gap). Gray

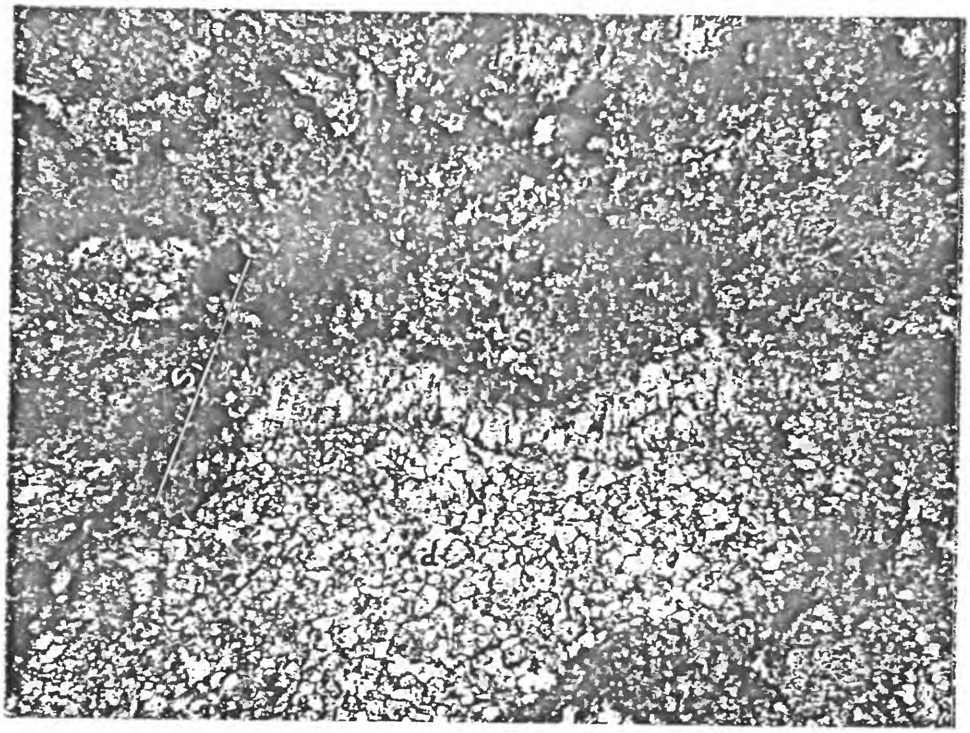

Figure 24. Photomicrograph (plane-polarized light, X 56) showing ferroan dolomite (d) replacing dolomitic shale or shaly dolomite (s). Rims of clear carbonate (calcite?) and minor quartz with comb structure (arrow), subparallel to cleavage (S_1), are believed to have grown during cleavage development. Cleavage cuts both dolomite and dolomitic shale. Sample from rock shown in figure 23.

quartzites and siltstones in Dunnfield Creek, Portland quadrangle, about 0.5 mile northeast of Delaware River, were mapped as Bloomsburg because it was not possible to determine whether they are continuous with upper Tammany rocks. If no red beds underlie them, then they are part of the Tammany Member.

Age of the Shawangunk Formation

The Shawangunk Formation of eastern Pennsylvania has been regarded as Early to Middle Silurian in age (Swartz and others, 1942). This age assignment was based primarily on the occurrence of eurypterids and *Arthrophycus* and on regional stratigraphic considerations. The evidence appears not to have been unequivocal and needs re-evaluation. The base of the Shawangunk conceivably could be latest Ordovician in age.

In central Pennsylvania, the clastic rocks immediately overlying the Martinsburg Formation are, in ascending order, the Bald Eagle Member of the Juniata Formation of Willard and Cleaves (1939), the Juniata Formation, and the Tuscarora Sandstone. No diagnostic fossils have been found in the Bald Eagle and Juniata, and their age is still uncertain (Willard, 1943, p. 1091; Swartz, 1942, p. 178), although they are generally believed to be Maysvillian and Richmondian in age (Twenhofel and others, 1954). East of the Susquehanna River, near Harrisburg, Pa., the Bald Eagle and Juniata pinch out, and at the Lehigh River the Shawangunk Formation, which is laterally continuous with the Tuscarora, rests directly on the Martinsburg Formation. For this reason, it was assumed that the base of the Shawangunk is Early Silurian in age. However, there is no reason to believe that parts of the basal Shawangunk are not correlative with rocks of the Juniata or Bald Eagle. Lack of diagnostic fossils in these rocks makes this suggestion a possibility. In southeastern New York, basal Shawangunk beds are believed to be Middle Silurian in age, but the lack of key fossils makes this correlation questionable (Fisher, 1960).

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

Further confusion regarding the Ordovician-Silurian boundary in eastern Pennsylvania can be traced to Willard and Cleaves (1939, p. 1185), who believed that a remnant of the Bald Eagle can be found at Lehigh Gap and east into Northampton County. If this were true, the basal clastics underlying the Blue Mountain in this area would be Maysvillian in age (Willard, 1943, p. 1118). The identification of the Bald Eagle at Lehigh Gap is suspect. Epstein and Epstein (1967, 1969) placed the basal conglomerates at Lehigh Gap in the Shawangunk. There is no compelling reason to believe that the conglomerates are distinct from overlying beds, and the disconformity that Willard and Cleaves (1939) postulate between what they believe to be Bald Eagle and the Shawangunk, because of the absence of the intervening Juniata, does not exist.

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

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

The Shawangunk Formation is sparsely fossiliferous. No fossils were found in the lower 300 feet which consist predominantly of quartzite and conglomerate between Lehigh and Delaware Rivers. In the overlying interbedded shales, siltstones, and sandstones (Clinton Formation of Swartz and Swartz, 1931; quartzite-argillite unit of Epstein and Epstein, 1967, 1969; Clinton Member of this report), the only reported fossils are rare occurrences of _Arthrophycus_ (Schuchert, 1916), eurypterids (Clarke and Ruedemann, 1912), Dipleurozoa (Johnson and Fox, 1968), and _Lingula_ (Epstein and Epstein, 1969). _Lingula_, a long-ranging facies fossil, and dipleurozoans, very rare as fossils, cannot be used for correlation.

Arthrophycus alleghaniense, in the Shawangunk-Tuscarora of Pennsylvania, New Jersey, and New York, was believed to be a guide fossil for the Lower Silurian (Medinan) by Schuchert (1916), Willard (1928), and Swartz and Swartz (1930). Arthrophycus has been regarded as a fossil worm or plant remains (Becker and Donn, 1952) but is now generally recognized as a feeding burrow (Häntzschel, 1962). According to Seilacher (1955), these ichnofossils generally have no age significance but are environmentally controlled. Amsden (1955), Pelletier (1958), and Yeakel (1962) showed that Arthrophycus was strongly facies controlled, apparently limited in occurrence to transitional fluvial and marine environments. It is obvious, therefore, that Arthrophycus is a facies fossil and cannot be used to date the Shawangunk.

Eurypterid remains have been found in the Shawangunk Formation at Otisville, N. Y., and Delaware Water Gap, Pa., and in the Tuscarora Sandstone at Swatara Gap, Pa. (Clarke and Ruedemann, 1912; Swartz and Swartz, 1930, 1931). These fossils were considered to be Early Silurian in age. Swartz and Swartz (1930, p. 473), however, sounded a note of caution, "It would seem inevitable to conclude that the Shawangunk is early Silurian unless the eurypterids are without significance for correlation." Grabau (1913) gave arguments for the fact that eurypterids were river-dwelling organisms, had wide ranges, and do not form "exact horizon markers" (p. 526). Clarke and Ruedemann (1912) were likewise a bit cautious, indicating that the identifications at Delaware Water Gap were tentative because (1) the eurypterids were altered and fragmented, (2) the evolution of eurypterids may have been slow and the complete ranges of species unknown, and (3) eurypterids are apparently facies controlled. Both Amsden (1955) and Størmer (1955) emphasize the scarcity and environmental control of eurypterids. Apparently, eurypterids are confined to brackish and fresh waters, which agrees with the environmental interpretation of the Shawangunk as a fluvial-transitional marine sequence (Epstein and Epstein, 1969; this report).

Thus, the eurypterids in the Shawangunk Formation and Tuscarora Sandstone, as well as *Arthrophycus*, cannot be used for precise age determination because of facies control and uncertainty of species ranges. It is interesting, in this regard, that Willard (1928, p. 257) compared the Shawangunk eurypterids with those found in the Upper Silurian Pittsford Shale and Upper Ordovician (Edenian) Frankfort Shale of New York. He found the closest faunal similarity with the Frankfort and concluded that the Shawangunk must be Early Silurian in age because "the presence of *Arthrophycus* in the Shawangunk points to its being Lower Silurian, since that organism is conceded to be of that age."

In summary, the evidence used to date the Shawangunk Formation of eastern Pennsylvania has been based on insecure stratigraphic evidence and fossils that are strongly environmentally controlled and whose ranges are poorly known due to rare occurrences and facies control. The evidence needs re-evaluation. It is conceivable that the Shawangunk is Late Ordovician in age as well as Early Silurian. Perhaps intensive investigations of the phytoplankton assemblages, as was done by Cramer (1969) for the Rose Hill and Tuscarora Formations of central Pennsylvania, can be used to accurately date these clastic rocks.

Bloomsburg Red Beds

The name Bloomsburg was first used by White (1883) for red beds at Bloomsburg, Pa. In eastern Pennsylvania, he (1882) called the same interval the Clinton red shale, whereas Rogers (1858) used the term Surgent for these rocks. The name High Falls, defined by Hartnagel (1905), has been used in New Jersey at the Delaware Water Gap (Stose, 1922). However, the Bloomsburg has priority and is, therefore, used in the Stroudsburg and Portland quadrangles. Regional relations of the Bloomsburg are given by Swartz and Swartz (1931) and details in easternmost Pennsylvania were described by Epstein and Epstein (1969).

The base of the Bloomsburg Red Beds in the area under study is at the base of the lowest red bed in the section. The top of the Bloomsburg is not exposed but is seen in cores drilled by the U.S. Army Corps of Engineers in the Delaware River, in the Bushkill quadrangle. This contact, with the Poxono Island Formation, is transitional and is placed where the ratio of red beds to nonred beds is 50:50. So defined, the Bloomsburg is between 800 and 1,500 feet thick in the Delaware Water Gap area (see discussion of Shawangunk-Bloomsburg contact under the Tammany Member of the Bloomsburg Formation). This thickness is much less than previously reported: Chance (1882), 1,685+ feet; Grabau (1913), more than 2,300 feet; Swartz and Swartz (1931), 1,264 feet; Willard and Stevenson (1950), 2,300 feet. Much of the variation in reported thickness at Delaware Water Gap can be attributed to complex folding and the rapid color changes. Many of the beds included by Swartz and Swartz (1931, p. 648) in the upper part of the Bloomsburg are part of the Shawangunk Formation as herein defined. Similarly, the nonred sandstones at Delaware Water Gap village were thought to overlie the Bloomsburg and to be part of the Poxono Island Formation by Johnson and others (1933) and Willard (1938). Actually, these rocks belong to the Shawangunk Formation brought up in an anticline.

The Bloomsburg consists of sandstone, siltstone, and silty shale (measured section 2). The sandstones are quartzitic, limonitic, hematitic, crossbedded to planar-bedded, very fine to coarse grained, and some are conglomeratic. Angular to rounded quartz and jasper pebbles are as much as 0.5 inch long. Red shale clasts, similar in appearance to interbedded shales, are common. Beds are as much as 10 feet thick. The shale and siltstone are pale red to grayish-red purple, grayish green, pale green, greenish gray, and dark gray. Mud cracks, small-scale ripples, cut-and-fill structure, and ferroan dolomite concretions are common. The beds are generally thin or laminated, bedding is absent in many of the silty shales and shaly siltstones because it was destroyed by burrowing animals while the sediment was still soft. Fish have been found locally (Beerbower and Hait, 1959), as at the locality 1,000 feet north of the tollgate on U.S. Interstate 80, near the village of Delaware Water Gap, Pa. Fish scales, as much as 0.5 inch long, are common in the bioturbated grayish-red shaly siltstone that is interbedded with laminated grayish-green siltstone and minor medium-gray fine-grained sandstone. Color boundaries between these rocks are very irregular. Green reduction spots around pyrite in the red beds are common at this locality and elsewhere. Many of the rock units in the Bloomsburg occur in upwards-fining cycles (fig. 25). These are discussed further in the section on environments of deposition.

Mineralogically and texturally, the sandstone and siltstone in the Bloomsburg are immature. They probably range from lithic and feldspathic

Figure 25. Upward-fining cycles in the Bloomsburg Red Beds, 0.5 mile northwest of Dunnfield, N. J., Delaware Water Gap. The upper photograph shows the cycles, consisting of medium-grained crossbedded to planar-bedded sandstone resting sharply on the underlying unit and grading up into thin-bedded, laminated, and ripple-laminated sandy siltstone and fine-grained sandstone which in turn grade up into laminated and bioturbated sandy and shaly siltstone that is partly mudcracked and contains dark-yellowish-orange ferroan dolomite concretions averaging 1-2 inches in length. Three complete cyles and the top of a fourth are shown. Note southeast-dipping cleavage (to right). Photograph below shows details of the upper part of one cycle, with finely bedded to laminated siltstone and fine-grained sandstone grading up into mud-cracked sandy and shaly siltstone with dolomite concretions. Ripple lensing is common. Burrows are more abundant upward and in the uppermost beds bedding is nearly destroyed by bioturbation.

graywackes to subgraywackes. A thin section of a medium-grained lithic graywacke, from Lehigh Gap, similar to rocks in the Delaware Water Gap area, shows a matrix of hematite (probably mostly an alteration product of iron-rich chlorite) and muscovite that constitutes 25 percent of the rock. Plagioclase is common, but more abundant rock fragments (slate, phyllite, schist, myrmekite?) comprise 6 percent of the rock. Of the 65 percent quartz, 15 percent is composite, sutured, and stretched, presumably indicating a metaquartzite source. Figure 26 shows a hematitic siltstone to feldspathic graywacke in Delaware Water Gap.

Poxono Island Formation

The Poxono Island Formation (misspelled in Wilmarth, 1957, p. 1724, as Pox<u>i</u>no Island) is not exposed in the Stroudsburg quadrangle but presumably lies within a few tens of feet of the surface along the south slope of Godfrey Ridge at several localities. It was named the Poxono Island Shale by White (1882) for at least 200 feet of buff, green, and variegated, nonfossiliferous limy shales exposed on the north bank of the Delaware River near Poxono Island in the Bushkill 7½-minute quadrangle. These beds formed the base of Rogers' (1858) Scalent Formation which included all rocks up to and including the basal Coeymans of this report.

White (1882, p. 240) reported 5 feet of the shale exposed in the Croasdale quarry at the east end of Godfrey Ridge in the Stroudsburg quadrangle. These rocks are presently concealed. Johnson and others (1933, p. 27) and Willard (1938, p. 10) believed that the Poxono Island crops out in the village of Delaware Water Gap. However, as previously mentioned, the gray and green shales and sandstones at Delaware Water

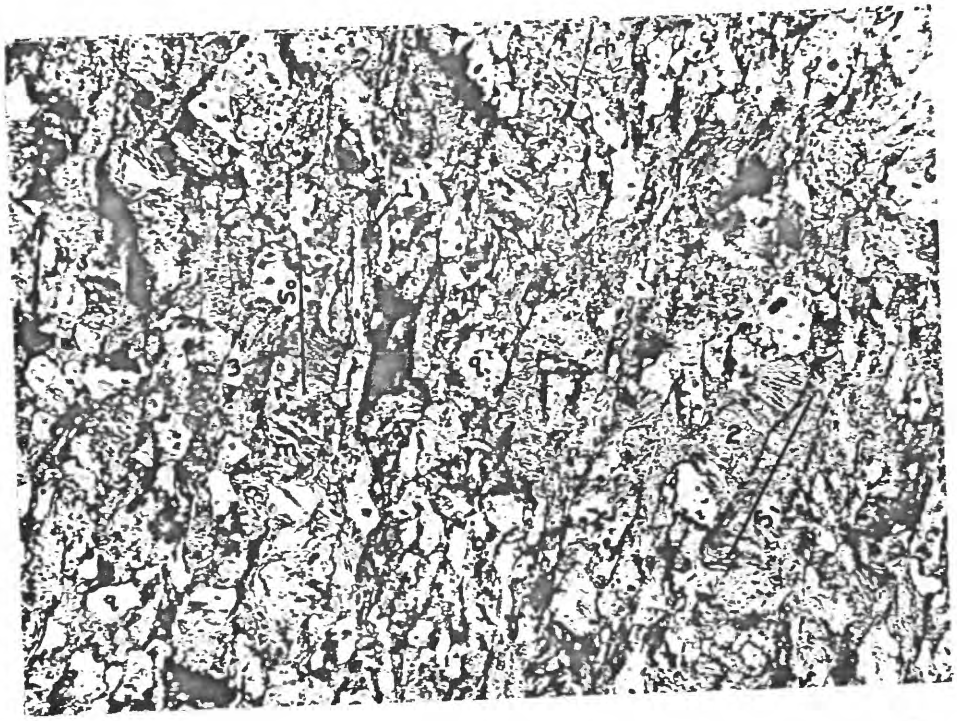

Figure 26. Photomicrograph (plane-polarized light, X 105) of hematitic coarse siltstone to very fine grained feldspathic graywacke, Bloomsburg Red Beds, 0.5 mile northwest of Dunnfield, N.J., Delaware Water Gap. Rock consists of quartz (q), muscovite (m), and chlorite (ch) in a finer matrix of the same minerals and hematite. The chlorite is pleochroic from light green to colorless and presumably is iron-rich. Some intergrown chlorite and muscovite grains, which are presumably detrital, are elongated and have mineral cleavage parallel to bedding, S_o (at 1). Others (at 2) are believed to have recrystallized because they lie parallel to and have mineral cleavage at right angles to rock cleavage (S_1). Some grains of muscovite (at 3) are dragged into rock cleavage as shown by sigmoidal mineral cleavage. The rock cleavage is defined by the parallel alignment of micaceous minerals that are more apparent under crossed polarizers.

Gap village are part of the Shawangunk Formation brought up in the Cherry Valley anticline.

Exposures of the Poxono Island Formation occur along the north and west slopes of Cherry Valley 0.5 mile northeast and east of Bossardsville in the Saylorsburg quadrangle. The formation consists of greenish-gray calcareous and dolomitic shale, very finely crystalline light-greenish-gray limy dolomite that characteristically weathers pale-yellowish orange and grayish orange, lesser amounts of fine- to medium-grained light- to dark-gray limestone resembling the limestone of the overlying Bossardville (White's Poxono Island Limestone? (1882, p. 146-147)), greenish-gray fine-grained sandstone, and moderate-grayish-red sandy shale. Most of the rock is laminated, probably few individual beds are more than 1 foot thick. Many beds are mudcracked. The probable thickness of the Poxono Island Formation, based on limited exposures and the outcrop width in the Bossardsville area, is estimated to be about 700 feet. The upper contact was seen only in the quarry south of Bossardsville and was placed at the top of the uppermost yellowish-orange-weathering dolomitic bed in the section (Epstein and others, 1967, p. 71). So defined, the Poxono Island contains some limestone typical of the overlying Bossardville above. Moderate-grayish-red sandy shales were seen near the middle of the Poxono Island and probably increase in abundance downward. The boundary with the underlying Bloomsburg Red Beds is concealed but is probably transitional.

BOSSARDVILLE LIMESTONE [1]

The type locality of the Bossardville Limestone is at Bossardville, Pa., in Cherry Valley, 1 mile west of the Stroudsburg quadrangle, where the limestone is extensively quarried. The Bossardville was named by White (1882), who did not designate a type section, but who described (p. 240) the limestone at the north Croasdale quarry at the east end of Godfrey Ridge in the Stroudsburg quadrangle (0.5 mile southwest of Minisink Hills, Pa.). The rocks in the quarry could serve as the type section. At this locality, White reported a basal 25-foot unit consisting of bluish-gray, laminated, impure limestone; a middle ("quarry") portion of 65 feet of dark, almost black, massive limestone; and an upper 20 feet of siliceous shaly beds overlain by 12 feet of greenish limy shales. The limy shales were not seen by Swartz and Swartz (1941, p. 1183).

In the northwest corner of the Croasdale quarry, not easily accessible, there is perhaps 12 to 13 feet of medium-gray to dark-gray dolomite that weathers yellowish gray to grayish orange. It is probably White's "greenish limy shales." It is herein placed in the Bossardville, but regional studies in progress suggest that it may be the Rosendale Waterlime of New York. Swartz and Swartz (1941, p. 1164) measured an incomplete thickness of 91 feet at the north Croasdale quarry consisting of an upper 19.5 feet of thin-bedded blue limestone with calcareous shale at the base; 51.5 feet of massive, dark-blue, laminated limestone

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[1] In previous geologic literature the name has been spelled Bossardsville and Bossardville. The spelling used herein conforms to the Code of the American Commission on Stratigraphic Nomenclature (1961, p. 652, Art. 12, a). White (1882) originally spelled the name without the last s.

("quarry rock"); and 20 feet of basal blue-gray, shaly limestone with crinkly stratification and mud cracks, partly concealed. Since the two quarries near the Croasdale Manor house are largely overgrown and covered at the bottom by loose blocks, the section was not measured. The base of the Bossardville is not exposed in the report area.

Regional relations and faunal lists of the Bossardville Limestone, as well as overlying Late Silurian and Early Devonian rocks, are given by Swartz and Swartz (1941). Epstein and others (1967) discussed the stratigraphic details of the rocks between easternmost Pennsylvania and southeastern New York.

In the Stroudsburg quadrangle, the Bossardville Limestone is exposed only at the east end of Godfrey Ridge in and near the two abandoned Croasdale quarries. The thickness of the Bossardville is about 100 feet. It is medium-gray to dark-gray, light-gray to grayish-orange-weathering, fine-grained to sublithographic, laminated to fine-bedded (figs. 27, 28), slightly argillaceous, sandy, and dolomitic limestone. Scattered pyrite is common. Light-olive-gray calcareous shale and siltstone occur as less abundant laminae. In thin section, the laminae appear as concentrations of quartz and rare plagioclase feldspar and muscovite in a matrix of micrite and lesser sparry calcite (fig. 29). The quartz is etched and partly replaced by the calcite. Many of the calcite laminations are less than 0.04 mm thick and may be of organo-sedimentary (algal) origin.

Many laminations are replete with leperditiid ostracodes (fig. 29). Many laminae and thin beds grade upwards from coarse sandy limestones to finer calcitic shales or limestones. Many of these fining upward sequences have scoured bases (fig. 28).

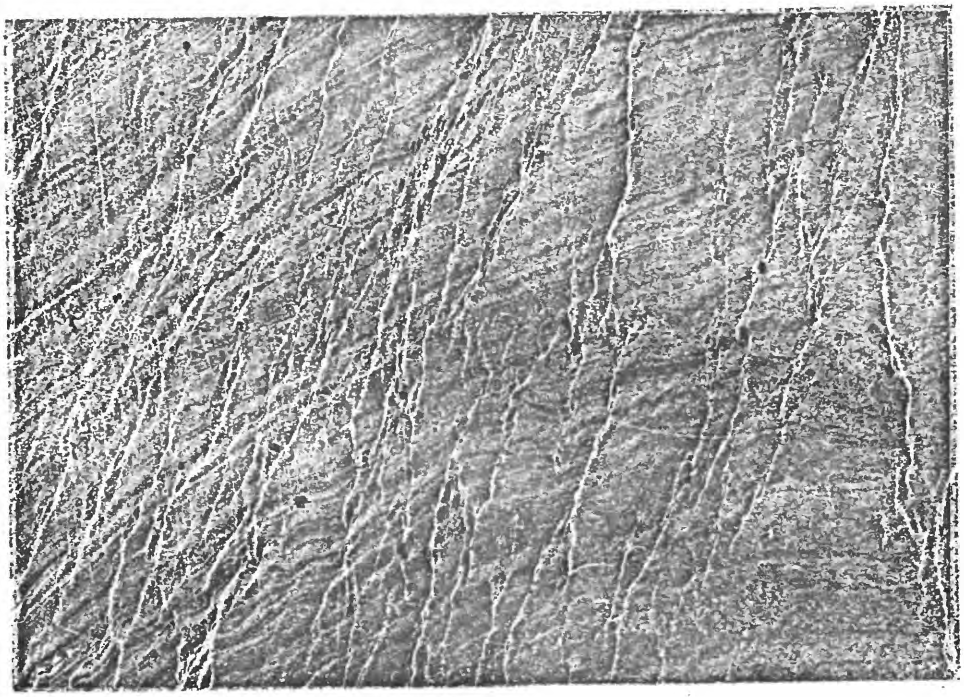


Figure 27. Laminated micrite (light) and calcareous shale (dark) in mud-crack column, Bossardville Limestone, abandoned north Croasdale quarry, about 0.5 mile southwest of Minisink Hills, Pa. Laminations may be partly of organo-sedimentary (algal) origin. Some laminations are channeled into units below. Prominent cleavage offsets laminae. Specimen stained with Alizarin Red S. Negetive print of acetate peel, X 2.6. Peel from specimen collected at the outcrop shown in figure 30.

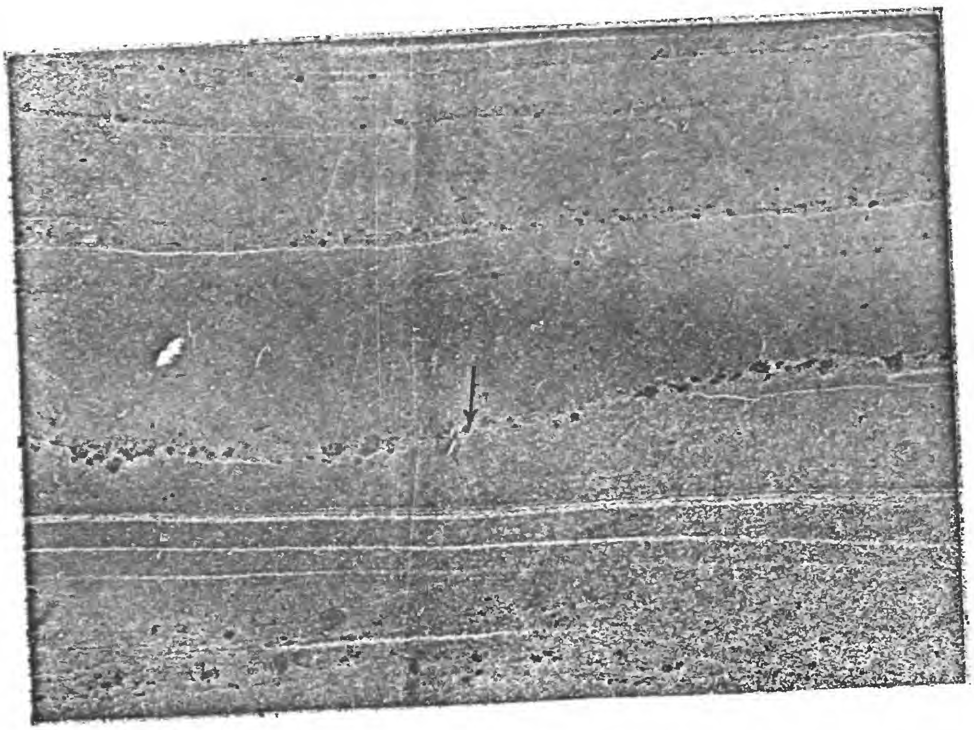


Figure 28. Graded cycles in thin-bedded and laminated sandy calcarenites and calcisiltites (quartz grains are dark) and micritic limestones (light). Note small scoured base at arrow. Bossardville Limestone, abandoned south Croasdale quarry. Specimen stained with Alizarin Red S. Negative print of acetate peel, X 2.6.

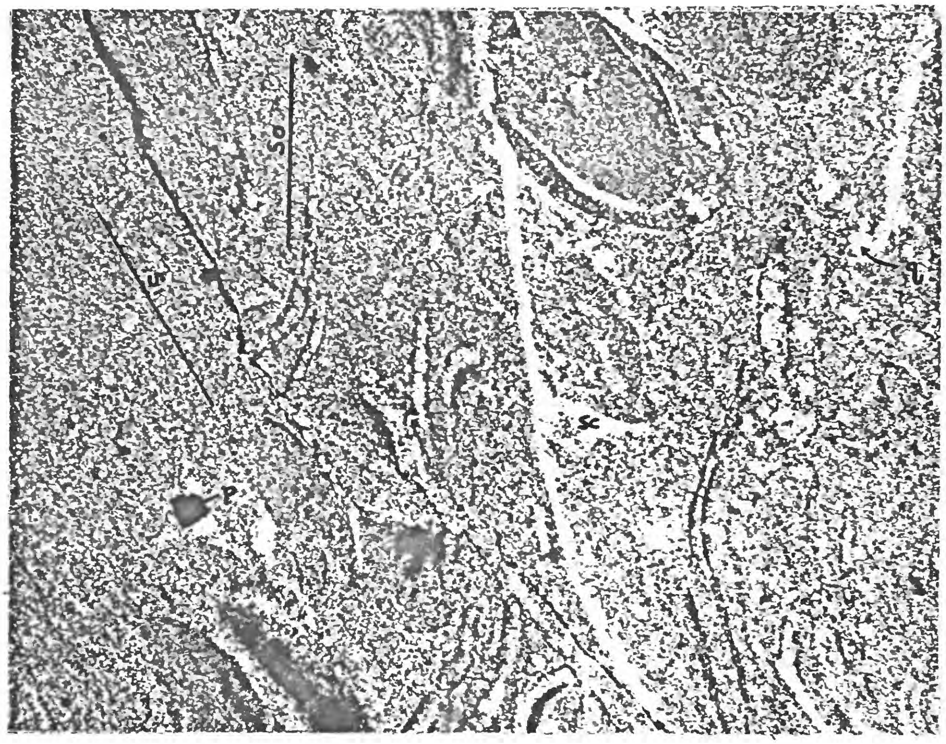


Figure 29. Photomicrograph (plane-polarized light, X43) of finely bedded ostracode-biomicrudite and micrite, Bossardville Limestone, south Croasdale quarry. Minor silt-sized to very fine sand-sized quartz (q) with etched borders and pyrite cubes (p) with calcite grown in pressure-shadow areas. Bedding (S_0). Note offset and solution of fossils along some cleavage planes (S_1). Small patches of sparry calcite (sc) were probably produced by neomorphism of micrite.

In the northern Croasdale quarry at the east end of Godfrey Ridge, two mud-crack units, each nearly 6 feet thick, are separated by about 10 feet of laminated beds (fig. 30). Dark-gray calcareous shale occurs as fillings between the columns. The mud cracks were compressed during folding, and it is probable that the shale fillings were remobilized during the formation of rock cleavage, thus accentuating the shape of the columns.

Decker Formation

Rocks herein assigned to the Decker Formation were originally called Decker's Ferry by White (1882) and later included in the Keyser Limestone or Keyser Group, along with the overlying Rondout Formation and Manlius Limestone (Depue Limestone Member of the Coeymans Formation of this report) by Swartz (1929) and later workers. The confused history of nomenclature was reviewed by Epstein and others (1967) who defined the Decker Formation as consisting of two members: a limestone facies northeast of the Wallpack Center area, New Jersey (Clove Brook Member); and a sandier facies to the southwest (Wallpack Center Member). Because only the Wallpack Center facies is present in the Stroudsburg quadrangle, the rock unit is herein referred to as the Decker Formation. The type locality of the Wallpack Center Member is 1 mile northeast of Wallpack Center, N. J., on the southeast slope of Wallpack Ridge, where it consists mainly of 82 feet of calcareous, partly conglomeratic sandstone and arenaceous limestone.

In the Stroudsburg quadrangle, the Decker Formation is exposed on the south slope of the east end of Godfrey Ridge (where the boundary with the underlying Bossardville Limestone is gradational) and near

Figure 30. Compressed mud-crack columns, more than 5 feet long, in the lower beds of the Bossardville Limestone at the abandoned north Croasdale quarry, about 0.5 mile southwest of Minisink Hills, Pa.

Stormville. It consists of medium-gray to medium-dark-gray, fine- to medium-grained, arenaceous and argillaceous, fossiliferous limestone (fig. 31) and calcareous fine- to coarse-grained sandstone and conglomerate with rounded to subangular quartz pebbles as much as 1.5 inches long. Both sandstones and conglomerates are crossbedded and planar-bedded. These bedding characteristics are best observed in near-vertical beds at the east end of Godfrey Ridge at an altitude of 450 feet. The Decker characteristically weathers grayish orange, a valuable aid in distinguishing it from the similar Stormville Member of the Coeymans Formation. The Decker is 84 feet thick at the south Croasdale quarry. It is the youngest undisputed Silurian unit in eastern Pennsylvania, bearing *Eccentricosta jerseyensis* and halysitids. Other poorly preserved brachiopods and corals were seen.

SILURIAN AND DEVONIAN

The location of the Silurian-Devonian boundary in eastern Pennsylvania has been a problem for many years (see Epstein and others, 1967, for terse summary). The upper part of the Depue Limestone Member of the Coeymans Formation contains a conodont fauna with *Icriodus woschmidti* Ziegler and *Lonchodina cristagalli* Ziegler, index fossils for the earliest Devonian (A. G. Epstein, oral commun., 1970). The Decker Formation is Silurian. No conodonts have been found in the Rondout Formation in the Stroudsburg area, and, to date, no definitive work has been done on the megafossils in the Rondout. Thus, the Rondout is either Silurian or Devonian, or the systemic boundary lies within it.

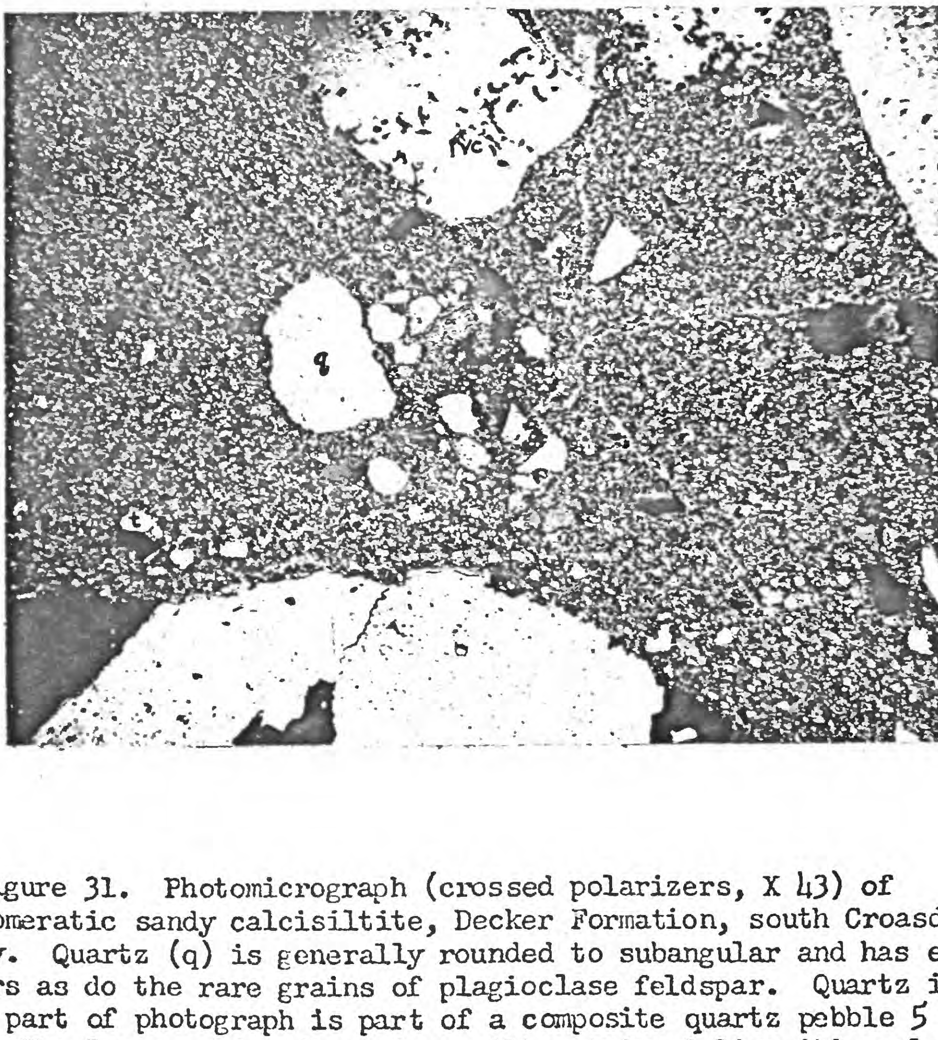


Figure 31. Photomicrograph (crossed polarizers, X 43) of conglomeratic sandy calcisiltite, Decker Formation, south Croasdale quarry. Quartz (q) is generally rounded to subangular and has etched borders as do the rare grains of plagioclase feldspar. Quartz in lower part of photograph is part of a composite quartz pebble 5 mm long. The large grains float in a silt matrix of limonitic calcite (70 percent of total sample), quartz, and lesser muscovite. Note subround tourmaline (t) and vermicular chlorite (vc) in quartz.

Rondout Formation

Clarke and Schuchert (1899) named the Rondout Waterlime for rocks overlain by the Manlius Limestone and underlain by Salina beds at Rondout, N. Y. The subsequent nomenclatural history of rocks assigned to the Rondout is summarized by Rickard (1962) and Epstein and others (1967). The Rondout was divided into three members in eastern Pennsylvania by Epstein and others (1967). These are, from base upwards, the Duttonville, Whiteport Dolomite, and Mashipacong. Exposures of the Rondout are rare in the Stroudsburg quadrangle. It is completely exposed at only one locality--along the south bank of Brodhead Creek, 1,500 feet southwest of where U.S. Interstate Highway 80 crosses the creek in the northeast corner of the quadrangle. The strata are vertical and the Rondout is 28.5 feet thick (measured section 3). The contact with the Decker Formation is abrupt.

The Whiteport Dolomite Member was called the Stormville hydraulic cement bed by White (1882) and was cited to be 5 to 10 feet thick. The Decker Ferry Limestone of White, about 20 feet thick, is the Duttonville Member of this report. At Stormville, Swartz and Swartz (1941) measured 14.5 feet of their Rondout Limestone in a partially concealed section. They also report 11 feet of Rondout at the south Croasdale quarry. Herpers (1951) measured 10 feet at the same place. O'Neill (1941) described and figured the mud cracks in the Whiteport Member near Stormville but identified the rock as Bossardville Limestone.

Duttonville Member

The Duttonville Member was proposed by Epstein and others (1967) for 30 feet of gray, fine-grained limestone, calcareous shale, and mudcracked dolomite in the William Nearpass quarry, 1.8 miles southwest of Duttonville, N. J. In the Stroudsburg quadrangle, the Duttonville is 12 to 17 feet thick and consists of medium-gray, medium-gray to yellowish-gray-weathering, very fine to fine-grained, laminated to fine-bedded, argillaceous, ostracode-rich limestone and mudcracked calcareous shale. Near the middle of the member is a 1-foot-thick biostromal limestone with abundant corals and brachiopods (fig. 32). Paleontologic studies of this bed may aid in determining the age of the Rondout Formation in eastern Pennsylvania.

The Duttonville exposed along an overgrown lane on the northeast slope of Godfrey Ridge at an altitude of 500 feet, overlooking U.S. Interstate Highway 80, about 2,000 feet west of Minisink Hills is yellowish-gray-weathering, very fine grained, dense, medium-gray limestone. Slabs with multitudes of smooth-shelled ostracodes lie nearby. A similar exposures is in a field 1,400 feet northeast of the church at Stormville, 250 feet south of Cherry Valley Road.

Whiteport Dolomite Member

The Whiteport Dolomite Member of the Rondout Formation was named by Rickard (1962) for 14 feet of buff-weathering argillaceous and calcitic dolomite near Whiteport, N. Y.

In the Stroudsburg quadrangle, the Whiteport is 7 to 9 feet thick and is a medium-gray to dark-gray, yellowish-gray to grayish-orange-weathering, very fine grained, slightly argillaceous, massive, pyritic, ferroan dolomite. It characteristically is mudcracked (fig. 33) and laminated (fig. 34). Its lower contact is sharp.

Many writers have used the term "peth-stone" for the Whiteport, a

Figure 32. Photomicrograph (plane-polarized light, X43) of biomicrudite in the biostromal bed of the Duttonville Member of the Rondout Formation, unit 2 of measured section 3. Sparry calcite (Sc) occurs as pore filling in many of the ostracodes and brachiopod shell fragments.

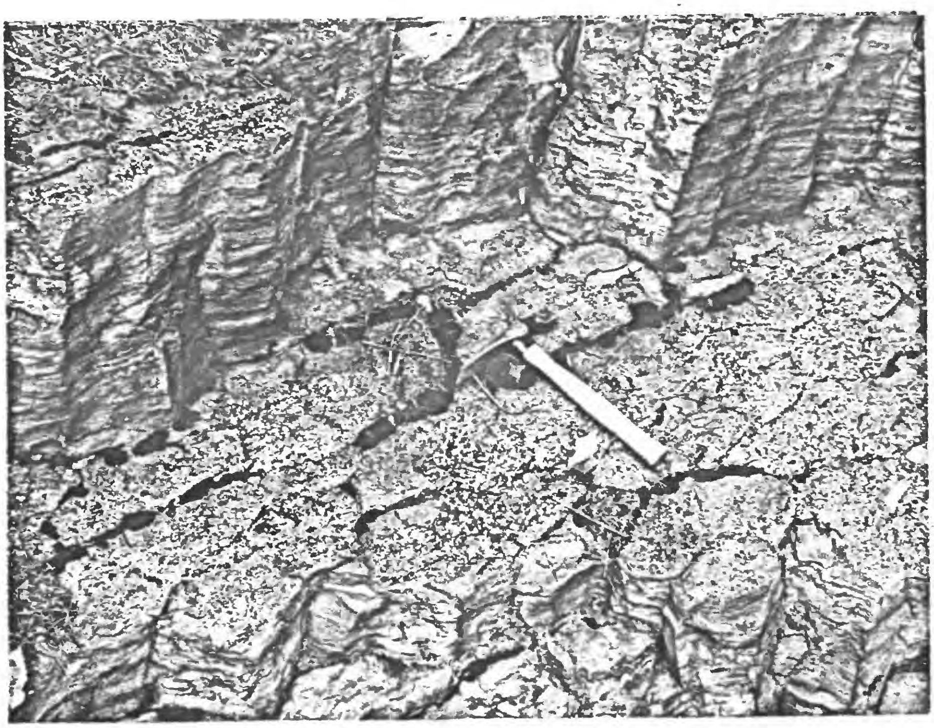


Figure 33. Mud cracks in the massive Whiteport Dolomite Member of the Rondout Formation in roadcut on north side of Cherry Valley Road, 2,000 feet northeast of the church in Stormville. The dolomite is laminated (see fig. 34) and dark-gray calcareous shale fills some of the interpolygon cracks.

Figure 34. Laminated and mud-cracked ferroan dolomite from outcrop shown in figure 33. Rock cleavage is concentrated along shale-filled cracks, offsetting the laminae. Note disrupted bed, a penecontemporaneous soft-rock feature possibly due to slumping during a storm. Negetive print of acetate peel, X 2.4.

usage originally employed by Cook (1868, p. 159) as "a local name, applied to a thickbedded argillaceous limestone, light-blue color, fine-grained, containing iron pyrites in small and detached crystals. It is used to make water-lime when burned." The buff (yellowish gray to grayish orange) weathering color of the "beth-stone" is distinctive, and is due to weathering of the ferrous carbonate in solid solution in the dolomite (Pettijohn, 1957, p. 421). The composition of the Whiteport, determined by averaging five analyses given by White (1882, p. 136, 137), is $CaCO_3$, 39 percent; $MgCO_3$, 25 percent; SiO_2, 22 percent; iron oxide, 4.4 percent; Al_2O_3, 4.4 percent; S and P, <0.1 percent.

Mashipacong Member

The type section for the Mashipacong Member is the William Nearpass quarry, 1.8 miles southwest of Duttonville, N.J., where it consists of fine-grained argillaceous limestone and calcareous shale (Epstein and others, 1967). Mashipacong Island is in the Delaware River, 1.7 miles west-northwest of the type section.

In the Stroudsburg quadrangle, the Mashipacong is light-gray to medium-dark-gray, medium-gray to light-olive-gray weathering, fine- to medium-grained, argillaceous, laminated to fine-bedded limestone and fissile mudcracked shale. It is 8 feet thick at the east end of Godfrey Ridge. The lower contact is sharp. Mud-cracked shaly limestone crops out in an excavation at 500 feet altitude, 400 feet southwest of the north Croasdale quarry. The polygons are deformed and they are nearly 1 foot wide.

DEVONIAN

Helderberg Group

The Helderberg Group, named for Lower Devonian rocks in the Helderberg Mountains, N.Y., was first adequately described by Clarke and Schuchert (1899). Nomenclatural problems and regional relations of the Helderberg Group are given by Swartz (1929), Swartz and Swartz (1941), Richard (1962), and Berdan (1964). In the Stroudsburg area, the Helderberg is about 325 feet thick and is divided into the following formations, in ascending order: Coeymans Formation, New Scotland Formation, Minisink Limestone, and Port Ewen Shale (Epstein and others, 1967). The group is part of Rogers' (1858) Scalent, Pre-Meridian, and Meridian Series, and is the upper part of White's (1882) Lower Helderberg Formation.

The Helderberg Group is best exposed in the vicinity of Minisink Hills, especially in roadcuts where U.S. Interstate Highway 80 cuts through Godfrey Ridge (fig. 35). Lithologic details are given in measured sections 3 to 7. Faunal lists are presented by Willard (1938).

Coeymans Formation

Clarke and Schuchert (1899) named the Coeymans Formation for strata between the Manlius and New Scotland Limestones at Coeymans, N.Y. White (1882) included strata in eastern Pennsylvania in his Stormville Conglomerate and Limestone which were later correlated with the Coeymans by Grabau (1906). Epstein and others (1967) have redefined the Coeymans Formation in eastern Pennsylvania, New Jersey, and southeasternmost New York. In the Stroudsburg quadrangle, it consists of approximately 75 feet of gray fossiliferous limestone, arenaceous

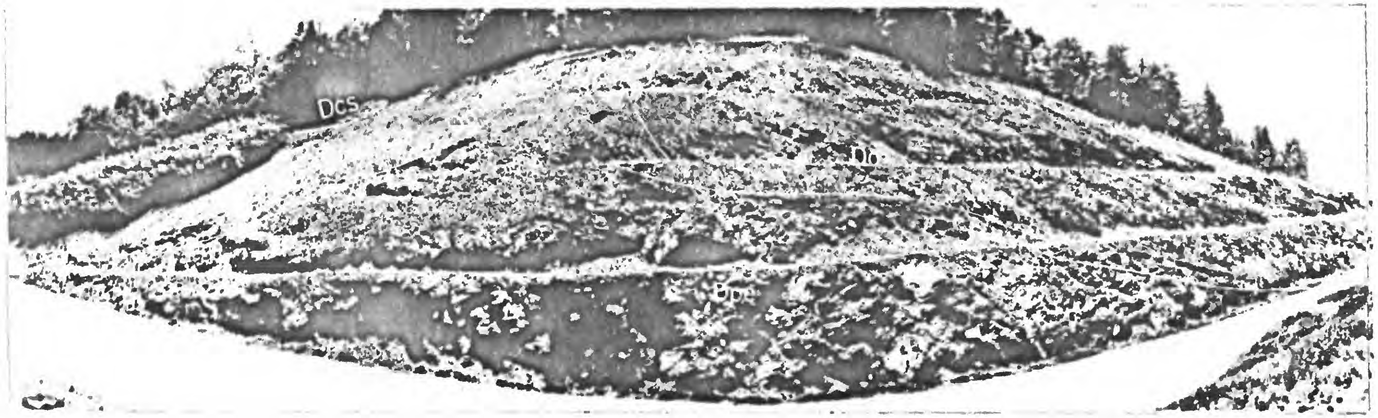


Figure 35. Overturned syncline exposed in roadcut along U.S. Interstate Highway 80, approximately 0.4 mile southwest of Minisink Hills, Pa. Measured section 7 gives lithologic details. Dcs, Stormville Member of the Coeymans Formation; Dns, Flatbrookville and Maskenozha Members of the New Scotland Formation; Dmi, Minisink Limestone; Dpe, Port Ewen Shale; and Do, Oriskany Group. Dashed lines are bedding traces on construction benches. Overturning of beds seems greater because of foreshortening in photo.

limestone, calcareous sandstone, and calcareous quartz-pebble conglomerate. These rocks have been divided into four members, which are, from oldest to youngest, the Depue Limestone, Peters Valley, Shawnee Island, and Stormville.

Depue Limestone Member

Rocks of this lowest member of the Coeymans Formation in eastern Pennsylvania were placed in the Manlius Formation by Swartz (1929, 1939), Willard (1938), Swartz and Swartz (1941), and others. However, these rocks are not similar to the unevenly bedded, fine- to medium-grained "ribbon" limestone with thin yellowish-gray shale partings of the Manlius of New York State, and were placed in the Coeymans Formation as the Depue Limestone Member by Epstein and others (1967). The type section of the Depue is about 0.5 mile southwest of Shawnee on Delaware, Pa., where it consists of 13 feet of slightly arenaceous and argillaceous, fine-grained, evenly bedded limestone with scattered coarse-grained limestone. Depue Island is in the Delaware River east of Shawnee on Delaware. The Depue Member of the Coeymans Formation grades laterally into the Thacher Member of the Manlius Limestone near Hainesville, N.J.

The Depue Limestone Member is 18 feet thick on Brodhead Creek in the northeast corner of the Stroudsburg quadrangle (measured section 3) where it consists of medium-gray to dark-gray, medium-gray to medium-light-gray weathering,, slightly arenaceous and argillaceous, fine- to coarse- grained, slightly limonitic, evenly and fine-bedded, fossiliferous limestone that contains brachiopods, ostracodes (fig. 36), stromatoporoids, and corals. The contact between the Depue and underlying Rondout Formation is abrupt.

Good exposures are found along the overgrown lane west of U.S.

Figure 36. Negative print of a thin section of Depue Limestone Member of Coeymans Formation, from southeast bank of Brodhead Creek, approximately 0.1 mile above power dam (unit 5 of measured section 3). Silty and fine sand ostracode biosparrudite lies above a thin bed of fossiliferous calcareous quartz siltstone in which micrite fills interstices. The biosparrudite contains intraclasts from underlying siltstone (1). Note sparry calcite beneath ostracode umbrella (2) and concave upward ostracode carapaces filled with debris (3). Pellets (4) are abundant. Sparry calcite (dark areas) occurs as pore filling and replacement of micrite (neomorphism) and some quartz and fossil debris. Micrite comprises about 40 percent of rock. A trace of plagioclase feldspar is present in the sample.

Interstate 80 at an altitude of 500 feet and in an excavation at an altitude of 500 feet, 400 feet southwest of the north Croasdale quarry.

In the Stormville area, the Depue is seen only in small exposures except for a small quarry on the south slope of Godfrey Ridge, 2,000 feet northeast of the Stormville church about 50 feet above the Cherry Valley Road. In this quarry gray ribbony limestone with ostracodes and *Favosites* are found.

Peters Valley Member

The Peters Valley Member of the Coeymans Formation is about 5 feet thick in the Stroudsburg quadrangle and consists of medium-gray, medium-light-gray-weathering, very arenaceous to conglomeratic (quartz pebbles as much as ¼ inch long), fine- to medium-grained, slightly limonitic, massive, crossbedded, fossiliferous limestone and calcareous sandstone. Fossils include *Gypidula coeymanensis*, other brachiopods, stromatoporoids, and corals. The lower boundary is gradational. The member is exposed along Brodhead Creek (measured section 3), the east end of Godfrey Ridge, and 2,200 feet northeast of Stormville church 140 feet above Cherry Valley Road.

Rocks of similar type 1.5 miles northwest of Flatbrookville, N. J., serve as the type section (Epstein and others, 1967) for the member. It is named after Peters Valley, N. J.

Shawnee Island Member

Rocks of the Shawnee Island Member are, for the most part, the Coeymans Limestone of many previous workers in eastern Pennsylvania. The Shawnee Island was defined by Epstein and others (1967) for 56 feet of argillaceous and arenaceous, fine- to medium-grained, cherty limestone, about 0.5 mile southwest of Shawnee on Delaware, Pa., just north of Shawnee Island. This rock type is characteristic of the nonbiohermal or interreef facies which is the only facies exposed in the Stroudsburg quadrangle. Elsewhere in eastern Pennsylvania and New Jersey, several unbedded to massively bedded coarsely crystalline limestone bioherms have been found.

On the now-abandoned Erie Railroad grade west of Minisink Hills, more than 26 feet of Shawnee Island was reported by Willard (1938), 28 feet by Swartz (1939), and about 63 feet by Swartz and Swartz (1941). White (1882) measured 30 feet at this locality. White (1882) reported 50 feet and Swartz and Swartz (1941) assigned 66 feet to the partly concealed Shawnee Island Member at Stormville. The section at Stormville is too poorly exposed for measurement, but on Brodhead Creek (measured section 3), the Shawnee Island is 35 feet thick. It is exposed in many other places in the Stroudsburg quadrangle (see geologic map of Godfrey Ridge, pl. III, and also measured sections 4-6).

The Shawnee Island is medium-gray to medium-dark-gray, medium-light-olive-gray to medium-gray-weathering, fine- to medium-grained, arenaceous and argillaceous, slightly limonitic, irregularly bedded, locally burrowed fossiliferous limestone (fig. 37). Gypidula coeymanensis is abundant and weathers in relief on bedding surfaces. Other fossils include crinoid columnals, bryozoans, and corals. The upper 10-25 feet contains nodules and lenses of dark-gray chert. The member is sandier in the western part of the quadrangle. The boundary with the underlying Peters Valley Member is gradational.

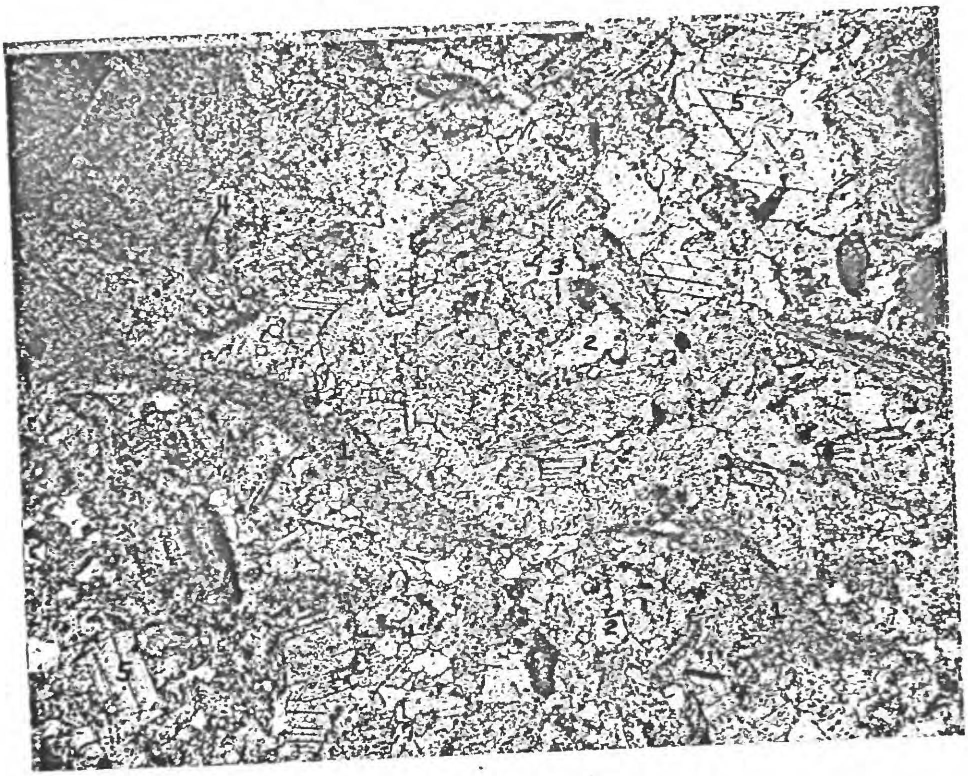


Figure 37. Photomicrograph (plane-polarized light, X 43) of sandy biopelsparrudite in Shawnee Island Member of Coeymans Formation, unit 7 of measured section 3. Note cross section of Gypidula coeymanensis (1), etched quartz (2), and plagioclase feldspar (3), pellets (4), and sparry calcite (5).

Stormville Member

White (1882, p. 132) named the Stormville Conglomerate for "a series of alternating beds of quartz pebble rock, and pebbly limestone" lying between his Stormville Limestone below and Stormville Shales above (New Scotland through lower part of Oriskany Group of this report). At Stormville, Pa., the type locality, White measured 45 feet, whereas Swartz and Swartz (1941), upon reexamining the section, reported only 14 feet referrable to the Stormville. Nearby, at Hartmans Cave, in an incomplete exposure, the Stormville is nearly 25 feet thick (measured section 5). On Brodhead Creek near Minisink Hills, where White (1882) measured 17.5 feet and Swartz (1939) and Swartz and Swartz (1941) measured 14 feet, the Stormville Member is nearly 17 feet thick (measured section 6). The Stormville is at least 26.5 feet thick near the intersection of Cherry Valley Road and State Route 191 (measured section 4), where Swartz and Swartz (1931, p. 646) assigned these rocks to the Decker Ferry.

The Stormville was adopted as a member of the Coeymans by Epstein and others (1967). The reference section is at Hartmans Cave (measured section 5). It is comparatively well exposed in the Stroudsburg quadrangle, generally forming easily traced ribs of medium-gray to medium-light-gray, light-olive-gray- to medium-light-gray-weathering, fine- to coarse-grained, conglomeratic, calcareous and planar-bedded, lenticular, partly limonitic sandstone and quartz-pebble conglomerate with rounded pebbles as much as 1 inch long (fig. 38), and fine- to coarse-grained arenaceous limestone (fig. 39). It is fossiliferous, containing scattered rugose corals, stromatoporoids, crinoid columnals, and Gypidula coeymanensis. It

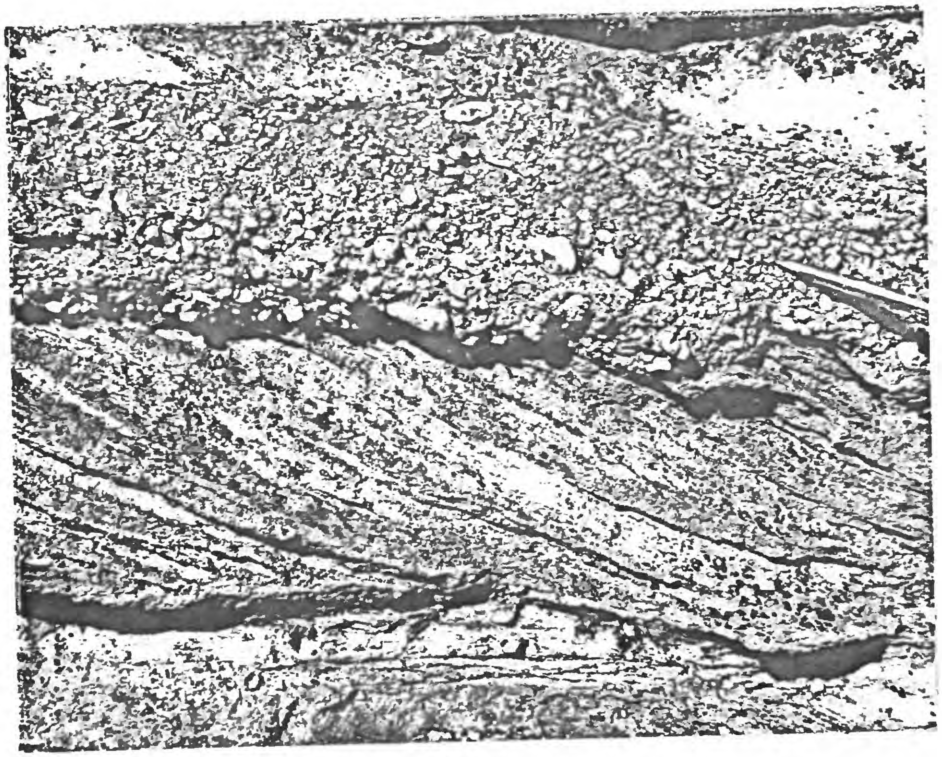


Figure 38. Stormville Member of the Coeymans Formation, intersection of State Highway 191 and Cherry Valley Road, 2.4 miles northeast of Stormville, Pa. From bottom to top: laminated to planar-bedded quartzose crinoidal fine- to coarse-grained limestone; crossbedded calcareous sandstone; and planar-bedded calcareous quartz-pebble conglomerate with pebbles as much as 1 inch long and scattered crinoid columnals (at pen point). Unit 5 of measured section 4.

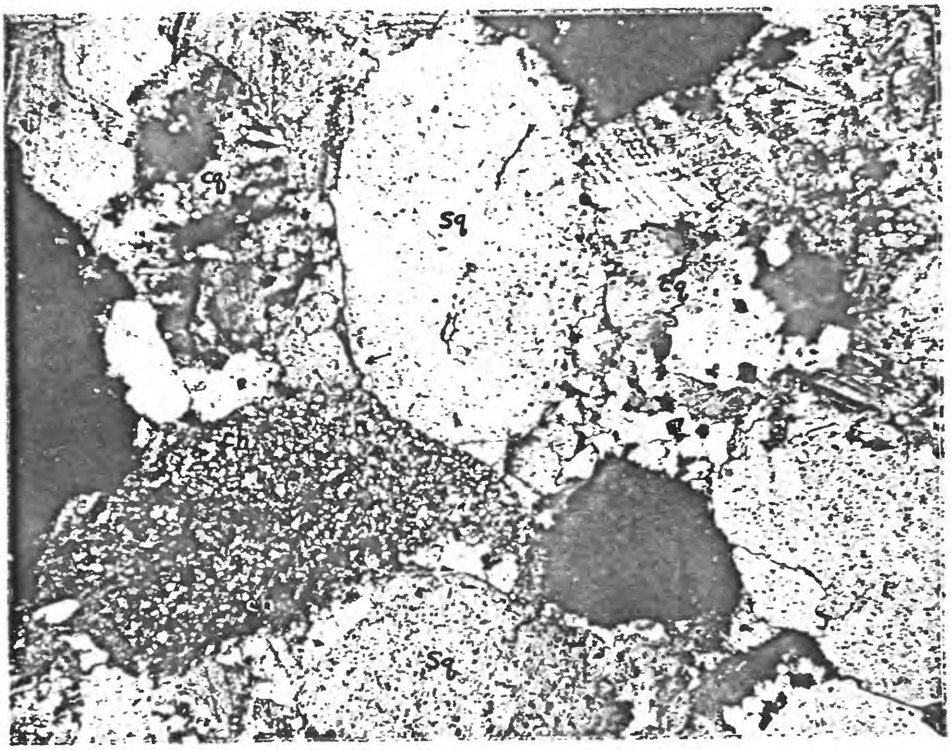


Figure 39. Photomicrograph (crossed polarizers, X 43) of very coarse grained calcareous orthoquartzite made up of rounded to subangular quartz and lesser chert (ch) in a sparry calcite cement, Stormville Member of Coeymans Formation, unit 4 of measured section 6. The quartz grains are either single grains with undulose extinction (sq) or composite grains (cq), implying a presolved sedimentary quartzite or metaquartzite as well as a sedimentary source. Grain contacts are generally concave. Some quartz overgrowths were noted (arrow).

rests with an abrupt erosional contact on the Shawnee Island Member. Grabau (1906, p. 173) believed that this disconformable contact represents a marked break. However, based on paleoenvironmental considerations to be discussed later, and lack of fossil evidence to the contrary, only a slight hiatus is indicated.

New Scotland Formation

The lower part of White's (1882) Stormville Shales in eastern Pennsylvania is the New Scotland Shale of Willard (1938), New Scotland Shale and Limestone of Swartz (1939), and New Scotland Formation of Swartz and Swartz (1941). The name New Scotland was carried in from eastern New York where it was originally used by Clarke and Schuchert (1899). The New Scotland was divided into two members, the Flatbrookville below and Maskenozha above, following the earlier recognition of its bipartite nature by Swartz (1939) and Swartz and Swartz (1941). In the northeast corner of the Stroudsburg quadrangle, the New Scotland is about 75 feet thick (measured section 6).

Flatbrookville Member

The Flatbrookville was proposed by Epstein and others (1967) for siliceous and calcareous shales, about 3.5 miles northeast of Flatbrookville, N. J., where it is 17.5 feet thick. The Kalkberg was used for rocks in the Flatbrookville in eastern Pennsylvania by Swartz (1939) and Swartz and Swartz (1941), but Epstein and others (1967) showed that the Kalkberg of New York laterally grades into strata of the Stormville and Shawnee Island Member of the Coeymans Formation near Wallpack Center, N. J.

In the Stroudsburg quadrangle, the Flatbrookville is 33 feet thick (measured section 6). A similar thickness was reported by earlier workers mentioned above. The member consists of dark-gray, medium-gray- to medium-light-gray-weathering, silty, fossiliferous shale with about 10 percent nodules, lenses, and beds of medium-gray to medium-dark-gray, fine-grained, argillaceous, fossiliferous limestone, containing coral fragments, brachiopods, bryozoans, trilobites, and ostracodes, and about 10 to 15 percent lenses and nodules of dark-gray chert. The lower contact is abrupt. It is very poorly exposed, as is the underlying Maskenozha Member. The best exposures are in the Minisink Hills area.

Maskenozha Member

The upper part of the New Scotland Formation was named the Maskenozha Member by Epstein and others (1967) for Lake Maskenozha, 5.5 miles northwest of the type section, which is about 3.5 miles northeast of Flatbrookville, N. J., and which contains about 45 feet of dark-gray siliceous laminated shale and scattered beds and lenses of argillaceous limestone.

On Brodhead Creek, the Maskenozha is 43 feet of dark-gray, medium-gray- to medium-light-olive-weathering, calcareous and siliceous, laminated shale with scattered pods and beds of medium-dark-gray to medium-gray fine-grained fossiliferous argillaceous limestone containing brachiopods, trilobites, bryozoans, corals, ostracodes, and crinoid columnals. The basal contact is abrupt and is placed at the top of the lowest bed containing dark-gray chert.

Minisink Limestone

A thin argillaceous limestone in eastern Pennsylvania and New

Jersey, between the New Scotland Formation and Port Ewen Shale, was somewhat hesitatingly identified as the Becraft Limestone by Willis (1912), Swartz (1939), and Swartz and Swartz (1941). The uncertainty of this correlation was expressed by Willard (1953), and Epstein and others (1967) renamed the unit the Minisink Limestone because it is very different from the coarse-grained, very fossiliferous, gray and pink limestone of the type Becraft of New York.

There are scattered exposures of the Minisink in Godfrey Ridge, and the completely exposed 14 feet of the unit along U.S. Interstate 80 is the type section (fig. 35, measured section 7). There are also good exposures near Minisink Hills, the type locality (measured section 6). The Minisink is a medium-gray, light-tannish-gray-weathering, fine-grained, argillaceous, irregularly bedded limestone, in beds as much as 3 feet thick, with thin interbeds of medium-dark-gray calcareous shale. Lenses of fossil hash, including corals, bryozoans, brachiopods, and crinoid debris, are common. A pulverized channel sample from the type locality, when dissolved in dilute hydrochloric acid, showed that the Minisink is about 70 percent calcium carbonate. It appears to be more argillaceous in outcrop. The lower and upper contacts of the Minisink are sharp.

Port Ewen Shale

The shaly limestone near Port Ewen, N. Y., was named Port Ewen Limestone by Clarke (1903). The name was first used in Pennsylvania by Swartz (1929) and later by Willard (1938). Swartz (1939) and Swartz and Swartz (1941) measured 136 feet of Port Ewen Shale along the now-abandoned railroad grade west of Minisink Hills. In the complete exposure of the Port Ewen along U.S. Interstate Highway 80 (fig. 35), 151 feet were measured (measured section 7). Such thicknesses may be somewhat misleading because relative thinning of orthogonal thicknesses of shale beds in the limb of the overturned fold along the highway is about 50 percent.

The Port Ewen is a medium-gray, light-tannish-gray-weathering, calcareous, pyritic, laminated, irregularly bedded and burrowed shaly siltstone and silty shale (fig. 40). It is fossiliferous, especially in its upper 90 feet, containing brachiopods, corals, ostracodes, trilobites, crinoids, and some conodonts (fig. 41). Slaty cleavage is conspicuous in all exposures.

Oriskany Group

Sandstone, chert, and siliceous and argillaceous limestone overlying the Port Ewen Shale were included in the Meridian Series of Rogers (1858) and in the Oriskany Sandstone and Stormville Shales of White (1882). The name Oriskany was first proposed by Vanuxem (1839) for the sandstones exposed at Oriskany Falls, N. Y.

The Oriskany Group in eastern Pennsylvania is transitional into the underlying Port Ewen through a sequence of interbedded chert, argillaceous limestone, and calcareous shale. Sandstone is more abundant upwards, and dominates the section at the top. Cleaves (1937) summarized the nomenclatural history of the Oriskany in Pennsylvania, recognized the twofold nature of the group, and divided it into the Ridgeley Formation above and the Shriver Formation below. The base was placed at the bottom of the lowest chert above the Port Ewen. Later, Cleaves (1939) was hesitant in assigning the lower Oriskany to the

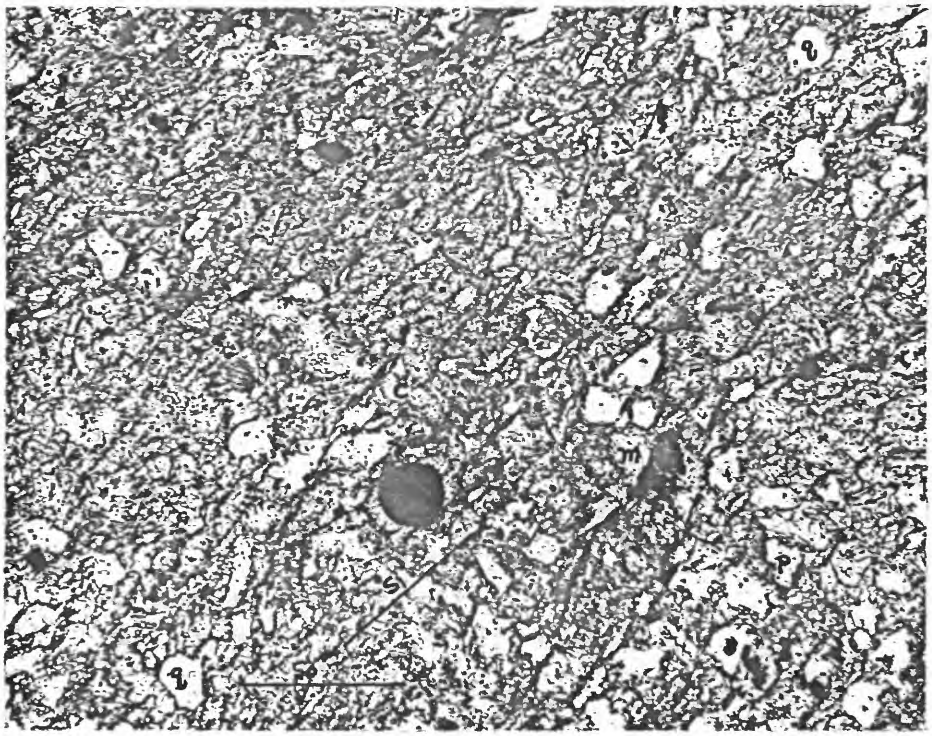


Figure 40. Photomicrograph (plane-polarized light, X 106) of calcareous shaly siltstone, Port Ewen Shale, unit 3 of measured section 7, roadcut along U.S. Interstate 80. Major minerals are angular to ragged quartz (q), calcite (c), muscovite (m), and lesser plagioclase (p), chlorite, pyrite (circular dark grain), and possibly very minor orthoclase. The grains lie in a nearly irresolvable finer matrix of quartz, muscovite, chlorite, calcite, and opaque minerals. Cleavage (S_1) makes an angle of about 45° to bedding (S_0). Note growth of quartz, chlorite, and muscovite parallel to cleavage on edges of pyrite grain.

Figure 41. Calcareous siltstone to quartzose calcisiltite containing scattered skeletal debris of predominantly brachiopod shells. Bedding obliterated by burrowing. Port Ewen Shale, unit 5 of measured section 7, roadcut along U.S. Interstate 80. Southeast-dipping cleavage trends to lower right. Negative print of acetate peel, X 2.5. Specimen stained with Alizarin Red S (calcite, mainly in shells, is dark gray to black in photo).

Shriver and placed these rocks in the lower part of the Ridgeley Sandstone, having explained (Cleaves, 1938, p. 1109) that "....the Shriver can not be established because of paleontological deficiencies ...." Swartz and Swartz (1941) used the names Oriskany Sandstone and Oriskany Shale for the corresponding units. Willard (1952) agreed and maintained that the Shriver was absent in eastern Pennsylvania. According to Swartz and Swartz (1941), their Oriskany Shale is similar lithologically and has the same stratigraphic position as the Shriver, but the fossils are sparse and do not aid in correlation. Accepting the thesis that age does not make a formation, Epstein and Epstein (1967, 1969) retained the name Shriver in eastern Pennsylvania in the way Cleaves first described it, because it is an easily recognizable sequence. The name Shriver Chert was retained following the original usage of Swartz (1913). However, because of difficulty in mapping due to poor exposures of the contact between the Shriver and Ridgeley, and because of apparent vertical migration of the contact along strike, the Shriver and Ridgeley were mapped as a single unit in the Stroudsburg quadrangle, the Oriskany Group.

Many good exposures of the Oriskany, and especially the Ridgeley, are found in the quadrangle. A complete sequence crops out along U.S. Interstate 80 (fig. 35), along Brodhead Creek, 1 mile southeast of East Stroudsburg, and along Route 191 just north of its intersection with the Cherry Valley Road. The Oriskany Group ranges between 67 and 137 feet in thickness in the eastern half of the Stroudsburg quadrangle. The Ridgeley, along with the Esopus Formation, generally holds up the highest parts of Godfrey Ridge.

Paleontologic and regional stratigraphic details of the Oriskany Group are given by Cleaves (1937, 1939) and Swartz and Swartz (1941).

Shriver Chert

Shriver Ridge, at Cumberland, Md., is the type locality of the Shriver Chert (Swartz, 1913). In the Stroudsburg quadrangle, the Shriver consists of interbedded chert, limestone, and sandstone. It is nearly 85 feet thick along U.S. Interstate 80 (measured section 7) and 54 feet thick on the southeast side of Brodhead Creek, 1 mile southeast of East Stroudsburg, a distance of only 1 mile from measured section 7. Two miles farther to the southwest, along Route 191 just north of its intersection with Cherry Valley Road, the Shriver thickens to about 102 feet at the expense of the Port Ewen because thin beds, nodules, and lenses of chert appear lower down in the section. The chert is dark gray and occurs as nodules, lenses, and irregular beds from about 2 inches to more than 5 feet thick with abundant spiriferid brachiopods (fig. 42). The limestone is medium-dark gray, light- to medium-gray- and light-tannish-gray weathering, fine grained, siliceous, and fossiliferous. It occurs in nodules, lenses, and irregular beds about 2 inches to more than 10 feet thick. It is locally extensively burrowed (fig. 43). The sandstone is medium to light gray, calcareous, medium to very coarse grained and conglomeratic (pebbles as much as ½ inch long). It occurs as beds 1 inch to 2 feet thick (fig. 42). The sandstone is moderately to poorly sorted orthoquartzite (fig. 44). Occasional chert pebbles suggest that the chert in the Shriver formed during early diagenesis and was later reworked to form pebbles. Preserved bedding laminae in the chert and replacement of fossils by

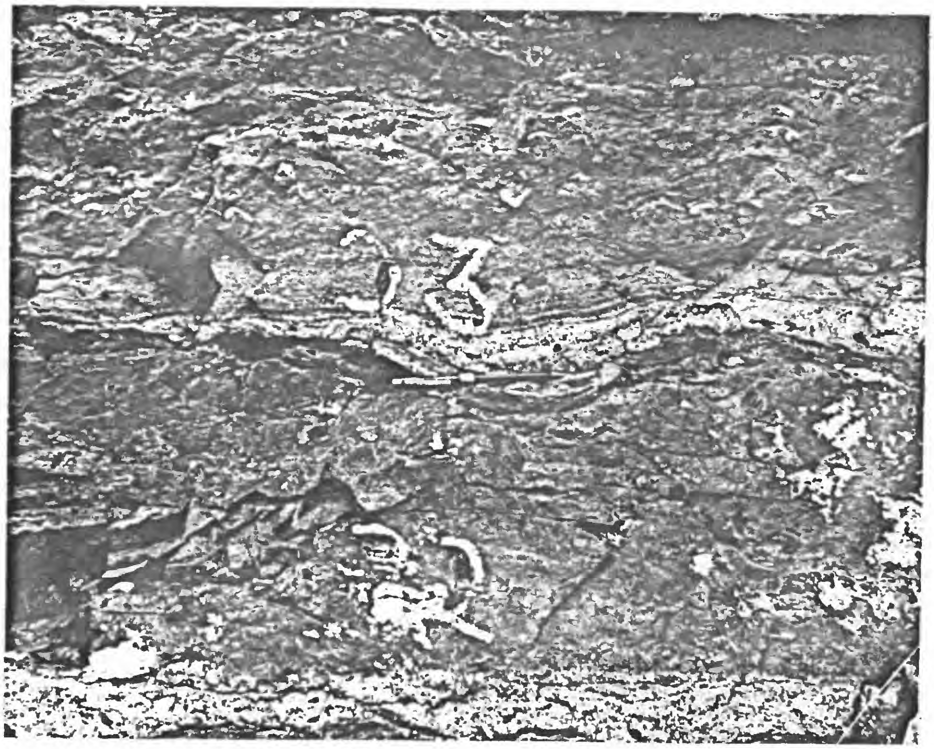


Figure 42. Shriver Chert of Oriskany Group. Laminated to partly crossbedded coarse-grained calcareous sandstone (base of unit 16, measured section 7) overlain by dark-gray chert with abundant spiriferid brachiopods that are made of calcite and which upon weathering leaves numerous molds. The sandstone is channeled into the underlying chert.

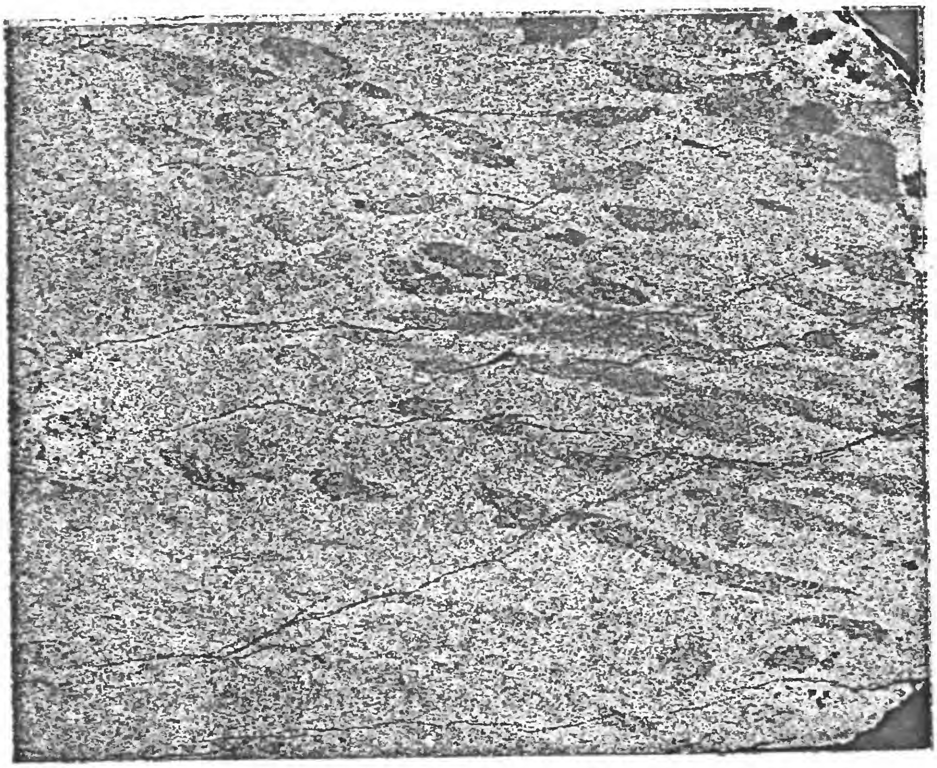


Figure 43. Burrowed calcisiltite, Shriver Chert of Oriskany Group. Unit 8 of measured section 7. Specimen stained with Alizarin Red S (darker grains are calcite). Negative print of acetate peel taken about parallel to bedding, X 2.6.

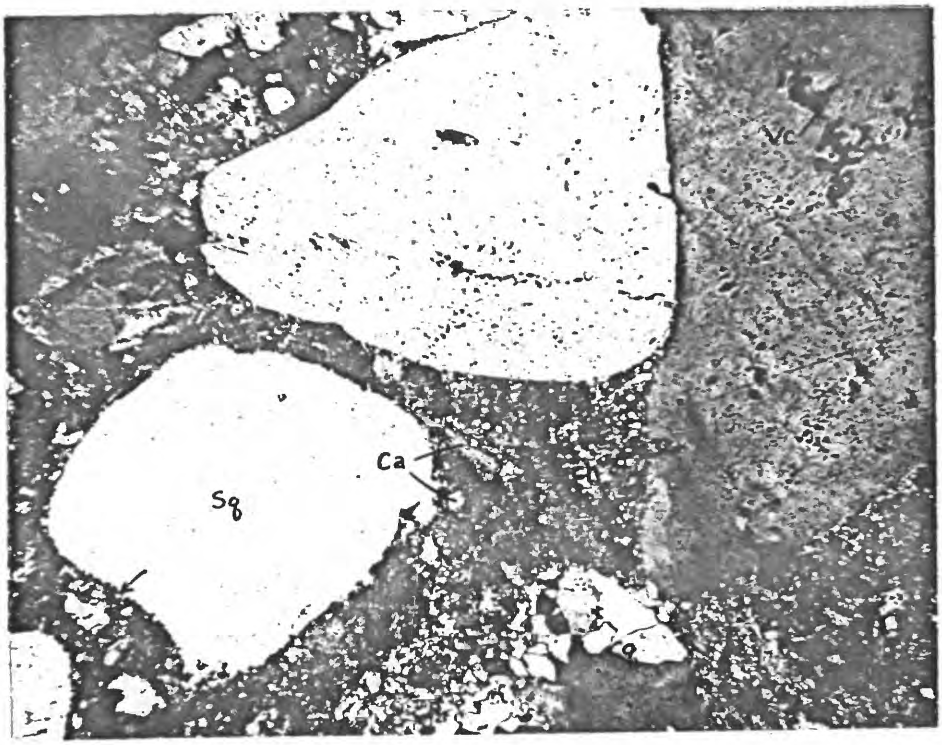


Figure 44. Photomicrograph (crossed polarizers, X 43) of very coarse-grained orthoquartzite in the Shriver Chert of the Oriskany Group, unit 19 of measured section 7. Quartz grains (79 percent) are rounded to subrounded, single (sq) to composite (cq) with undulose to strongly undulose extinction and minor overgrowths. The quartz is cemented by chert (ch, 16 percent) and calcite (ca, 5 percent). Minor muscovite (<1 percent) is present in the groundmass. Some quartz grains have vermicular chlorite inclusions (vc). The borders of some quartz grains are diffuse where replaced by chert (arrow).

chert also argue for a penecontemporaneous diagenetic origin.

Cleaves (1939) believed the Shriver was not present in eastern Pennsylvania and maintained that the Ridgeley rests directly on the Helderberg (Port Ewen). This unconformity was accepted by Cooper and others (1942) and Jones and Cate (1957). Its regional significance was shown by Swartz (1939) and Swartz and Swartz (1941) who demonstrated that many units were truncated by the pre-Oriskany unconformity in eastern Pennsylvania. Swartz (1939) also suggested the presence of a positive area near Harrisburg, Pa., the Auburn promontory, to account for depositional thinning or nondeposition of many of the Keyser and Helderberg units. Willard (1941), expanding on Ulrich (1911), noted that many Ordovician through Devonian units, including the Oriskany, thin or pinch out by onlap onto the Harrisburg axis, as he called the positive area. However, Willard (1952) questioned if there was any pre-Oriskany lost interval on Brodhead Creek in the Stroudsburg quadrangle. The Port Ewen-Oriskany boundary is transitional in the quadrangle (Epstein and others, 1967; this report), reflecting a gradual regression. Only minor diastemic breaks are indicated.

Ridgeley Sandstone

The Ridgeley was proposed for fossiliferous sandstones in Allegany County, Md., and adjacent West Virginia. It was named for Ridgeley, W. Va.

In the easternmost part of Godfrey Ridge, the Ridgeley is 14 to 16 feet thick, but along Route 191 on the south side of the ridge it thickens to 33 feet. It consists of medium- to light-gray, brownish-orange- to orange-gray-weathering, fine- to very coarse grained, evenly to unevenly bedded, planar-bedded to crossbedded calcareous sandstone (presumably orthoquartzites as in the underlying Shriver) and lesser quartz-pebble conglomerate with pebbles as much as 0.5 inch long. The Ridgeley also contains a few thin beds and lenses of medium-gray siltstone, arenaceous and argillaceous fine-grained limestone, and dark-gray chert. The lower contact is abrupt and placed at the base of the predominantly sandstone interval.

Post-Oriskany and Pre-Hamilton Rocks

Rogers (1858) termed the sequence of shale, siltstone, and cherty limestone overlying the Oriskany the Post-Meridian, which White (1882) and Prosser (1892) subdivided into the Caudi-galli Grit below and Corniferous Limestone above. Kindle (1912) replaced the name Corniferous with the Onondaga Limestone and the Caudi-galli with the Esopus Shale. Neither White (1882) nor Willard (1936a, 1939) recognized the Schoharie in eastern Pennsylvania. Willard (1936a) believed these rocks to be Middle Devonian in age and placed them in the Onondaga Formation of the Hamilton Group. He subdivided the Onondaga into two members, the Esopus for the lower shaly part and "upper cherty limestone" for the upper part in Monroe County, Pa. Willard (1939) later excluded these rocks from the Hamilton Group and raised the Onondaga to group rank with the newly proposed Buttermilk Falls Limestone overlying the Esopus Shale. The Schoharie Formation and Esopus Shale of Early Devonian age were carried into northeastern Pennsylvania by Cooper and others (1942), apparently based on the work of Goldring and Flower (1942). Cooper and others show these overlain by the Buttermilk Falls Limestone of Early or Middle Devonian age. The

Buttermilk Falls and Esopus are considered part of the Onondaga Formation on the state map of Pennsylvania (Gray and others, 1960). The Schoharie was first recognized in the Stroudsburg area by Herpers (1950) who called it the "X-beds," and later by Trexler (1953), Johnson (1957, 1959), and Johnson and Southard (1962). Oliver (1956, 1962) equated the Buttermilk Falls with parts of the Onondaga Limestone of New York and concluded that both are Middle Devonian in age. The latest correlations (Oliver and others, 1969) place the Buttermilk Falls in the Middle Devonian and the Esopus and Schoharie in the Lower Devonian. Faunal lists for the Esopus through Buttermilk Falls are given by Prosser (1892), Kindle (1912), and Willard (1936a, 1938, 1939).

In the Stroudsburg quadrangle, the rocks between the Oriskany and Hamilton Groups include, from the base upward, the Esopus Formation, the Schoharie Formation, and the Buttermilk Falls Limestone. The Buttermilk Falls is divided into three new mappable members. The distribution and stratigraphic relations of these rocks between Delaware and Lehigh Rivers in eastern Pennsylvania are given by Epstein and Epstein (1967, 1969).

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 of his Caudi-galli Grit and Willard (1936a, 1938) reported more than 250 feet of the Esopus Shale and later (1939) revised the figure to more than 300 feet. In their measurements, both Willard and White included rocks herein assigned to the Schoharie

Formation. Johnson (1957) and Johnson and Southard (1962) believed the Esopus to be more than 200 feet thick in the Stroudsburg area.

The Esopus is 181 feet thick in bluffs north of the Erie-Lackawanna Railroad, 1 mile east of East Stroudsburg. It is a medium- to dark-gray, medium-gray-weathering, shaly to finely arenaceous siltstone and lesser silty shale and minor calcareous siltstone. Cleavage is very well developed, masking the sedimentary features. The rock is laminated except where it is burrowed. The trace fossil Taonurus is common, as it is in the basal Schoharie (figs. 46, 58). Brachiopods are uncommon. Moderate-yellowish-brown to dark-yellowish-orange 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, the iron staining is characteristic, and, when hit with a hammer, it emits a dull "thud" as compared to the firmer "ring" of the more massive Schoharie.

In thin section, the Esopus is composed mainly of shaly graywacke siltstone and consists of medium- to coarse-silt-sized quartz (about 40-50 percent), muscovite, and chlorite (15-30 percent), calcite (probably averaging <3 percent), plagioclase, chert, and angular to rounded tourmaline and zircon (rare) in a fine-silt to clay matrix probably mostly of quartz, muscovite, and chlorite. Opaque minerals, including pyrite and leucoxene, comprise about 1 percent. The quartz is ragged and replaced with minor muscovite and chlorite in pressure-shadow areas of cleavage. Many of the muscovite, chlorite, and some quartz grains are oriented parallel to cleavage, apparently dragged to this position and crushed to smaller sizes.

The Esopus holds up some of the highest parts of Godfrey Ridge. Good exposures are numerous, as those along the abandoned railroad grade west of Minisink Hills, in and near Foxtown Gap, on the north slope of Godfrey Ridge along U.S. 611, and along the road east of Pine Grove Lake north of Stormville.

The base of the Esopus is in sharp contact with the underlying Ridgeley Sandstone and is reputed to be unconformable (Willard, 1936a; Cleaves, 1937; Cooper and others, 1942; Jones and Cate, 1957). This interpretation is supported by the faunal break, abrupt lithic changes, and inferred different environments of deposition to be discussed later.

Schoharie Formation

Vanuxem (1840) named the Schoharie for exposures in Schoharie County, N. Y. At Buttermilk Falls in the East Stroudsburg quadrangle (pl. III), Herpers (1950) placed 72 feet of rock in his "X-beds," including calcareous siltstones in his "Esopus senso stricto," which are part of the Schoharie as identified by Johnson (1957), who measured 102 feet of Schoharie at the same locality. The base of the Schoharie, as recognized by Johnson (1957) and Johnson and Southard (1962), is placed at the lowest prominent calcareous siltstones or mudstones overlying the Esopus. Accepting this contact, which also coincides with the base of the lowest massive siltstone, 103 feet of Schoharie was measured near Buttermilk Falls (measured section 8, fig. 45). The Schoharie in the Stroudsburg area is predominantly a medium-gray to grayish-black, thin-bedded to massive and laminated, fairly evenly

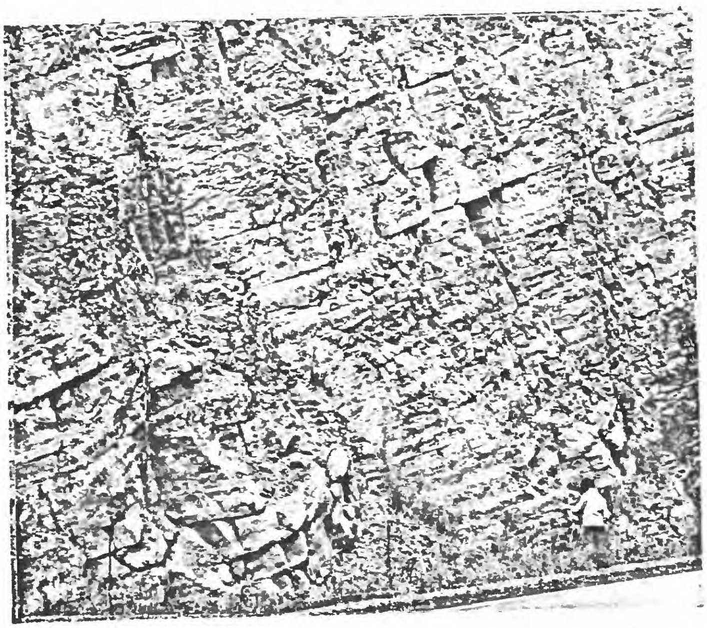


Figure 45. Moderately evenly bedded siltstones in the Schoharie Formation in roadcut along U.S. Route 209 near Buttermilk Falls, East Stroudsburg quadrangle (see pl. III, measured section 8). Lighter weathering beds are more calcareous.

bedded, calcareous siltstone with lesser fine-grained sandy siltstone. Beds are as much as 6 feet thick. Dark-gray chert which weathers light gray is scattered throughout as rounded and irregular nodules and lenses as much as 2 inches thick. The chert is more abundant towards the top. Burrow mottling is common. Horizontal burrows (Taonurus) are abundant in the lower half (fig. 46), and vertical burrows are more common in the upper half. Brachiopods are common. The base of the formation, according to Johnson (1957), is marked by a zone of Leptocoelia acutiplicata and is typical of his Carlisle Center facies. The Schoharie is transitional into the Esopus and the base locally is placed within a 10 to 20 foot interval with difficulty.

In thin section (fig. 47), calcite as microspar and as sparry calcite rhombs comprises 40 to 60 percent of most of the rock in the Schoharie. Quartz (35-55 percent) is etched and generally occurs as single grains, but a few composite grains and grains of chert were noted. Muscovite and chlorite make up less that 5 percent of the rock. Plagioclase feldspar (<1 percent) and rare tourmaline, zircon, and opaque minerals, including pyrite and leucoxene, are accessory minerals.

The Schoharie is fairly well exposed in Godfrey Ridge. It generally holds up high parts of the ridge. Besides the locality near Buttermilk Falls, good exposures are found in an abandoned quarry, 0.9 mile west of Minisink Hills, Pa., along the abandoned railroad grade just west of Minisink Hills, along U.S. 611 where it crosses Foxtown Hill in the railroad cut nearly 1 mile south of the East Stroudsburg post office (measured section 9), and on the north slope

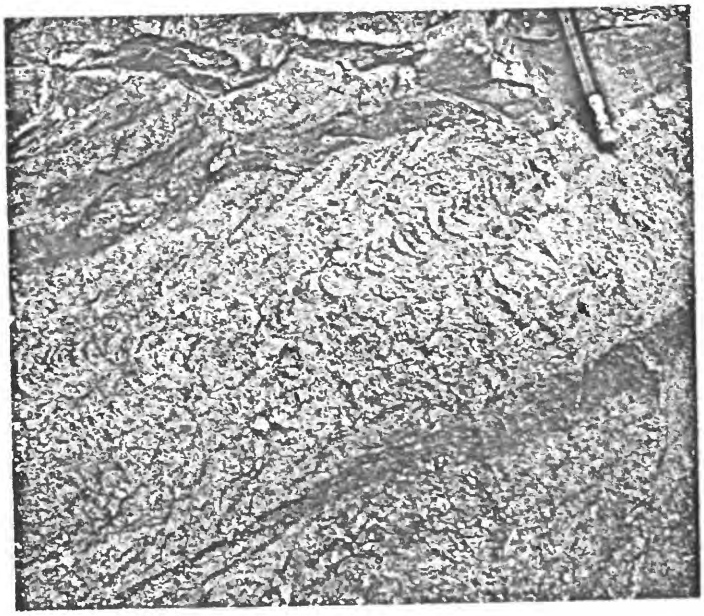


Figure 46. Taonurus, believed to be a horizontal burrow, in the lower half of the Schoharie Formation, in roadcut along U.S. 209 near Buttermilk Falls, Pa., East Stroudsburg quadrangle.

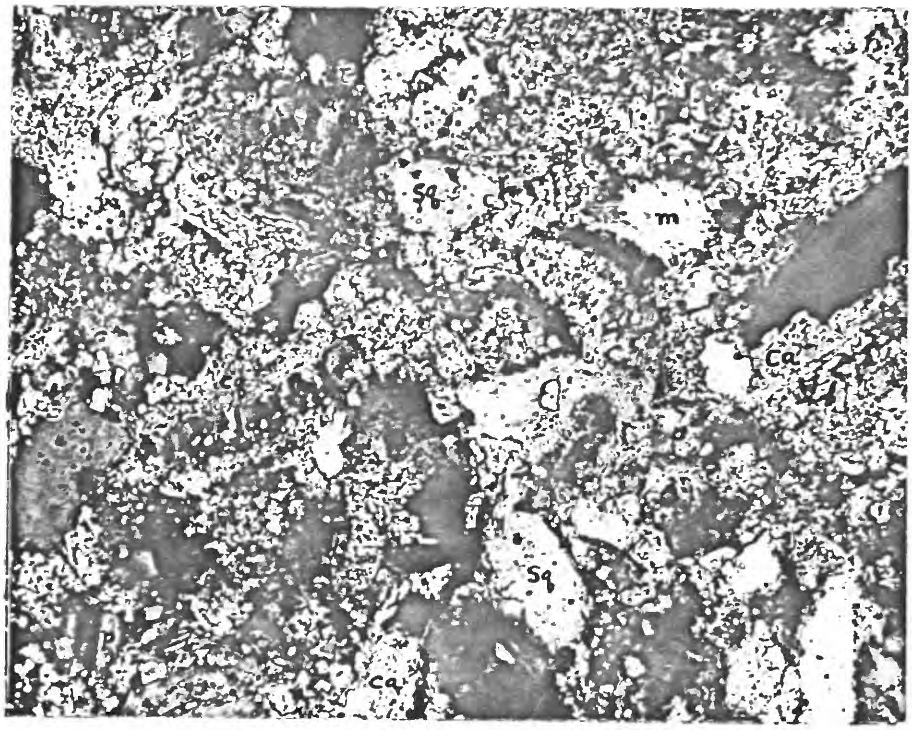


Figure 47. Photomicrograph (crossed polarizers, X 277) of very coarse grained quartzose calcisiltite or calcareous siltstone in the Schoharie Formation, 50 feet below the contact with the Buttermilk Falls Limestone. From roadcut along U.S. 209 near Buttermilk Falls, East Stroudsburg quadrangle, unit 4 of measured section 9. The rock contains about 50 percent calcite (ca) which occurs as microspar and recrystallized rhombs; etched, predominantly simple quartz (sq, about 45 percent) with a few composite grains (cq), and minor muscovite (m), chlorite, and plagioclase feldspar (p).

of Godfrey Ridge north of Stormville.

Buttermilk Falls Limestone

The type locality of the Buttermilk Falls Limestone is at Buttermilk Falls on Marshall Creek in the East Stroudsburg quadrangle. Willard (1939) named the unit and believed it to be about 200 feet thick. At the type locality (measured section 8), only the lower 25 feet are exposed. Elsewhere, as in the railroad cut of the Erie-Lackawanna Railroad, 1 mile south of the East Stroudsburg post office, the Buttermilk Falls is 272 feet 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.

Foxtown Member

The type section of the Foxtown and other members of the Buttermilk Falls Limestone is in the railroad cut of the Erie-Lackawanna Railroad, nearly 1 mile south of the East Stroudsburg post office (measured section 9). 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 bedded and lenticular, medium-gray to medium-dark-gray, light-gray- to medium-light-gray-weathering, cherty limestone in beds 1 inch to 2 feet thick (fig. 48). Grain size is generally fine (fig. 49), but very coarse grains are not uncommon. The limestones are interbedded with medium-dark-gray, calcareous, evenly bedded shale and siltstone in beds 1 inch to 1 foot thick, and contain dark-gray to grayish-black chert. The chert in the lower half occurs as irregular nodules $\frac{1}{2}$ to 6 inches in diameter. Chert is more

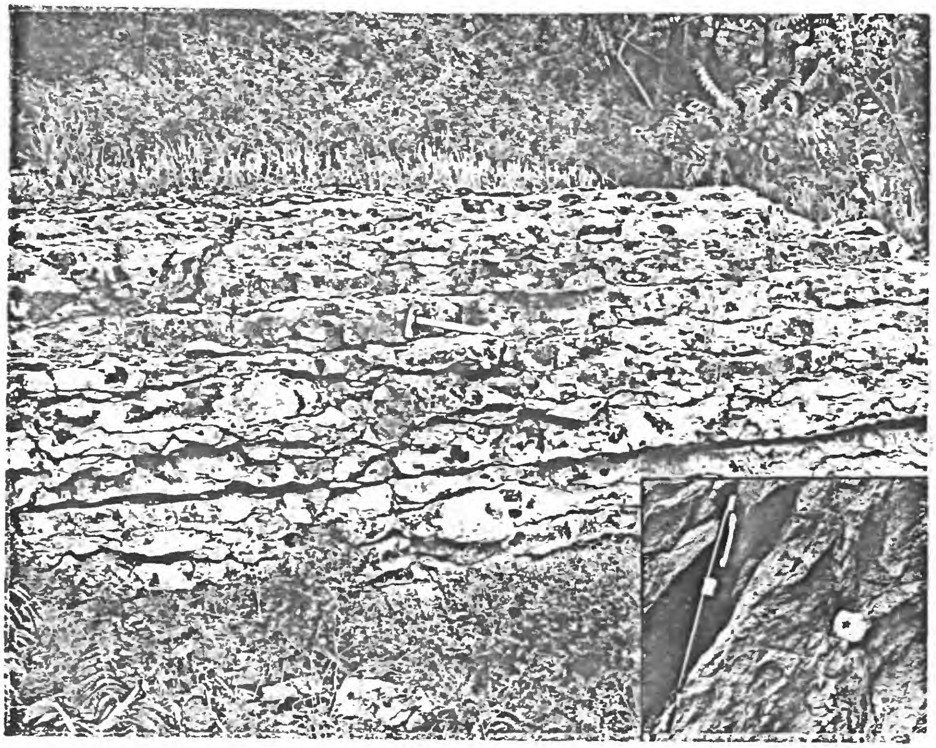


Figure 48. Irregularly bedded cherty limestone in the upper half of the Foxtown Member of the Buttermilk Falls Limestone, in roadcut on Brown Street, 5,000 feet northeast of the hospital in East Stroudsburg. Inset shows 1-inch diameter crinoid columnals from the lower part of the Foxtwon Member at the type section on the Erie-Lackawanna Railroad, south of East Stroudsburg, Pa.

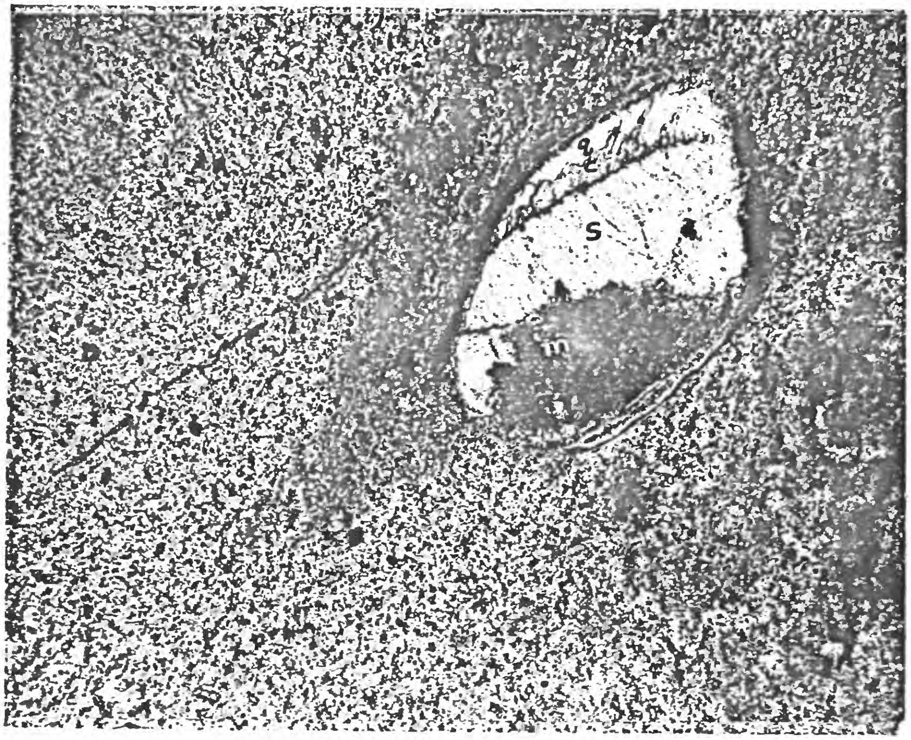


Figure 49. Photomicrograph (plane-polarized light, X 42) of cherty biomicrite (light areas) and biomicrite (dark areas) with ostracode partly filled with micrite (m), a probable geopetal structure, and sparry calcite (s). Shell is partly filled with quartz (q), and calcite (c), aligned parallel to rock cleavage. Foxtown Member of Buttermilk Falls Limestone, near Buttermilk Falls, East Stroudsburg quadrangle, unit 5 of measured section 8. Some other samples of the Foxtown are biomicrudites, partly neocrystallized to microspar and pseudospar.

abundant in the upper half where it makes up more than 50 percent of the unit and contains interbeds of calcareous argillite 1 to 2 inches thick and limestone pods 2 to 6 inches in diameter. The chert contains varying amounts of calcite and mica (fig. 49).

Large crinoid columnals (fig. 48), as much as 1 inch in diameter, are conspicuous in the lower half of the Foxtown Member. W. A. Oliver (1962, and written commun., 1962) traced large crinoid columnals, marking the base of his Edgecliff Member at the bottom of the Onondaga Limestone, from Onondaga, N.Y., to Port Jervis, N.Y. He saw a similar crinoid marker bed at the bottom of the Buttermilk Falls Limestone near Stroudsburg and belives that the Buttermilk Falls of eastern Pennsylvania is the equivalent of the Onondaga of southeastern New York. Although stratigraphic relations have not been worked out between Monroe County, Pa., and southeast New York, the facies changes alone are sufficient to justify the new names in the Stroudsburg quadrangle (W. A. Oliver, written commun., 1963).

At the type section, the base of the Foxtown Member is marked by a 1-foot-thick, medium-gray, medium- to very coarse grained limestone in abrupt contact with the underlying Schoharie Formation. In the western part of the Stroudsburg quadrangle, the boundary between the Foxtown and Schoharie is transitional through about 6 feet of cherty calcareous siltstone and silty limestone.

The Foxtown Member is 82 feet thick at the type section. In the abandoned quarry south of U.S. Interstate 80 and 1,200 feet west of where the highway crosses Brodhead Creek (Slater-Canfield quarry, according to Johnson, 1957, who assigned the beds to the Schoharie

Formation), the Foxtown is 80 feet 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. Epstein, 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 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 highs on the north slope of Godfrey Ridge. In addition to the localities mentioned, good exposures are found at the foot of Godfrey Ridge along the junction of U.S. 611 and State Route 191, and at the west edge of the Stroudsburg quadrangle near McMichael Creek.

McMichael Member

The member is named for McMichael Creek north of Godfrey Ridge. At the type section, along the Erie-Lackawanna Railroad (fig. 50), it is 41 feet thick and at the Slater-Canfield quarry it is 42 feet thick. It consists of evenly bedded to lenticular, medium-gray to medium-dark-gray, medium-gray weathering, calcareous, partly silty, fossiliferous shale or argillite in beds 2 inches to 1 foot thick, and interbedded medium-gray, fine-grained (probably biomicrite and biomicrudite) fossiliferous limestone in beds, lenses, and nodules 1 to 3 inches 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. Epstein, 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
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

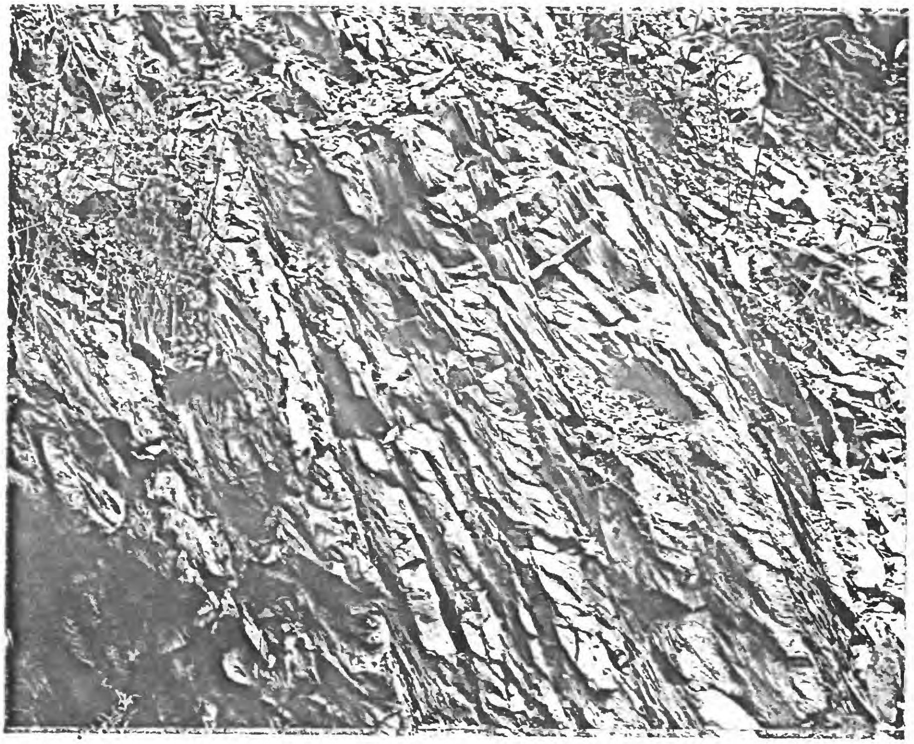


Figure 50. Evenly bedded and lenticular limestone (light) and calcareous argillite (dark) in the McMichael Member of the Buttermilk Falls Limestone at the type locality along the Erie-Lackawanna Railroad, nearly 1 mile south of the East Stroudsburg post office. The beds are overturned to the southeast (to right) and dip more steeply than the prominent cleavage in the argillite. Note refraction of the cleavage in the limestone.

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 forms a topographic saddle between the cherty limestones above and below. The lower boundary is gradational.

Stroudsburg Member

This member is named for Stroudsburg, Pa., where good exposures are seen along U.S. Interstate 80 (fig. 79). At the Slater-Canfield quarry, the lower 15 feet are exposed and at the type section (fig. 51) 149 feet are exposed. The Stroudsburg consists of irregularly bedded, medium-gray to medium-dark-gray, light-gray to medium-light-gray-weathering, fossiliferous, fine- to medium-grained, locally argillaceous limestone in beds and lenses 1 inch to 1 foot thick, and dark-gray to grayish-black chert in irregular beds, lenses, and pods 0.25 inch to 1 foot thick. The upper 15 feet at the type section and also to the south of Stroudsburg contain several beds, 3 to 6 inches thick, of medium-gray to medium-light-gray, light-gray-weathering, medium- to very coarse grained limestone (probably biosparrudite) with abundant brachiopod, coral, and crinoid debris and some conodonts. These conodonts, as well as some ostracodes from the rest of the member, have not as yet been identified. The McMichael and Stroudsburg Members have a gradational boundary. The Stroudsburg Member is generally exposed

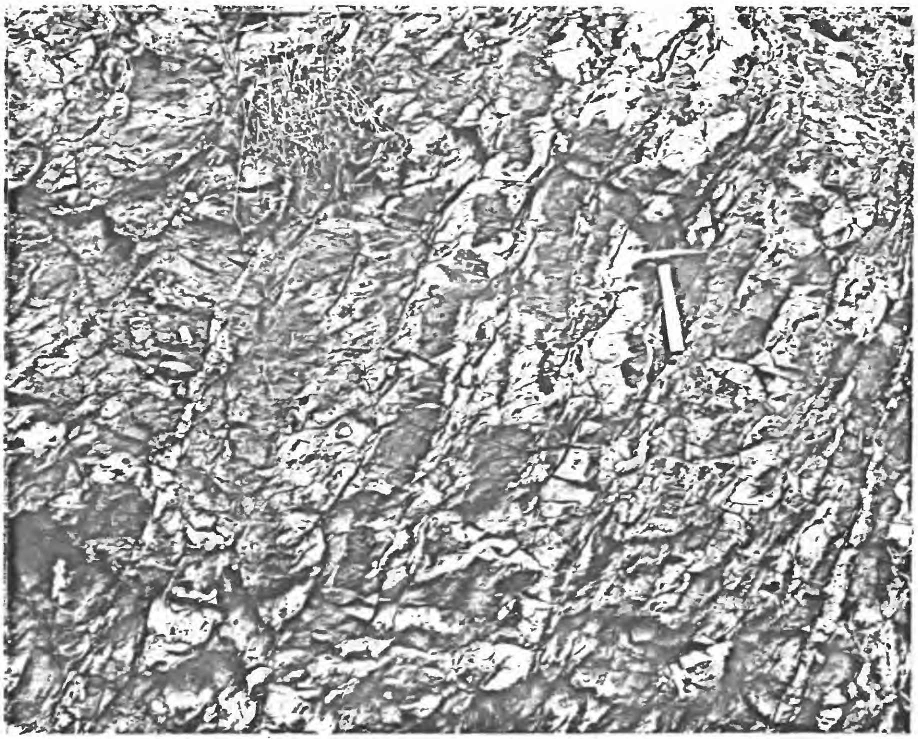


Figure 51. Unevenly but distinctly bedded chert (dark) and limestone (light) in the Stroudsburg Member of the Buttermilk Falls Limestone at the type section along the Erie-Lackawanna Railroad south of East Stroudsburg. Beds are overturned to the southeast (to left). Note poorly developed cleavage dipping gently to the southeast.

in several small hills that rise above the valleys of McMichael and Brodhead Creeks.

The Tioga Bentonite that may be present at the top of the Buttermilk Falls (see Oliver and others, 1969) has not been seen in the Stroudsburg quadrangle, although it is present 25 miles to the southwest in the Lehighton quadrangle. If present, and presumably it is, it is in the covered interval between the Buttermilk Falls and the exposed Marcellus Formation.

Hamilton Group

The predominantly cherty limestones of the Buttermilk Falls Limestone are succeeded by a thick sequence of predominantly fine clastic rocks, to which Rogers (1858) applied the term "Cadent Series." White (1882) divided these rocks into the Hamilton Sandstones above and Marcellus Shale or Lower Hamilton below, correlating them with the Hamilton of New York. The Hamilton Group was named by Vanuxem (1840) for exposures at West Hamilton, N.Y., and later the Hamilton was redefined by Vanuxem (1842) to include rocks from the base of the Tully to the top of the Marcellus. Clarke (1885) redefined the Hamilton to include the Marcellus in New York. In Pennsylvania, Willard and Cleaves (1933) recognized, in descending order, the Moscow, Ludlowville, Skaneateles, and Marcellus facies. Later, Willard (1935, 1937, 1938, 1939) noted that the rocks above the Marcellus could not be lithically subdivided in eastern Pennsylvania and named them the Mahantango Formation. Willard (1936b) recognized a biostrome within the Mahantango, which he correlated with the Centerfield Limestone of

York. The basal 150 feet of the Marcellus in the Stroudsburg area is made up of calcareous shaly siltstone and shale which have been placed in the Marcellus or in the Buttermilk Falls by various workers. As defined below, these beds are assigned, as members, to the Stony Hollow of Cooper (1941) and Union Springs of Cooper (1930) and included in the Marcellus Shale. Overlying these rocks is the Brodhead Creek Member, first suggested by Willard (1938). At the top of the Hamilton Group in the Stroudsburg area is the Mahantango Formation containing the Centerfield biostrome.

Marcellus Shale

The name Marcellus was given to some rocks exposed near Marcellus, N.Y., by Hall (1839). White (1882) recognized 800 feet of the Marcellus in the Delaware Valley of eastern Pennsylvania. Willard (1938) believed the thickness to be between 800 and 900 feet, and later (Willard, 1939) gave a maximum thickness of 880 feet. In the Stroudsburg quadrangle, the Marcellus is poorly exposed or covered in many places by drift; it could be as much as 1,100 feet thick.

Stony Hollow and Union Springs Members, undifferentiated

White (1882) recognized 300 feet of gray shale at the bottom of his Marcellus in the Stroudsburg area. Willard (1938) believed that the basal Marcellus is transitional into the Buttermilk Falls Limestone and named these transitional beds the Shamokin Black Shale, but later (Willard, 1939) maintained that these shaly transitional beds were in the Buttermilk Falls. Alvord (oral commun. to Oliver, 1961, in Oliver, 1962) believed that about 50 feet of interbedded shale and limestone is an upper member of the Buttermilk Falls Limestone in the Bushkill quadrangle. Oliver (1964) later placed these beds within the lower part of the Marcellus, correlating them with the Stony Hollow Sandstone of Cooper (1941) of New York, which Cooper (in Cooper and others, 1942) traced to Echo Lake, Pa., about 9 miles northeast of Stroudsburg in the Bushkill quadrangle (fig. 1). The Stony Hollow at Echo Lake was described as a calcareous sandstone, but in actuality it is predominantly a calcareous siltstone and shale, as it is near Stroudsburg. According to Cooper and others (1942), the Bakoven Shale underlies the Stony Hollow, but the name Bakoven was dropped in favor of the Union Springs Shale (originally named by Cooper, 1930) in southeast New York (Rickard, 1964). Both the Stony Hollow and Union Springs are members of the Marcellus Formation in New York. North of Lehigh Gap, along the northeast extension of the Pennsylvania Turnpike, in the Lehighton quadrangle (fig. 1), Willard (1957) recognized 15-20 feet of black shale at the base of the Marcellus that he believed resembled the Union Springs of New York. The black shale along the Turnpike, which I measured to be 29 feet thick, is overlain by 42 feet of interbedded calcareous shale and shaly limestone, which I place in the Stony Hollow. These members can be traced in very scattered exposures to the Stroudsburg area.

Thus, the lower beds of the Marcellus in easternmost Pennsylvania are placed in the Stony Hollow and Union Springs as members. Based on these identifications (written commun. to A. A. Drake, Jr., 1[illegible]6), these members were mapped in the Bushkill quadrangle by Alvord and Drake (in press).

In the Stroudsburg quadrangle, the Union Springs is exposed in only one place--a small shale pit north of a secondary road at the west end of the Glen Brook Golf Course, about 1 mile southwest of the Stroudsburg Boro line. Ten feet of medium-gray to medium-dark-gray noncalcareous laminated, carbonaceous shale, which weathers moderate-reddish brown to dark-yellowish orange, is exposed, and is referred to the Union Springs Member. An estimated 30 to 40 feet of rock lies between the base of this exposure to the top of the Buttermilk Falls Limestone. Between 40 and 50 feet of Union Springs is believed to underlie the covered interval between the Route 191 bridge over Brodhead Creek and the top of the Buttermilk Falls Limestone to the south.

The Stony Hollow Member is exposed in a number of places in the Stroudsburg quadrangle. One of the best exposures is in Brodhead Creek under the Route 191 bridge, on the south side of Stroudsburg (fig. 52). The unit here consists of about 25 feet of finely bedded to laminated medium-dark-gray to medium-gray, sparingly fossiliferous (poorly preserved brachiopods), pyritic, interbedded calcareous shaly siltstone, silty shale, and argillaceous limestone (fig. 53). The argillaceous limestone beds are continuous, but pinch and swell slightly along strike. The calcium carbonate content in these rocks, determined by dissolving three samples in hydrochloric acid, ranges from 15 to 65 percent. The calcareous siltstones average about 20 percent calcium carbonate. These percentages are in agreement with semiquantitative X-ray analyses which show that quartz ranges from about 10 to 40 percent, chlorite 5 to 15 percent, and muscovite 10

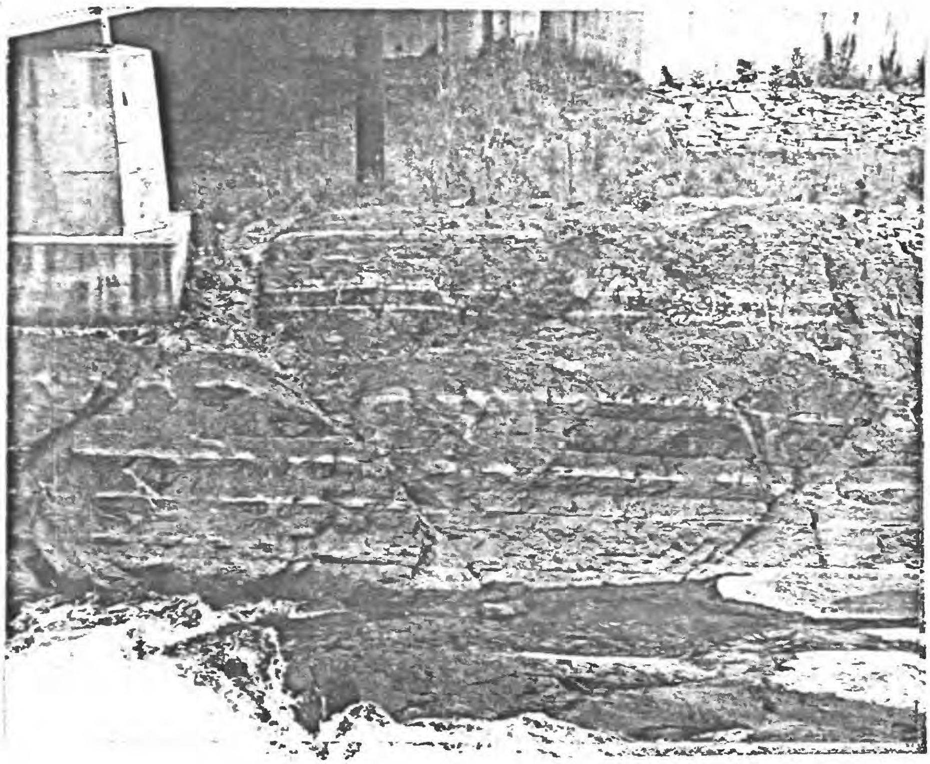


Figure 52. Exposure of the Stony Hollow Member of the Marcellus Shale along Brodhead Creek, under the bridge where Route 191 crosses the creek on the south side of Stroudsburg. The unit is predominantly calcareous shaly siltstone. Lighter weathering argillaceous limestone, a few inches thick, is evenly bedded to lenticular. Cleavage dips toward observer.

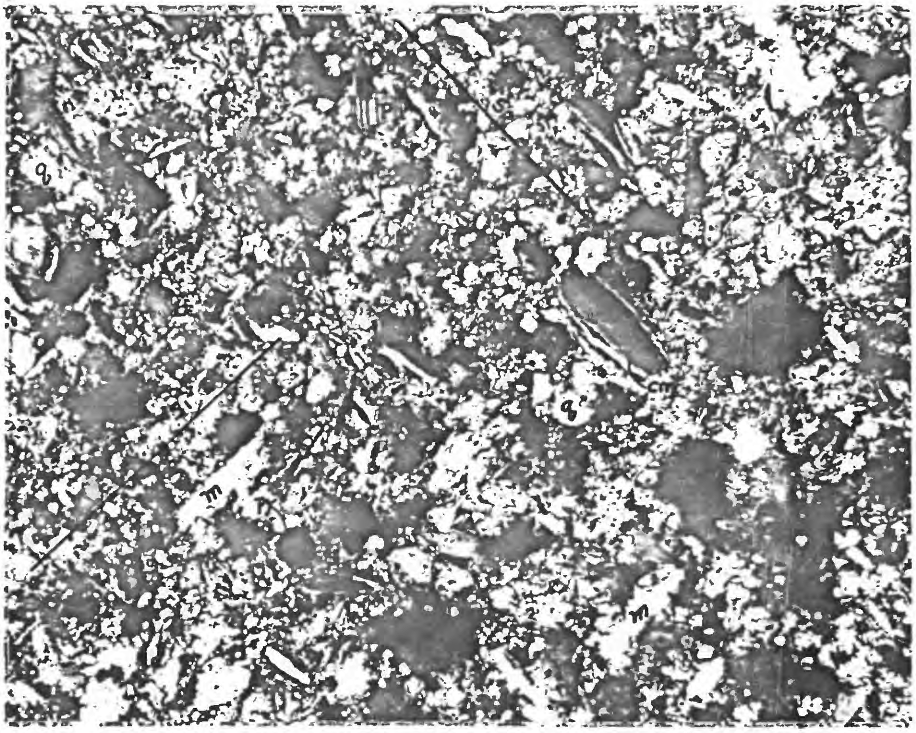


Figure 53. Photomicrograph (crossed polarizers, X 277) of calcareous siltstone in the Stony Hollow Member of the Marcellus Shale at the same locality as figure 52. Bedding (S_0); cleavage (S_1) is poorly defined by the alignment of muscovite laths (m); pyrite (py); quartz (q); plagioclase feldspar, rare (p); intergrown chlorite and muscovite (cm). Alternating with the siltstone are thin beds of quartzose calcisiltite.

to [illegible] percent. Rocks higher in the section contain fewer limestone beds and, with the decrease in calcium carbonate, grade up into the Marcellus Shale.

At the shale pit on the west edge of the Glen Brook Golf Course, about 10 feet of the Stony Hollow is exposed above the Union Springs, and at least an additional 60 feet of moderately exposed rock overlies it in the hill above. Based on construction of cross sections, the Stony Hollow is estimated to about 150 feet thick in the Stroudsburg quadrangle.

Brodhead Creek Member

The Brodhead Creek Member was named for Brodhead Creek by Willard (1938). Willard described fossiliferous finely arenaceous shale exposed in a shale pit northwest of the intersection of Fulmer Avenue and Wallace Street (one block north of Scott Street and two blocks west of Fifth Street). The member is predominantly dark-gray, laminated to poorly bedded, generally sparingly fossiliferous, carbonaceous, silty shale and shaly siltstone (fig. 54). Faunal lists are given by Willard (1932, 1938, 1939). The Brodhead Creek contains dark-gray shaly limestone concretions as much as 1 foot long. X-ray diffraction analysis of one sample of a concretion shows it to contain about 55 percent calcite, 20 percent quartz, 15 percent muscovite, and 10 percent chlorite. No microfossils were recovered from one limestone concretion that was dissolved in dilute acetic acid. The Brodhead Creek Member has a maximum thickness of between 800 and 900 feet, based on construction of cross sections. The boundary with the underlying Stony Hollow Member is not exposed,

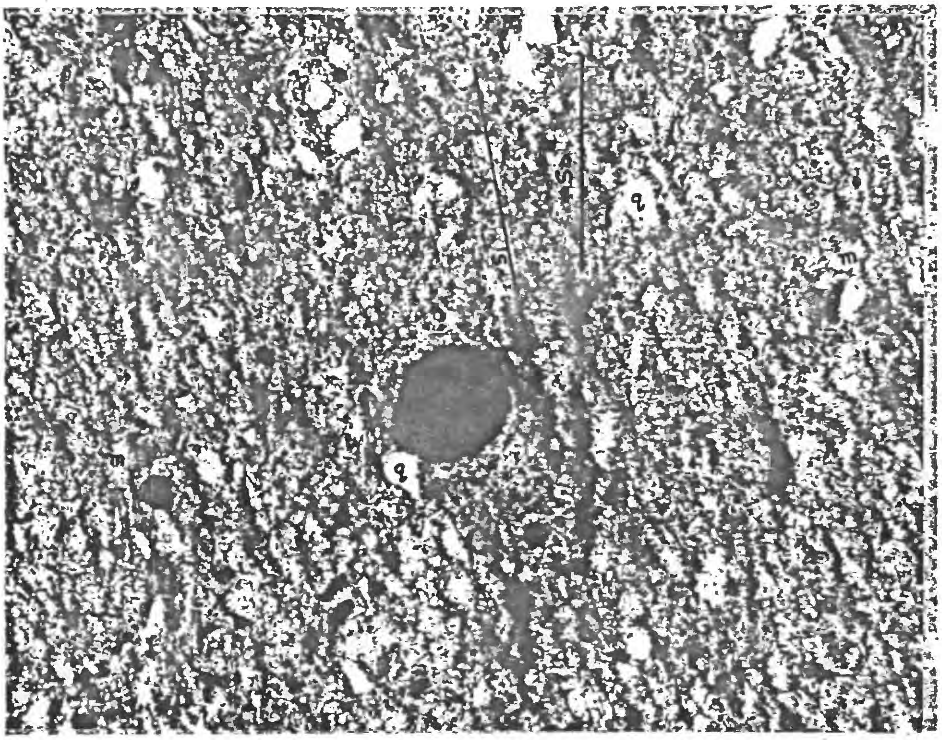


Figure 54. Photomicrograph (plane-polarized light, X 270) of silty shale, Brodhead Creek Member of Marcellus Shale, roadcut at Interchange 47 of U.S. Interstate 80, 0.5 mile southwest of Arlington Heights. Rock consists of irregular grains of quartz (q) and muscovite (m) in a finer groundmass of muscovite, chlorite, and quartz. Only minor pressure-shadow effects are seen on the edge of a spherical pyrite grain (large black grain) in the plane of cleavage. Cleavage (S_1) is faint and marked by some parallelism of platy minerals. Bedding (S_0) makes an angle of 11° to cleavage.

but is believed to be gradational.

Mahantango Formation

The Mahantango Formation was proposed by Willard (1935) for strata between the Marcellus Shale and Tully Limestone exposed along Mahantango Creek in Juniata and Snyder Counties, Pa. Ellison (1965) reviewed previous work on the Mahantango and, along with Willard (1938, 1939), presents faunal lists. In Monroe County, Pa., the Mahantango was reported to be 1,200 feet thick by White (1882; his Hamilton Sandstones), about 1,200 feet thick by Willard (1938), 1,320 feet thick by Willard (1939), and 1,400 feet thick by Willard and Stevenson (1950). Approximately 850 feet of the lower Mahantango is present in the northwest corner of the Stroudsburg quadrangle. It is about 2,000 feet thick in the Saylorsburg quadrangle to the west.

The Mahantango in the Stroudsburg quadrangle consists of medium-gray to medium-dark-gray shaly siltstone to coarse siltstone, but very fine grained sandstone is exposed to the west of the quadrangle. The Mahantango weathers medium gray to grayish orange and is gradational through about 25 to 50 feet of rock into the underlying finer grained rocks of the Marcellus Shale. Very fossiliferous beds are numerous; these contain brachiopods, corals, cephalopods, pelecypods, crinoid columnals, trilobites, and other forms. An especially fossiliferous, medium-dark-gray, calcareous and noncalcareous, thick-bedded to irregularly bedded siltstone occurs about 800 feet above the base of the Mahantango. This biostrome was designated the

Centerfield coral zone by Willard (1936b, 1938, 1939), Beerbower (1957), and Beerbower and McDowell (1960). The Centerfield biostrome is exposed at only one locality in the Stroudsburg quadrangle--in the roadcut along U.S. Interstate 80 at the west border of the quadrangle (fig. 55). About 30 feet of the biostrome are exposed. The dominant fossils are favositid corals and Heliophyllum, neither of these appear to have moved far from their growth position.

QUATERNARY

Surficial deposits of Quaternary age unconformably overlie two-thirds of the bedrock in the Stroudsburg quadrangle. These consist of Pleistocene glacial deposits of Illinoian(?) and Wisconsin age and Holocene (Recent) sediments of alluvial, swamp, and man-made origin. These deposits have been described in detail by Epstein (1969) and are discussed briefly in the section on surficial geology and illustrated in plate IV.

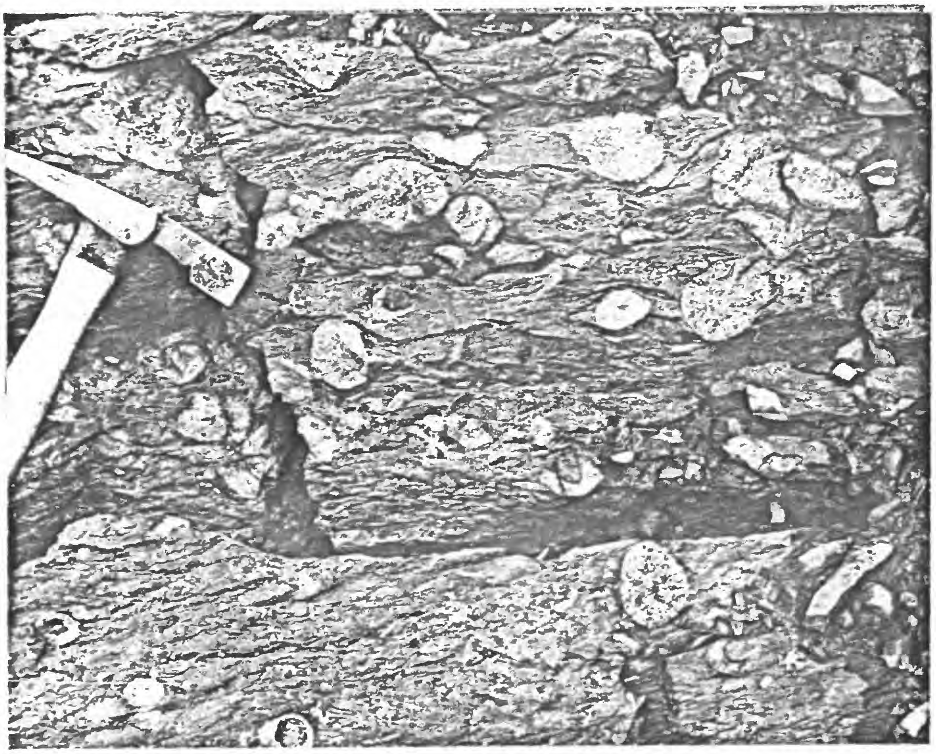


Figure 55. Heliophyllum in poorly bedded calcareous shaly siltstone in Centerfield biostrome of Mahantango Formation, exposed along U.S. Interstate 80 at the west border of the Stroudsburg quadrangle. Note horizontal trace of cleavage that wraps around fossils.

ENVIRONMENTS OF DEPOSITION

The Middle Ordovician through Middle Devonian rocks in the Stroudsburg quadrangle and adjacent areas compose parts of two shelf-flysch-molasse sequences related to two tectonic cycles attributable to the Taconic and Acadian orogenies.

From Cambrian through Late Ordovician time, the Appalachian basin in eastern Pennsylvania gradually deepened and the influx of terrigenous sediments gradually increased. The rock record indicates that the area slowly changed from a supratidal-shallow shelf (Hardyston Quartzite, Leithsville Formation, Allentown Dolomite, and Beekmantown Group: dolomite, limestone, arkose, and orthoquartzite) to a deeper neritic-flysch basin (fossiliferous calcarenite and calcilutite of the Jacksonburg Limestone to thick accumulations of rhythmically bedded graywacke and slate of the Martinsburg Formation).

Rocks older than the Martinsburg are exposed south of the Stroudsburg quadrangle. Jacksonburg time marked the onset of flysch-type sedimentation, which culminated in Martinsburg time with rhythmic graded sequences of graywacke and dark-gray slate. The graywackes are immature sediments that contain sedimentary features characteristic of deposition by turbidity currents (McBride, 1962; Van Houten, 1954). The Martinsburg sediments reflect Taconic orogenic activity, which reached its peak with t emergence of the area sometime in the Late Ordovician. The mineralogy of the Martinsburg graywackes, dominated by muscovite, chlorite, quartz, and calcite, with minor amounts of biotite (some of which has been retrograded to chlorite), high sodic plagioclase feldspar, and a mature heavy-mineral suite (mostly rare zircon and tourmaline), along with chert and rock fragments of shale and slate, which together indicate a source including low-grade metamorphic and sedimentary rocks with possible contributions from volcanic rocks.

The Martinsburg is succeeded by a molasse and carbonate-orthoquartzite sequence of Silurian to early Middle Devonian age. The inferred environments of deposition of these rocks in the area between the Stroudsburg quadrangle and Lehigh River in eastern Pennsylvania is shown in figure 56.

The Silurian clastic sequence in the Stroudsburg area (Shawangunk-Bloomsburg interval) consists of four distinct units: a basal sandstone and conglomerate (Minsi Member of the Shawangunk Formation); interbedded very fine to medium-grained sandstone, siltstone, and minor shale (Clinton Member of the Shawangunk Formation), a sandstone-conglomerate unit similar to the basal member (Tammany Member of the Shawangunk Formation); and an upper redbed sequence dominated by repretative fining-upward cycles of fine- to coarse-grained sandstone, siltstone, and silty shale. These form a clastic wedge derived from sourcelands to the southeast that rose during the Taconic orogeny.

Figure 56. Generalized blcok diagram showing sedimentary nvironments and major lithofacies in northeasternmost Pennsylvania rom Silurian through early Middle Devonian time.

lluviated coastal plain

1, Streams of high gradient, coarse load, low sinuosity (braided).
A, Bedforms in upper flow regime (planar beds, antidunes) and upper lower flow regime (dunes); chiefly conglomerate and sandstone; lower conglomerate unit of Shawangunk Formation, 12 miles southwest of the Stroudsburg quadrangle.
B, Bedforms in lower upper flow regime (planar beds) and upper lower flow regime (dunes); chiefly conglomeratic quartzite and quartzite; Minsi and Tammany Members of the Shawangunk Formation.

2, Streams of low gradient, medium load and fine flood-plain deposits, high sinuosity (meandering). Bedforms in lower flow regime (dunes and ripples). Sandstone, siltstone, and shale. Bloomsburg Red Beds and Poxono Island Formation.

'idal flats

3, Supratidal flat, may include tidal creeks. Dolomite, limestone, shale, sandstone. Laminated (algal), massive, mud-cracked, intraclasts, sparse fauna. Clinton Member of Shawangunk Formation and Poxono Island, Rondout, and Decker Formations.

4, Intertidal flat, may include tidal channel and gully, estuary, lagoon, beach. Shale, siltstone, sandstone (equivalent limestone in areas of low terrigenous influx), minor nodules and oolites of collophane, siderite, and chlorite. Irregularly bedded and laminated, graded, rippled, flaser-bedded, cut-and-fill, ball-and-pillow structure, burrowed, restricted fauna (Lingula, Dipleurozoa, eurypterids in noncarbonates; abundant leperditiid ostracodes in carbonates). Clinton Member of Shawangunk Formation, Poxono Island Formation, Bossardville Limestone, and Rondout and Coeymans Formations.

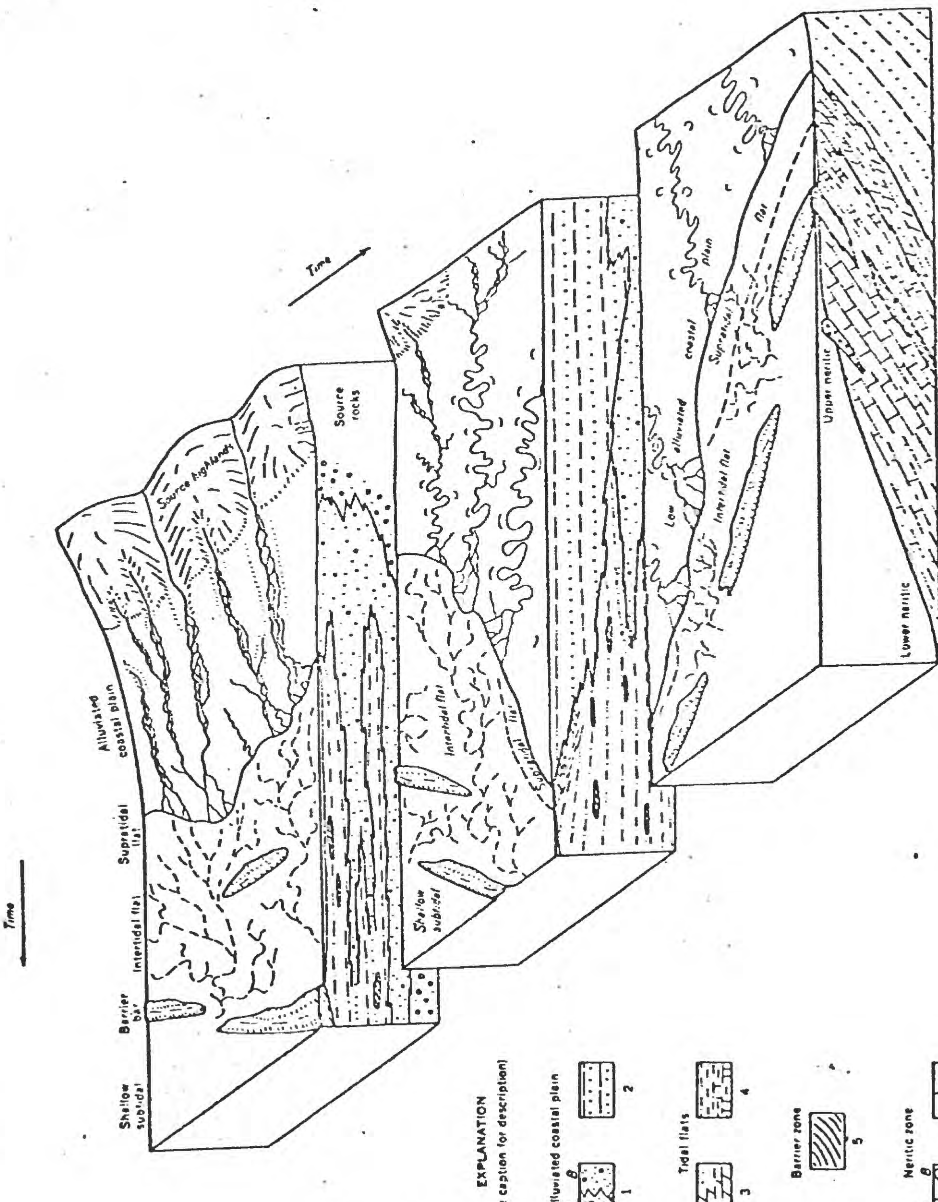
arrier zone

5, Offshore bar and beach. Conglomerate, sandstone, and siltstone, and equivalent limestone. Foreshore laminations, crossbedding, scouring, abundant wave-tossed shell debris, textural maturity. Clinton Member of Shawangunk Formation, Decker and Coeymans Formations, Oriskany Group, Palmerton Sandstone 2 miles west of the Stroudsburg quadrangle.

Neritic zone

6, A, Upper neritic. Cherty, calcisiltite and calcareous siltstone, unevenly bedded (burrowed), diverse fauna, and B, Bioherm and biostromal bank. Biolithite and biogenic limestone containing minor terrigenous sediment. Decker, Coeymans, and New Scotland Formations, Minisink Limestone, Port Ewen Shale, Oriskany Group, Schoharie Formation, Buttermilk Falls Limestone.

7, Lower neritic. Shaly siltstone, calcareous shaly siltstone, and calcareous shale. Laminated, burrowed, skeletal debris less abundant than in upper neritic. New Scotland Formation, Port Ewen Shale, Esopus and Schoharie Formations.


Time
Shallow subtidal
Barrier bar
Intertidal flat
Supratidal flat
Alluviated coastal plain
Source highlands
Source rocks
Time
Shallow subtidal
Intertidal flat
Supratidal flat
Low alluviated coastal plain
Intertidal flat
Supratidal flat
Upper neritic
Lower neritic
EXPLANATION
(See caption for description)
Alluviated coastal plain
A B
1
2
Tidal flats
3
4
Barrier zone
5
Neritic zone
A B
6
7

This clastic wedge is considered to be predominantly fluvial in origin, but the Clinton Member is a transitional marine facies and parts of the Bloomsburg may have been deposited in a shallow marine environment. These major environments of deposition for the Shawangunk-Bloomsburg interval that I have previously interpreted (Epstein and Epstein, 1967, 1969) are in general agreement with those of Smith (1967a, 1967b) and Smith and Saunders (1970) who made and independent study of this interval from New York to central Pennsylvania.

In general, previous workers on the Shawangunk have considered it to be predominantly deltaic or fluvial in origin (for example, Grabau, 1909, 1913; Swartz. 1948; Yeakel, 1962; Epstein and Epstein, 1967, 1969; Smith, 1967a, 1967b), although an exclusively littoral origin has been proposed by others (Schuchert, 1916; Willard, 1928).

Initially, uplift was rapid, as evidenced by the unconformable Shawangunk-Martinsburg contact and the coarse texture of basal Shawangunk rocks, as shown by the conglomerate unit in the Lehigh Gap area to the west (fig. 8). Sediments become finer from the Minsi Member through the Clinton Member in the Stroudsburg area. This interval is about 575 feet thick at Delaware Water Gap and about three times as thick at Lehigh Gap. This represents a transgressive phase and the lowering of the source area concomitant with basin subsidence.

The initial deposits of this sequence, the conglomerate unit of the Shawangunk Formation at Lehigh Gap (see fig. 8) (possibly present at one time southeast of Delaware Water Gap, but removed by erosion), are characterized by rapidly alternating conglomerate beds, medium- to very coarse grained sandstone, and very minor argillite. The conglomerates, containing pebbles as much as 6 inches long, are indistinctly bedded to planar-bedded and the sandstones are planar-bedded to crossbedded, indicative of relatively rapid flow (upper lower flow regime to upper flow regime; Simons and Richardson, 1962; Fahnestock and Haushild, 1962), and probably are channel and bar deposits of streams. Grain size is variable and pebbles are well rounded to subangular, indicative of a fluviatile environment (Sames, 1966). The sandstones are generally immature (high muscovite-chlorite matrix). Paleocurrent trends are unidirectional to the northwest, also indicating a fluvial environment (Yeakel, 1962; fig. 57). The bedforms and sedimentary structures indicate deposition by streams which had great competency and steep gradients and are characteristic of streams of low sinuosity (braided). Properties of braided streams have been discussed in many papers; e.g., Doeglas (1962) and Allen (1965a). The lack of channel-fill deposits in channels with relief greater than 5 feet also indicates that the streams were not confined to a single channel but flowed in many anastomosing channels that shifted position continuously. The nearly complete absence of fine siltstone and shale in the conglomerate unit is

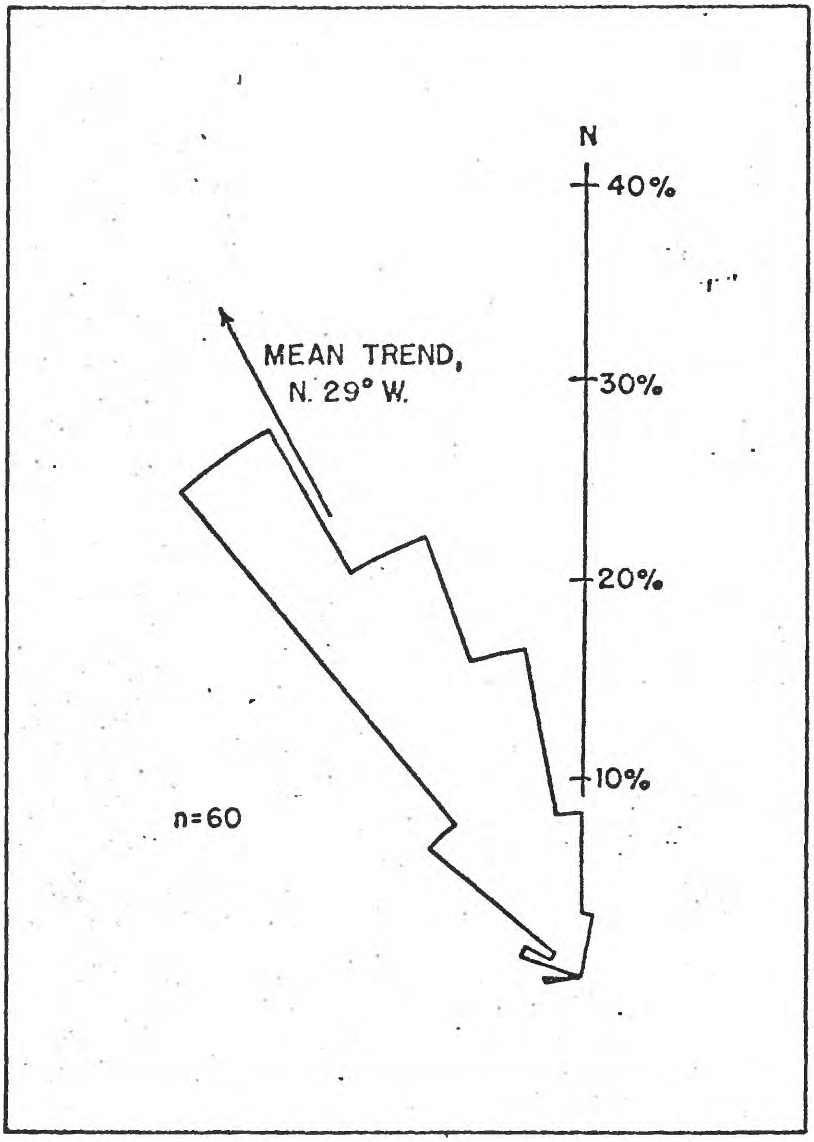


Figure 57. Histogram showing current trends from crossbedding in the Shawangunk Formation at Delaware Water Gap. Beds rotated to horizontal.

also characteristic of braided stream deposits. Braided streams shift so rapidly across the fluvial plain that they are able to remove fine-grained sediment. Some of the shale and silt was incorporated in the coarser sediment as flattened mud balls.

Glaciofluvial deposits of Pleistocene age in the Stroudsburg area are very similar to the conglomerates and sandstones in the Shawangunk (see section on surficial geology). The glacial sediments were undoubtedly deposited by braided streams with high velocity and coarse load. Fahnestock (1963) described similar deposits of the White River, Mount Rainier, Wash.

The Minsi Member, which overlies the conglomerate unit at Lehigh Gap and forms the basal unit of the Shawangunk Formation at Delaware Water Gap (see fig. 8) is similar to the conglomerate unit except that pebbles are smaller (less than 2 inches long), and argillites, probably representing overbank and backwater deposits, are more abundant. Mudcracks in at least one siltstone bed (fig. 10) show that these deposits were subject to subaerial exposure. Numerous sedimentation units are superposed, as in the conglomerate unit and also represent deposition by braided streams. The finer grain size suggests that the source highlands were lowered or eroded back at this time.

The long linear outcrop belt of the lower part of the Shawangunk suggests that it was deposited on a coastal plain of alluviation with a linear source to the southeast. The pebbles in the conglomerate unit are as much as 6 inches long near Little Gap, Pa., suggesting that the Fall Line could not have been far to the southeast, perhaps in the area of the Reading Prong (see Yeakel, 1962). The maturity of the pebbles (quartz, chert, and quartzite) and heavy minerals (preponderance of zircon and tourmaline, many of which are rounded) suggests a sedimentary source. Basal beds in the Shawangunk contain enough potash feldspar (fig. 11; see also chemical analysis 1, table 2) to suggest that the source was at least partly composed of granitic or gneissic rocks. The feldspar and absence of kaolinite in the clay-size fraction (indicated by X-ray diffraction studies) may exclude a deeply weathered crystalline source, but any kaolinite that may have been present could have converted to muscovite by diagenesis or metamorphism following deep burial. Mainly quartzose and feldspathic metasedimentary rocks and lesser amphibolite, marble, and granitic rocks are now exposed in the Reading Prong (Drake, 1969). Conceivably, equivalent rocks that may have been exposed during Silurian time could have been the source for some of the Shawangunk, and chert-bearing carbonates and quartzites of Cambrian and Ordovician age could have supplied other components. Hornblende is extremely rare in the Shawangunk, and pyroxene and epidote, all common in Prong rocks, were not seen in the Shawangunk at Delaware Water Gap. Quartz is the most abundant mineral in pebbles in the Shawangunk. Much of the quartz contains vermicular chlorite, indicating derivation from quartz veins. The Reading Prong characteristically lacks abundant quartz veins. Could it be that rocks dissimilar to those now found to the southeast were the source for the Shawangunk, emplaced in their position in thrust sheets or ap but long since eroded? Drake (1970) reported that a equence of low-grade metasedimentary and metavolcanic rocks are 'ound on the north border of the Prong. These are apparently 'ounger than the more highly metamorphosed rocks they overlie and could have been more extensive. They could have been a source for much of the Shawangunk.

The coarse clastic rocks of the Minsi Member grade rapidly ıp into interbedded shale, siltstone, and sandstone of the Clinton Member. This unit is generally evenly bedded (fig. 13) and is interpreted to have been deposited in a complex transitional (continental-marine) environment.

The Clinton thickens to the west and at Lehigh Gap it is about 1,200 feet thick (fig. 8). In addition to similar deposits described at Delaware Water Gap, the Clinton contains redbeds, beds with chlorite pellets, phosphate nodules, and Lingula fragments which, as a group, are interpreted as shallow water, transitional (tidal-flat, lagoon, barrier bar or beach, and other complex environments characteristic of deltas described by Shepard and Lankford, 1959; Coleman and Gagliano, 1965; Bernard and LeBlanc, 1965; Donaldson, 1966) deposits (Epstein and Epstein, 1969; Hunter, 1970) The differentiation of these environments will require more detailed work. The Clinton thins towards Delaware Water Gap and is replaced by coarser clastic fluviatile sediments of the overlying Tammany Member. This change in facies supports the interpretation that the Clinton at Delaware Water Gap is partly estuarine, and partly tidal flat in origin; that is, the finer material transported across the alluviated coastal plain was carried into the transitional environment and distributed into a number of subenvironments (fig. 56). This interpretation is consistant with the environment suggested by the fossils that have been found--Arthrophycus in a block of rock in the retaining wall in Delaware Water Gap on the New Jersey side of the river, eurypterids (Clarke and Ruedemann, 1912), and Dipleirozoa (Johnson and Fox, 1968)(see age of the Shawangunk Formation, p. 46-50).

Deposits believed to be tidal flat in origin consist of irregularly interlaminated to finely interbedded burrowed shale, siltstone, and sandstone. Flaser bedding (ripple lensing, fig. 16), a characteristic of sediments reworked by tidal currents (Häntzschel, 1939) is common. These beds also contain mud flasers such as have been found in recent tidal-channel deposits (Reineck and Singh, 1967). Phosphate nodules (calcium fluorapatite) are common in these beds. At Lehigh Gap these nodules are associated with chlorite and siderite which are believed to be early diagenetic replacements in an agitated environment. Lingula was also found, indicating that water depths were probably less than 60 feet. Many of the Lingula and nodule-bearing beds are interbedded with sandstones belived to be beach or barrier-bar deposits (Epstein and Epstein, 1969). Thus, there can be little doubt that the phosphate nodules are of very shallow water origin.

Some crossbedded sandstones containing mud clasts may be tidal channel or tidal gulley deposits (see van Straaten, 1961) or fluviatile deposits that prograded out onto the tidal flats. This distinction may be difficult to make (Land and Hoyt, 1966). Many sandstones in the Clinton appear generally evenly textured and massive in outcrop, but on polished or wet sawed surfaces are finely bedded to laminated (fig. 14). These are mature sandstones (orthoquartzites) with primary current lineation; they are interpreted as beach or bar deposits associated with the tidal flats. If correct, the paleogeography may have been similar to the chenier plains along the southern coast of Louisiana. Some ripple-topped sandstones (fig. 15) are similar to the sand-flat sandstones described by Evens (1965). Rare silty sandstones have ball-and-pillow structure, due to soft-rock slumping (fig. 17), that were possibly produced during storms. Ore (1964), however, describes similar intraformational deformation in braided streams, due to movement of saturated sediment, a condition also prevalent on tidal flats.

Regression in the Stroudsburg area occurred as fluvial sediments of the Tammany Member, similar to those of the Minsi Member, overlapped the transitional environment. As such, the Tammany represents the topset plain of a delta that was built out over the transitional environment (fig. 8). This regression may have been localized by the shifting of the site of major stream debouchment, rather than due to uplift in the source area, because the coarse deposits of the Tammany die out to the west.

The occurrence of ferroan dolomite in the Tammany indicates proximity to salt water that supplied magnesium for dolomitization, possibly in the same manner as has been described for the penecontemporaneous dolomitization of limestone in supratidal environments (for example, see Shinn and others, 1965). In the case of the Shawangunk, as herein envisioned, ground water carrying salts in solution from the nearby body of water was enriched in magnesium at or near the surface by evaporation and also by precipitation of gypsum, thus increasing the Mg:Ca ratio. Capillary action resupplied water to the surface. In this way, the sediments in the Tammany Member were dolomitized by the magnesium-rich brines. A certain amount of aridity (evaporation exceeding rainfall), and lack of flushing of the salty ground water by fresh ground water derived upslope, is implied in this scheme. The water body may have been the sea or a lake on the alluviated coastal plain. An inland sea is favored, because the dolomites are within a few hundred feet of the overlying Bloomsburg Red Beds that are interpreted to be of fluvial origin and deposited very close to sea level, but may have also been partly tidal flat in origin. Similar replacement by ascending brines may account for the dolomite nodules that are near the dolomite bed in the Tammany Member, as well as in the overlying Bloomsburg Red Beds.

Fluvial conditions persisted through Middle Silurian time, but the braided stream deposits of the Tammany Member give way to predominantly meandering stream deposits of the Bloomsburg. This indicates lowering of the source highlands to the southeast.

The Bloomsburg consists predominantly of red sandstone, siltstone, and shale, which occur in poorly to well-defined upward-fining cycles (fig. 25). The cycles are as much as 10 feet thick and consist of, from bottom to top:

(1) Very fine- to coarse-grained, large-scale crossbedded to planar-bedded sandstone that locally contains red shale clasts as much as 3 inches long. The basal contact is a sharp erosion surface of very low relief that cuts into the underlying finer beds. The lower few inches of the sandstone are locally gray. The abruptness of the basal contact in places is accentuated by bedding slippage described in the section on structural geology.

(2) Finely interbedded and irregularly interlaminated siltstone and very fine grained sandstone containing small-scale ripples. Mud clasts occur locally in the sandstone beds.

(3) Shaly siltstone that is extensively burrowed is indistinctly mud cracked in places and contains scattered irregular dark-yellowish-orange concretions averaging about 1 inch in length. X-ray diffraction analysis and staining techniques show that the nodules are ferroan dolomite. The cycle described is somewhat idealized and does not represent all rocks in the Bloomsburg.

Cyclicity in the Bloomsburg is readily explained by vertical and lateral accretion from migrating streams concomitant with basin sinking. Each fining-upward cycle represents superposition of beds of successively lower flow regime.

ese fining-upward cycles are generally considered to have een deposited by meandering streams (e.g., Allen, 1965b). The oarse basal sands were deposited in stream channels and point bars hrough lateral accretion as the stream meandered. The mud clasts were derived from bank caving. Large-scale crossbedding and planar-bedding are indicative of the upper lower and lower upper flow regimes, respectively. These basal beds grade up into laminated sandstone and siltstone containing small-scale crossbedding that indicates decreasing flow regime. Similar rocks have been interpreted to be levee and crevasse-splay deposits (Allen, 1965b). Next in succession are the fine overbank or flood-plain deposits that accumulated by vertical accretion. Burrowing animals obliterated stratification in many of these beds in this low-energy, tranquil environment. Mud cracks show that subaerial exposure was common. Evaporation at the surface may have caused the precipitation of calcareous concretions (see Bernard and Major, 1963; Moody-Stuart, 966), but, as mentioned previously, the concretions in the Bloomsburg are ferroan dolomite. It is possible that the Bloomsburg rivers were not far above the strandline, and that the dolomite concretions may have formed in a high tidal-flat environment by a mechanism similar to the one described for the dolomitization of rocks in the Tammany Member of the Shawangunk Formation.

Fossils are very rare in the Bloomsburg. Fish scales were found near the toll booth at the village of Delaware Water Gap. The fish are believed to have lived in a fluvial or lagoonal environment by erbower and Hait (1959). Thus, some of the redbeds in the

Bloomsburg could have been deposited in shallow marine waters. In many places, such as in the steep-sided valley 0.4 mile north of Poplar Valley church, the Bloomsburg is made up of interlaminated and finely interbedded green and red sandstone and siltstone. The colors are believed to have formed at the site of deposition (see Walker, 1967a, b) and may mark the oxidation-reduction boundary at or near mean tide level (McKee, 1957; Nichols, 1962). A similar situation prevails at the top of the Bloomsburg where tidal-flat deposits of the Poxono Island Formation are interbedded with red beds in a transition interval a few hundred feet thick (seen outside the Stroudsburg quadrangle). Clearly, the land surface in Bloomsburg time was at low altitudes. Encroachment of the sea over broad tidal flats during Poxono Island time initiated a transgression which continued through part of Early Devonian time.

The above discussion does not mean that all color changes in the Bloomsburg are related to the site of deposition. Certainly the massive color change between the Shawangunk and Bloomsburg Red Beds as seen at the north end of Delaware Water Gap may be due to late diagenesis, as suggested by Horowitz (1969) and Thompson (1970b) for the red-nonred sequences in the central Appalachians.

Between Late Silurian (Bloomsburg) time and Oriskany time, deposits in this part of the Appalachian basin are of the marine shelf carbonate-orthoquartzite facies. During the first half of this interval, the rates of sedimentation and basin sinking were about equal and the area was maintained near sea level, so that rocks from the Poxono Island through lower Coeymans were deposited in tidal flats (supratidal and intertidal) and barrier bars or biostromal banks (intertidal and shallow subtidal). Repetition of lithofacies characterizes this stratigraphic sequence. These lithofacies are indicative of broad subenvironments within this major shallow marine transgression (fig. 56). Details are given in Epstein and others (1967).

Sediments that accumulated in supratidal flats are characterized by: (1) laminations or organo (algal)-sedimentary origin (fig. 34); (2) slightly quartzose, dominantly very fine to fine-grained, laminated and very thin bedded to massive dolomite, limestone, and interlaminated dolomite and limestone; (3) very restricted fauna (mainly leperditiid ostracodes); (4) mud cracks (fig. 33). Supratidal sediments occur in the Poxono Island Formation, upper Bossardville Limestone, and Rondout Formation.

The intertidal zone can be subdivided into intertidal flats and barrier bars or beaches. Intertidal flat sediments are characterized by: (1) generally graded and rippled laminae to thin beds of slightly quartzose, very fine to medium-grained limestone (fig. 28); (2) cut-and-fill structure, small-scale crossbedding, and intraclasts; (3) abundant ostracodes (mainly leperditiids; figs. 29, 36); (4) scattered beds containing diverse marine fauna believed to be storm-tossed skeletal debris on a tidal flat behind a barrier bar; (5) rare mud cracks which may have formed during exposure above the intertidal zone (fig. 30). Barrier-bar deposits of the intertidal zone are distinguished by: (1) quartzose fine- to coarse-grained limestone and calcareous sandstone and conglomerate containing foreshore laminations and large-scale crossbedding (fig. 38); (2) cut-and-fill structure and intraclasts; (3) abundant skeletal debris of a variety of marine organisms; (4) scattered burrows. Intertidal sediments occur in the Poxono Island Formation, Bossardville Limestone, Decker Formation, Rondout Formation, and Depue Limestone Member of the Coeymans Formation.

Sediments that may have accumulated in the shallow subtidal zone of a barrier bar are characterized by: (1) laminated to bedded, fine- to coarse-grained quartzose limestone and calcareous siltstone to sandstone containing scattered to abundant burrows, (2) flaser bedding (ripple lenses), (3) abundant and diverse marine fauna. Shallow subtidal sediments occur in the Bossardville Limestone west of the Stroudsburg quadrangle, Decker Formation, Rondout Formation, and Coeymans Formation.

From Coeymans to Oriskany time, the area underwent a major transgressive-regressive episode. The basin steadily deepened from Coeymans through most of Port Ewen time (sinking exceeded sediment accumulation). Regression began in late Port Ewen time and culminated with post-Oriskany emergence.

In northeastern Pennsylvania, the Lower Devonian outcrop belt crosses several Early Devonian depositional zones. In Coeymans time, the shoreline probably lay near Hazard, Pa., about 20 miles southwest of the Stroudsburg quadrangle, and areas southwest of that were probably emergent (Epstein and Epstein, 1969). Silt, sand and gravel were carried into the basin by streams and spread along the shore as bars by marine currents (Stormville and Peters Valley Members of the Coeymans Formation). Ostracode biosparrudites of the Depue Limestone Member of the Coeymans Formation (fig. 36) were probably deposited in a protected lagoon behind the Peters Valley bar or biostromal banks of the Shawnee Island. Areas more distant from shore, or areas receiving less terrigenous material, were occupied by biostromal banks (Shawnee Island Member of the Coeymans Formation). These rocks are generally burrowed silty and sandy biosparrudites (fig. 37). In areas of inconsequential terrigenous sediment influx, reefs grew during Shawnee Island time (Epstein and others, 1967). A flood of terrigenous material, the Stormville Member (fig. 38), entered the basin at the end of Shawnee Island time and was spread as bars as far northeast as Wallpack Center, N.J., about 25 miles northeast of the Stroudsburg quadrangle.

A deeper subtidal phase followed Stormville deposition. Rickard (1962) interprets the lithofacies of the New Scotland Formation and Port Ewen Shale as indicative of a deep neritic environment. From New Scotland through most of Port Ewen time, the basin slowly subsided (fossiliferous burrowed quartzose calcilutite and calcisiltite containing beds and lenses of very fossiliferous limestone, both having an abundant benthonic fauna, and beds and lenses of chert, gradually give way to laminated quartzose calcisiltite and calcareous siltstone with a less abundant fauna). Sediment influx exceeded basin deepening from ate Port Ewen through Oriskany time. Deposition, however, was continuous, and a gradual transition from a deep-water to shallow-water nertic shelf environment proceeded from Port Ewen to Oriskany time. The abundance of bioturbation structures and skeletal debris increases from the base of the Port Ewen into the Shriver chert of the Oriskany Group (figs. 41, 43). In late Oriskany time (Ridgeley Sandstone), the strandline continuously shifted and barrier bar or beach deposits were laid down, consisting of lenses and beds of laminated, planar-bedded, and crossbedded quartzose sandstone and conglomerate with abundant thick-shelled spiriferid brachiopods (Spirifer arenosus). The coarse beds abruptly overlie and grade up into beds of quartz calcisiltite containing abundant brachiopod hash, probably of a shallow subtidal probar apron (fig. 42). Seilacher (1968) also interpreted the Oriskany as a beach deposit based on its faunal characteristics--heavy shelled brachiopods that are fragmented and worn along with lack of foreign faunal elements indicate considerable reworking in place. The entire area was emergent following Oriskany time.

Deep neritic conditions were re-established following post-Oriskany emergence. Shallow neritic deposits of this transgression are absent. The Esopus Formation and lower part of the Schoharie are interpreted to be deep neritic deposits because of abundant lateral burrows (Taonurus, fig. 46) which are placed in the deep-neritic Zoophycos facies by Seilacher (1967). Plicka (1968), on the other hand, believes that "Zoophycus" are prostomia of marine worms. Seilacher's interpretation is favored because in cross ection Taonurus resembles burrows seen in other rocks in the area, and individual paths of the trace fossil cut across others (fig. 58).

Shallowing of the basin is interpreted to have occurred in upper Schoharie time because Taonurus disappears and long vertical burrows become prominant, and because the Schoharie grades up into the shallow neritic cherty and argillaceous limestone of the Buttermilk Falls. The Buttermilk Falls Limestone contains an abundant and diverse fauna including corals, suggesting depths within the photic zone and warm, well-oxygenated, and gently circulating water.

The carbonaceous, pyritic, sparsely fossiliferous, laminated shales of the Marcellus are belived to represent sublittoral conditions below wave base in a reducing environment. These rocks have not been studied in any detail, but this interpretation is strengthened by comparison with similar rocks (e.g., Ellison, 1965; Friedman and Johnson, 1966) and gradation of the Marcellus into the Mahantango Formation, a probable neritic siltstone with abundant fossils, biostromal layers, and coquinite lenses, and including the Centerfield biostrome with abundant corals. Apparently, there was generally rapid and fluctuating sedimentation during Mahantango time. Coquinites and very fossiliferous beds represent periods of low clastic influx; poorly fossiliferous beds reflect flooding of the living niches and perhaps killing off of local populations which were re-established in different areas and stratigraphically at different levels.

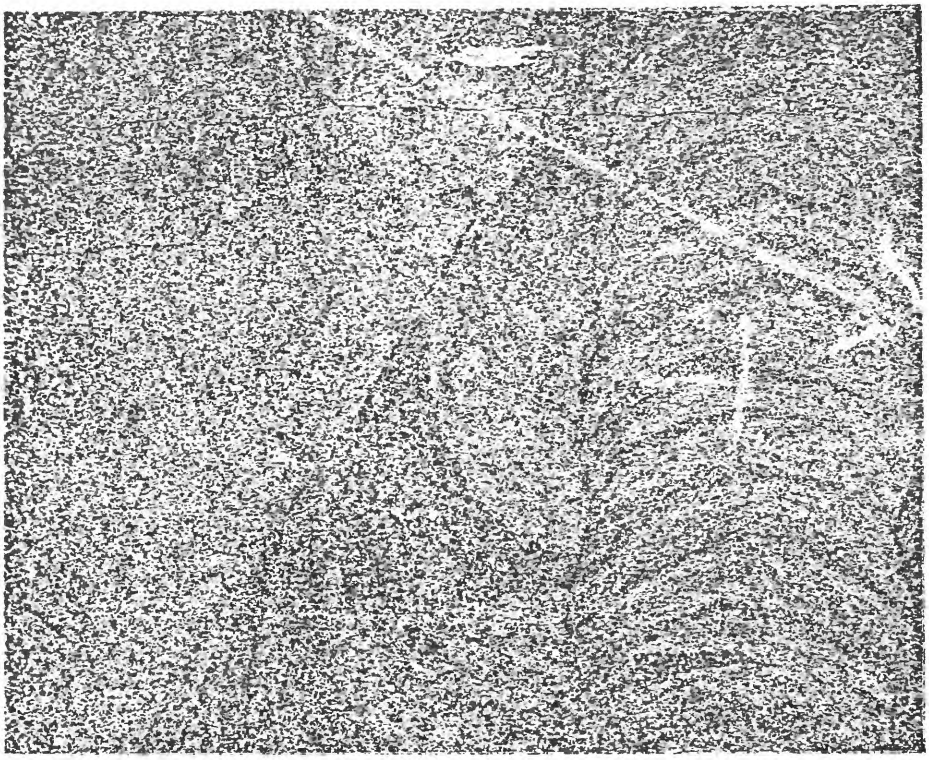


Figure 58. Crosscutting burrows (Taonurus) in coarse quartz-muscovite-chlorite siltstone, Esopus Formation, 650 feet southwest of WVPO radio tower, Godfrey Ridge. Negetive print of thin section (X7.5). Dark laminae are more quartz-rich than lighter laminae. Horizontal lines are cleavage. White markings are orientation scratches on thin section.

The Mahantango Formation is the youngest bedrock unit in the Stroudsburg quadrangle. Beyond the quadrangle, the Mahantango is overlain by the Trimmers Rcok Sandstone, an apparently deep neritic deposit, partly of turbidity current origin (composed of beds containing transported fossil hash at the base). The Trimmers Rock is overlain by the deltaic Catskill Formation, thus ending another major transgressive-regressive cycle.

SURFICIAL GEOLOGY

Details of the surficial geology in the Stroudsburg quadrangle are given by Epstein (1969) and Epstein and Epstein (1969). A brief summary is presented here. Abbreviated descriptions of the deposits are given on plate IV.

The Stroudsburg quadrangle is within the Valley and Ridge and Great Valley physiographic provinces. Evidence of at least two glaciations is indicated by one deeply weathered till, possibly Illinoian in age, and another fresher till and melt-water deposits of Wisconsin age. After deglaciation, alluvial fans, alluvium, talus, and swamp deposits accumulated.

Illinoian(?) Glacial Deposits

Illinoian(?) drift is poorly exposed. It caps bedrock around slate quarries in the West Bangor area, in the southwest corner of the quadrangle. It consists of compact grayish-orange to dark-yellowish-orange silty clayey till, lacks stratification, and is poorly sorted. Angular to subrounded quartzite boulders, mostly from the Shawangunk Formation, are numerous. These have a weathering rind as much as 2 inches thick. No limestone fragments were found. The till is leached to a depth of at least 10 feet, and weathering has advanced down to the slate bedrock. As determined by X-ray diffraction techniques, the clay-size fraction consists of chlorite, illite, quartz, hematite, and kaolinite. The kaolinite is believed to be a prolonged weathering product of feldspar. The greater depth of leaching, rubification, more muddy texture, lack of limestone pebbles, and presence of kaolinite, as well as more subdued topography, stands in sharp contrast to the younger Wisconsin drift and suggests a long period of interglacial weathering. Thus, this older till may be Illinoian in age, or even older.

Wisconsin Glacial Deposits

Glacial sediments of Wisconsin age are composed of varying proportions of gravel, sand, silt, and clay. On the basis of texture, internal structure, bedding and sorting characteristics, and generally well preserved landforms, the deposits are subdivided into till (ground, end, and terminal moraine (fig. 59) and stratified drift (delta, glacial-lake-bottom, kame, kame-terrace, and outwash deposits; fig. 60). Plate IV shows the location of these deposits.

Numerous striae, grooves, and rouches moutonnée formed by Wisconsin glacial erosion are found on bedrock surfaces in most parts of the quadrangle. The trends of striae show that the ice was strongly deflected by underlying bedrock topography. Average direction of flow of the ice sheet was about S. 20° W. Similar features are not found beyond the Wisconsin drift margin, and none can be ascribed to Illinoian(?) glaciation.

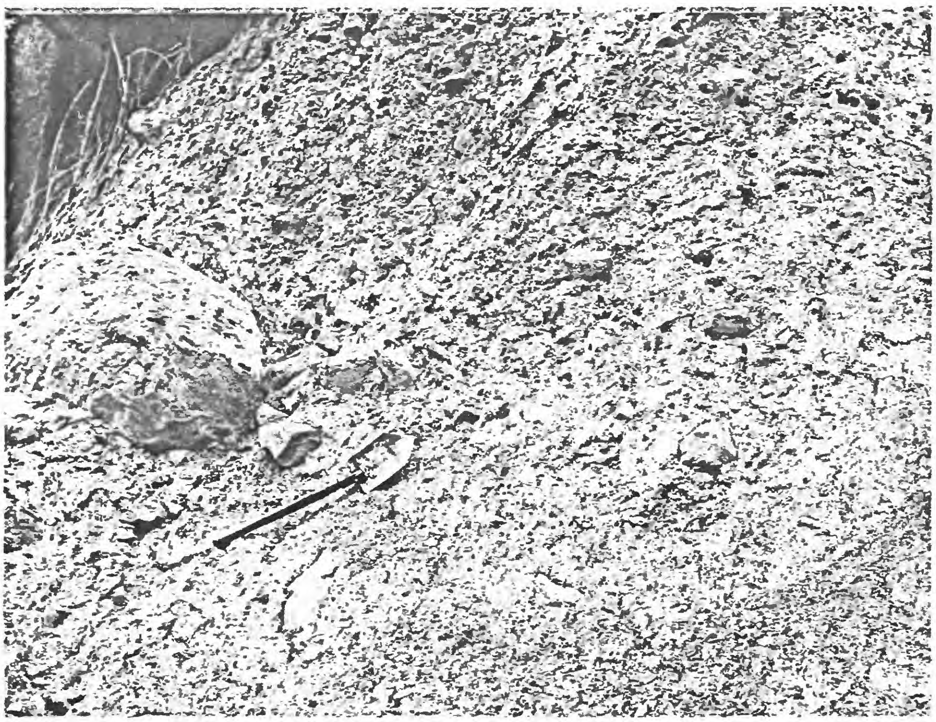


Figure 59. Wisconsin till exposed in cuts along the Erie-Lackawanna Railroad (formerly the Delaware, Lackawanna, and Western Railroad) at sample locality 6b, plate IV. The till is a silty sandy gravel with boulders as much as 10 feet long. A sample collected from this exposure was very poorly sorted (S_0=21.0).

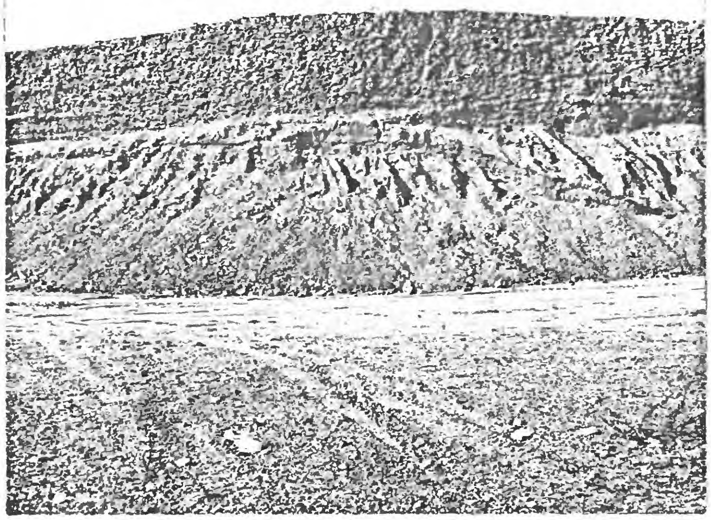


Figure 60. Coarse topset beds beveling finer foreset beds in delta deposit. Gravel pit of Javelyn Mobile Mix, Inc., in Arlington Heights. Height of face about 25 feet.

Phases of Deglaciation

Successive phases of ice-margin retreat northeastward across the quadrangle are shown on plate IV. Areas of ice stagnation are characterized by ice-contact deposits such as kames, whereas end moraines and certain deltas are interpreted to reflect the front of active ice.

A conspicuous terminal moraine (Bangor moraine) in the southwest corner of the quadrangle marks the limit of Wisconsin glaciation (phase 1). Widespread ground moraine, locally more than 100 feet thick, containing boulders more than 30 feet long, was also deposited. Because the slope of the land just in front of the terminal moraine was northeastward, toward the Delaware River, a basin formed in which lake clays accumulated (fig. 61). The pre-Wisconsin drainage divide lay about 5 miles west of Saylorsburg where the valleys are narrowest. Melt waters from the northeastward-retreating ice were trapped between the ice front and the terminal moraine, forming a lake, Lake Sciota. Lake Sciota was probably continuous with the lake in front of the terminal moraine through the col in the moraine at Saylorsburg. Ice-marginal deltas and rhythmically laminated lake beds were laid down in the pro-glacial lake in the Saylorsburg quadrangle during phase 2 (fig. 61). Perhaps the end moraine south of Kittatinny Mountain formed at this time. At first, the outlet of Lake Sciota was across the terminal moraine at Saylorsburg at an altitude of about 680 feet, to which the first delta to have formed in the Stroudsburg quadrangle (phase 3) is graded. The lake

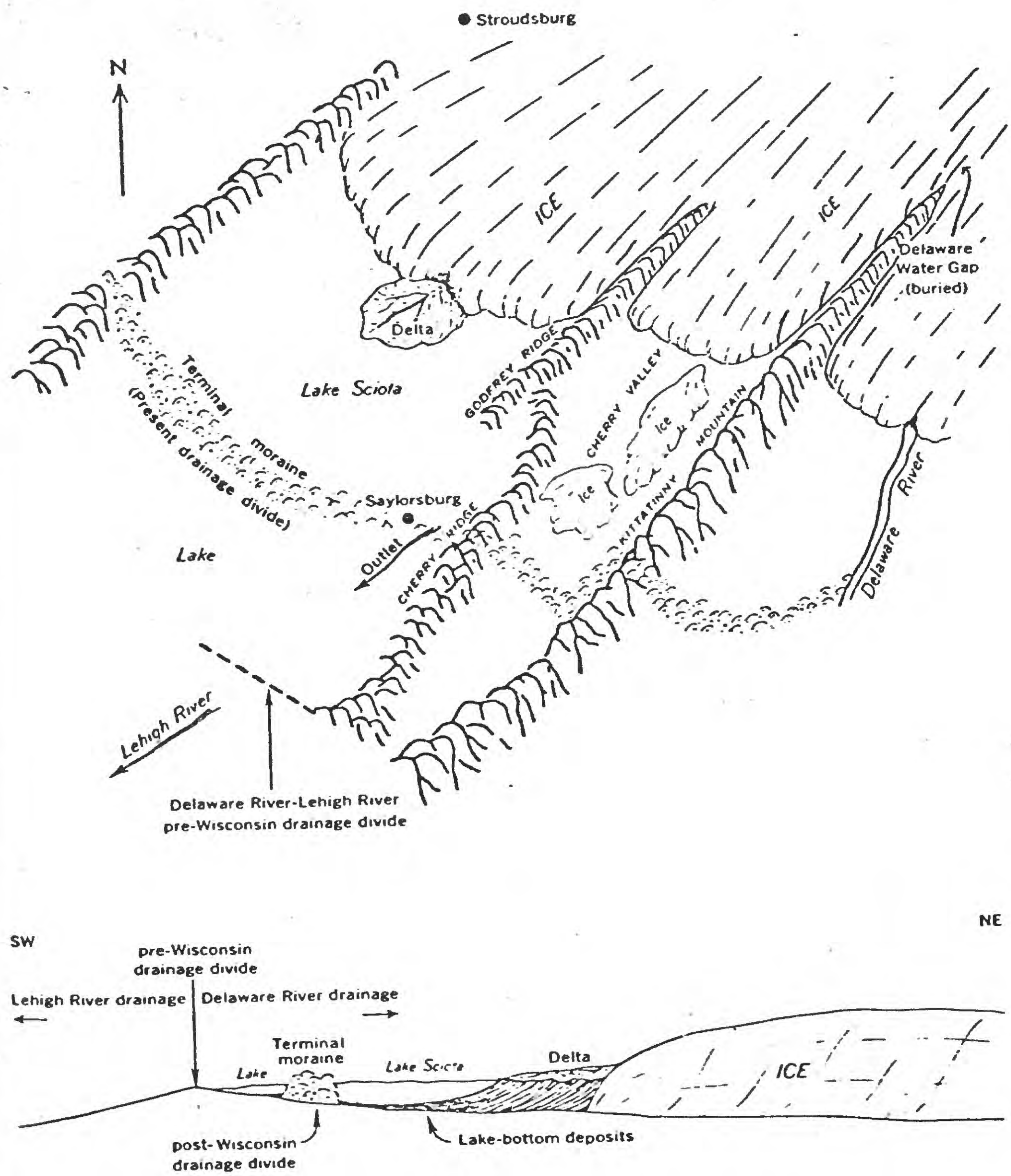


Figure 61. Diagrammatic sketch and section showing pre-Wisconsin drainage divide and position of Wisconsin glacier at time of deposition of delta in Lake Sciota (Saylorsburg quadrangle) during deglaciation phase 2. A kame moraine (not shown in sketch) was built in Cherry Valley at this time. The terminal moraine marks the present Delaware River-Lehigh River drainage divide.

maintained its level during continued ice retreat and a linear kame was deposited north of Godfrey Ridge, perhaps subaqueously, during phase 4, and a kame terrace was deposited at the north slope of the ridge during phase 5. Kames in Cherry Valley probably mark stagnated ice margins that are related to phases 3-5 north of Godfrey Ridge. The normal retreat of phase 2 was transitional into stagnation of the ice margin during phases 6 and 7. During this time, the level of Lake Sciota dropped continuously as Delaware Water Gap opened and the lake drained. A kame was deposited in Cherry Valley in the stagnated zone at this time, and deltas were deposited at successively lower altitudes in the Arlington Heights area. Finally, the lake drained.

Late- and Postglacial Deposits

After deglaciation, alluvial fans, talus, swamp deposits, and flood-plain deposits accumulated. Alluvium of present streams contains admixtures of pebbles and cobbles derived from underlying and surrounding glacial drift, but consists, for the most part, of brownish silt to coarse-grained sand. Slate dumps are conspicuous features in the area of slate quarries in the Martinsburg Formation. Some dumps rise more than 100 feet above surrounding surfaces. The material consists of waste blocks of slate.

STRUCTURAL GEOLOGY

Generalized summaries of the structural geology in the Stroudsburg area are given by Rogers (1858), White (1882), and Willard (1938). Behre (1933) described the structure in the slate quarries in the Martinsburg Formation in detail. O'Neill (1940) gave a general account of the structure of part of Godfrey Ridge. The structure as depicted by Willard (1938) and given publicity in structural texts by King (1951, p. 99) and Eardley (1951, p. 99) consists of gentl homoclinal northwest dips in rocks younger than the Martinsburg Formation and complex folds and faults in the Martinsburg. The Martinsburg-Shawangunk contact is thus a marked angular unconformity separating structures assigned to the Taconic and Appalachian orogenies.

This structural picture is too simplified. The structure in post-Martinsburg rocks is certainly more complex than hitherto envisioned. The attempt to subtract structures definitely of Appalachian age from structures found in pre-Silurian rocks, and to be left with the remainder assignable to the Taconic orogeny, meets with perplexing difficulties. Certainly there was a Taconic orogeny--the Silurian clastic wedge and certain structural features attest to that. But it is here tentatively concluded that most of the structural features in the Stroudsburg quadrangle (most folds and minor structures, such as cleavage) are of Appalachian age.

Tac[illegible]c folding and large-scale faulting are also recognized. The nature and origin of cleavage in the report area and the age of its formation have of late been of paramount importance in deciphering the structural history of eastern Pennsylvania. These will be discussed in detail.

The rocks in the Stroudsburg area can be divided into four lithotectonic units; that is, four rock sequences of dissimilar lithology and competency that have different styles of deformation. Each sequence has been deformed semi-independently of rocks above and below and are presumed to be set off from those by décollements (detachments along a basal shearing plane or zone). Type and amplitude of folds are apparently controlled by lithic variations within each lithotectonic unit, and as a result folding is disharmonic (see pl. II). The lithotectonic units, their lithologies, thickness, and styles of deformation are listed in table 3.

Two mechanisms were operative in producing the folds: (1) flexural folding, in which bedding was active and movement was either by slip (flexural slip) or flow (flexural flow); and (2) passive folding, in which movement was along laminar-flow planes (passive flow) or slip planes (passive slip), and in which bedding was passive and merely indicates deformation in the direction movement (see Donath and Parker, 1964). Flexural-slip folding in the area is characterized by extensive development of bedding-plane slickensides and by maintenance of constant orthogonal bedding thickness in all parts of the fold, whereas in flexural-flow folding, thickness

Table 3. Lithotectonic units in the Stroudsburg area. [Adjacent units are believed to be separated by a décollement or zone of décollement; Blue Mountain décollement separates units 1 and 2; Godfrey Ridge décollement separates units 2 and 3; Weir Mountain décollement separates units 3 and 4.]

Litho-tectonic unit	Age of lithotectonic unit and stratigraphic sequence	Lithologic characteristics	Style of folding	Average size of folds
4	Upper and Middle Devonian Brodhead Creek Member of the Marcellus Shale and younger rocks, mostly north of the Stroudsburg quadrangle	More than 10,000 feet of sandstone, conglomerate, siltstone, and shale	Nearly symmetric, concentric, predominantly flexural slip. Broad open folds	Half wavelengths about 3,000 feet and amplitudes about 600 feet that increase to more than 5 miles and 4,200 feet, respectively, west of the Saylorsburg quadrangle
3	Middle Devonian to Upper Silurian Stony Hollow and Union Springs Members of the Marcellus Shale to upper part of Poxono Island Formation	1,700 feet of limestone, shale, siltstone, sandstone, and dolomite; heterogeneous stratigraphic units between 5 and 180 feet thick	Asymmetric, concentric, and similar, flexural slip and flow, passive slip and flow. Cascade folds	Wavelengths average about 700 feet; amplitudes about 250 feet
2	Upper to Lower Silurian Lower part of Poxono Island Formation to Shawangunk Formation	3,200 feet of sandstone, siltstone, shale, and conglomerate; coarser toward base of sequence	Asymmetric, concentric; flexural slip with minor passive slip and flow. Bedding slip and wedging in the Bloomsburg Red Beds	Wavelengths average about 1 mile; amplitudes 1,500-5,000 feet
1	Upper and Middle Ordovician Martinsburg Formation	About 12,000 feet of thick monotonous sequences of slate and graywacke	Asymmetric, similar nearly isoclinal, nearly recumbent; mainly passive flow and slip, flexural slip near contact with Shawangunk Formation. Folds probably superimposed on upright limb of large regional nappe	Wavelengths 1,000-3,000 feet; amplitudes 400-2,000 feet. Small-scale imbricate faults; major thrusts with possible displacements in miles south of quadrangle

perpendicular to bedding need not be constant. Passive folds have the shape, or form, of similar folds and constant axial-plane thicknesses (the length between bedding planes measured along cleavage, if cleavage is parallel or subparallel to the axial planes, for example) are generally maintained. If the planes of movement (the cleavage planes) are macroscopically discontinuous, the folding is by passive slip, but if the movement planes are so closely spaced as to be indistinguishable to the unaided eye, the folding is termed passive flow.

<u>Décollements</u>

Three décollements, or zones of décollement in relatively incompetent rocks separate the four lithotectonic units, described in table 3.

The Blue Mountain decollement, parallel to the Martinsburg-Shawangunk contact, is a zone of detachment between lithotectonic units 1 and 2. The contact is not exposed in the quadrangle, but at the tunnel of the Yards Creek hydroelectric plant on Kittatinny Mountain, 4.5 miles northeast of Delaware Water Gap, and at Lehigh Gap, fault gouge that is several inches thick occurs at the contact, and microscarps or steps on bedding-plane slickensides in the Martinsburg near the contact indicate northwest translation of the overlying Shawangunk. This sense of movement is corroborated by small drag folds at the contact at Lehigh Gap (Epstein and Epstein, 1969, fig. 22).

A thick detachment zone, the Godfrey Ridge decollement, separates lithotectonic units 2 and 3. The change in style of deformation between the two units takes place in the Poxono Island Formation. Considerable northwest movement is indicated by wedging and and bedding slip in the underlying Bloomsburg Red Beds. This will be described under lithotectonic unit 2 below. The differences in the amount of shortening between rocks in lithotectonic unit 3 as compared to rocks in lithotectonic unit 2 is more than 15 percent, if all the complex folding shown on plate III is considered to be flexural slip. However, some of the folding was passive, so the net difference in shortening is somewhat less than 15 percent.

Differential movement between lithotectonic units 3 and 4 appears to have been concentrated along a zone in the Marcellus Shale (Weir Mountain décollement), but outcrops that would provide proof of the décollement are lacking due to thick drift cover. Because movement on the Godfrey Ridge and Weir Mountain décollements appears to have occurred in fairly thick intervals of rock, their general location is shown on plate I, but they are not shown in the cross sections on plate II.

Several other explanations for the disharmonic relations between lithotectonic units 2, 3, and 4 are possible. First, the folds in lithotectonic unit 3 may be the result of drag on a southeast-dipping thrust fault that lies in the covered interval of the Marcellus Formation. Thus, the drag folds would not continue under cover to the northwest as depicted in plate II. The fault could be the extension of the Sweet Arrow fault farther to the west (Wood and Kehn, 1961). Its presence could be verified by drilling or mapping to the southwest in the Saylorsburg quadrangle where the fault presumably would cut off the Weir Mountain syncline (see Epstein and Epstein, 1969, fig. 3). This mapping is currently underway, but the fault hypothesis is tentatively rejected because reconnaissance suggests no crosscutting relationship. Also, the folds in lithotectonic unit 3 are not considered to be drags, because they do not die out southeast of the hypothetical fault. The second possibility is that décollements do not separate the units. Rather, lithotectonic unit 3 is itself a décollement zone separating strata in the lithotectonic units above and below that have moved relative to each other. This scheme has been described by Kehle (1970). The third possibility is that there has been no relative movement between the lithotectonic units and that the disharmony is the result of buckling of a series of layers of different competencies (viscosities) (for example, see Ramsey, 1967, p. 380). Thus, no relative differences in shortening has taken place. The interpretation of décollements separating the lithotectonic units is favored over the last two alternative possibilities because of evidence of northwest translation of rocks as mentioned above and to be described below. Moreover, this interpretation is in harmony with similar interpretations in the Appalachians elsewhere in Pennsylvania (Gwinn, 1964; Wood and Bergin, 1970). Dahlstrom (1969) presented a similar example of décollements separating lithotectonic units in the Fernie Basin of British Columbia.

The detachment zones generally dip to the northwest and may be rootless. Therefore, northwest movement into the Appalachian basin may have been primarily by gravitational sliding off uplifted areas to the southeast, albeit aided by northwest-directed tectonic forces. Upward thrusting from these décollements, as described by Gwinn (1964) in central Pennsylvania, has not been observed in the Stroudsburg quadrangle. Possibly these décollements are similar to or continuous with those described by Gwinn (V. E. Gwinn, written commun., 1967). Examples of small-scale internal disharmony in all lithotectonic units are found in the Stroudsburg area. These will be described under a separate heading below.

Lithotectonic Unit 1

The Martinsburg Formation of Ordovician age comprises lithotectonic unit 1. Passive folding was the dominant mechanism of deformation, although bedding-plane slickensides and its relationships to cleavage indicate that flexural slip occurred at times both before and after passive folding. Slaty cleavage is the most dominant planar feature, although it is less prominent within a few hundred feet of the Shawangunk Formation. The cleavage fans the folds slightly, especially in silty and sandy beds. In places, the cleavage is folded, commonly near thrust faults, and a second-generation slip cleavage has formed. The intensity of deformation increases to the southeast. In the southern part of the quadrangle, axial planes of folds generally dip gently to the southeast (pl. II), and in places the folds are nearly recumbent. Farther southeast, beyond the Stroudsburg quadrangle, deformation increases to the point where the second cleavage is locally nearly as prominent as the first cleavage. To the northwest, axial planes dip more steeply, but disappointingly, thick cover by glacial deposits conceals most of the Martinsburg. In the Delaware River, abundant exposures show that the Ramseyburg Member trends northeastward under the Shawangunk Formation. The Pen Argyl-Ramseyburg contact is unconformably overlain by the Shawangunk 3/4 mile southwest of the gap (pl. I). The beds in this area dip homoclinally to the northwest with a few small superimposed folds and faults (pl. II, cross sections G-G' and F-F'; see also Drake and others, 1969). Lack of continuous exposures makes it impossible to trace small thrusts for any great distance. The farthest any fault could be traced was about 3,000 feet. While there are no marker horizons to indicate amount of displacement, the tracing of one thrust fault into an unbroken fold within a short distance indicates that displacement is not great, possibly less than 100 feet.

The Portland fault in the southeast part of the Stroudsburg quadrangle is the only fault of very large displacement recognized within lithotectonic unit 1. It has been mapped to the northeast in the Portland quadrangle (Drake and others, 1969) and separates carbonate rocks of Cambrian and Ordovician age in the Paulins Kill valley of New Jersey from rocks of the Martinsburg Formation on both sides of that valley. The belief that the fault traces on both sides of the valley are part of the same fault is proved in the Stroudsburg quadrangle by sparse water-well data that show carbonate rocks in the lower plate of the fault and slate in the upper plate (pl. I). The fault is folded by the Flicksville anticline and plunges to the southwest under the slate quarries in the East Bangor-Bangor area. It is not recognized in the area of the quarries. In the portland quadrangle, Drake and others (1969) show that the fault cuts bedding at low angles. In places, more than 3,500 feet of strata have been cut out, implying that displacement is at least on the order of miles. The fault can be traced for about 25 miles to the northeast in New Jersey (Lewis and Kümmel, 1912). Based on geologic and aeromagnetic data, Drake (in U.S. Geological Survey, 1969, p. A. 28) interpreted the Portland fault as extending in the subsurface for about 40 miles southwest of Bangor. He concluded that the fault is part of a large regional nappe that is mostly buried in Pennsylvania and underlies the Musconetcong nappe exposed to the southeast. As will be discussed under the chronology of deformation, the Flicksville anticline, as well as similar folds in the Martinsburg, is believed to be Appalachian in age. The Portland fault is probably a Taconic feature because similar faults are not known in rocks younger than Ordovician immediately to the northwest. Its regional significance, however, has yet to be deciphered.

The Flicksville anticline is shown on plate I to trend more northeasterly than folds west and north of it. This trend may be in error. The axial trace of the Flicksville anticline was drawn to join folds with the same name in the Bangor quadrangle to the south (Davis and others, 1967) and the Portland quadrangle to the east (Drake and others, 1969). In all probability it is not continuous with either of these folds but is probably continuous with the anticline southeast of the Old Bangor syncline, and its position shown on plate I could not be corrected before submission of this report.

The Blue Mountain décollement, as mentioned above, separates lithotectonic units 1 and 2. The amount of displacment is unknown, but based on inferences from the Godfrey Ridge décollement, displacement could be thousands of feet or miles.

The best exposures in the Martinsburg Formation, hence places where the most structural detail can be obtained for lithotectonic unit 1, are in the slate quarries shown on plates V and VI. The Capitol slate quarry (no. 14) is presently the only one active in the Stroudsburg and Portland quadrangles, the others are mostly flooded. A rubber liferaft was used to get into all the quarries except two, the Bangor Central (no. 17) and Bangor Royal (no. 18). Most of the openings have been described by Sanders (1883) and especially Behre (1933), and their operational histories mentioned. However, some were inaccessible to Behre, many have been modified by quarrying operations since his investigations, and a few require different structural interpretations.

Bangor Fidelity and West Bangor quarries (1)

The Bangor Fidelity is a rectangular opening about 550 feet long and 250 feet wide. Adjoining it to the northeast is the West Bangor quarry with dimensions of 450 to 350 feet. The two quarries are abandoned and are separated by a wall of slate about 100 feet wide. Behre (1933, p. 246) reported that the openings reached a depth of about 300 feet. The dumps to the southeast are about 100 feet high. About 10 feet of Illinoian(?) till caps the northeast part of the openings. The exposed rocks are weathered and consist mostly of slate, but thin silty beds with convolute bedding are not uncommon. The quarries are cut into the overturned West Bangor syncline whose axial plane dips 20°SE. (fig. 62). A bedding-slip fault is described and illustrated by Behre (1933, p. 237, 247). Intersections of bedding and cleavage, which are presumed to indicate the plunge and trend of the fold, plunge to the southwest in the upright limb of the fold and to the northeast in the overturned limb. The fold is, therefore, noncylindrical.

Bangor Superior quarry (2)

Two openings, a large square one about 250 feet long and a smaller one to the southwest, make up this quarry. A maximum of 15 feet of bedrock crops out above water, except in the southeast corner. No sandy beds were seen. Between 5 and 10 feet of Illinoian(?) drift covers the slate. The dumps to the east are about 80 feet high. Cleavage dips moderately to the southeast and beds are upright and dip gently to the southwest. Thus, the quarry is

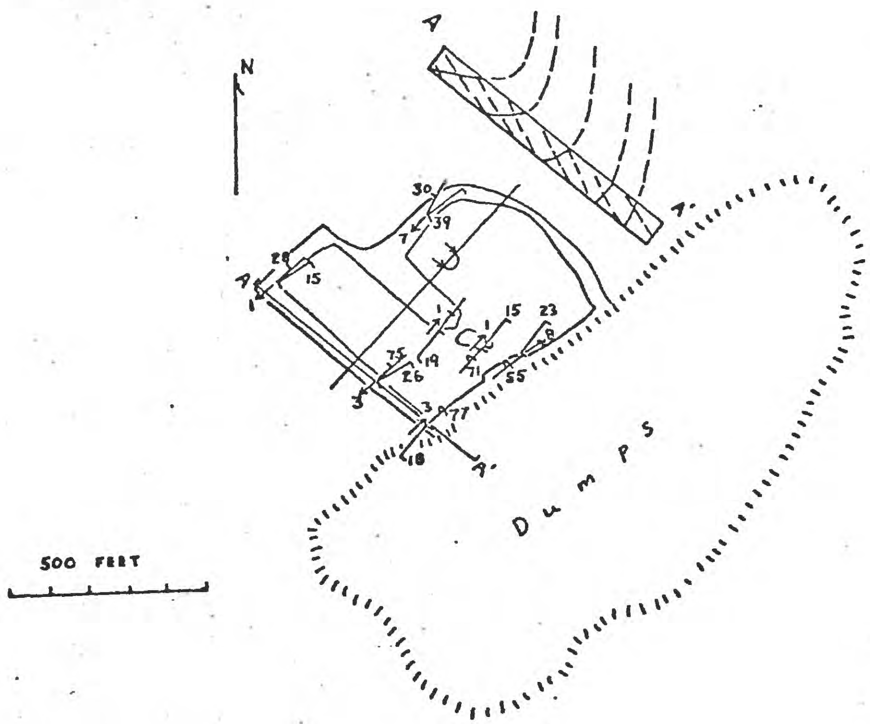


Figure 62. Geologic map and section of the Bangor Fidelity and West Bangor quarries. See plate I for explanation of map symbols. Areas of bedrock exposure enclosed by solid lines. In cross section, solid lines are bedding, dashed lines are cleavage.

located in the trough of the southwest-plunging overturned syncline exposed in the Bangor Fidelity and West Bangor quarries to the southwest.

Northampton quarry (3)

The Northampton quarry is situated on the nose of the gently southwest-plunging overturned Roseto anticline whose axial plane dips about 15° SE. (fig. 63). Behre describes (1933, p. 222) and illustrates (p. 218) a bedding slip fault along which there has been distortion of cleavage. Some of the slate in the quarry is silty. Beds range from about 6 inches to 3 feet thick. About 10 feet of till covers bedrock in the northern part of the quarry. The quarry is abandoned and is presently being used as a garbage dump for the borough of Roseto.

Hoboken quarry (4)

In this water-filled quarry, a maximum of 8 feet of carbonaceous slate and lesser slightly calcareous silty beds are exposed, ranging from 1 inch to 2 feet thick. Strike of bedding averages N. 28° E. and dip ranges between 10° and 20° NW. Attitude of cleavage is consistent--N. 61° E., 37° SE. Thus, the quarry is in the trough of a broad southwest-plunging syncline which extends at least to the New York quarry (no. 5). The quarry is about 100 feet by 150 feet. The dumps lie to the northeast and south and are about 30 feet high.

New York quarry (5)

The New York quarry is about 230 feet square. The dumps to the e[illegible] are more than 80 feet high. At present this flooded quarry is

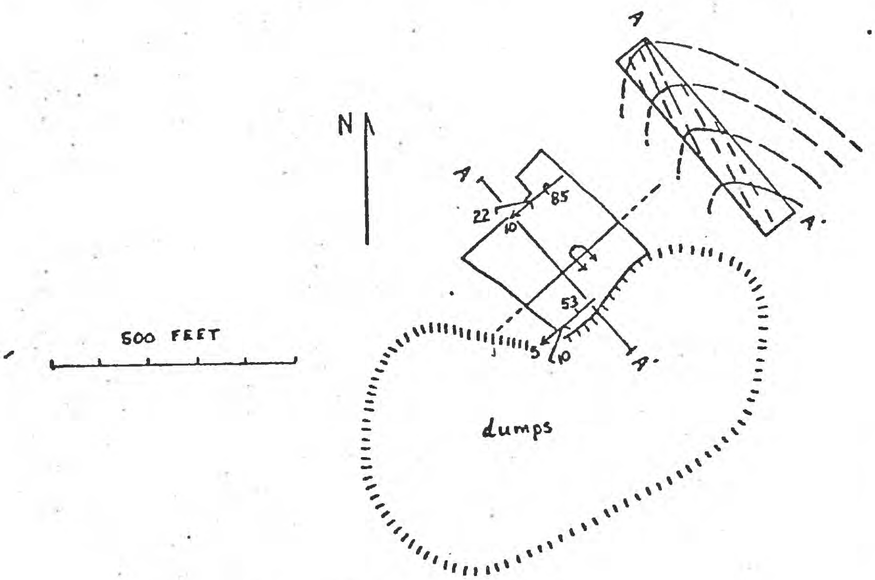


Figure 63. Geologic map and section of the Northampton quarry. See plate I for explanation of map symbols. In cross section, solid lines are bedding, dashed lines are cleavage.

used for local water supply. The trend of cleavage is parallel to the regional trend of folds, but bedding strikes more northeasterly. Thus, the position of the quarry is in the trough of the same syncline as described for the Hoboken quarry (no. 4). Behre (1933, p. 203) described the quarry in detail and mentions two "loose ribbons" or calcite-quartz-filled bedding-plane slickensides. These developed primarily prior to the development of cleavage.

New Peerless (Bangor Vein) quarry (6) and Strunk quarry (7)

These two quarries show similar structures and will be described together. The New Peerless is larger and measures about 650 feet by 300 feet. The Strunk quarry lies about 120 feet to the northeast and is roughly 200 feet square. Drift cover is thin to absent. Dumps to the north and between the quarries rise about 40 feet above water level. The quarries are abandoned, but some machinery and unworked slate blocks remain. A maximum of 20-30 feet of bedrock is exposed above water level. Slate of varying quality predominates over thin siltstone beds that average about 2 inches in thickness.

The quarries are located in a southwest-plunging, nearly recumbent and isoclinal syncline (West Bangor syncline) that is overturned to the northwest (fig. 64). The axial plane of the fold is exposed in the Strunk quarry (fig. 65), whereas it plunges southwestward beneath water level in the New Peerless quarry and only the upper limb of the fold is seen in the New Peerless (fig. 66). Behre (1933, p. 204) reported that the axial plane dips between 8°

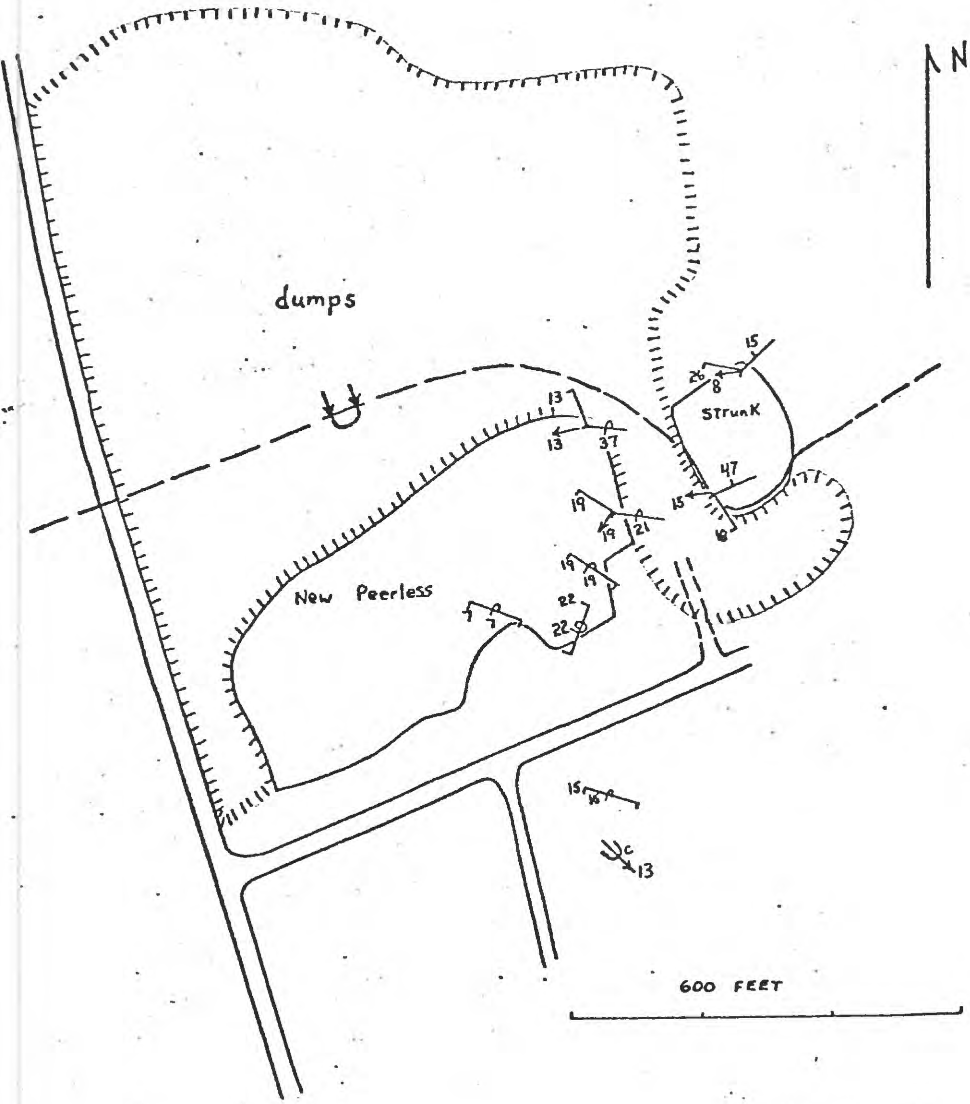


Figure 64. Geologic map of the New Peerless and Strunk quarries. Map symbols are the same as on plate I, except for 22 which shows bedding rotated more than 180° (doubly overturned).

Figure 65. Nearly recumbent West Bangor syncline in the Strunk quarry, Pen Argyl Member of the Martinsburg Formation. Slaty cleavage dips gently southeast (left). This is an example of passive flow in lithotectonic unit 1. Beer bottles in flooded quarry give scale. Note refraction of cleavage in siltier beds.

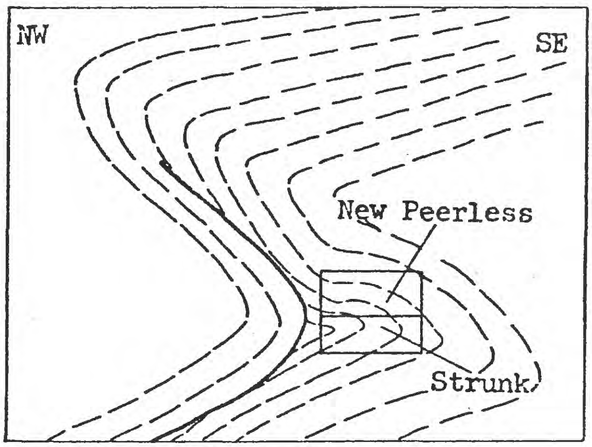


Figure 66. Diagrammatic section showing the structural position of the New Peerless and Strunk quarries. Dashed lines are bedding. The bedding-slip fault described by Behre (1933, p. 167) is shown as a solid line.

and 13° SE. The upper limb is more severely deformed and in the New Peerless quarry bedding and cleavage are about parallel, showing that this part of the fold is essentially isoclinal in places. Several minor cleavage arches were seen, but attitudes were difficult to obtain. One, however, in a small pit about 300 feet south of the New Peerless quarry, plunges 13° S. 45° E. (fig. 64). The arch is broken by a small fault, the attitude of whose plane is warped but is essentially N. 10° E., 15° SE. (fig. 67).

Behre (1933, p. 166, 167, 205, 206) illustrates and describes a bedding-slip fault in the New Peerless quarry. This fault was not seen because the quarry is flooded, but similar structures have been seen in active quarries adjacent to the Stroudsburg quadrangle. The faults generally are parallel to folded beds to the northwest and truncate more tightly folded beds to the southeast (see fig. 66). They apparently developed during later phases of deformation as a method of relieving excessive stress in the tightening folds. Cleavage is often warped at the fault contact and a second slip cleavage may have formed that is parallel to the axial planes of these small cleavage folds.

The West Bangor syncline extends to the southwest where it is exposed in the Bangor Fidelity and West Bangor quarries (no. 1). It is less tight in that direction.

<u>Little Bangor quarry (8)</u>

This small quarry has been filled in and no data could be obtained. Behre (1933, p. 205) reports that bedding and cleavage

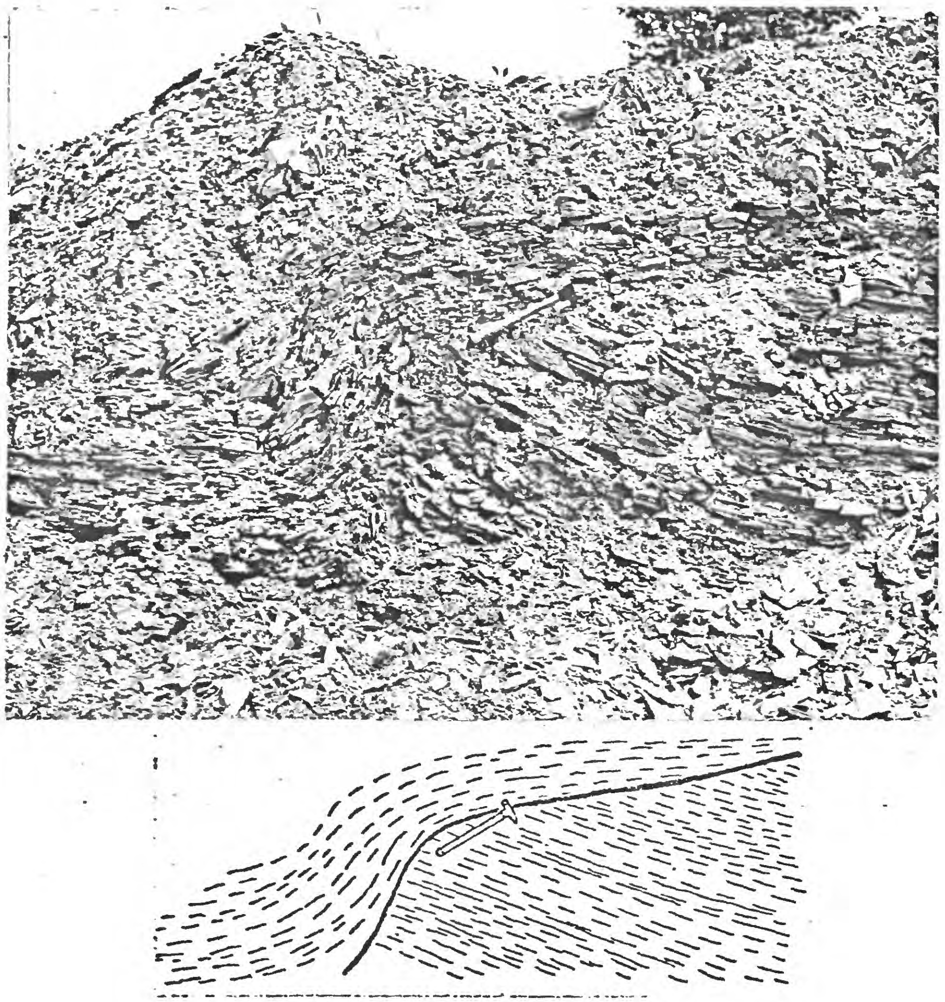


Figure 67. Photograph and sketch of minor cleavage arch and small fault in a borrow pit, about 300 feet south of New Peerless quarry. A thin gouge is present in the fault plane. Bedding and cleavage are subparallel. View looking southeast. Exposure has been removed since photograph was taken.

are about parallel and dip gently southward. The beds are, therefore, on the upper limb of the overturned West Bangor syncline described in the New Peerless and Strunk quarries.

Mountain View quarry (9a)

This square quarry is slightly more than 100 feet on a side. About 15 feet of slate is exposed above water. Dumps lie east of the opening. Beds of slate with a few thin silty intercalations dip gently to the southwest and are, therefore, near the trough or in the gently dipping upright limb of the Old Bangor syncline (pl. II, section B-B').

Quarry (9b)

This shallow rectangular opening lies 600 feet south of the Mountain View quarry. It is 150 feet long, 90 feet wide, and about 5 feet deep. About 4 feet of till overlie the bedrock. The low dumps are 200 feet to the southeast. Bedding dips northwestward between 12° and 17° and cleavage dips between 10° and 20° nearly due south.

Quarry (9c)

Slate of commercial quality was probably not obtained from this small digging because of the presence of several thin massive graywacke beds. The opening is 50 feet long and 25 feet wide and is located just east of the dumps of quarry no. 9b. Bedding dips gently to the northwest.

Quarry (10)

This nameless water-filled quarry is located in a small woods in the center of a cultivated field and is approximately 60 feet long and 30 feet wide. Bedding dips gently to the northwest, as it does in this general area, and cleavage dips 2° SE. in slate, but is refracted to 30° in a 10-inch-thick calcareous graywacke.

Shimer quarry (11)

About 15 feet of slate is exposed in the northern half of this quarry and approximately 5 feet of till overlies the slate. The beds dip gently northwestward (fig. 68). Behre (1933, p. 208) reported that it was at least 100 feet deep.

Consolidated No. 3 quarry (12)

This quarry is irregular in shape and its flooded portions are separated by dumps (fig. 68). It is about 700 feet long. Dumps rise more than 100 feet above water level. The southern part of the opening presently serves as the garbage dump for the town of East Bangor. Till ranges in thickness from 3 feet at the northern end to 8 feet on the western margin. The quarry was at least 100 feet deep (Behre, 1933, p. 207). Bedrock consists of thinly interbedded slate and siltstone. Some of the siltstone beds are crossbedded, and one set indicates a current direction of N. 75° E. Bedding-plane slickensides in the northeast part of the quarry indicate that the overriding beds moved to the northwest. In several places bedding is displaced about 1/100 inch along slaty cleavage, showing some slip has occurred on cleavage. Bedding generally dips gently westward and southwestward, as it does in the Consolidated No. 2 quarry (no. 13), showing that the

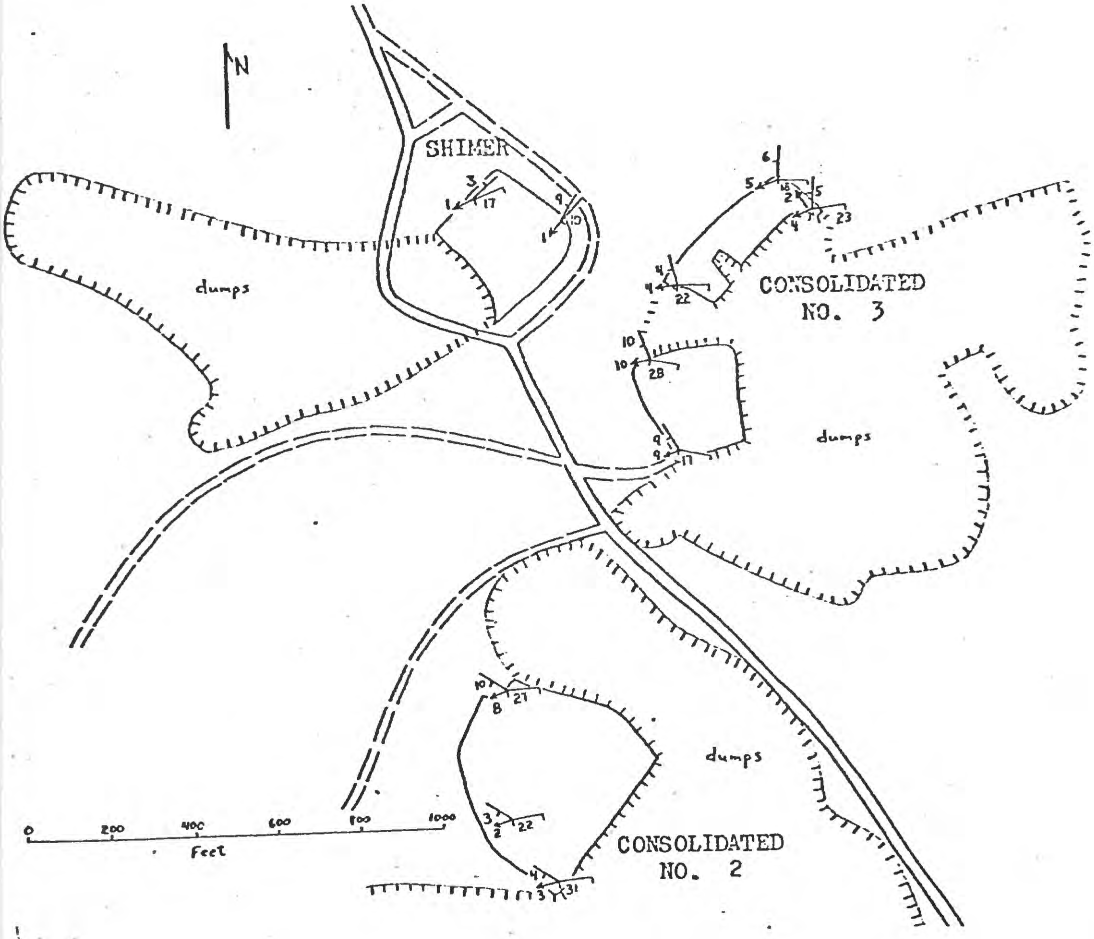


Figure 68. Geologic map of the Shimer, Consolidated No. 3, and Consolidated No. 2 slate quarries. See plate I for explanation of map symbols.

quarries are in the broad bottom of the overturned Old Bangor syncline.

Consolidated No. 2 quarry (13)

This irregular opening is about 500 feet long. Dumps are more than 100 feet high on all borders except the west one. A maximum of 40 feet of rock is exposed above water in the northwest wall. About 5 feet of till overlies the slate. Slippage of bedding planes along cleavage shows the same type of northwest movement of overriding as in the Consolidated No. 3 quarry.

Capitol Slate quarry (14)

This is the largest and only active slate quarry in the Stroudsburg quadrangle. It is listed by Behre (1933, p. 208-210) as the Consolidated No. 1-Star quarry. It is about 1,000 feet long and irregular in shape. The western part is presently being worked (fig. 69), and in 1961 it was about 250 feet deep, but continuing operations have made it deeper. Figure 70 is a detailed topographic and geologic map of the quarry showing the layout of the operation. The quarry is located in the undulatory broad trough of an overturned southwest-plunging syncline whose axial trace lies to the southeast (pl. I). Steepening northwest dips in the northeast corner of the opening indicate that the axis of the fold is not far away. Slippage along cleavage was observed in this quarry as in adjoining ones. Dumps completely surround the hole and are more than 100 feet high in places. Behre (1933, p. 209) noted the development of false (slip) cleavage in the northwestern corner. This was not seen, but in the northern corner

Figure 69. Operations in the northwest corner of the Capitol Slate quarry. Bedding (S_0) dips gently northwest and cleavage (S_1) dips gently southeast. Intersection of bedding and cleavage, as seen on cleavage plane in center of photograph, approximates the trend and plunge of the fold axis. Note wire saw (at A) used to divide the quarry into large "pieces" from which blocks of slate are separated either manually (as man in bottom is doing) or with dynamite. Bucket (at B) is being lowered to remove blocks of slate. The hole is more than 250 feet deep near this part of the quarry. The fairly thick beds of slate are typical of the upper part of the Ramseyburg Member of the Martinsburg Formation (see fig. 3).

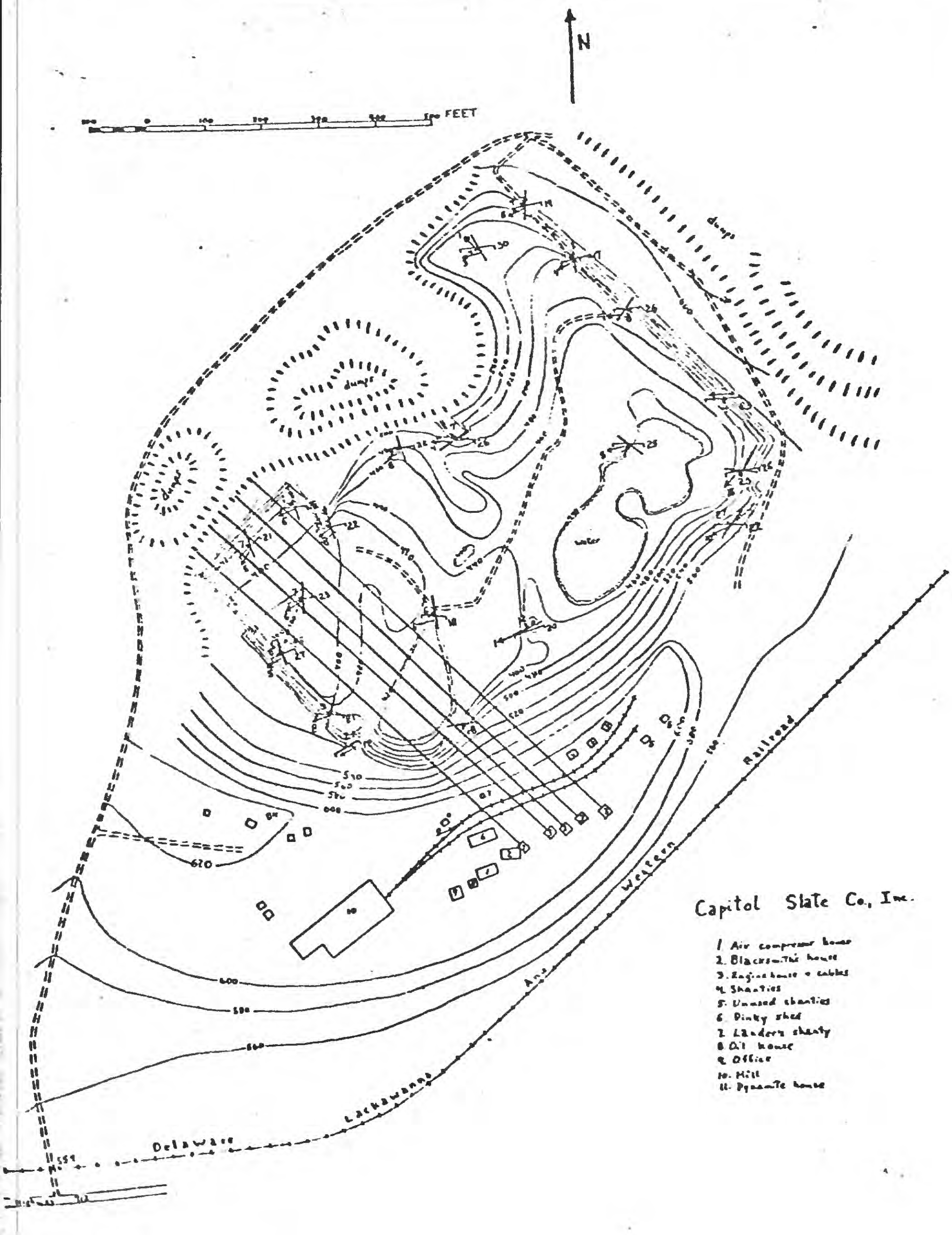


Figure 70. Geologic and topographic map of the Capitol Slate quarry, East Bangor, Pa., showing plan of operations.

there is a 5-inch-thick zone of quartz, calcite, and slate fragments parallel to bedding. Slickensides trend N. 42° W. showing that this is a bedding-slip fault. Cleavage is crumpled in the zone but well-defined slip cleavage was not apparent. More than 25 feet of till overlie bedrock in the northeast corner of the quarry.

Standard quarry (15)

The Standard quarry lies 200 feet west of the Capitol quarry and shows similar structural trends. About 30 feet of slate is exposed above water, and about 10 feet of drift overlies the slate. The quarry is roughly circular and about 250 feet across.

Bangor Valley (Bangor Eclipse) quarry (16)

About 50 feet of bedrock and 10 feet of drift are exposed in the northwest part of this quarry. Bedding dips gently northwest.

Bangor Central quarry (17)

This flooded rectangular opening is about 200 feet long. About 60 feet of slate and 20 feet of till are exposed in the northwest end. Bedding in the southwest corner is N. 36° W., 4° SW., but dips 13° NW. in the northwest wall.

Bangor Royal quarry (18)

This quarry now serves as the garbage dump for the town of Bangor and was, therefore, inaccessible. Attitudes shown on plate I were obtained by sighting across the quarry and are approximate. A few foundations and old rusted cables lie in the dump to the north. Apparently this opening was also inaccessible to Behre (1933, p. 212).

Columbia Bangor, New Bangor, and Bangor Excelsior quarries (19)

The Columbia Bangor and New Bangor quarries are flooded and presently appear as a single opening 1,200 feet long and 300 feet wide. The Bangor Excelsior is an irregular opening about 500 feet long and separated from the New Bangor by a narrow wall of slate. Only the northern corner of the New Bangor is in the Stroudsburg quadrangle. The dumps to the east apparently served all three quarries and are about 200 feet high. Many shanties, a furnace and engine house, and overhead cables still remain. The slate is covered by about 15 feet of glacial drift at the north end.

The structure as determined from surface exposures (fig. 71) corroborates Behre's observations (1933, p. 212-214). Bedding in the northeast wall of the Columbia Bangor quarry is overturned to the southeast. In a small exposure on the southeast wall of the quarry, bedding dips gently southwest on the crest of an overturned anticline. In the New Bangor and Bangor Excelsior quarries bedding is upright and dips to the northwest. The trend of intersection of bedding and cleavage (which approximates the trend of the fold axis) in the northeast wall of the Columbia Bangor quarry shows that the overturned limb plunges beneath the upright beds to the southwest, substantiating the fact that the quarry is opened in an overturned anticline. The axial plane of the fold dips gently southeast. Cleavage in the overturned limb is rotated to the southwest, as it is in the New Peerless and Strunk quarries described above. No second-generation slip cleavage was observed,

: Encloses area of outcrop

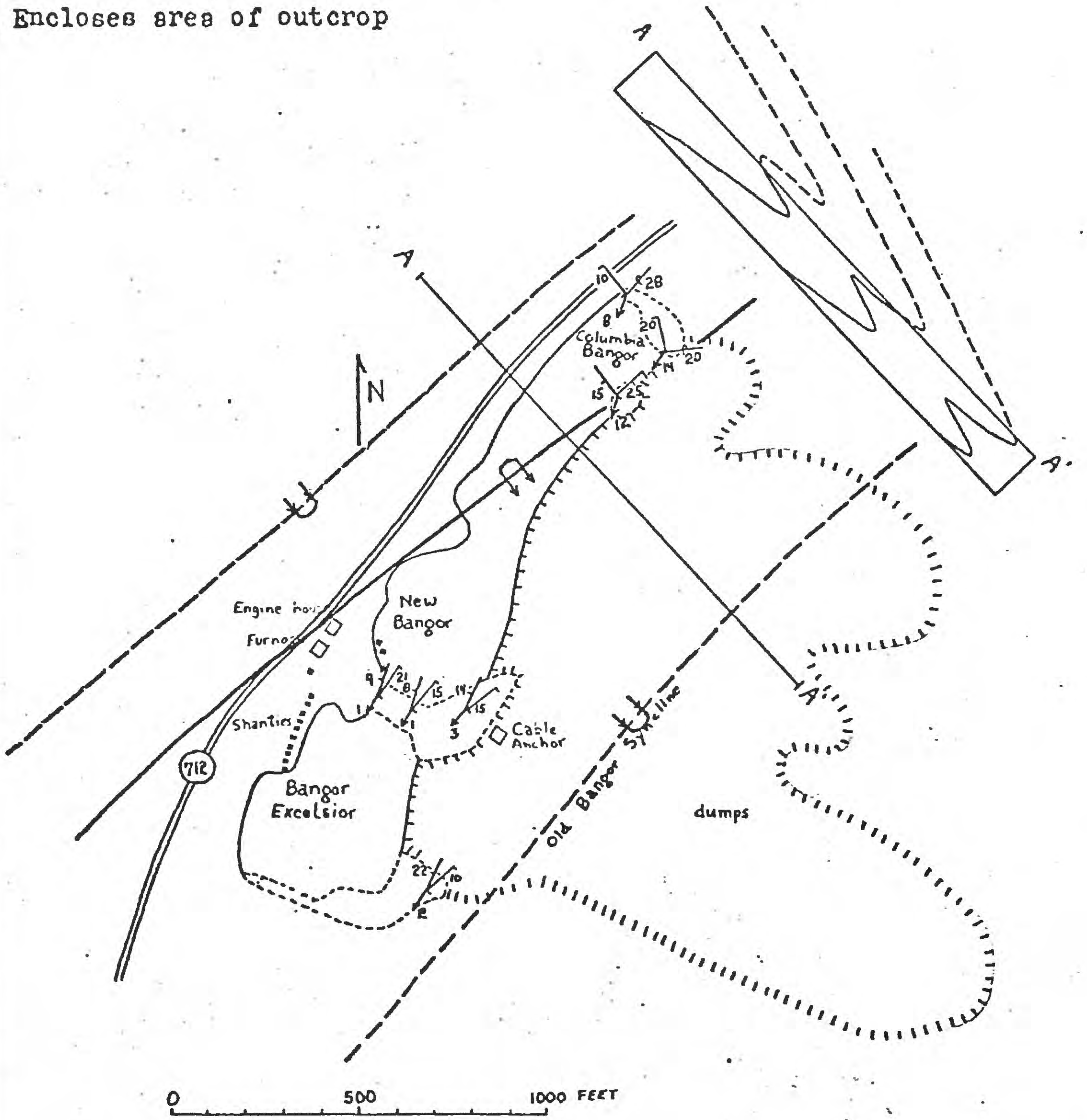


Figure 71. Geologic map and section of the Columbia Bangor, New Bangor, and Bangor Excelsior quarries, East Bangor, Pa. Map symbols are explained in plate I.

but contorted cleavage was seen in fragments on the dumps. An overturned syncline is inferred to lie to the northwest between the overturned limb of the anticline and the upright northwest-dipping beds in the quarries immediately to the northwest. An overturned syncline, the Old Bangor syncline of Behre (1933, p. 214), is exposed in the Old Bangor quarry 500 feet south of the Bangor Excelsior quarry. The inferred position of the axial trace of this fold in the Stroudsburg quadrangle is shown in figure 71 and plate I.

Emory Pipher quarry (20)

Known locally as the Enterprise, this quarry is located in a tributary of Slateford Creek. Most bedrock exposures are flooded, but small outcrops on the northwest side show bedding to dip 9° SE. and cleavage to dip 22° SE. A few thin graywacke beds were seen. Both bedding and cleavage are folded in a small arch, over 10 feet across, which trends S. 31° W., and plunges about 1° SW. Bedding on the northwest side of the arch is N. 28° E., 14° NW., and cleavage is N. 17° E., 9° NW. Dumps surrounding the quarry are about 20 feet high. The bedrock is overlain by a few feet of till.

Quarry (21)

This small circular opening is about 40 feet wide. A small creek flows through it, and it is now the site of a reservoir for local water supply. Slate and some graywacke beds are exposed. Bedding is N. 44° E., 22° NW.; cleavage is N. 84° E., 11° SE., with slight variation. Of particular interest is the divergence in strike between these beds and beds in the Shawangunk Formation immediately to the north.

Washington Brown quarry (22)

In this 100-foot long oval-shaped opening about 8 feet of slate and interbedded graywacke are exposed. In the southeast corner bedding strikes N. 31° E. and dips 20° NW. The attitude of cleavage is N. 12° W., 14° SW. This is part of an apparent cleavage arch with cleavage dipping to the northwest as the contact with the Shawangunk Formation is approached (see pl. I). Sanders (in Lesley and others, 1883, p. 86) referred to this opening as the John Morrison's quarry. The Washington Brown quarry, according to Prime, is the small opening 2,600 feet northeast of this quarry in the Portland quadrangle (no. 23).

Quarry (23)

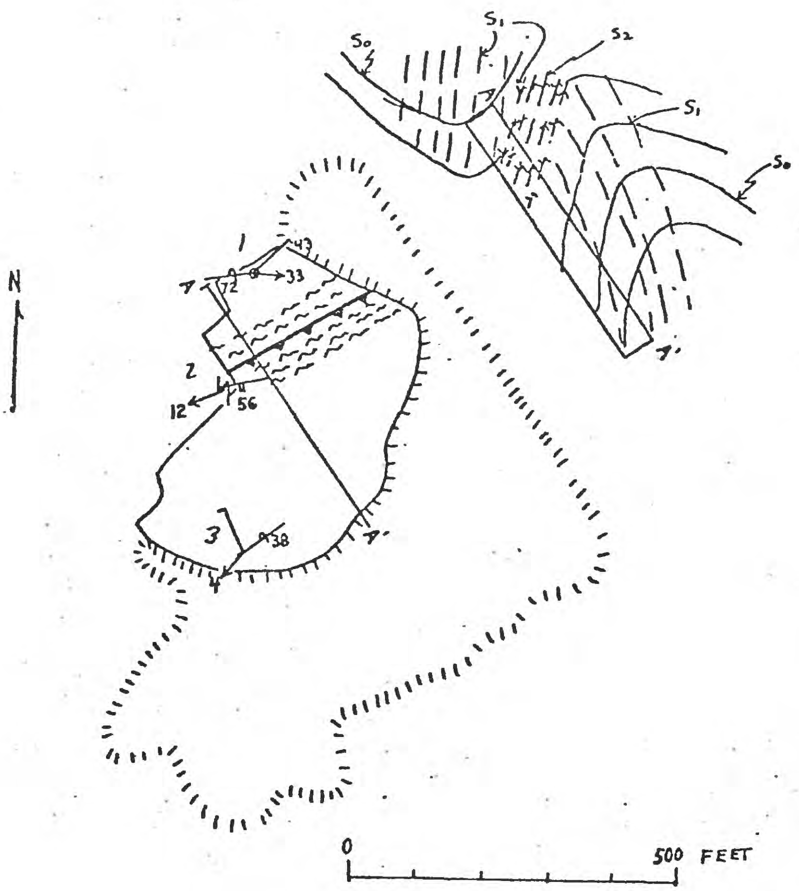
This quarry is about 200 feet above Delaware River. It is square, 100 feet on a side, and about 40 feet deep. Bedding dips moderately to the northwest and cleavage dips in the same direction at a gentler angle. Bedding, however, is not overturned as will be discussed later.

Williams quarry (24)

This quarry is located in Slateford Creek and is about 600 feet long. At the western end the creek falls over the 80-foot-high wall of the quarry and at the eastern end it flows between [illegible]-foot-high walls of slate that are 10 feet apart. Approximately [illegible] feet of drift overlie the slate. The slate is underlain by a massive 20-foot-thick unit of graywacke sandstone and siltstone and 50 feet of interbedded slate and graywacke that is exposed 1,500 feet downstream. The slates in the quarry are also overlain by graywackes to the northwest showing that the quarry is in the Ramseyburg Member of the Martinsburg Formation (see discussion on p. 8 and 9). Bedding fairly constant in the quarry, but the dip of cleavage changes from 11° SW. in the eastern end to 44° SE. in the western end. In the southwest corner of the opening, about 2 inches of quartz is found in a slickensided zone parallel to bedding. Microscarps indicate that the overlying beds moved N. 53° W. Small crenulations in the zone whose axes trend perpendicular to the slickensides were also produced by this movement.

Snowdon quarry (25)

This is an irregular opening about 500 feet long and 300 feet wide. About 40 feet of slate and some graywacke is exposed above water. Operations began about 1870 and discontinued about 1920 (Behre, 1933, p. 199). About 15 feet of till overlies the slate in the northwest part of the quarry, and beds on both sides are overturned (fig. 72). The fault is actually a shear zone about 50 feet wide in which slaty cleavage is folded and a second (slip) cleavage has developed (fig. 73). Dump blocks have bedding-plane slickensides deformed by slaty cleavage indicating that flexural slip preceded passive flow which was in turn followed by faulting and the development of slip cleavage. The quarry is discussed



EXPLANATION

Strike and dip of overturned bedding (S_0)

Strike and dip of slaty cleavage (S_1)

Strike and dip of slip cleavage (S_2)

Intersection of bedding (S_0) and slaty cleavage (S_1)

Minor cleavage crinkle showing style and plunge

Thrust fault, sawteeth on upper plate

Shear zone, much calcite and quartz, slip cleavage developed

Figure 72. Geologic map and section of the Snowdon slate quarry.

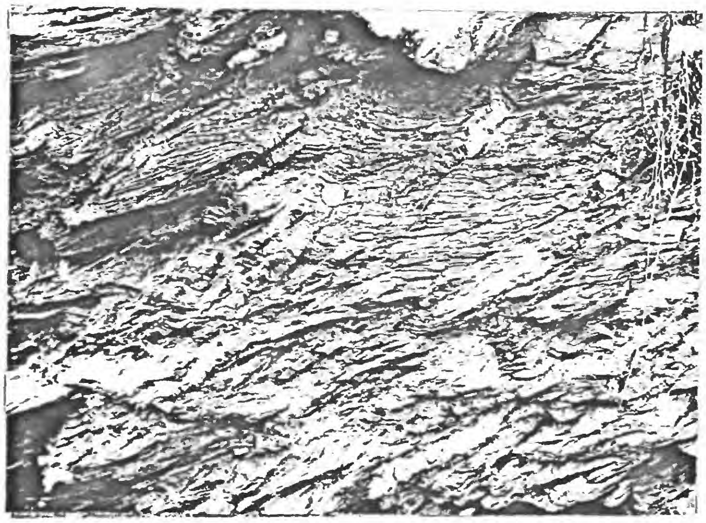


Figure 73. Slip cleavage in Snowdon quarry (no. 25) dipping steeply to the southeast (left) deforming nearly horizontal slaty cleavage. These megascopic features have been called shear zones by Behre (1933, p. 37) and are equivalent to his smaller scale false cleavage (slip cleavage of this report).

by Sanders (in Lesley and others, 1883, p. 88-89) who reported that the quarry was 150 feet deep. Evidently, slate was obtained from beds south of the fault zone.

Frye quarry (26)

The Frye quarry is about 400 feet long and has a maximum width of about 75 feet. It has a maximum depth of about 20 feet and is cut into arenaceous and carbonaceous slates. No machinery is present and large trees in the bottom indicate that it has not been worked for many decades. The northwest section was probably worked for slate because a fault is close to and parallels the southeast wall (fig. 74). The fault zone has a 1-inch-thick gouge but is fairly smooth. Numerous quartz-filled tension fractures are near the fault. The rock is deeply weathered in places so that bedding and cleavage are indistinct.

Quarry (27)

This is a small opening about 25 feet long and 15 feet deep. Dumps lie to the east and west. Cleavage is N. 35° E., 32° SE., and bedding dips 7° SW. Thus, the quarry is on the upper limb of a southwest-plunging fold (see section F-F'-F", pl. II).

Quarry (28)

This is an overgrown quarry cut into the Bushkill Member of the Martinsburg Formation on the southwest bank of the Delaware River about 300 feet west of U.S. Highway 611A. It is about 100 feet long and as much as 75 feet wide. About 25 feet of slate is exposed on the uphill side overlain by about 10 feet of glacial

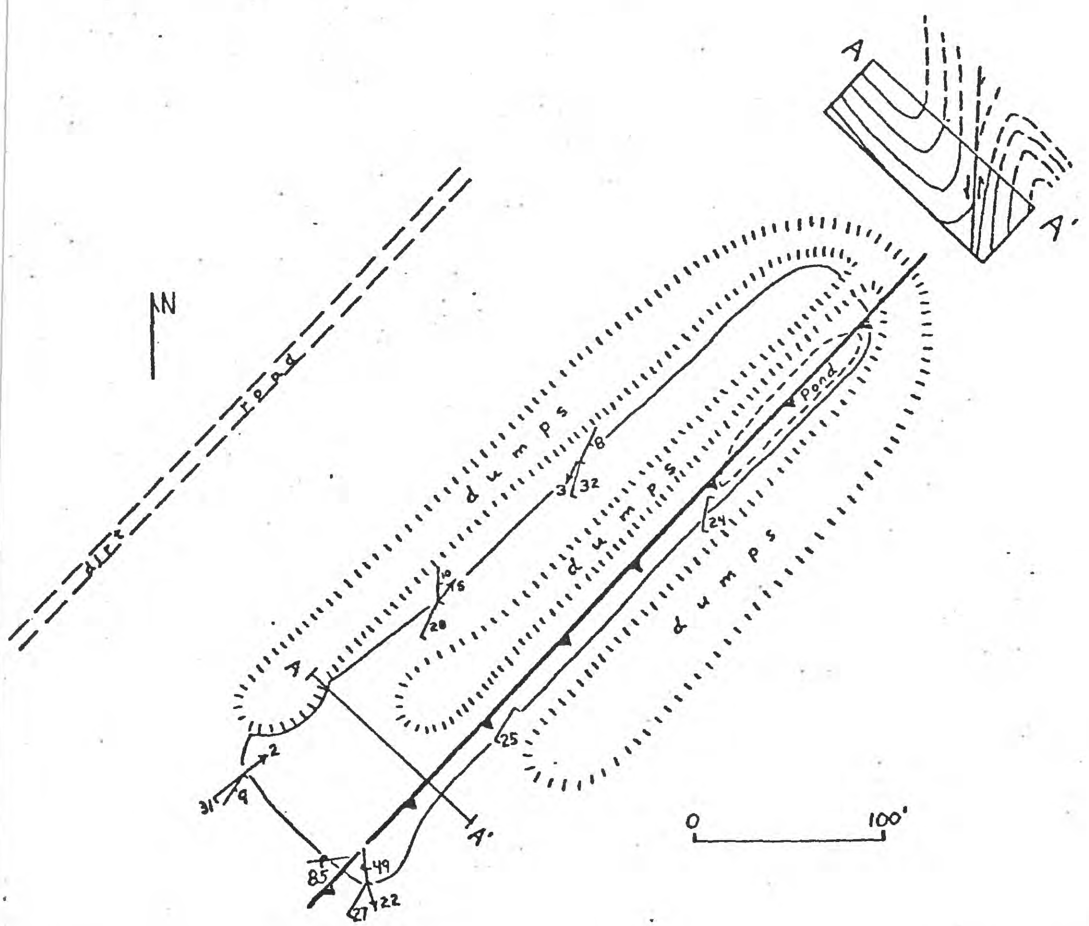


Figure 74. Geologic map and section of the Frye quarry. See plate I for explanation of map symbols.

drift. The dumps extend along the southeast side of the quarry to the highway, paralleling the creek that flows through the quarry. Bedding and cleavage dip to the northeast, possibly rotated to that position along a concealed fault nearby. There is a fault about 400 feet to the north. A dense, dark-gray to medium-dark-gray, very fine grained quartzose, micaceous, and chloritic dolomite concretion about 4 feet long and 2 feet wide was found near the bottom of the quarry. It is flattened parallel to bedding and cleavage wraps around it.

New Jersey quarry (29)

The early history of this quarry is given by Cook (1868, p. 519) and Chance (in Lesley and others, 1883, p. 149-151). The quarry is uneven in plan, about 500 feet long and 250 feet wide. A creek falls over a 75-foot wall of slate at the northeast end and flows out to the southwest. The dumps extend for about 1,000 feet to the southwest opening along the creek. No thick graywacke beds were seen. About 20 feet of glacial deposits overlie the slate. Bedding and cleavage remain fairly constant. Cleavage attitudes are N. 53°-73° E., 12°-25° SE.; bedding is N. 38°-47° E., 26°-44° NW. The beds clearly strike into the Shawangunk Formation. Some movement along bedding is shown by slickensides.

Quarry (30)

This small quarry is mentioned by Chance (in Lesley and others, 1883, p. 148). It is about 100 feet long, 40 feet deep, and is located in a small ravine about 200 feet above Delaware River.

About 60 feet of interbedded slate and graywacke is exposed. Graywacke occurs in thick massive beds and is most abundant near the top. Bedding strikes N. 53° E. and dips between 19° and 30° NW. Cleavage dips gently to the northwest, varying between 2° and 15°. Dumps extend down the hillside for about 300 feet on both sides of the quarry. This opening is of interest because of the near parallelism of bedding with that of the overlying Shawangunk, a departure from trends in the Martinsburg to the south in New Jersey and southwest in Pennsylvania, and because of the thick graywacke beds showing the proximity of the middle member of the Martinsburg Formation (Ramseyburg Member) to the Shawangunk Formation in New Jersey.

Lithotectonic Unit 2

The Shawangunk Formation and Bloomsburg Red Beds comprise this lithotectonic unit. In general, folds are more upright and open than those folds in the Martinsburg about 1 mile or more southeast of the Shawangunk-Martinsburg contact. Some folds are tighter, however, such as the Little Offset anticline and Poplar Valley syncline, in places. The geometry as shown in the cross sections, plate II, may not be exact because of poor exposures due to thick drift cover, and some of these tight folds may be faulted. If so, the displacement is not great. The limited exposures can be interpreted to suggest that faulting is not necessary to explain the structural relations. The fold axes in this unit are interpreted to extend into the Martinsburg terrane, although there is no definitive evidence of this in the quadrangle. However, in the Bushkill quadrangle, 5 miles to the northeast, the Dunnfield syncline and Cherry Valley anticline extend into the Martinsburg and beds in the Martinsburg are folded concordantly with the overlying Shawangunk, except for slight divergence in dip between the two formations due to the Taconic angular unconformity. All of the folds plunge gently to the southwest. There is generally good topographic expression on the folds on Blue and Kittatinny Mountains. They also show up well on aerial photographs. Outcrops are very poor southwest of the Wisconsin terminal moraine at the Little Offset, especially on the broad top of Kittatinny Mountain north of Big Offset, but the folds can be traced with a fair degree of confidence by using photographs and the topographic map. The Big and Little Offsets are topographic expressions of the Big Offset syncline and Ross Common Creek syncline, respectively.

The monoclinal dip of the Shawangunk Formation on the southeast limb of the Dunnfield Creek syncline is broken by a few small folds and faults (see figs. 21, 75). The small fold seen in figure 21 is shown in detail and described in figure 76. A small thrust fault subparallel to bedding and a fold above the fault were seen about 50 feet above the fold and fault shown in figure 76. Drag in bedding along the small fault shows that the overriding limb moved downward to the northwest, an oppsoite sense of movement to that generally envisioned for "drag" towards the crest of an anticline. These folds are thus incongruent and are also

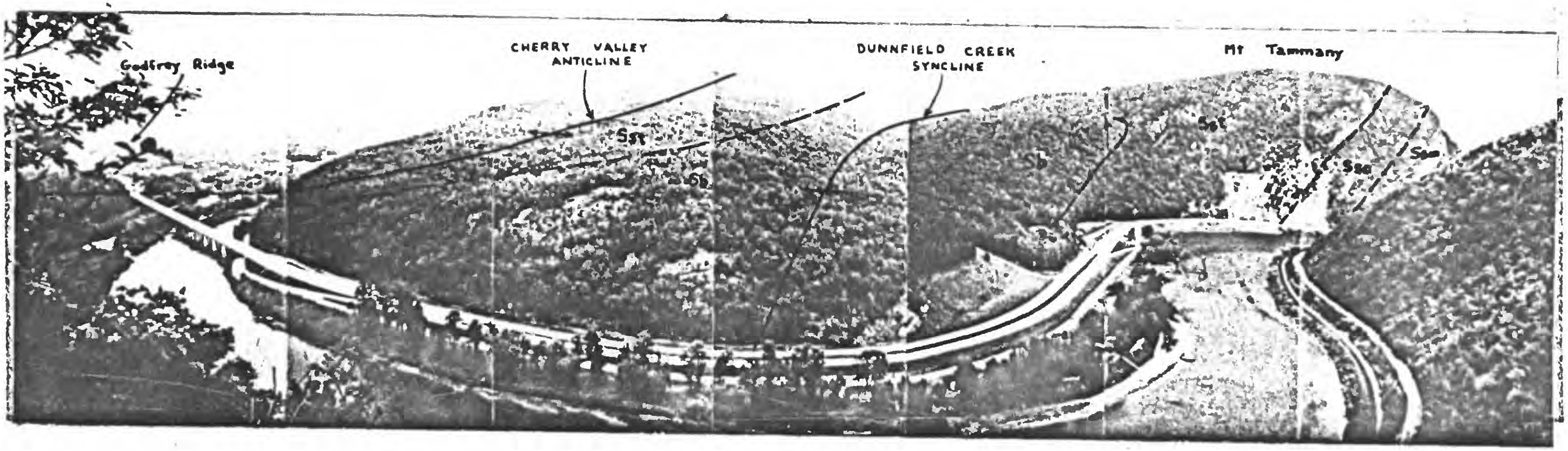


Figure 75. Panoramic view of Delaware Water Gap looking northwest (left) to southeast (right) showing axial traces of Cherry Valley anticline and Dunnfield Creek syncline. Note kink fold in Mt. Tammany (1) and smaller folds superimposed on the northwest limb of the Dunnfield Creek syncline in the Bloomsburg. The southeast limbs of these folds are partly covered by foliage. Sb, Bloomsburg Red Beds; Sst, Tammany Member of the Shawangunk Formation; Ssc, Clinton Member of the Shawangunk Formation; Ssm, Minsi Member of the Shawangunk Formation. Hills of Marcellus Shale and younger rocks lie beyond Godfrey Ridge to northwest.

Figure 76. Fold and thrust fault in the Clinton Member of the Shawangunk Formation at Delaware Water Gap, N.J. The strike of the fault parallels local structural trends. The fault dips steeply to the northwest (left) at the bottom and dies out upward into a bedding plane. The sense of movement is shown by drag on the upper plate. Note crumpling of beds in the center of the syncline near the top of the fold.

disharmonic with beds above and below. Most bedding-plane slickensides indicate that the sense of movement of overriding beds was to the northwest. Thus, it is believed that these folds and faults developed after folding began by northwest movement, perhaps under the influence of gravity. By analyzing deformation lamellae in the fold shown in figure 76, Scott and others (1965) concluded that the lamellae formed early in deformation and were externally rotated during the later stages of folding. The deformation in lithotectonic unit 2 was, therefore, not simple, as will be mentioned again.

About 600 feet north of the structures shown in figure 76 is a structural terrace, 50 feet wide, with beds that dip gently southeastward interrupting the northwest homoclinal dip in conglomerates and quartzites of the Tammany Member of the Shawangunk Formation. The fold produced is similar (the fold form extends upwards for 500 feet unchanged) and the axial planes dip steeply southeastward. Faill (1969, fig. 2) describes it as a kink band, but perhaps that term ought to be reserved for microscopic and small-scale (hand sample) features. The terrace formed by flexural slip because bedding-plane slickensides are present, and there is no apparent change in thickness of beds in different parts of the fold. I do not believe that the major folds in this lithotectonic unit can be ascribed to kink-folding--the crests and troughs are not abrupt enough and the limbs are not generally straight sided (pls. II, III). However, lithotectonic unit 3 may have deformed by kinking and the structural geometry may meet the qualifications for that process.

The Kemmererville anticline rises from the western part of the Stroudsburg quadrangle and extends to Delaware Water Gap where it dies out and is traced into a series of smaller folds (pl. I). Willard (1938) believed that the anticline is the major structure in the Bloomsburg Red Beds in the gap and that the anticline is broken by a number of high-angle normal faults. No such faults occur, and the major structure at Delaware Water Gap is a complexly folded syncline (Dunnfield Creek syncline) or, assuming the northwest limb to be nearly flat, a structural terrace (see cross section F-F'-F", pl. II, and fig. 75). The small folds superimposed on the Dunnfield Creek syncline in the Bloomsburg Red Beds average a few hundred feet in wavelength, they have amplitudes generally less than 40 feet, and can be traced for about 1 mile along the length of their axes. Bedding-plane slickensides are abundant and small steps or microscarps on them clearly indicate that translation of overriding beds was to the northwest in all parts of the folds. This northwest movement is corroborated by numerous wedges that are small imbricate shears from sole bedding-plane slips (fig. 77). Cleavage dips southeast in all parts of the fold and would appear to have formed after the small-scale folding, except that the cleavage is dragged at many bedding-slip surfaces. By rotating bedding back to horizontal in the fold that is partly shown in figure 77, it was found that cleavage was not

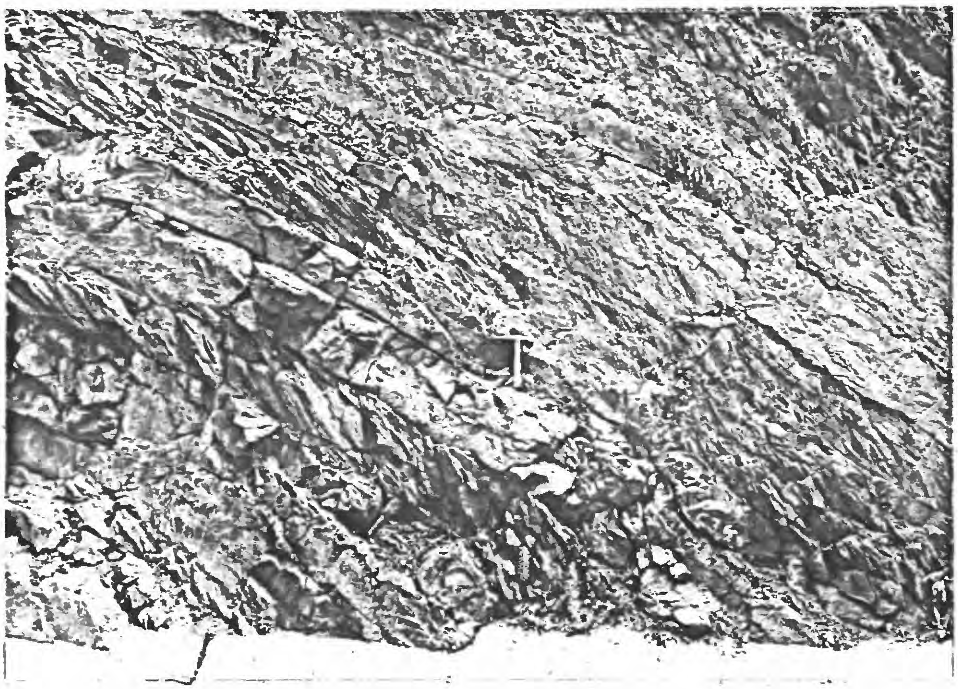


Figure 77. Wedging and bedding-plane slip in the Bloomsburg Red Beds, just east of where U.S. Interstate Highway 80 crosses Delaware River, Delaware Water Gap, N.J. The bedding plane at bottom of hammer handle is slickensided and microscarps indicate northwest movement of overriding beds. Wedge lies to left of hammer. Note southeast-dipping (to left) cleavage in silty beds. The sigmoidal shape of the en echelon tension fractures are probably not due to frictional drag but to rotation during continued movement indicated by the wedge. The movement picture is corroborated by the orientation of the fractures (for example, see Shainin, 1950). The cleavage is perpendicular to the last-formed part of the tension crack, thus also perpendicular to maximum compressive stress.

rotated back to parallel orientations in all parts of the fold. Thus, the cleavage did not simply develop prior to folding and later become rotated to its present position during folding. As mentioned previously, the deformational pattern in lithotectonic unit 2 is far from simple, and folding, cleavage development, bedding-plane slippage, and wedging were probably overlapping features. Maxwell (1962, fig. 9) showed some of these structures and claimed that the cleavage is a fracture cleavage that developed by interbed shear. But, as will be discussed later, there is some mineral alignment along cleavage planes. The cleavage in the Bloomsburg parallels the cleavage developed regionally.

The relative ages of the structures in the Bloomsburg at Delaware Water Gap seem to be (1) uplift and start of folding of the Dunnfield Creek syncline, possibly accompanied by the initiation of cleavage development; (2) northwest sliding of beds into the broad trough and onto the northwest limb of the syncline forming small folds with superposition of the regional cleavage on the folds; (3) continued bedding-slip and wedging draging cleavage at the bedding-slip surfaces and shearing off the tops of several anticlines (as pictured by Maxwell, 1962, fig. 9, for example). These features probably developed during one continuous period of deformation and their order may have varied from place to place due to differences in local stress conditions. The accumulated displacement (net telescoping) of the bedding slips and wedges may amount to thousands of feet or more.

Lithotectonic Unit 3

The structure in lithotectonic unit 3 is too complex to be shown on the quadrangle map (pl. I) in detail, and a larger scale map is presented for this purpose (pl. III). The folds, in general, are smaller than in other units (fig. 78). They are overturned or asymmetrical to the northwest, en echelon, and the plunge is variable so that when viewed perpendicular to axial traces, they appear to be crossfolded (fig. 79). The variability in plunge may be due to convergence and divergence in the moving rock mass parallel to the b-tectonic axis, which, in turn, is due to differential foward motion of the northwestward-migrating mass. The difference in amount of shortening between rocks in lithotectonic unit 3 as compared to rocks in lithotectonic unit 2 is more than 15 percent, if all the complex folding shown on plate I was by flexural slip. However, some of the folding was passive, so the net difference in shortening is somewhat less than 15 percent. In some folds beds in argillaceous stratigraphic units, such as the Port Ewen Shale shown in figure 35, are thickened as much as 50 percent in the hinge areas relative to the limbs. In most cases cleavage fans in the folds open toward fold troughs (convergent fanning, fig. 78), but in others the cleavage fan is divergent (fig. 80). In the Slater-Canfield quarry, 1,200 feet west of where U.S. Interstate 80 crosses Brodhead Creek in the northeast part of the Stroudsburg quadrangle (labeled "gravel pit" on the topographic map), crumpling in the core of an overturned syncline has produced reversed folding--a small anticline has developed in the trough of the syncline.

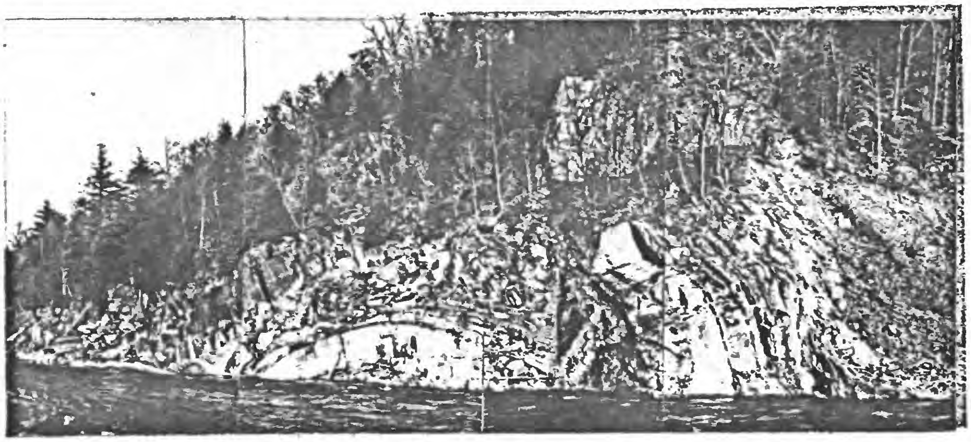


Figure 78. Folds interpreted to be cascades in the Ridgeley Sandstone (massive bed and underlying rocks) and overlying Esopus Formation (with convergent cleavage fan in syncline) along Brodhead Creek, 1 mile east of Stroudsburg, Pa.

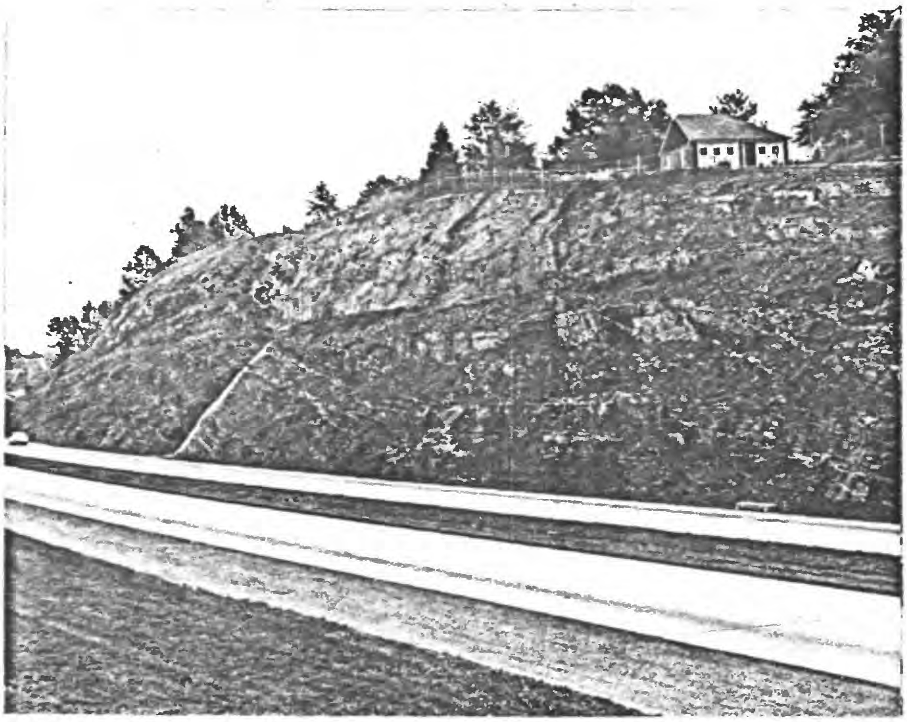


Figure 79. View parallel to the axis of an anticline (northwest limb dips northwest, to the left) in the Stroudsburg Member of the Buttermilk Falls Limestone in roadcut along U.S. Interstate 80, Stroudsburg, Pa. The variation in plunge is apparent. The fold is noncylindrical, and because its axial plane appears to vary in dip, it is also nonplanar. Outcrop patterns are of folds in lithotectonic unit 3 thus complex (pl. III).

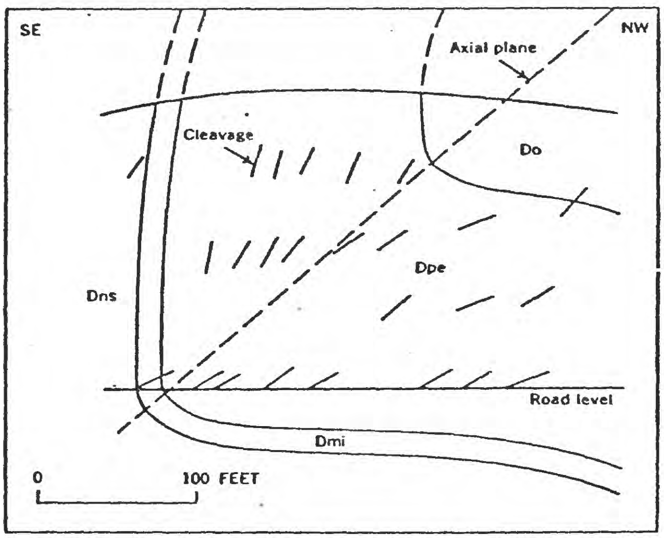


Figure 80. Geologic section showing divergent fanning of cleavage in the Port Ewen Shale in Godfrey Ridge along U.S. Interstate 80, approximately 0.4 mile southwest of Minisink Hills, Pa. Figure 35 is a photograph of the exposure. Section is perpendicular to strike of beds. Vertical scale same as horizontal. Do, Oriskany Group; Dpe, Port Ewen Shale; Dns, New Scotland Formation; Dmi, Minisink Limestone.

Few faults were seen in lithotectonic unit 3. A few 1-foot-thick shear zones, filled with calcite, quartz, and fragments from surrounding rock, were seen in the Port Ewen Shale in the northeast section of Godfrey Ridge. Displacment was insignificant, and they are not shown on the geologic maps. The fault cutting the Oriskany shown on the geologic map of Pennsylvania (Gray and others, 1960) nearly 2 miles east-northeast of Stroudsburg is best interpreted as a fold. One fault was mapped along Brodhead Creek in the northeast section of the quadrangle. It is a high-angle fault with the northwest block down and rotated to the southeast relative to the southwest block (fig. 81).

Folding and development of deformation lamellae followed by rotation in lithotectonic unit 3 has been demonstrated by Hansen and Borg (1962) as it was in lithotectonic unit 2 discussed above.

Lithotectonic Unit 4

The change from complicated folds of lithotectonic unit 3 to gently undulating beds of lithotectonic unit 4 takes place fairly abruptly, apparently in the covered zone at the base of the Brodhead Creek Member of the Marcellus Shale. One fold was mapped in the Stroudsburg quadrangle--the East Stroudsburg syncline. It is a broad open fold with a half-wavelength of about 4,000 feet. A moderate to gently dipping southeast cleavage is found in all exposures, but the cleavage is not as well developed as in older [illegible]lites.

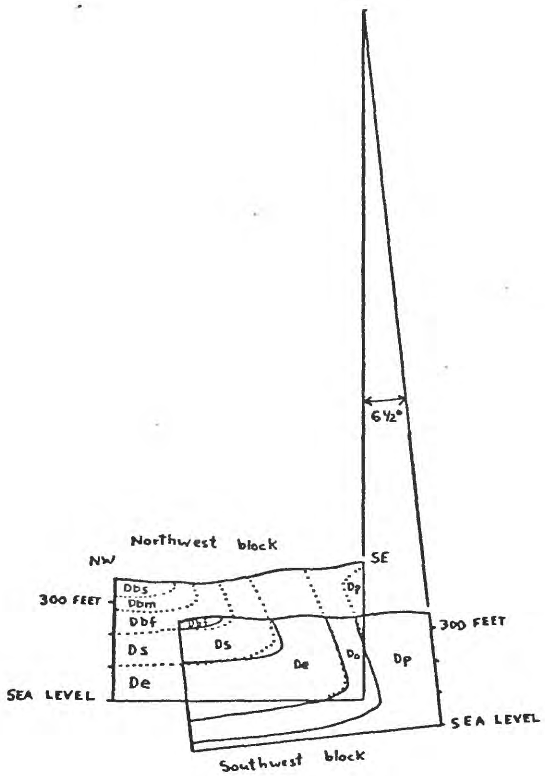


Figure 81. Cross sections of blocks on either side of high-angle fault 5,000 feet southwest of Minisink Hills in Brodhead Creek. Sections are rotated so that structures and stratigraphic units are superimposed as they were before faulting. To have reached their present position, the northwest block must have moved down and rotated to the southeast with the pivot point above 1,700 feet above. Dp, Port Ewen Shale; Do, Oriskany Group; De, Esopus Formation; Ds, Schoharie Formation; Dbf, Foxtown Member of Buttermilk Falls Limestone; Dbm, McMichael Member of Buttermilk Falls Limestone; Dbs, Stroudsburg Member of Buttermilk Falls Limestone.

Small-scale Structures

Lineations and planar elements are numerous in the Stroudsburg quadrangle and vicinity. Lineations include slickensides, elongated fossils and minerals, axes of folds, intersections of bedding and cleavage, and intersections of cleavage and cleavage. Planar elements include joints, bedding, slaty cleavage, and slip cleavage.

Lineations

Bedding-plane slickensides and slickensides on cleavage are shown on the geologic maps (pls. I, III). In general, their trends are similar in all lithotectonic units. Unfortunately, not enough were recorded so that a structural plot could be made. Of interest is the increase in the number of bedding-plane slickensides in the Martinsburg Formation within a few hundred feet of the Shawangunk Formation. The significance of this will be discussed shortly.

Mineral streaks and elongated fossils are common. These comprise the "transport lineation" of some workers. These were not recorded, but they generally trend perpendicular to fold axes and parallel to direction of tectonic transport. Distinct lineations of this type are generally not well developed in slates in the Martinsburg Formation. The growth of minerals in pressure shadow areas parallel to cleavage will be discussed under cleavage.

Aside from the possibility that the variably-plunging folds in lithotectonic unit 3 are cross folds, at only one locality (in the Martinsburg Formation) were small-scale cross folds seen. These are located in Slateford Creek 500 feet west of the east border of the Stroudsburg quadrangle. Their axes parallel bedding-plane slickensides that trend N.38° W. The folds have wavelengths of about 6 inches (fig. 82), and they apparently developed by convergence in the b-tectonic direction as the rock was transported parallel to a.

Intersections of cleavage and cleavage are rare in the Stroudsburg area because a second cleavage was seen in outcrop in only a few places--in the Snowdon slate quarry in the Martinsburg Formation (no. 25) and in the Rondout Formation on Godfrey Ridge. These will be discussed in the section on cleavage.

The only lineations that were consistently recorded are intersections of bedding and cleavage. These approximate the trend of the axes of the folds in which they occur, but it can be shown geometrically that some variation from this trend is to be expected if there is any fanning of the cleavage; that is, if the cleavage is not parallel to the axial surface of the fold in all parts of the fold. Cleavage in all rocks in the area fan the folds to some extent, but nevertheless, it does give an approximation of axial trends. Figure 83 is an equal-area plot of the recorded intersections of bedding and cleavage in the four lithotectonic units in the Stroudsburg quadrangle. A synoptic plot (fig. 106) shows that the trends are very similar in all lithotectonic units in the quadrangle. There is, however, a slightly

Figure 82. Small cross folds in the Martinsburg Formation in Slateford Creek, 500 feet west of the east border of the Stroudsburg quadrangle. Fold axes parallel slickensides that trend to the northwest, parallel to hammer handle.

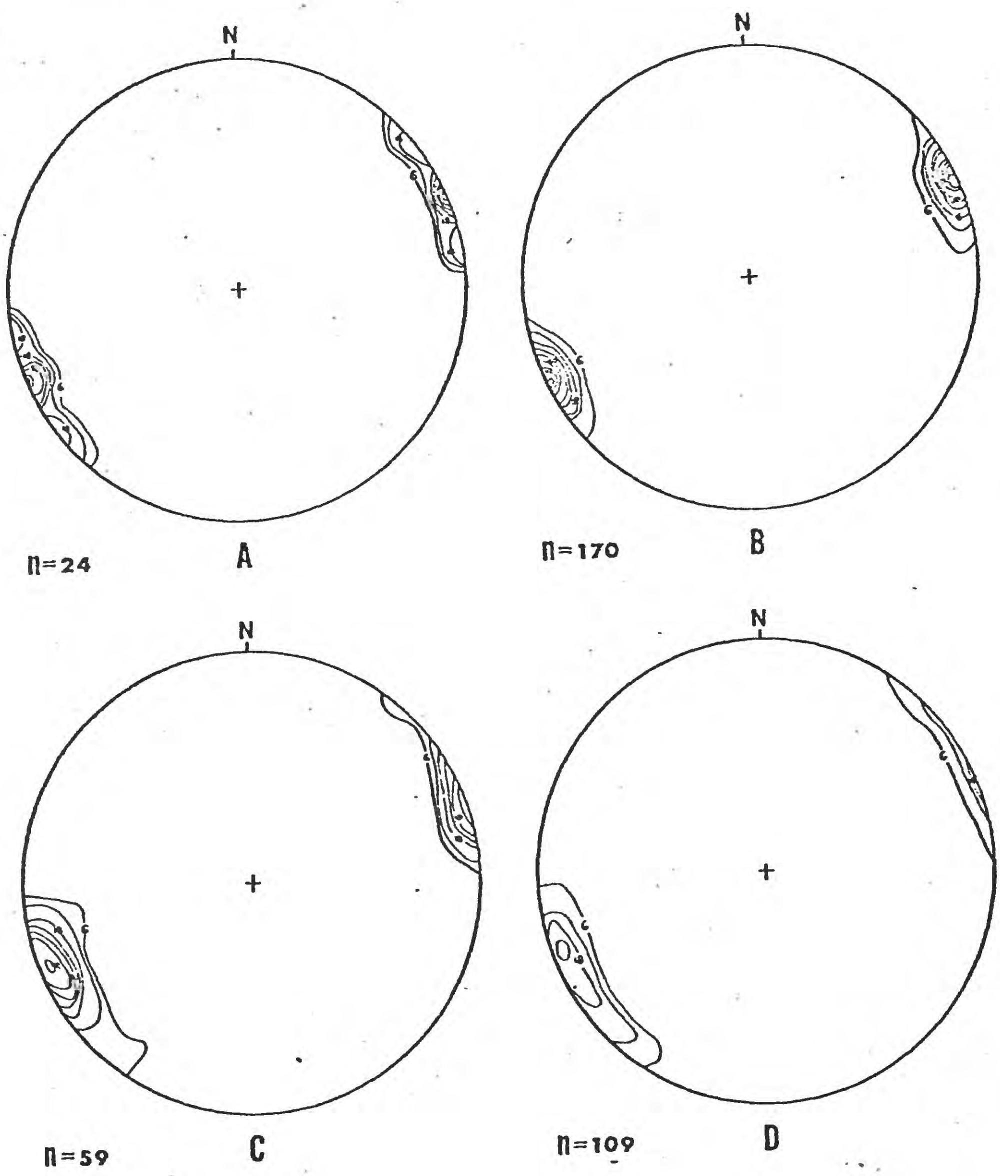


Figure 83. Equal-area projections (lower hemisphere) of intersections of bedding (S_o) and cleavage (S_1), a lineations, in the four lithotectonic units in the Stroudsburg quadrangle. Contour interval 6 percent per 1 percent area.

A, lithotectonic unit 4, maximum at 2°, S. 68° W.
B, lithotectonic unit 3, maximum at 1°, S. 66° W.
C, lithotectonic unit 2, maximum at 5°, S. 70° W.
D, lithotectonic unit 1, maximum at 4°, S. 70° W.

greater spread in the Martinsburg Formation (fig. 83D).

Joints

These planar features can be conveniently related to folds as cross, longitudinal, and oblique joints. They are generally smooth to rough, planar to slightly curved fractures usually tens of feet or more in length. Calcite or quartz may line some joints. Displacement along joints, if present is never more than a few inches. Equal-area plots of joints (fig. 84) show that cross (ac) joints are very well developed in relatively competent rocks (i.e., lithotectonic units 2 and 3) and that longitudinal joints are less well developed. The joint pattern in lithotectonic units 1 and 4 (predominantly in shales and siltstones) is more complex, and no attempt is made to decipher its structural significance. Two useful conclusions may be made of the joint plots, however. The first is that ac joints are not oriented perpendicular to strike of bedding (see fig. 85). They are as much as 20° off from the perpendicular. This further evidence that there has been rotation of joints (as well as beds) following their initial development, presumably during the latest stages of folding or just after. They are a later feature than cleavage because no cleavage was seen transecting them. The second conclusion is that joint sets served as lines of weakness during erosion and that the numerous wind and water gaps in the area are located along these lines of weakness. This will be discussed further under geomorphology.

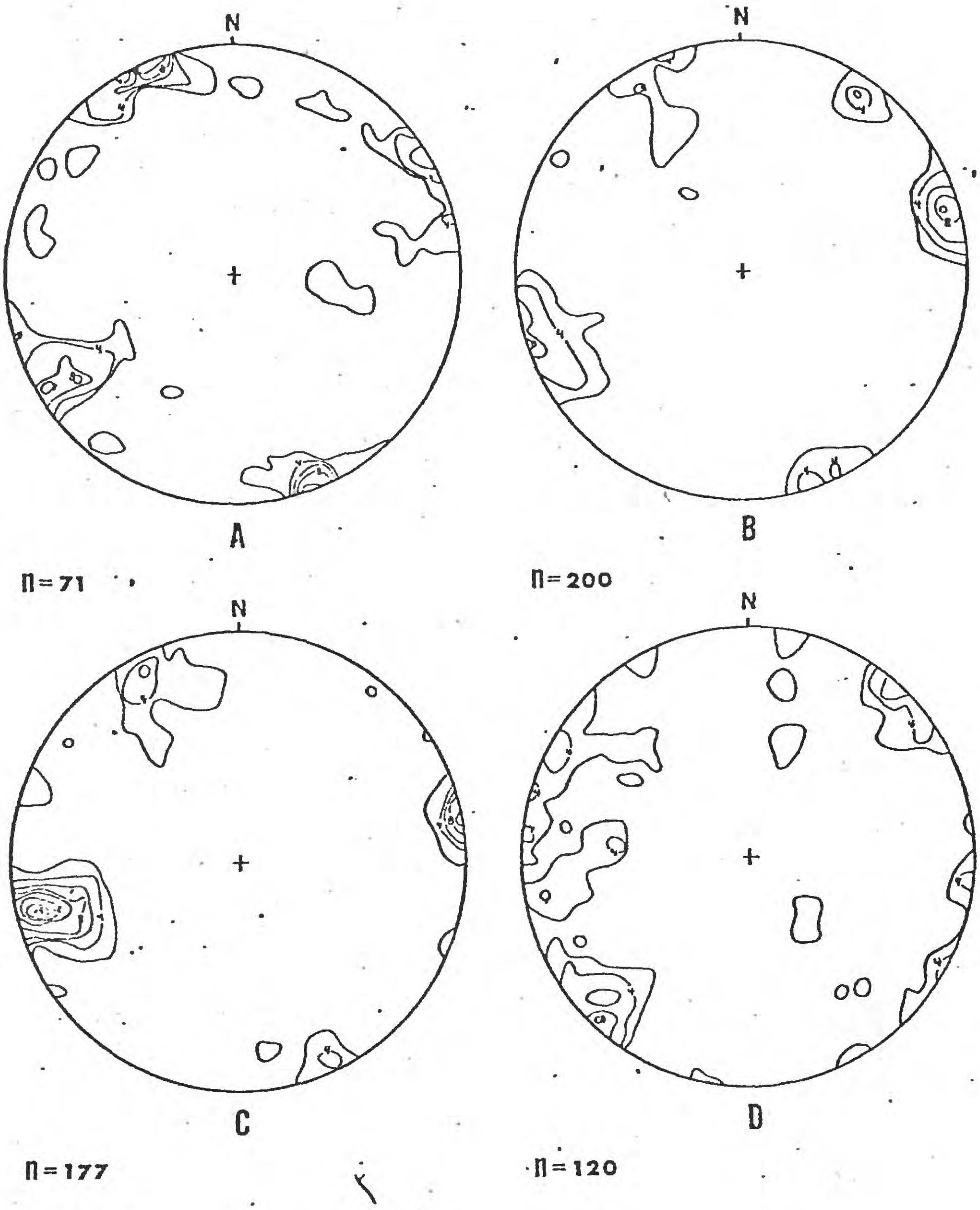


Figure 84. Equal-area projections (lower hemisphere) of poles to joints in the four lithotectonic units in the Stroudsburg quadrangle. Contour interval 2 percent per 1 percent area.

A, lithotectonic unit 4
B, lithotectonic unit 3
C, lithotectonic unit 2
D, lithotectonic unit 1

Bedding

Bedding is a primary planar structural feature that is used to define the geometry of folds. The characteristics of folds have been described under the lithotectonic units and their geometries may be further expanded by plotting bedding on equal-area nets (fig. 85). In general, the plots of bedding substantiate the low angle of plunge of folds in the area that is shown by plots of intersection of bedding and cleavage. Slight arcuation of the girdles, especially in lithotectonic unit 2 (fig. 85C) shows the gentle southwest plunge.

The plot of beds in lithotectonic unit 4 shows the upright nature of the folds in that unit. The asymmetric overturning in units 2 and 3 are well shown in the nets. The lack of overturned beds in the net for the Martinsburg Formation (lithotectonic unit 1) is due to the low concentration of such beds in the area, and is not to be construed that overturning is not present in that unit. Note that bedding maxima in the Martinsburg is more northerly than in the other lithotectonic units, substantiating the unconformable relationship between it and overlying rocks. There is also the suggestion that bedding in the Martinsburg was rotated to a more northeasterly direction parallel to beds in overlying rocks. Figure 106 shows a synoptic summary of bedding in the four lithotectonic units.

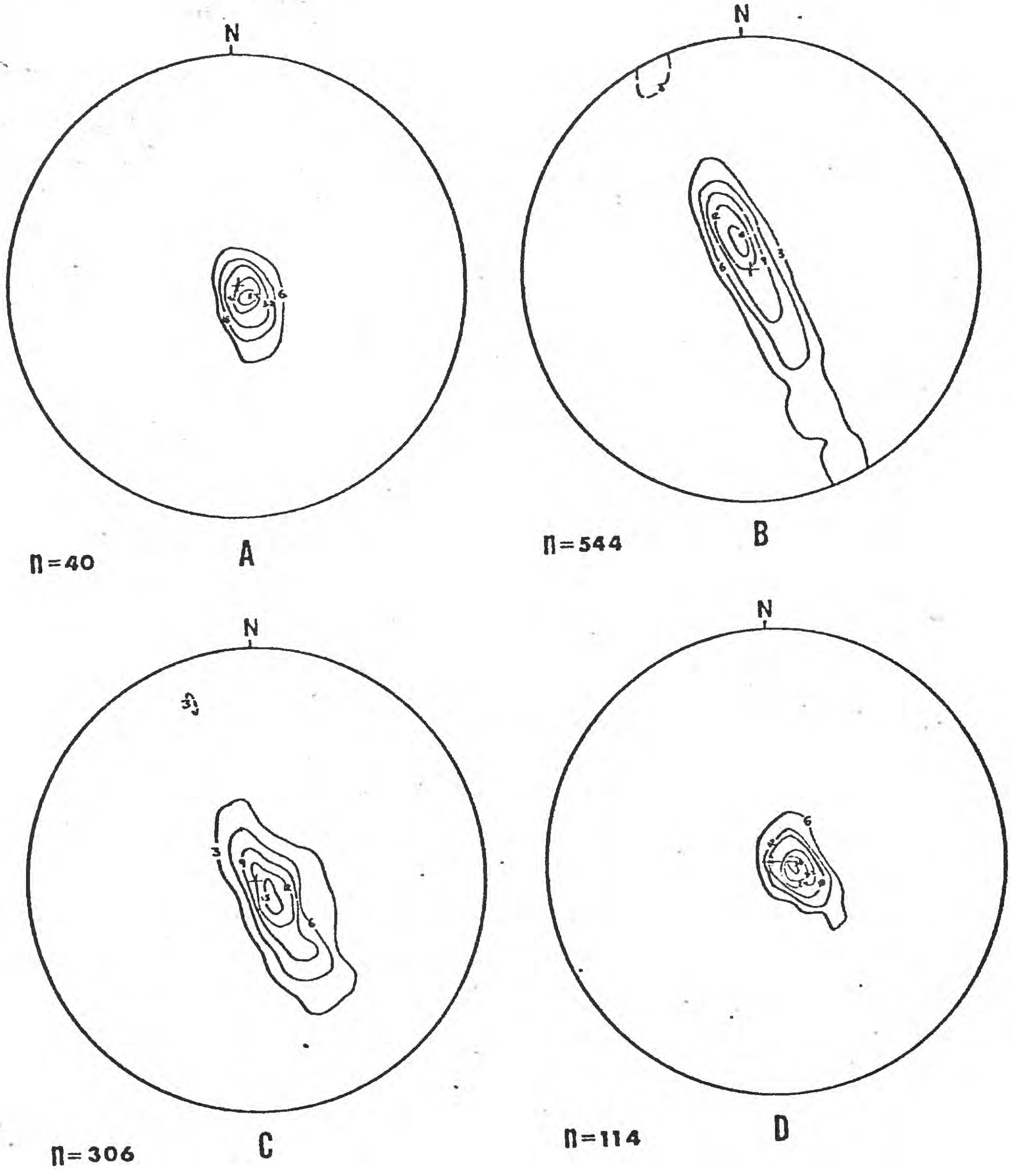


Figure 85. Equal-area projections (lower hemisphere) of poles to bedding (S_0) in the four lithotectonic units in the Stroudsburg quadrangle. Contour interval for A and D is 6 percent per 1 percent area, and for B and C is 3 percent per 1 percent area. Dashed contours are overturned beds.

A, lithotectonic unit 4, maximum at N. 46° E., 6° NW.
B, lithotectonic unit 3, maximum at N. 66° E., 10° SE.
C, lithotectonic unit 2, maximum at N. 50° E., 13° NW.
D, lithotectonic unit 1, maximum at N. 21° E., 8° NW.

Cleavage

All pelitic rocks in the Stroudsburg area have a secondary foliation or cleavage, the intensity of which, both megascopically and microscopically, decrease to the northwest. For years there has been disagreement concerning the conditions under which cleavage forms. In general, two types of cleavage have been recognized; (1) flow cleavage (often used synonymously with slaty cleavage, axial-plane cleavage, etc.), which formed either by recrystallization of platy minerals perpendicular to the direction of maximum stress, or by movement parallel to planes of maximum shear; and (2) fracture cleavage, which is closely spaced fractures that are generally not believed to be controlled by any mineral alignment. A third type, slip cleavage (also called crenulation cleavage, false cleavage, etc.), is sometimes categorized as fracture cleavage by some workers. It is usually described as closely spaced fractures along which a previous foliation (either bedding lamination or an earlier cleavage) is dragged due to movement along the cleavage planes. Slaty and fracture cleavage are generally described in the same outcrop, the slaty variety found in pelitic interbeds and fracture cleavage found in more competent siltstones and sandstones. The two types of cleavage are lithically controlled, they are gradational, and they apparently have a common origin.

The cleavage in the Stroudsburg area is a regional feature that maintains a fairly consistent range of attitudes in all lithotectonic units (fig. 86). It generally appears to be related to the folds in that it is subparallel to the axial planes of the folds and is oriented symmetrically in the folds (fans the folds). Dips are steeper in more competent units (coarse siltstone, argillaceous sandstones, and limestones) than in less competent shales and finer siltstones. In graded pelite-sandstone sequences, the change in dip of cleavage is gradual and the cleavage appears to be folded (fig. 87), but this is due to gradual "refraction" of cleavage in more competent beds. In many rocks cleavage is the most prominent structure and results in a cleavage banding that may be mistaken for bedding.

Several "types" of cleavage are found in rocks of the Stroudsburg area. It is not the purpose of this discussion to delve deeply into the mechanics of cleavage formation. Rather, I shall describe the cleavages as they affect interpretation of the ages of deformation in the area and present some discussion concerning the conclusion of Maxwell (1962) that the slaty cleavage in the Martinsburg Formation is a product of diagenesis (and not metamorphism) during mild deformation of the Taconic orogeny, and that all other cleavages in the area, particularly in post-Martinsburg rocks, are the fracture type.

No rock seen in this section, from the best slate in the Martinsburg Formation to Marcellus Shale with poor cleavage, has perfect alignment of all component minerals. However, every rock seen has at least some preferred mineral alignment, even where

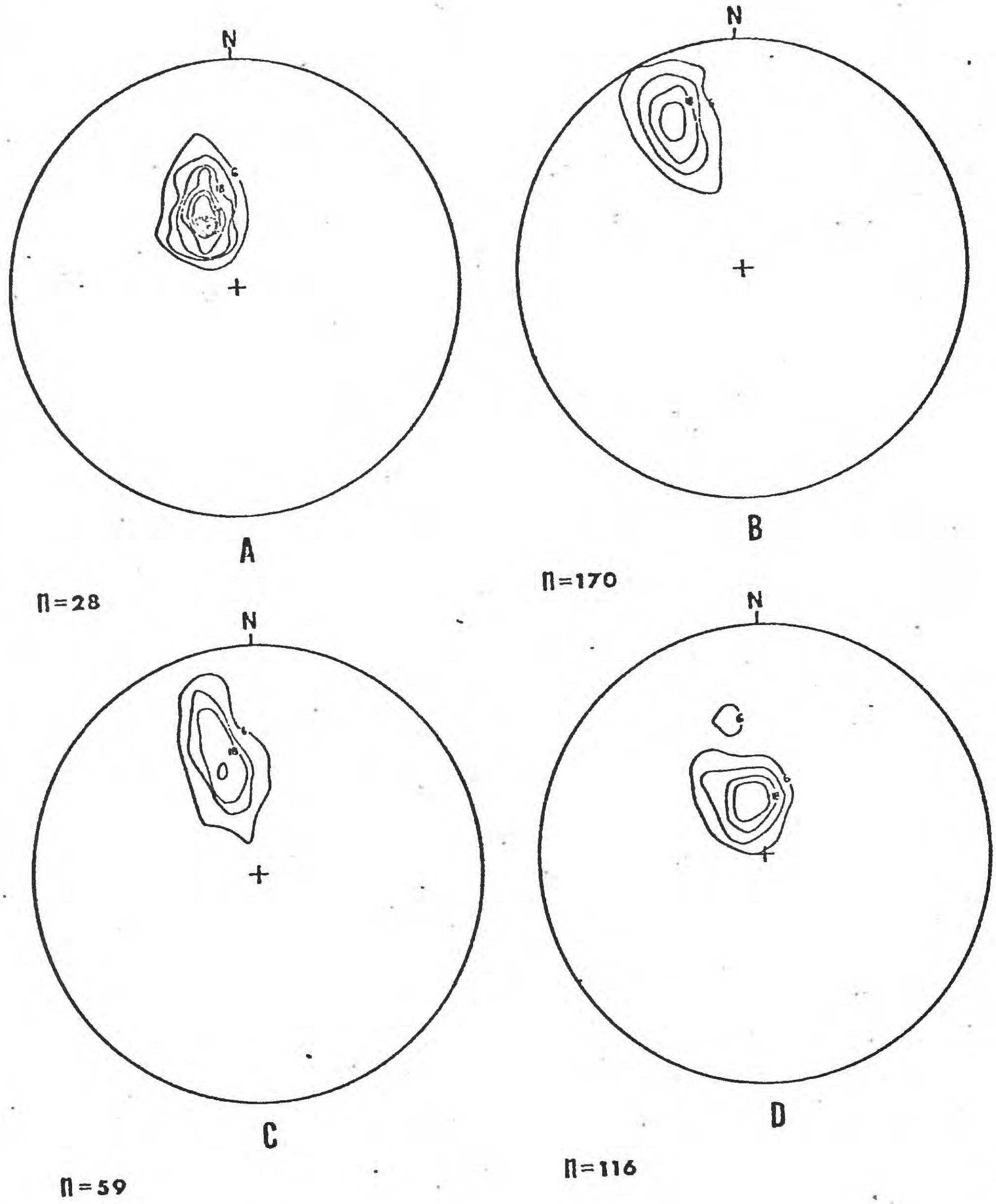


Figure 86. Equal-area projections (lower hemisphere) of poles to cleavage (S_1) in the four lithotectonic units in the Stroudsburg quadrangle. Contour interval 6 percent per 1 percent area.

A, lithotectonic unit 4, maximum at N. 66° E., 23° SE.
B, lithotectonic unit 3, maximum at N. 66° E., 60° SE.
C, lithotectonic unit 2, maximum at N. 72° E., 42° SE.
D, lithotectonic unit 1, maximum at N. 73° E., 19° SE.

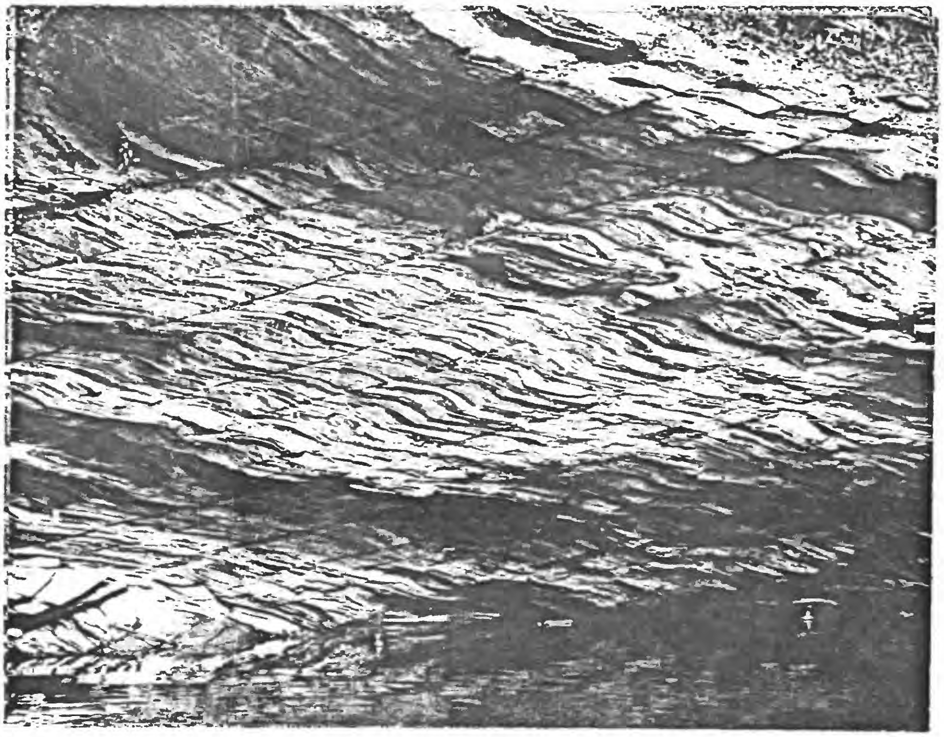


Figure 87. Refracted slaty cleavage in Pen Argyl Member of the Martinsburg Formation, Strunk quarry (no. 7), 0.5 mile southeast of North Bangor, Pa. Bedding dips gently northwest (left) and cleavage dips gently southeast. Cleavage is steeper in siltier beds. Beer bottles floating in flooded quarry give scale.

cleavage is poorly developed. Therefore, fracture cleavage is a term that is not applicable in this area and slaty cleavage is herein used to define that cleavage which allows a rock to be split into thin folia and is dependent upon the parallelism of platy minerals and dimensional alignment of prismatic minerals for that property. Thus, the slates in the Martinsburg Formation have slaty cleavage and the less perfectly developed cleavage in siltstone of the Bloomsburg Red Beds, even though Bloomsburg siltstones are not slates in a commercial sense, also have slaty cleavage. I shall use "cleavage" and "slaty cleavage" interchangeably. There has been too much confusion stemming from the complex plethora of names that exist for this foliation for me to suggest others. Slip cleavage is used as a separate type (a foliation along which others are crenulated) with the full realization that it too may be mechanically equivalent to slaty cleavage; i.e., slip cleavage may develop in laminated or foliated rocks while slaty cleavage developes in rocks of different lithology elsewhere.

Megascopically, cleavage is characterized by the easy splitting of the rock parallel to the cleavage direction (figs. 3, 50, 98). Microscopically, in rocks of the Delaware Water Gap area, the cleavage is shown by thin folia of muscovite, chlorite, elongate quartz and calcite, and opaque minerals, presumably carbonaceous matter and iron oxides, that are oriented parallel to one another and are separated by thin layers of quartz, mica, chlorite, and other minerals that are not oriented parallel to the cleavage direction (figs. 4, 6, 12, 24, 26, 40, 49, 53, 54, 88, 97, 99, 100, 102, 103). No sample seen has all mineral grains parallel to the cleavage direction. These observations are in accord with those of Schamel (1969) and Powell (1969). The proportion of aligned minerals in cleavage folia apparently increases (1) as the intensity of deformation increases, (2) in finer grained rocks, (3) with increased percentages of platy minerals in a rock. Thus, cleavage folia are farthest apart in coarser grained rocks and in more quartz-rich rocks (to which the term fracture cleavage is generally applied). Cleavage that is most closely spaced occurs in such fine-grained rocks as lithographic (micritic) limestone, such as the Bossardville Limestone (fig. 29), and fine-grained pelites of the Martinsburg Formation (figs. 4, 88).

Cleavage surfaces are never perfectly smooth in outcrop. Often there are small steps that appear to be the result of the intersection of two or more cleavages. Likewise, microscopically, the cleavage folia are wavy and anastomose around other grains, such as quartz, in the interfolial areas (figs. 54, 88, 97, 99). The divergence in the direction of cleavage may be more than 20° in small domains and gives the false appearance of two intersecting cleavages. Cleavage diverges around more rigid obstacles, such as fossils and quartz-filled burrows, by more than 35°, as seen in many lithologic units. Certainly, these divergent trends cannot be ascribed to more than one generation of cleavage. Perhaps the best example of this irregularity is illustrated by Behre

(1933, p. 31, pl. 7A), and shows a sample from the Martinsburg Formation cut perpendicular to bedding and cleavage (the bc plane).

Cleavage is at least partly the result of recrystallization and new mineral growth (neomorphism), but probably is largely the result of mechanical reorientation of minerals. Flowage is evidenced by laminar intrusions of fine pelitic, often carbonaceous, material across more rigid laminae (figs. 88, 94, 101). Dragging of minerals into the cleavage plane is common (fig. 26). Occassionally, the cleavage folia extend across shells (fig. 102), bedding-plane slickensides (fig. 88), and stylolites (fig. 103), indicating that mobility of the material in the folia occurred after a certain amount of lithification occurred. The mobility induced after lithification can certainly be ascribed to the presence of water in the rocks under conditions of, or approaching, low-grade regional metamorphism (quartz-muscovite-albite-chlorite subfacies of the greenschist facies).

How much recrystallization occurs after flowage starts is difficult to say, but undoubtedly there has been some recrystallization and grain diminution in cleavage folia (figs. 88, 95, 100, 102) as well as growth of porphyroblasts (fig. 88) and growth of new minerals in pressure-shadow areas around other grains such as pyrite (figs. 29, 88, 99, 101). Similarly, quartz, derived from pebbles adjacent to a shale layer, and was intruded into the shale parallel to the cleavage, is strong evidence for recrystallization (fig. 95).

There appears to be crushing and stretching of mineral grains in cleavage folia, suggesting considerable recrystallization. In general, minerals are finer grained in the cleavage folia than in interfolial areas. Evidence of grain diminution and stretching is to be found where cleavage cuts through coarse quartz-rich laminae, quartz grains, shells, etc. Extensive recrystallization has not taken place in all cases. In many instances, it appears that quartz grains have "floated" during flowage of material making up the cleavage folia (fig. 101). Thus, it is concluded, that slaty cleavage is the result of flowage of material, crushing of certain mineral grains, recrystallization, and growth of new minerals. Both cataclasis and lowest grades of regional metamorphism are apparently involved. Initiation of cleavage, as represented in the youngest rocks (those in the highest tectonic levels), appears to have occurred below the level generally ascribed to lowest greenschist facies metamorphism.

The intensity of cleavage development and other tectonite phenomena in the Stroudsburg area appears to be related to (1) lithology--fine-grained pelites show greater mineral readjustment than coarser grained, heterogeneous, and more competent rocks, (2) age and depth of burial--younger rocks were less deeply buried, (3) total strain related to distance from source of tectonism--all rocks, including those in the Martinsburg Formation, become more severely deformed to the southeast.

Several methods may be used to compare degree of deformation in rocks in the Stroudsburg area. The first is empirical observation in outcrop--well developed cleavage occurs as nearly flat continuous planes over large areas of the outcrop (figs. 69, 98) as opposed to more poorly developed irregular cleavage surfaces (fig. 52). This of course may depend to a large part on lithology, so rocks of the same type must be compared. The second is to what degree porphyroblasts have grown in the rock (figs. 4, 88). The third is amount of pressure-shadow mineral growth in the cleavage planes around original rigid grains such as pyrite (figs. 29, 88, 99, 101). The new minerals in the pressure-shadow areas suggests that these are zones of least pressure parallel to the direction of maximum extension. Zones of greatest pressure (perpendicular to the greatest stress axis) occur parallel to cleavage, so that quartz grains and other minerals, and most dramatically, fossils (fig. 29), are dissolved adjacent to cleavage laminae. Finally, there are the effects of deformation on quartz. Fellows (1943) has shown that quartz has certain textures that progressively change from one into the other with increasing intensity of deformation. Four of his types are recognized in the Stroudsburg quadrangle: 1) original grains--these show little apparent effect other than the development of strain shadows. These do not appear to be common--most quartz grains have corroded or intergrown borders; 2) peripheral growth quartz--optically continuous quartz overgrowths characterize these forms. They are often accompanied by adjoining quartz grains with sutured or straight contacts (perhaps solution of silica along these contacts supplied quartz for the overgrowths; 3) crush quartz--perhaps a poor term, indicating apparent granulation or growth of smaller grains of quartz as well as shreds of mica, chlorite, and calcite around the grain in the plane of movement (generally parallel to cleavage where apparent in the rock); and 4) needle quartz--slivers of quartz that have been stretched parallel to a to lengths greater than three times their widths. These "tailed" clusters may join two parent quartz grains (fig. 100) and be intergrown with neocrystallized mica. Recrystallized quartz with a granoblastic texture, the last variety discussed by Fellows, is very rare in the rocks of the Stroudsburg area.

Slip cleavage is not as pervasive as slaty cleavage. It appears as a series of subparallel planes where a previous slaty cleavage or bedding laminations have been crinkled (figs. 73, 89, 96). The slip cleavage is generally parallel to axial planes of the crinkles, the limbs of which are thinned and in places sheared off along the cleavage. Mica, chlorite, and other minerals are transposed by mechanical rotation into the new cleavage direction, but there may be some new mineral growth (figs. 89, 96). When enough minerals have been rotated subparallel to the slip-cleavage direction, fractures appear in the rock, apparently not before. This mechanism discounts the usual supposition that slip cleavage is a fracture cleavage along which the minerals have been dragged. Rather, it is the parallel alignment of the minerals that allows the rock to be fractured. With continued rotation, the minerals may be nearly completely transposed so as to obliterate bedding or any earlier cleavage that may have been present.

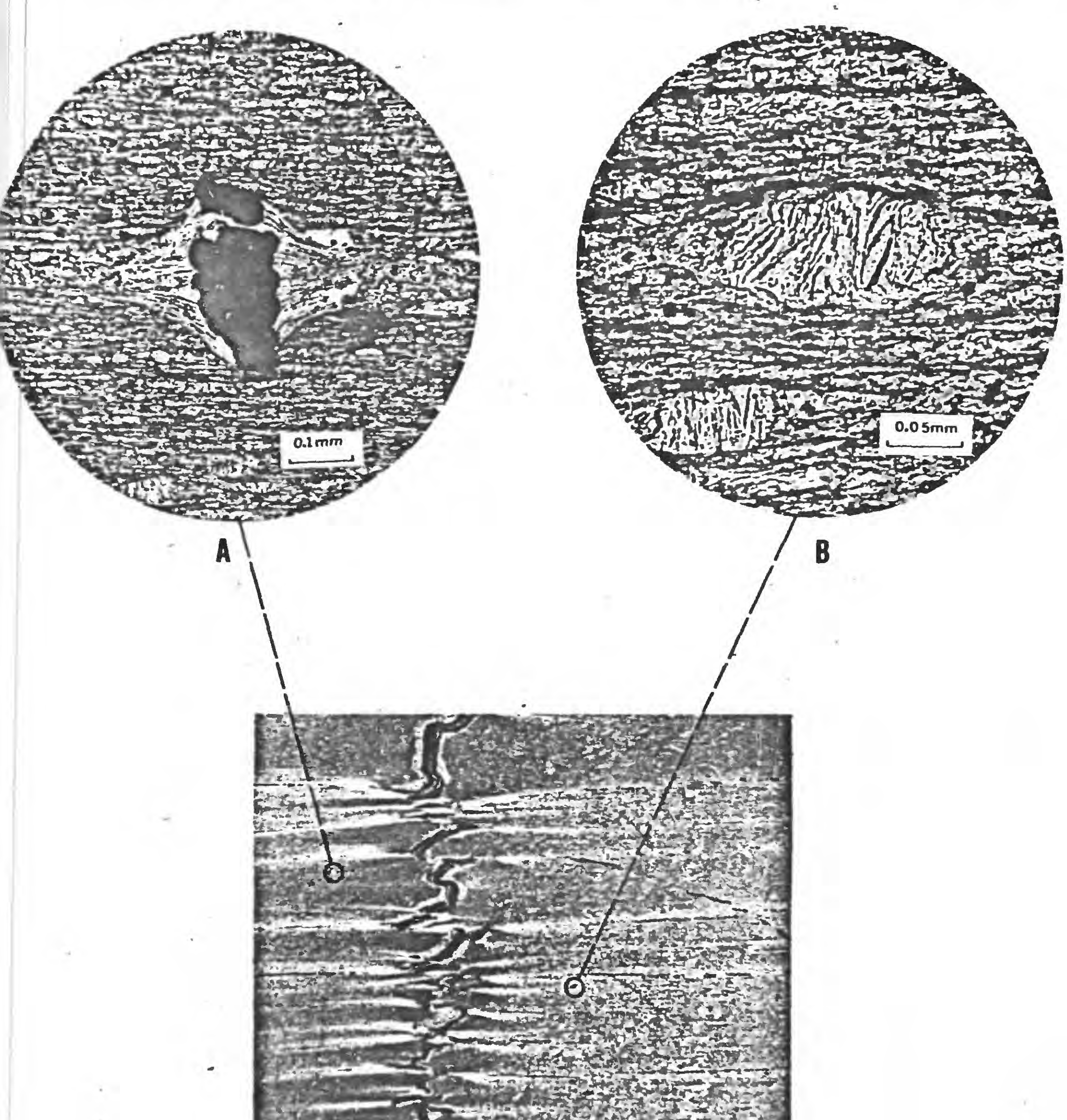
Slip cleavage is common in the Martinsburg Formation south of the Stroudsburg quadrangle and rare within the quadrangle, a fact noted by Behre (1933, p. 36). It is rare in younger rocks and was found only in the Shawangunk and Rondout Formations (figs. 96, 105). Southwestward, slip cleavage becomes common in progressively younger rocks, so that it transgresses the Martinsburg-Shawangunk contact in the Lehigh River area and is also common in that area in rocks younger than the Martinsburg (Epstein and Epstein, 1969).

Cleavage In Lithotectonic Unit 1

Slaty cleavage is perhaps the most prominent planar feature in fine-grained rocks of the Martinsburg Formation (figs. 3, 69) and it is because of this excellent cleavage that the Martinsburg has been extensively quarried in eastern Pennsylvania for more than 140 years. The cleavage consists of thin folia of oriented minerals separated by interfolial areas dominated by quartz in which mineral orientation is not as marked. Very pale green chlorite, intergrown with muscovite, in grains as much as 20 times the size of the groundmass minerals, are found in many samples. The chlorite-muscovite grains are elongated parallel to cleavage and are thought to be porphyroblasts. This contention is strengthened by the fact that chlorite and muscovite with similar optical properties have grown parallel to cleavage in pressure-shadow areas around pyrite. This is also supported by comparison with similar chlorite-muscovite grains in younger rocks, such as the Bloomsburg Red Beds (fig. 26). These grains in the Bloomsburg are mostly detrital and are about the same size as, or perhaps a little larger than, associated quartz. Moreover, the chlorite-muscovite grains are elongated parallel to bedding. Similar grains in the Martinsburg, on the other hand, are elongated parallel to cleavage, and are 5-10 times larger than the largest quartz grain. Clearly, the large muscovite-chlorite grains in the Martinsburg are metamorphic. Many quartz grains in the Martinsburg are elongated parallel to cleavage and have "crush" borders and mineral growth parallel to cleavage (fig. 4). Behre (1933, p. 177) noted that elongate quartz may have a length: width ratio of as much as 5:1, and maintained that their elongation was due to metamorphism. The features just described are shown in figure 88.

One plausible explanation for the relations shown in figure 88 is that the Martinsburg was competent enough to fail by flexural slip during the initial phases of folding (indicated by the bedding-plane slickensides) and later, as deformation increased in intensity the rock failed plastically with the development of cleavage and shortening of the slickensided bed. Mobilization causing intrusion of the pelitic folia along cleavage may have been aided by expulsion of interstitial water or water liberated from hydrous minerals during initiation of metamorphism.

Figure 88. Negative print of thin section (below) and photomicrographs (above) showing relations in slaty cleavage in Pen Argyl Member of the Martinsburg Formation, New Peerless quarry (no. 6), 3,000 feet southeast of North Bangor, Pa. Dark (graphitic?) pelitic material (appearing white in lower photograph) intrudes slate along cleavage planes for distances of more than 2 cm. The folia cut across bedding-plane slickensides (dark vertical calcite bed) and converge where they do so. Quartz grains as much as 0.15 mm long have grown parallel to cleavage along the slickensides, although this is not visible in the photograph. Quartz grains in the area where cleavage is most appressed have length:width ratios averaging 4:1 and are elongated in the cleavage direction. Porphyroblasts of intergrown chlorite and muscovite (B) are much larger than the groundmass minerals and as much as 10 times larger than associated detrital quartz grains. Chlorite and muscovite, and minor quartz, have grown in pressure-shadow areas around botryoidal pyrite (A).


0.1mm
0.05mm
A
B
5mm

As mentioned previously, slip cleavage (fig. 73) is not common in the Martinsburg in the area of this study. Behre (1933) reported a few occurrences in quarries that I did not see because of cover, but he noted the general paucity of slip cleavage in this area. Slip cleavage increases in intensity to the southeast, and reorientation of minerals along the new cleavage may nearly transpose the alignment from the earlier cleavage. In figure 89, about 25 percent of the minerals have been rotated into, or nearly into, the slip cleavage direction, although in other parts of the sample the figure is as high as 50 percent. This sample is from the Bushkill Member of the Martinsburg Formation in the Wind Gap quadrangle, 10 miles southwest of the southwest corner of the Stroudsburg quadrangle. No samples of complete transposition have been seen, but it is suspected that if the process went to completion, a second slaty cleavage, as defined here, might have formed, as suggested by Broughton (1946) for the Martinsburg in New Jersey. Note in figure 89 that pressure-shadow growth of muscovite and chlorite parallels the earlier slaty cleavage and has been rotated into the slip cleavage. Also note that new mineral growth has occurred along the second cleavage cutting across the earlier formed minerals. Thus, neocrystallization is shown to accompany both slaty cleavage and later developed slip cleavage.

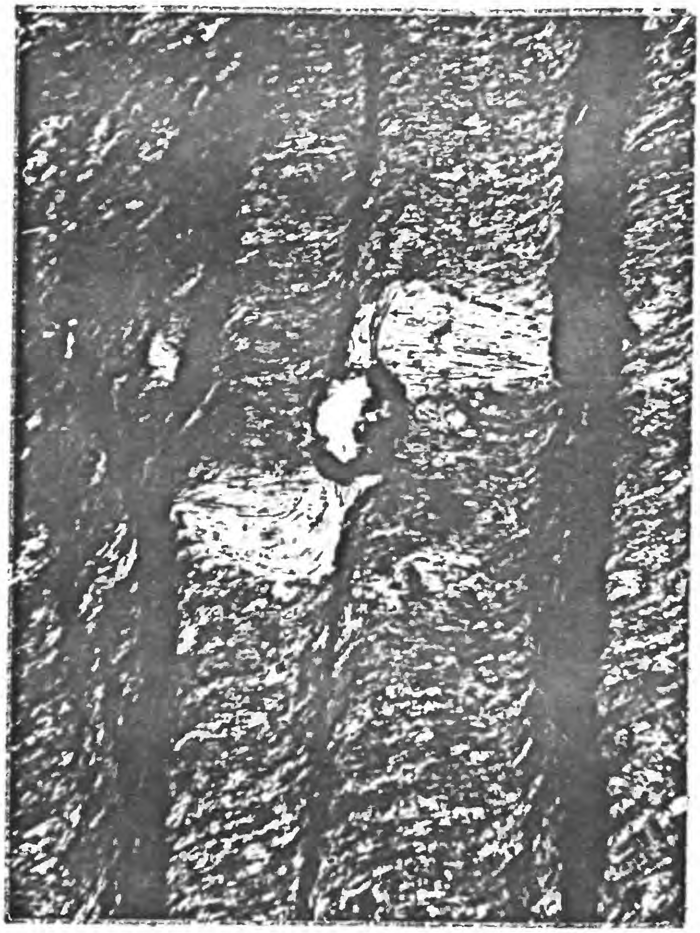


Figure 89. Photomicrograph (plane-polarized light, X 170) of slip cleavage (vertical graphitic? folia) crinkling horizontal slaty cleavage. About 12 percent of the field has been transposed into the slip cleavage direction and another 13 percent is dragged towards this direction. Quartz and lesser chlorite, and possibly minor muscovite, in the pressure-shadow fringes around dark circular limonite grain (probably pseudomorphous after pyrite; grain partly missing due to grinding in preparation of thin section) is rotated into the second cleavage direction. Note also that there has been new growth in the pressure-shadow areas in the slip cleavage direction and that new growth cross cuts the older generation minerals (arrow). This shows that neocrystallization occurred during development of both slaty cleavage and later slip cleavage. Sample from Bushkill Member of the Martinsburg Formation, south edge of the Wind Gap quadrangle, 10 miles southwest of the southwest corner of the Stroudsburg quadrangle, and 4 miles west of Stockertown, Pa.

Slaty cleavage penetrates all pelitic rocks of the Martinsburg Formation and is well developed except within a few hundred feet of the contact with the overlying Shawangunk Formation where the cleavage either disappears (as at Delaware Water Gap, Beerbower, 1956, and Lehigh Gap, Epstein and Epstein, 1969, p. 182, and at the Yards Creek hydroelectric pumped storage facility, 4.5 miles northeast of Delaware Water Gap) or becomes very poorly developed and resembles cleavage in younger rocks such as the Marcellus Shale (i.e., the Martinsburg near the Big and Little Offsets and south of Totts Gap in the Stroudsburg quadrangle). This phenomenon takes place just beneath the Shawangunk and occurs in many stratigraphic horizons within the Martinsburg. Thus, the poorly developed cleavage in the Martinsburg is related to proximity to the Shawangunk Formation and not any particular stratigraphic level within the Martinsburg.

In addition to the poorer development or disappearance of the cleavage, the moderately southeast-dipping cleavage in the Martinsburg Formation in the Delaware Water Gap area flattens within 2,000 feet of the Shawangunk contact and then dips gently to the northwest as the contact is approached (fig. 90). This is accompanied by development of numerous bedding-plane slickensides indicating northwest translation of overriding beds. These relations may be explained in four ways: 1) external rotation or arching during Appalachian folding of cleavage formed during Taconic orogeny (Drake and others, 1960, p. B181; Maxwell, 1962, p. 285). This

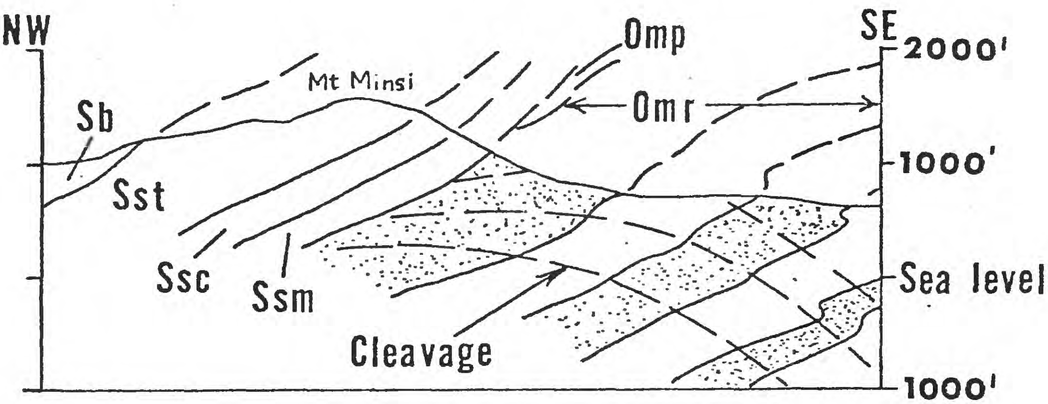


Figure 90. Geologic section through Mt. Minsi in the Delaware Water Gap area showing the "arching" of the cleavage in the Martinsburg Formation adjacent to the contact with the Shawangunk Formation. The cleavage is generally steeper than shown in graywacke beds. Trend of section is the same as for section F-F'-F", plate II. Sb, Bloomsburg Red Beds; Sst, Tammany Member of the Shawangunk Formation; Ssc, Clinton Member of the Shawangunk Formation; Ssm, Minsi Member of the Shawangunk Formation; Omp, Pen Argyl Member of the Martinsburg Formation; Omr, Ramseyburg Member of the Martinsburg Formation. Stipple indicates graywacke-bearing intervals in Omr. Horizontal scale = vertical scale.

hypothesis is rejected because (a) the cleavage "arch" is anticlinal--no similar structure is seen in bedding which should have been similarly rotated. Rather, the "arching" of cleavage occurs in a northwest-dipping sequence of beds; (b) a similar anticlinal arch cannot be reasonably extrapolated in the Shawangunk that would have overlain the arch; (c) cleavage in the Martinsburg is not rotated by an amount equivalent to the dip of beds in the nearby Shawangunk. For example, if the cleavage in the Martinsburg in the outcrop just south of Totts Gap were rotated back to the southeast by about 35°, the dip of beds in the Shawangunk above, then the cleavage would have originally been vertical. Similar rotation in areas to the southwest, where the Shawangunk is overturned, would mean that the cleavage in the Martinsburg originally dipped to the northwest, an obvious contradiction to assumptions that have been made concerning the regional orientation of cleavage in the Martinsburg and related rocks in eastern Pennsylvania.

2) Dragging of cleavage near the contact by the northwestward overriding Shawangunk (internal rotation in the domain envisioned). This implies that the cleavage is partly, at least, pre-Blue Mountain décollement and may therefore be Taconic in age. I suggested this possibility earlier (Epstein and Epstein, 1967, p. 31) but now discount it because the dragged cleavage should have a sigmoidal shape between bedding-plane slickensides, as they do in the Bloomsburg Red Beds where this has occurred. Such is

not the case--the cleavage is not deflected at bedding slip surfaces.

3) The cleavage was produced by force couples due to interbed shear. This implies that the cleavage formed during northwest movement of beds in the Martinsburg. Because this northwest movement take place near the Shawangunk contact (a similar situation at Lehigh Gap), it is presumed that it occurred after depsition of the Shawangunk (i.e., during the Appalachian orogeny). The reason for this is that the movement and "arching" of cleavage occurs in different stratigraphic levels within the Martinsburg (Ramseyburg Member in the Delaware Water Gap area and Pen Argyl Member in the Lehigh Gap area) and the only apparent controlling factor is the proximity to the Shawangunk. Therefore, it seems reasonable to suppose that the Shawangunk had some influence on the structures in the immediately underlying Martinsburg--the "arching" of cleavage, the dying out of cleavage, and the apparent decrease in metamorphic grade as the contact is approached that will be discussed shortly. There appears to be little argument agains this third suggestion, except that elsewhere to the southwest in the Stroudsburg quadrangle the cleavage does not dip to the northwest. The cleavage, however, does die out or is poorly developed near the Shawangunk contact. Unfortunately, exposures are very poor and relations are poorly known.

4) The orientation and dying out of cleavage is perhaps best explained by a pressure-shadow mechanism. On a smaller scale as

seen in thin section, cleavage is seen to curve around clastic grains, small lenses of sandstone (fig. 94), sand-filled burrows, fossils (fig. 101), etc. Cleavage is most intensely developed (flattening is greatest) on top and bottom of these more competent bodies and is absent or poorly developed in areas of maximum extension parallel to cleavage where neocrystallization may take place in the areas of lower pressure (fig. 88). In many small folds of interbedded cleaved pelites and poorly cleaved more competent rocks, cleavage diverges around synclinal troughs and is either poorly developed or absent in the pressure-shadow area next to the trough (fig. 91). If the relationship is true on a larger scale (compare with fig. 90) it may explain the arching of cleavage and dying out or poorer development of cleavage as the contact with the Shawangunk Formation is approached. This mechanism implies that the cleavage is post-Shawangunk in age.

Similar strongly divergent fanning of cleavage in incompetent beds with axial-plane foliation near concentrically folded more competent layers has been illustrated by numerous investigators (Dieterich, 1969, p. 157, for example).

Metamorphism in the Martinsburg Formation

Most previous studies of the slates of eastern Pennsylvania have attributed the origin of slaty cleavage to processes operating under metamorphic conditions. Maxwell (1962), on the other hand, suggested that cleavage in the Martinsburg Formation in the Delaware Water Gap area was produced during the Taconic orogeny

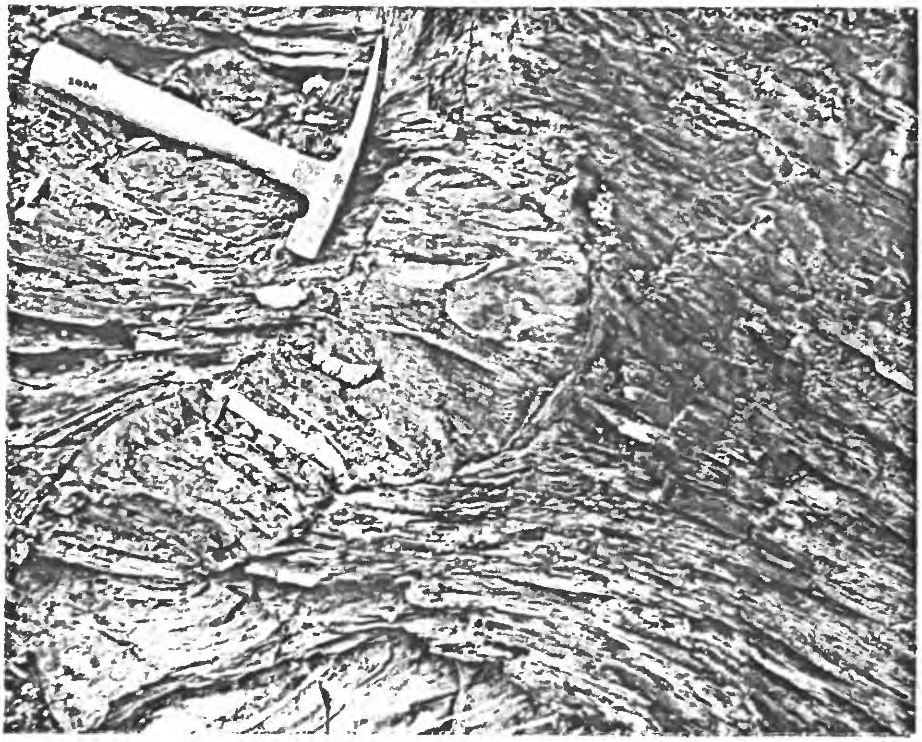


Figure 91. Divergent fanning of cleavage in flattened fold in lower part of the Bushkill Member of the Martinsburg Formation, along U.S. Route 46, 1.8 miles northeast of Belvidere, N.J. Slaty cleavage in pelite diverges around syncline to lower right of hammer in the more competent micaceous fine-grained dolomite and is less well developed at the trough. The relations in the area just under the trough compare well with those shown at Delaware Water Gap (fig. 89).

and was the result of only slight stress on pelitic sediments with high pore-water pressures. The slate produced, therefore, is not a metamorphic rock, but is rather a product of diagenesis. As a consequence, Maxwell concluded that the effect of the Taconic orogeny in this area was minor. Fracture cleavage was produced in the Martinsburg after it was dewatered and in younger rocks during the later, more intense, Appalachian orogeny. Maxwell's ideas have stimulated similar conclusions elsewhere (Moench, 1966, 1970; Carson, 1968; Clark, 1969; Powell, 1969; Braddock, 1970) and, because his hypothesis was formulated to explain cleavage in the Delaware Water Gap area, it will be discussed at length. The origin of cleavage as I have presented it above, disagrees with Maxwell's concept in certain important details--mainly, the age of the cleavage in the Martinsburg, the temperature-pressure conditions under which the cleavage formed, and type of cleavage identified in post-Martinsburg rocks, and the general field relations.

Most pertinent to the discussion of the age and origin of the slaty cleavage is the type of mica in the slate. Most workers have identified it as "sericite" and a product of metamorphism. Maxwell (1962), on the other hand, based on the work of Cuthbert (1946) and Bates (1947), suggests that the mica is dominantly "illite" and was not effected by elevated temperature and pressure. This is interesting because Bates (1947, p. 635) believed that the mica was a product of metamorphism. Cuthbert

46) identified the "clays" in the Martinsburg as "illite" using differential thermal analysis techniques; Whitten (1966) cautioned against the reliance on such identifications during 1946-47. Yoder and Eugster (1955) showed that many terms applied to micas, such as illite and sericite, are not meaningful, and that several polymorphs can be recognized which are sequentially transformed during progressive metamorphism of a sediment. For purposes of this discussion, 1M muscovite will be considered equivalent to "illite" that is stable under conditions of diagenesis, and 2M muscovite is the stable form at elevated temperatures associated with metamorphism (Yoder and Eugster, 1955, p. 246).

Several samples of Martinsburg slate were routinely X-rayed during mapping in the Delaware-Lehigh River area. Because of complex mineralogy, the traces were not well enough defined to accurately designate the polymorph of muscovite present in the rock, although 2M muscovite was indicated. The muscovite was concentrated in samples by boiling in 6M hydrochloric acid for 3 hours to remove chlorite and calcite. Muscovite and quartz were then the major minerals remaining and X-ray diffraction traces clearly show that the dominant polymorph is 2M muscovite. Albite is also a component of most Martinsburg pelites. Its presence created problems in polymorph identification, which need not be discussed here, but it too is considered to be partly a product of metamorphism, as discussed below.

Maxwell (1962, p. 298) stated that if the dominant micaceous mineral is "sericite", or 2M muscovite (which he disagrees with), then "the mica for the most part is a product of metamorphism of clay minerals, presumably at high pressure and elevated temperature." The occurrence of 2M muscovite, however, does not prove metamorphism (although it strongly supports it), because the source area for the Martinsburg may have supplied 2M muscovite. However, the contention that the dominant mica is "illite" (presumably 1M muscovite) is shown to be suspect.

All samples of slate from the Martinsburg that were X-rayed contain recognizable albite, except those samples near the Shawangunk contact where slaty cleavage is poorly developed or megascopically not prominent. This occurs in all quadrangles shown in figure 1. The assumption is that growth of albite accompanied the development of cleavage.

As previously pointed out, there is strong evidence for neomorphic growth of quartz, chlorite, and muscovite in the slates of the Martinsburg Formation. Also, the replacement of quartz and new mineral growth along the borders of quartz grains in graywackes suggest considerable reconstitution due to chemical interaction between framework grains and matrix, and probably of the matrix itself. Thus, there can be little doubt that the slate grew at or near conditions of low-grade regional metamorphism, judging from the assemblage of new minerals that was produced. It is not my intent to debate the vague zone of passage from diagenesis to metamorphism. However, I will suggest later that the cleavage in the Martinsburg formed during the Appalachian orogeny, and, because at that time the top of the Martinsburg was buried by approximately 24,000 feet of rock ranging in age from Silurian to Pennsylvanian, and the base of the Martinsburg was covered by about 35,000 feet of rock, it was at a temperature of at least 350°C, assuming a geothermal gradient of 1°C/100 feet. This is well within the temperature range of the greenschist facies of metamorphism. It is known that depth of burial alone probably cannot be held accountable for metamorphism, but the rocks in eastern Pennsylvania have been severely affected by orogenic deformation.

Further evidence for metamorphism in the Martinsburg is the occurrence of anthraxolite which Stevens (1966) showed is a metamorphic product, although he believed that the metamorphism occurred during the Taconic orogeny.

Lack of shearing at sandstone-shale contacts was taken as evidence by Maxwell (1962, p. 286) that the sandstones were incompetent during the folding and development of cleavage. However, there is evidence that bedding slip occurred prior to cleavage development (figs. 3, 88), and it is suggested that the incompetent behavior of the sandstones and the development of cleavage was due to deformation in a deeply buried sequence of rocks.

These conclusions do not rule out the dewatering mechanism of Maxwell (1962). His mechanism has been applied in other areas where it was concluded or implied that slate formed under low-grade metamorphic conditions (Moench, 1966; Clark, 1969; Powell, 1969). Water has long been known to be a contributing factor in the alignment of mineral grains. Fissility due to compaction and some dewatering of muds, is one example. The alignment of minerals due to flowage in sandstone dikes is another well known example. Axial-plane cleavage has been shown to have developed in penecontemporaneous folds formed by loading under near-surface conditions (Williams and others, 1969). On the other hand, penecontemporaneous slump folds have been shown to occur in flysch basins without the development of cleavage, but with superposition of a later "tectonic" cleavage that is coincidentally parallel to the axial planes of the slump folds because of the geometry of the basin and directions of tectonic stress (Helwig, 1970). The fact that mineral alignment can occur under conditions of low temperature and pressure does not mean that they cannot occur under metamorphic conditions. The role of water in metamorphism has been amply discussed, ranging from its effects during the development of cleavage (Hills, 1963; Leith, 1905, p. 70) to higher grades of metamorphism (Yoder, 1955). It is to be expected that water is liberated during progressive metamorphism. There is little reason to suppose that such water could not have been the mobility medium during the development of cleavage at elevated temperatures and pressures.

The possibility therefore exists that the disappearance of cleavage in the Martinsburg near the Shawangunk contact can be attributed to rapid dewatering of the Martinsburg near the permeable sands of the Shawangunk, thus precluding reorientation of mineral grains accompanying increased pore-water pressures that approached lithostatic pressures. The cleavage would then be younger than the Shawangunk. However, this argument loses some of its attractiveness because Carson (1968) shows that similar decrease in cleavage development occurs several thousand feet below the top of the Martinsburg in New Jersey.

Aside from mineralogical considerations, the belief that cleavage in the Martinsburg formed diagenetically while the rock was still wet stemmed from the discovery that sandstone dikes parallel cleavage in at least one locality (Maxwell, 1962, p. 287, fig. 4A). The dike pictured by Maxwell diverges a few degrees in dip from the dip of the cleavage (5° by my measurement). Maxwell attributed this to intrusion of the dike early in the folding and presumably reorientation of the cleavage to its present gentler position later on in the folding. However, more difficult to explain is the fact that the strike of the dike (N. 28° E.) differs from the strike of the cleavage (N. 48° E.) by 20°! This implies considerable reorientation of stress which may not be compatible with the mechanism as envisioned by Maxwell. The dike would have had to be intruded early along cleavage, then lithified while the muds were still wet and mineral grains reoriented along the subsequent new stress directions.

Mud dikes are perhaps more numerous than sandstone dikes in the Martinsburg. One sample collected near the sandstone-dike locality described by Maxwell intrudes fine-grained graywacke for a distance of at least 3.5 inches (fig. 92). There is mineral alignment parallel to the dike walls, as seen in thin section, and the slaty cleavage in the rock lies at nearly right angles to the mud dike. The mud dike extends in many directions that are not parallel to the regional cleavage. Proof that the dike was intruded prior to the development of regional cleavage is found in the fact that the cleavage produced by mineral alignment parallel to the dike walls is crinkled by the regional cleavage (fig. 93). Some neocrystallization has occurred parallel to the regional cleavage, but not parallel to dike-wall cleavage. Thus, the question arises, could the sandstone dike in the Martinsburg that is illustrated by Maxwell have been intruded before lithification and later have been rotated nearly parallel to the regional cleavage in the Martinsburg pelites during tectonism? Similar reorientation of early sedimentary features into near parallelism with later developed cleavage has been described by Wise (in Field Conference of Pennsylvania Geologists, 1960, p. 65).

The contention of Maxwell that the cleavage in rocks younger than the Martinsburg is "fracture cleavage" needs no further discussion because I have shown that the cleavage is best termed slaty cleavage.

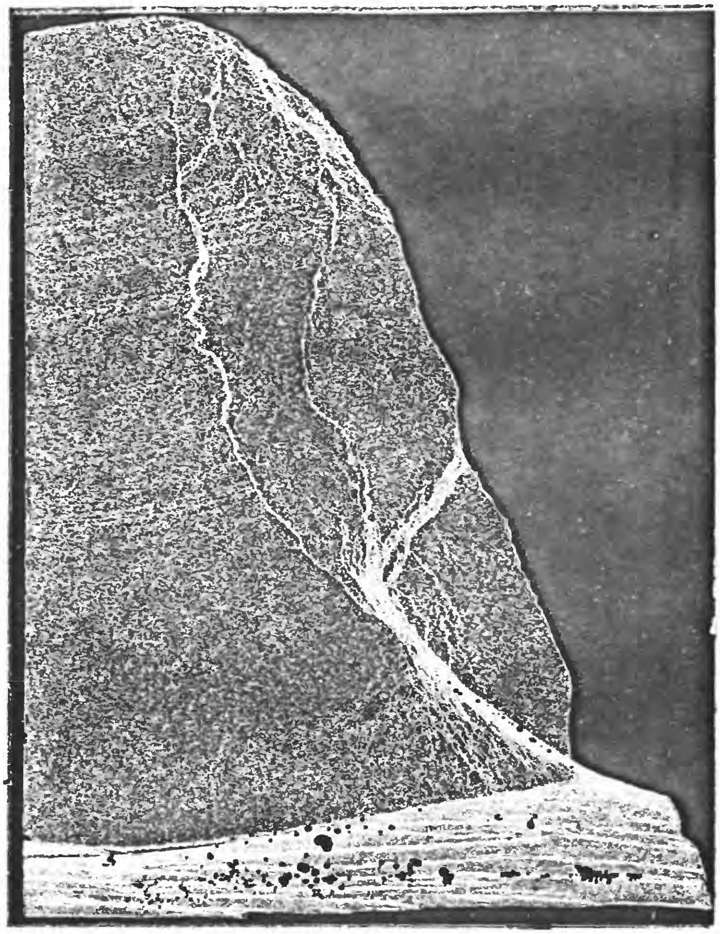


Figure 92. Mud dike (lighter vertical structure) intruded into laminated to thin-bedded, fine-grained, calcareous, feldspathic graywacke. Note arching of laminae in the graywacke in places near the dike, presumably due to arching during intrusion of the dike. A cleavage, not apparent in this photo, has developed by orientation of minerals parallel to the dike walls. A later slaty cleavage appears as white lines in the slate at the bottom. This slaty cleavage is refracted to steeper angles in the graywacke and crinkles the mud dike (see fig. 93), showing that it is post-dike in age. Sample from the Ramseyburg Member of the Martinsburg Formation, 2 miles southeast of Columbia, N.J., Portland $7\frac{1}{2}$-minute quadrangle. Negative print of acetate peel (X 2).

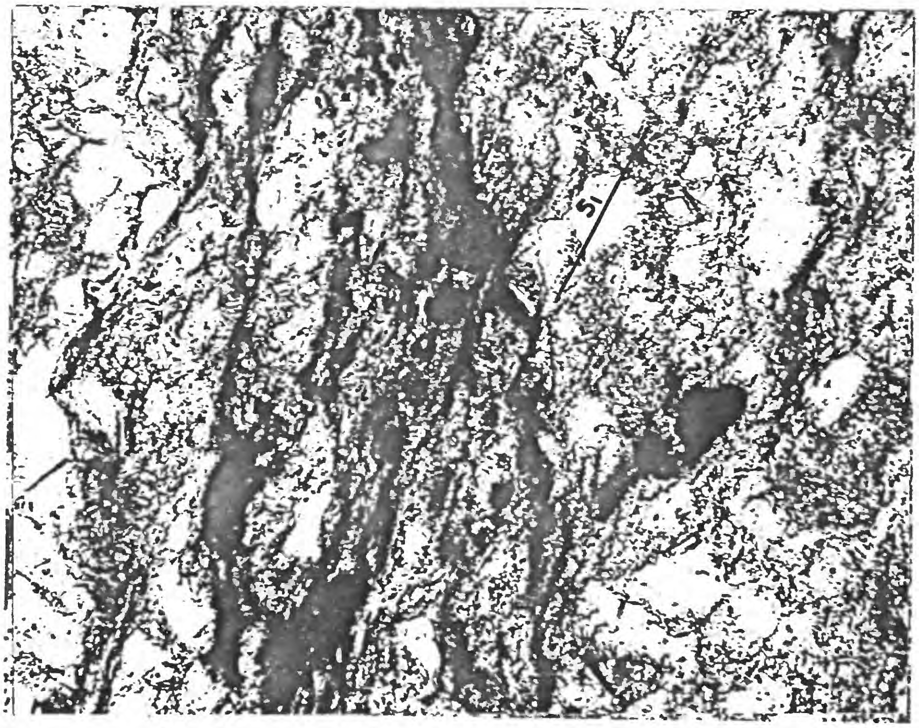


Figure 93. Photomicrograph (plane-polarized light, X 108) of mud dike (dark vertical lines) shown in figure 92, offset by slaty cleavage (S_1). An earlier cleavage has developed by mineral orientation parallel to the dike walls, but this is not apparent in the photograph. Sample locality same as for figure 92. Photograph is reversed (mirror image) in relation to figure 92, top is to upper left.

Cleavage In Lithotectonic Unit 2

The Shawangunk Formation, making up the basal part of lithotectonic unit 2, contains only subordinate amounts of pelitic material, and as a consequence, slaty cleavage is not readily apparent. Because of the high content of quartz, cleavage in siltstone of this formation is generally irregularly developed (fig.12). Sandstones show evidence of recrystallization (fig. 22) and neocrystallization parallel to the regional cleavage direction (fig. 24). Quartz grains have peripheral growth and interlocking contacts. Commonly cleavage is strongly reoriented around quartz clusters (fig. 94). In places where cleavage folia have intruded quartzose laminae the quartz has recrystallized and stretched to lengths more than 8 times their widths (fig. 95). Such elongate grains are not as well developed in the underlying Martinsburg. Slip cleavage was not seen in outcrop (often incipient development of slip cleavage is overlooked in the field), but it was seen by chance in thin section (fig. 96). Note that there is strong evidence that quartz has been replaced by muscovite during the development of slip cleavage. Growth of new quartz in cleavage planes next to other grains is commonly seen in thin sections of the Shawangunk. Clearly, even though the "competent" rocks that make up the Shawangunk Formation did not favor cleavage development, the effects of the process that produced the regional cleavage are recognizable.

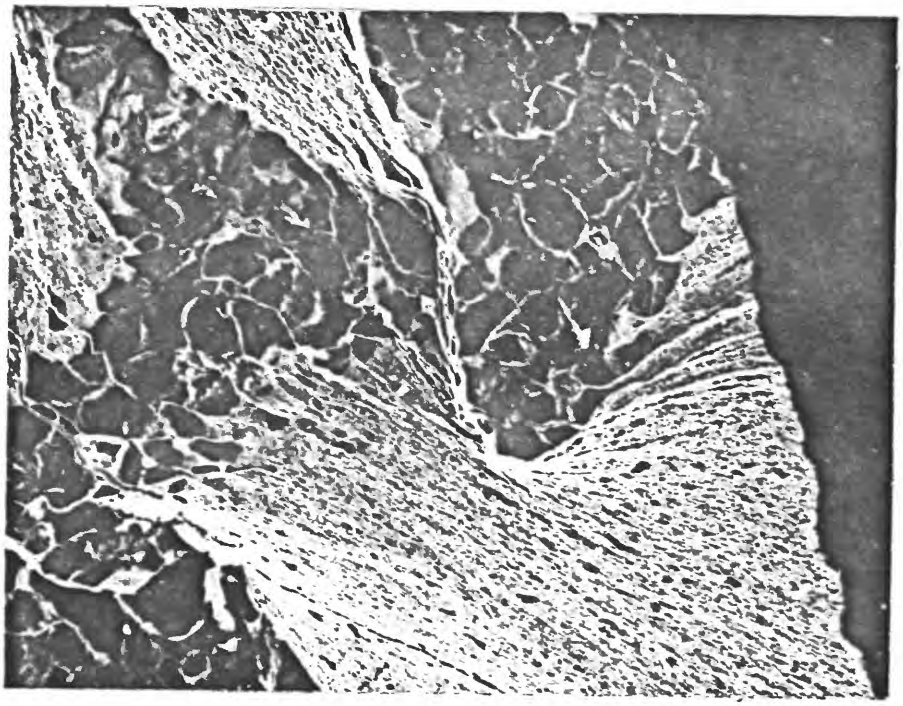


Figure 94. Negative print of thin section (X 37) showing strong divergence of cleavage in silty shale around irregular lens of medium-grained sandstone. Note the continuation of cleavage and intrusion of cleavage folia through the sandstone. Clinton Member of the Shawangunk Formation, Delaware Water Gap, N.J.

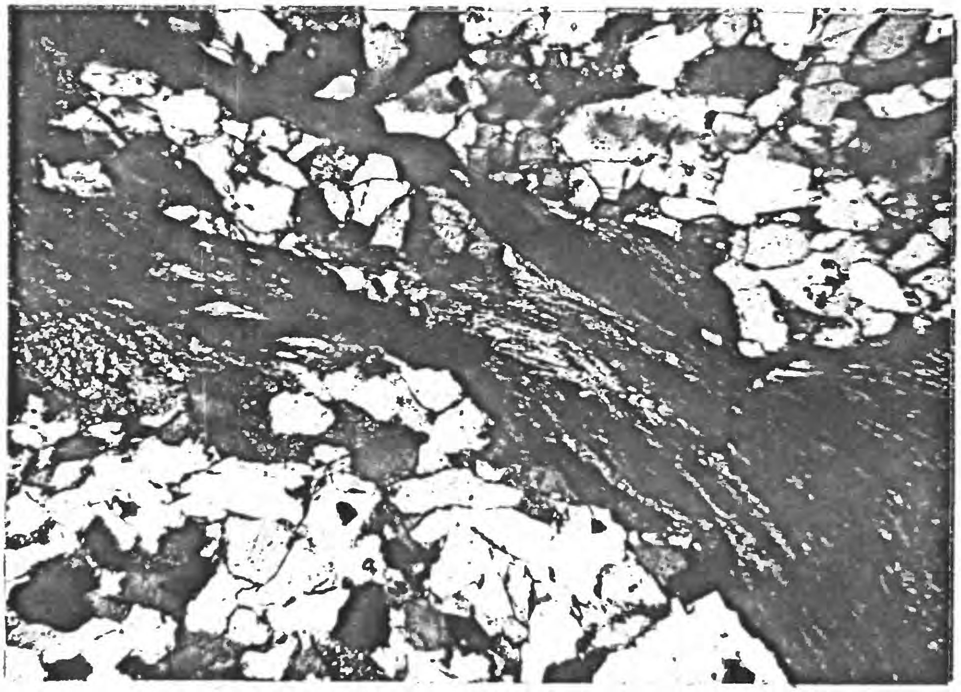


Figure 95. Photomicrograph (crossed polarizers, X 43) showing cleavage folia passing through a sandstone lamina between two silty shale lenses. The quartz grains (light area) "caught" in the cleavage are stretched into slivers that are more than 8 times their width. The original shapes of the quartz grains are shown above and below. The needle quartz is intergrown with minute muscovite shreds lying parallel to cleavage. A linear granoblastic texture has developed due to stretching, granulation, and recrystallization. Clinton Member of Shawangunk Formation, Delaware Water Gap, N.J.

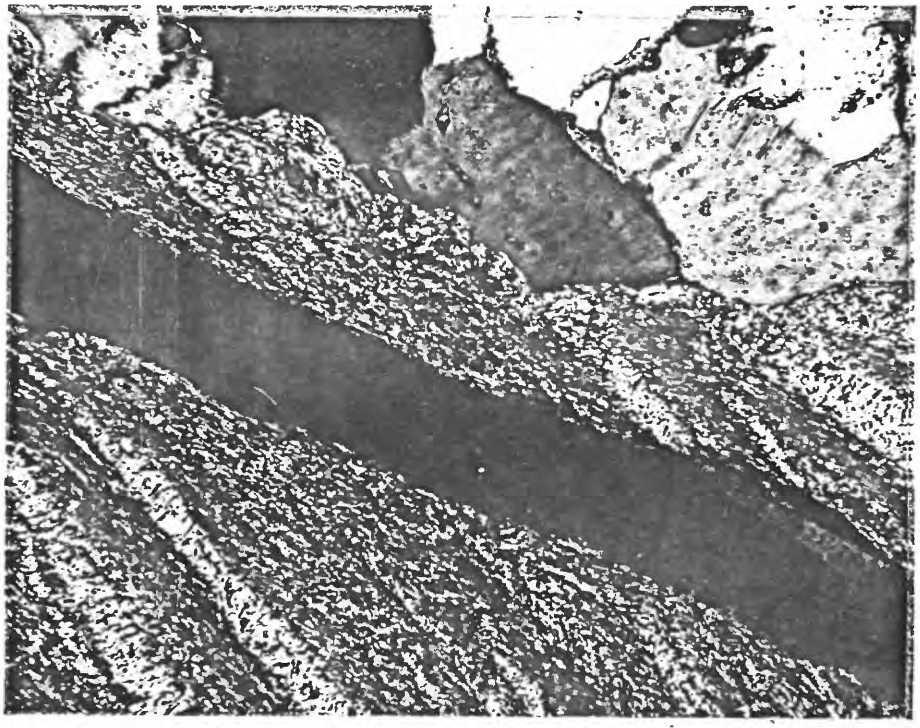


Figure 96. Photomicrograph (crossed polarizers, X 180) showing slip cleavage (kink bands extending to lower right) in shale of the Clinton Member of the Shawangunk Formation, Delaware Water Gap, N.J. Note solution of quartz grains parallel to tops of small kinks and growth of small grains of muscovite (about 0.007 mm long) replacing quartz (at arrow). Dark band in center is crack in thin section.

Cleavage in the Bloomsburg, which contains larger amounts of finer grained rock, is more apparent (fig. 25). In figure 26, the alignment of micas parallel to cleavage planes is not apparent because the photograph was taken in plane-polarized light. Figure 97 shows an enlarged section of the same thin section under crossed polarizers. The alignment of muscovite and elongation of some quartz parallel to cleavage is more apparent.

Cleavage In Lithotectonic Unit 3

Megascopically, slaty cleavage is very apparent in shales and siltstones of lithotectonic unit 3 (figs. 50, 98). Crush quartz is common in most thin sections of rocks from the unit as is neomorphic growth of muscovite, quartz, chlorite, and clacite (figs. 29, 40, 49, 99). Needle quartz has developed parallel to cleavage in some samples; length:width ratios in these may exceed 35:1 (fig. 100). Examples of laminar intrusion of pelitic material along cleavage folia are numerous in laminated and finely bedded rocks (fig. 101). Evidence that the cleavage formed after the rocks were lithified to some degree is afforded by cleavage cross cutting shells (fig. 102), stylolites (fig. 103), and bedding-plane slickensides (see Epstein and Epstein, 1969, fig. 65A). Many mud cracks are present in rocks in lithotectonic unit 3; these are all extended in the b tectonic direction. Slaty cleavage is preferentially concentrated in those mud-crack columns that are subparallel to the bc plane (fig. 104) giving the impression in some cases that the features are not mud cracks, but intrusions of

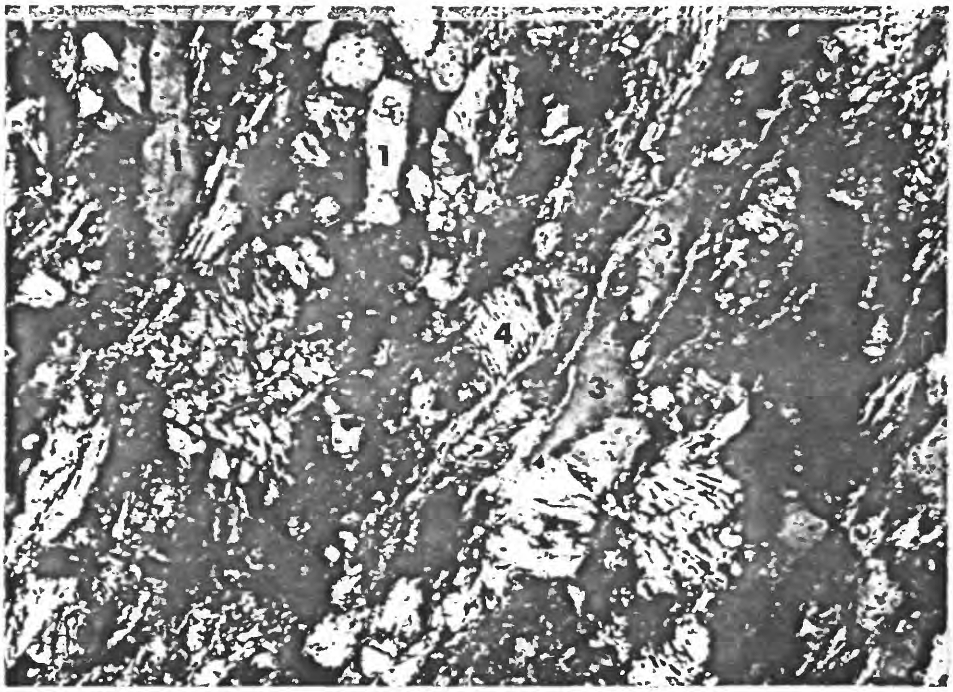


Figure 97. Photomicrograph (crossed polarizers, X 270) of coarse siltstone to very fine grained graywacke (see fig. 26) showing alignment of muscovite along cleavage extending to lower left, quartz grains (1) parallel to bedding that is vertical in photograph, corrosion and new mineral growth along edges of quartz (crush quartz) in the plane of the cleavage (at 2) so that some quartz is oriented subparallel to cleavage (3). Note dragging of muscovite into cleavage (4) and diminution of muscovite in cleavage folia. Bloomsburg Red Beds, 0.5 mile northwest of Dunnfield, N.J., Delaware Water Gap.

Figure 98. Prominent slaty cleavage dipping to the southeast (parallel to hammer handle) in the Port Ewen Shale, Godfrey Ridge, 0.9 mile northwest of tollgate on U.S. Interstate 80 in village of Delaware Water Gap. More gently dipping bedding is apparent on joint in lower part of photograph.

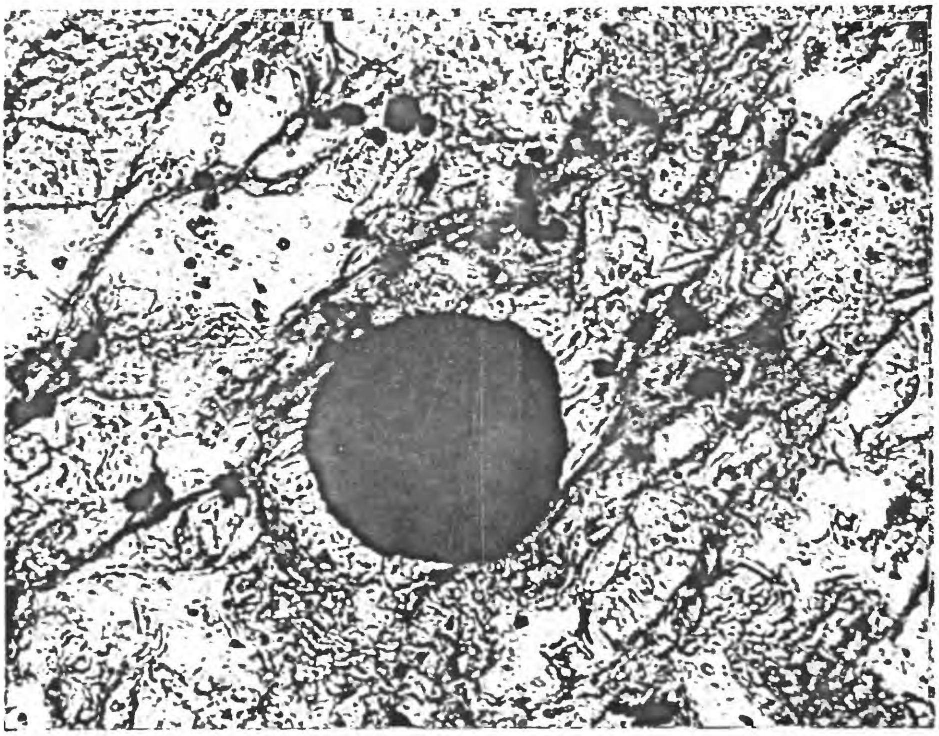


Figure 99. Photomicrograph (plane-polarized light, X 430) showing growth of quartz and lesser chlorite and muscovite parallel to slaty cleavage (trending to lower left) in pressure-shadow areas around pyrite grain. Corroded quartz grains are jagged along edges perpendicular to cleavage (crush quartz). Note warping of cleavage folia around quartz. Bedding is horizontal. This is an enlargement of figure 40. Port Ewen Shale, unit 3 of measured section 7.

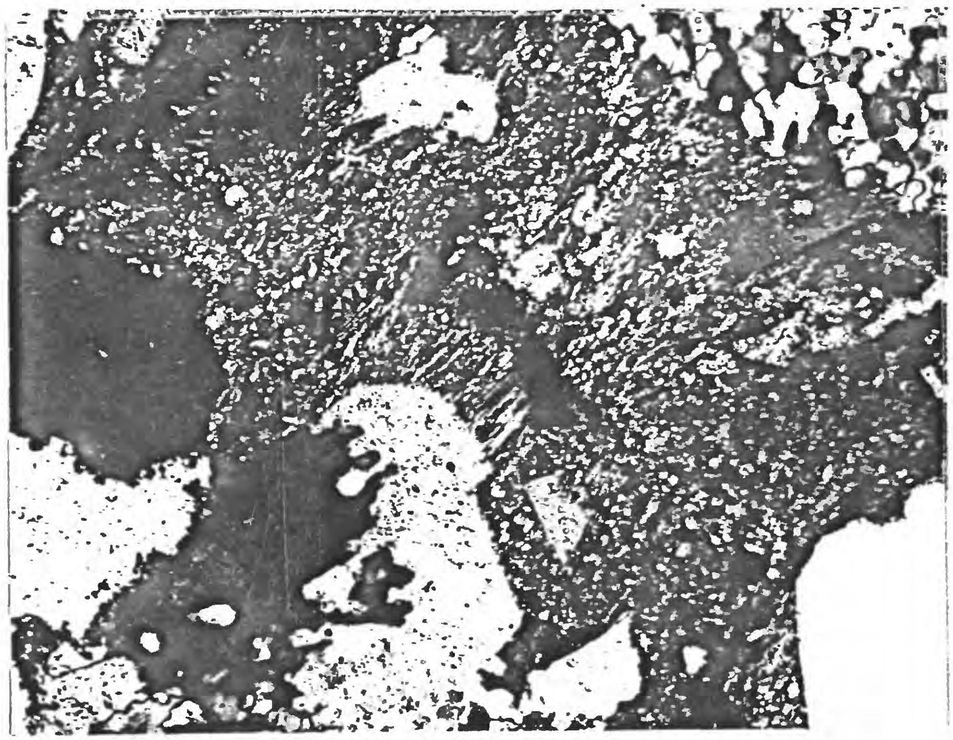


Figure 100. Photomicrograph (crossed polarizers, X 87) of needle quartz and muscovite, parallel to cleavage (S_1), extending from corroded edges of quartz grains in very coarse grained sandstone in the Shriver Chert of the Oriskany Group, unit 19 of measured section 7. Some of the needle quartz is more than 35 times longer than it is wide. A rudimentary granoblastic texture has developed in some areas. See figure 44 for lithologic details.

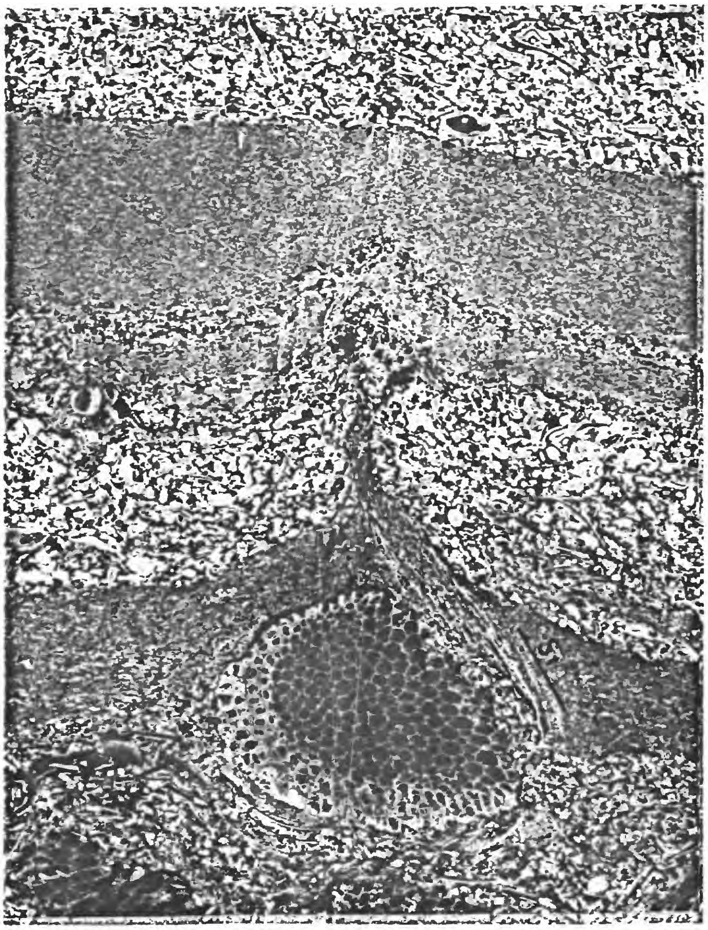


Figure 101. Negative print of thin section (X 9) showing intrusion of elongate calcite and quartz along cleavage folia (S_1) into biopelmicrite (dark lamina) and arching of biopelmicrite. Note divergence of cleavage around *Coenites* sp. Arrows mark places where quartz and calcite have grown subparallel to cleavage. Uppermost Bossardville Limestone, quarry of Hamilton Stone Co., Inc., Bossardsville, Pa., Saylorsburg $7\frac{1}{2}$-minute quadrangle, unit 23 of measured section 18 of Epstein and others (1967).

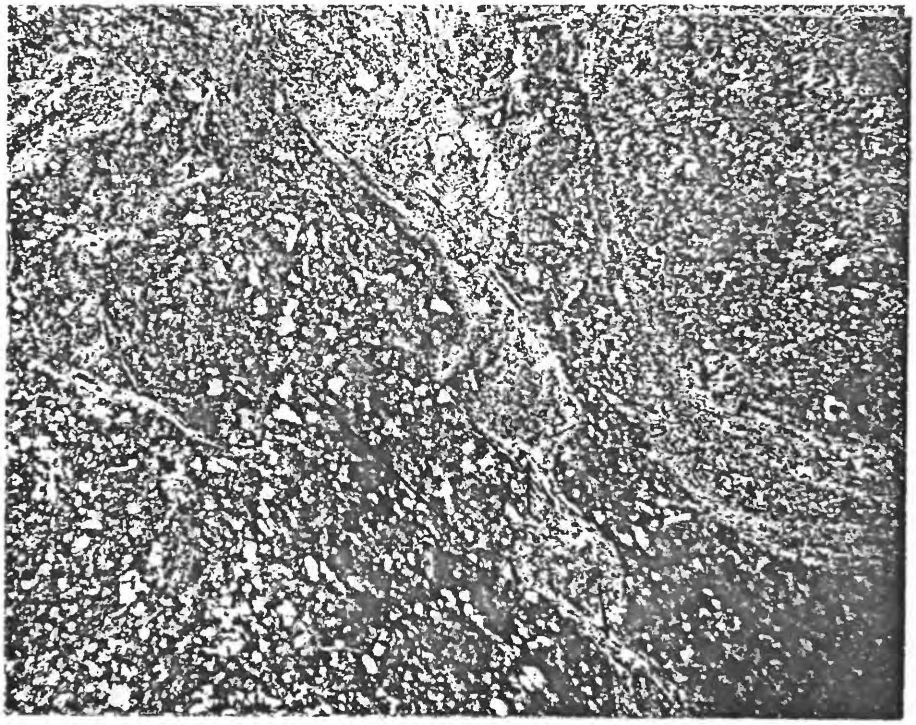


Figure 102. Photomicrograph (plane-polarized light, X 44) of very fine grained fossiliferous calcareous sandstone of the Schoharie Formation with cleavage (S_1) defined by aligned quartz, calcite, and minor muscovite, cutting across brachiopod shell. Elongate quartz has grown where cleavage cuts across the shell (arrows). Sample from roadcut along U.S. Route 209 near Buttermilk Falls, East Stroudsburg $7\frac{1}{2}$-minute quadrangle.

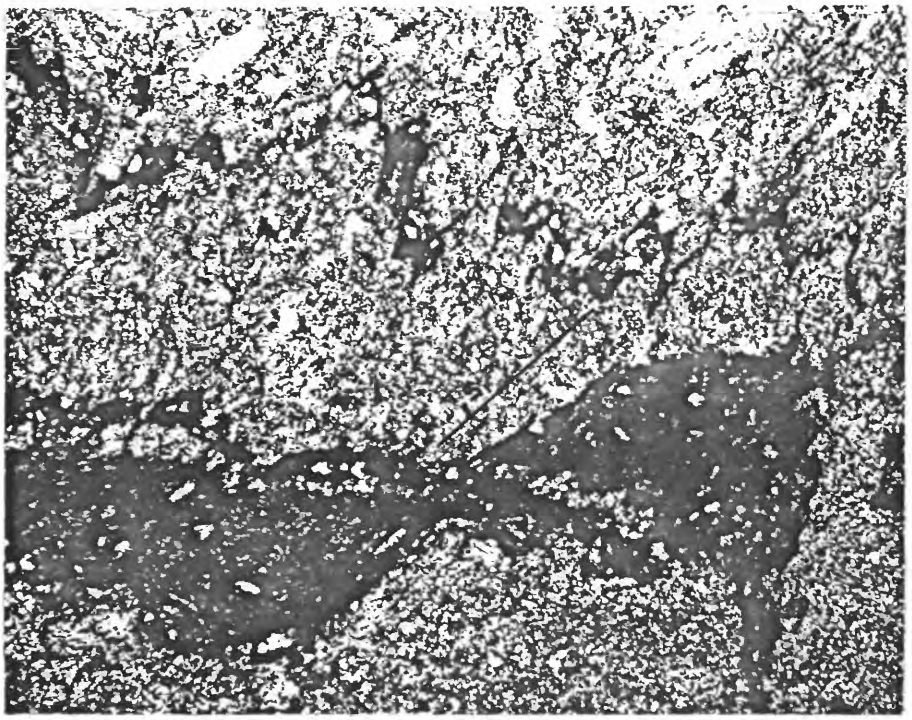
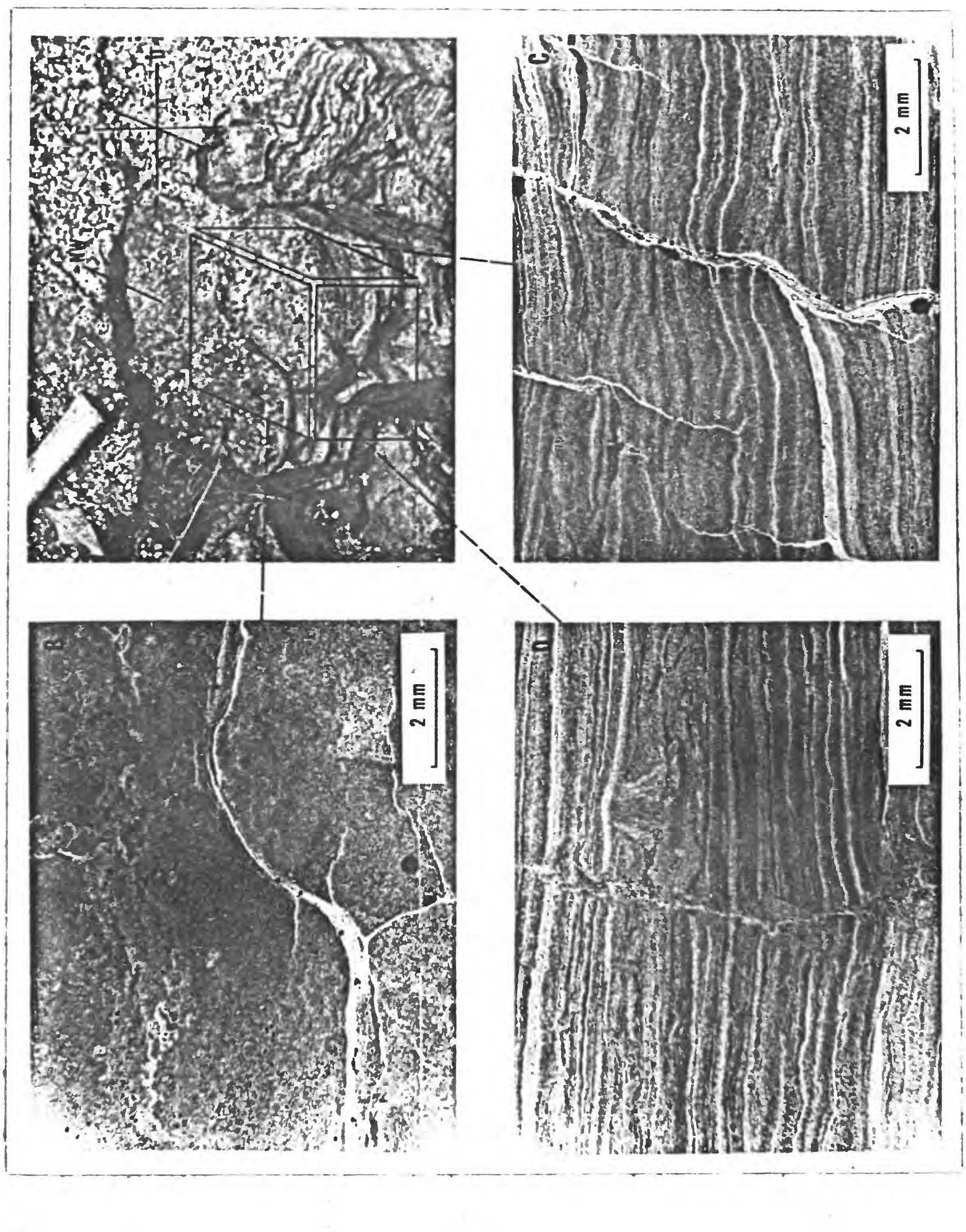


Figure 103. Photomicrograph (plane-polarized light, X 44) of stylolites (irregular dark seams) cut by cleavage (S_1) in silty fine-grained limestone. Shriver Chert of Oriskany Group, roadcut along U.S. Interstate 80, 0.5 mile west of Minisink Hills, Pa.

Figure 104. Deformed mud-crack polygons in laminated dolomite (A, same as fig. 33) that have been shortened in a northwest direction with a length (parallel to b):width (parallel to a) ratio averaging about 1.8:1. Coordinate axes are shown: a, direction of tectonic transport; b, direction of fold axes; c, perpendicular to ab plane. B, C, and D, are negative prints of acetate peels showing more pronounced development of cleavage and intrusion of pelitic material along columns that are subparallel to b (B, ab plane; C, ac plane) and lack of intrusion along cleavage folia in columns at right angles to b (B, arrow; D, bc plane). Whiteport Dolomite Member of the Rondout Formation, roadcut on north side of Cherry Valley Road, 2,000 feet northeast of church in Stormville.


B
C
D
2 mm
2 mm
2 mm

pelitic material along cleavage. Intrusion of some material has taken place along the cleavage, but it was the original columns that localized this movement.

Slip cleavage is rare in the unit, although many examples could have been overlooked. One locality where slip cleavage is present is in the Mashipacong Member of the Rondout Formation on Godfrey Ridge (fig. 105).

Cleavage In Lithotectonic Unit 4

Cleavage is poorly developed in the Marcellus and Mahantango formations (figs. 54, 55). It is faint in thin section and resembles the cleavage in the Martinsburg Formation near the contact with the Shawangunk Formation. Very little growth of new minerals has been observed in pressure-shadow areas. Most grains of pyrite seen in the Marcellus in thin section do not have any new mineral growth around them in the cleavage direction. The most obvious effect these grains have had on cleavage is the typical diverging of cleavage around them. It thus appears that there is a "tectonite front" (Fellows, 1943) between lithotectonic units 3 and 4 in this area. Farther southwest, however, cleavage is better developed so that in the Lehigh Gap area the Mahantango Formation has been quarried for slate, a fact noted many years ago by Dale and others (1914, p. 108) and Behre (1933, p. 119). Thus, the tectonite front crosses the boundary between lithotectonic units 3 and 4 somewhere between Delaware Water Gap and Lehigh Gap, probably near the border of the Wind Gap and Kunkletown quadrangles

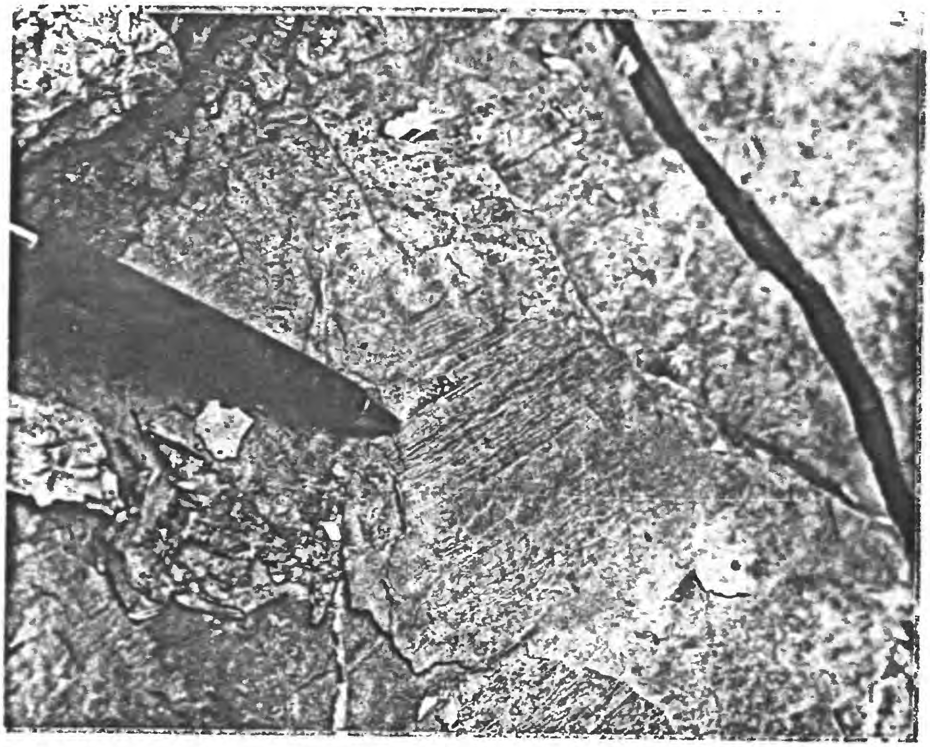


Figure 105. Slip cleavage in the Mashipacong Member of the Rondout Formation crinkling earlier slaty cleavage that dips steeply southeast (toward observer). Attitude of slip cleavage is N. 55° E., 41° NW. Intersection of slaty cleavage and slip cleavage is 5°, looking northwest. Outcrop is at an altitude of about 520 feet on Godfrey Ridge, 0.9 mile northwest of the toll-gate on U.S. Interstate 80 in the village of Delaware Water Gap, Pa.

(fig. 1), judging from the development of cleavage in the Marcellus in that area.

Cleavage Summary

In summary, microscopic study and field relations of cleaved rocks suggest that the cleavage in the Stroudsburg area is due to plastic laminar flow of pelitic material along "cleavage" folia accompanied by mechanical reorientation and neocrystallization. The cleavage folia are separated by more quartz-rich folia in which reorientation of platy minerals and dimensional alignment of prismatic minerals has not taken place, or is not as well developed. Numerous lines of evidence point to the conclusion that cleavage developed after the rocks were indurated. Plasticity increased during increased tectonism and the mobility may be ascribed to the presence of water, derived either from connate water squeezed out of the rocks during tectonic compaction, or by release of water from hydrous minerals during continued deformation. Neomorphism of quartz, chlorite, muscovite, calcite, and probably albite, in most rocks, argues for formation of cleavage at and just below the limits of low-grade metamorphism (quartz-muscovite-albite-chlorite subfacies of the greenschist facies). Cleavage is progressively more poorly developed to the northwest, and it is probable that cleavage was formed in the youngest rocks (those that were least deeply buried and farthest from the source of stress to the southeast) below the limits of metamorphism. These findings disagree with the concept of the origin of cleavage developed for the Delaware Water Gap area by Maxwell (1962) in certain important details. His contention that slaty cleavage is not a metamorphic phenomenon affected by extensive deformation of rocks at great depths is challenged. His belief that water facilitated the development of slaty cleavage is accepted. His conclusion that all cleavage in rocks younger than the Martinsburg Formation is fracture cleavage is rejected.

Slaty cleavage is less penetrative (cleavage folia are farthest apart) in rocks that (1) are less pelitic, (2) have not been as severely deformed, and (3) are coarser grained than rocks with more penetrative cleavage. Every rock examined that has cleavage has at least some mineral alignment parallel to cleavage. Hence, "fracture cleavage," as generally conceived and used by some other workers in the Delaware Water Gap area, is the same as and grades into slaty cleavage, and is a term that is inapplicable in this area.

Slip cleavage increases in prominence from southeast to northwest. It consists of kinked foliations and transposition of minerals into the new cleavage plane, and in the latter respect is similar to slaty cleavage. It is also similar to slaty cleavage in that new minerals may grow parallel to the cleavage direction.

The orientation of cleavage in all lithotectonic units is shown in figure 86. Cleavage maxima are consistent for all units. The cleavage in the Martinsburg (lithotectonic unit 1) has a slightly wider "spread" than the others, hence the question, what is the age of the cleavage (and of the major structural features) in the Martinsburg Formation and younger rocks in the Stroudsburg area?

Age of Deformation

The contact between the Martinsburg Formation of Ordovician age and Shawangunk Formation of Silurian age has attracted the attention of geologists ever since Rogers (1838) recognized that is was an unconformity and later proclaimed that the orogeny was the " . . . most momentous . . . revolution" in North America (Rogers, 1858, p. 785). White (1882) described the contact as unconformable at Lehigh Gap, Pa., and Otisville, N.Y., but Chance (in White, 1882) and Lesley (in Lesley and others, 1883) maintained that the angular relations were due to faulting. Later, Clark (1921) and Keith (1923), among others, maintained that the angular unconformity seen between Ordovician and Silurian rocks to the northeast is not to be seen in Pennsylvania.

Miller (1926) disagreed. He believed that an angular unconformity is present in Pennsylvania and based his conclusions on the following reasons: (1) the disconformable relations seen in exposures; (2) sericitized slate pebbles, apparently derived from the underlying Martinsburg, in the basal beds of the Shawangunk Formation; (3) omission of beds along strike; (4) the Martinsburg Formation is more highly metamorphosed than Devonian shales a few miles away; (5) structures in Ordovician and Cambrian rocks are more complex than those in Devonian and Silurian rocks; (6) the cleavage in the Martinsburg, which was formed during the Taconic orogeny, is itself deformed into folds and was faulted during the Appalachian orogeny.

Behre (1924, 1933) argued that the Taconic orogeny produced slaty cleavage, close overturned folds, and thrust faults and was more intense than later Appalachian deformation which merely distorted the slaty cleavage. Behre (1927, 1933) divided the Martinsburg into three members, a lower and upper slate separated by a sandstone unit. Stose (1930), however, maintained that the upper slate member of Behre is the lower member repeated by folding; hence, the Taconic orogeny must have been intense, for the Shawangunk Formation rests on the lower member of the Martinsburg. Work by Drake and Epstein (1967) reestablished the threefold subdivision of the Martinsburg and showed Stose's structural interpretations were wrong.

Willard and Cleaves (1939) showed that the angular unconformity extends as far southwest as Susquehanna Gap in Pennsylvania, where the Bald Eagle Conglomerate of Grabau (1909) rests conformably on top of the Martinsburg Formation. Willard (1938) had previously presented a cross section of the unconformity at Delaware Water Gap, but his interpretation is not in agreement with the interpretation presented in this report.

Hess (1955) believed that the Taconic orogeny was so intense that it was not only the cause of folding of the sediments in the

Appalachian geosyncline, but rather the cause of the geosyncline itself. Woodward (1957) maintained that the slate belt of the Martinsburg is the result of the superposition of three periods of folding, each having a different trend. However, no field evidence has been recognized to support Woodward's views.

Work in the Delaware Valley by Drake and others (1960) led to the interpretation that the Taconic orogeny was more severe than the Appalachian orogeny in that area, that far more complex structural terrane was present to the southwest, and that the slaty cleavage in the Martinsburg is Taconic in age. At the same time, Arndt and Wood (1960) concluded that the Appalachian orogeny was by far the stronger. Wood and others (1963, p. 78) suggested that the discordant contact between the Martinsburg and Shawangunk might be largely the result of faulting. Maxwell (1962) concluded that the flow cleavage in the Martinsburg Formation in the Delaware Water Gap area was produced by relatively minor deformation during the Taconic orogeny.

The recent interpretation that a large nappe underlies the Great Valley in easternmost Pennsylvania (Drake and others, 1961, 1967; Drake, 1967a, 1967b, 1969; Drake and Epstein, 1967; Davis and others, 1967) with no structural counterpart in rocks younger than Ordovician strongly suggests an intense Taconic orogeny. Nappes have been reported in other parts of the Great Valley (Stose, 1950; Gray, 1954; Field Conference of Pennsylvania Geologists, 1966). Root (1970), however, maintained that the Lebanon

Valley nappe in the Harrisburg, Pa., area, contains rocks that were deformed during the Taconic orogeny and thrust into their present position during the late Paleozoic orogeny. Bird and Dewey (1970) explained the Taconic nappes in Pennsylvania in their plate-tectonic model for evolution of the Appalachian orogen, although they were not certain to what extent Alleghenian (Appalachian of this report) deformation affected pre-Silurian rocks.

Thus the relative intensities of the Taconic and Appalachian orogenies in eastern Pennsylvania have not been resolved. On the basis of field evidence in the Stroudsburg area, outlined in the previous sections, it is concluded that (1) there is an angular unconformity between the Martinsburg and Shawangunk Formations as shown in plate I and described elsewhere by Epstein and Epstein (1969, p. 169); (2) the Taconic orogeny was a period of mountain building, indicated by the clastic wedge overlying the Martinsburg; (3) most of the folding seen in the area, as well as the associated slaty cleavage, is Appalachian in age; (4) deformational effects of the Taconic orogeny include the folding that can be seen under the Shawangunk-Martinsburg unconformity and probably the Portland fault; (5) the observed effects of the Appalachian orogeny in this small area are more intense than the observed effects of the Taconic orogeny--however, if the Taconic nappe reported in the Great Valley was atectonitic (no tectonite fabric was developed), then evidence for this nappe would not be present and the Taconic orogeny may have been extremely intense. Work currently in progress by I. B. Alterman, Columbia University, in the Martinsburg outcrop belt from southeasternmost New York to eastern Pennsylvania, indicates that in several localities an earlier cleavage, previously unreported, which has been nearly obliterated by the later deformation, can be identified. I have not seen this cleavage, but if present, then Alterman is correct that this less distinct, earlier cleavage may have developed as an axial-plane foliation in the nappe (I. B. Alterman, written commun., 1968).

The evidence that the folds and slaty cleavage in the Martinsburg Formation were produced during the Taconic orogeny, as presented by other geologists included deformation of the slaty cleavage and production of slip cleavage during the later Appalachian orogeny, folding of the slaty cleavage into cleavage arches, the higher degree of metamorphism in the Martinsburg than in younger rocks, occurrence of large nappes and thrust faults in the Martinsburg and not in younger rocks, and occurrence of slate fragments in basal Shawangunk beds. However, acceptance of some of these arguments leads to certain bewildering contradictions. If the structures in the Martinsburg are Taconic in age, then there should be an abrupt structural discontinuity, other than the angular unconformity, at the Martinsburg-Shawangunk contact. This is difficult to find. Figure 106 is a composite diagram showing the average trends of the major

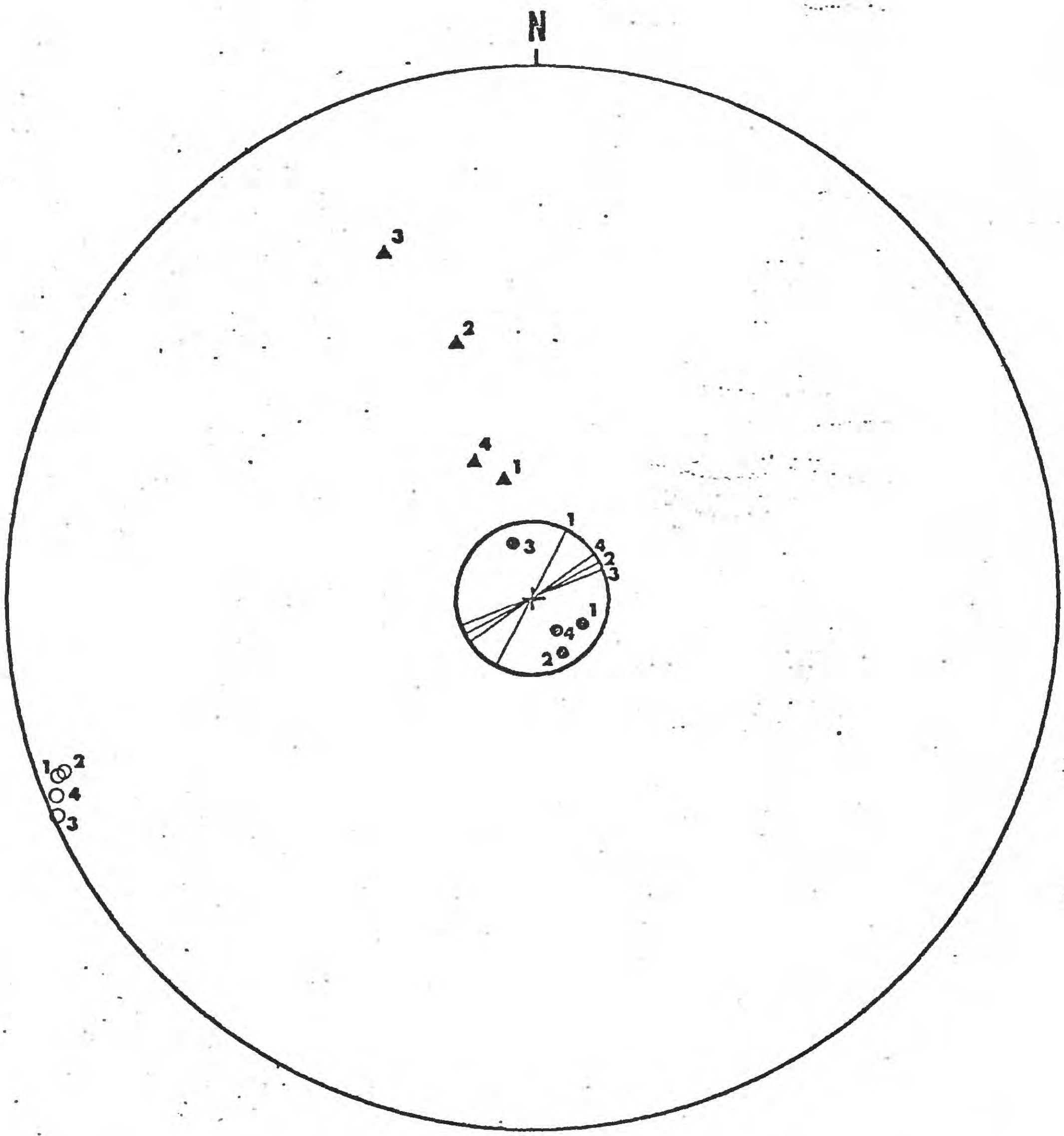


Figure 106. Composite equal-area projections (lower hemisphere) showing maxima of poles to bedding (solid circles), poles to cleavage (solid triangles), intersections of bedding (S_0) and cleavage (S_1) (open circles), and average strike of bedding determined from maxima of bedding (lines in small central circle) in the four lithotectonic units (as numbered) in the Stroudsburg quadrangle.

structual features in the Stroudsburg quadrangle. Note that bedding in Ordovician rocks (lithotectonic unit 1) strikes more northerly than in the other units, but all other structural features, including cleavage, are remarkably similar. This strongly suggests that the Martinsburg was folded prior to Appalachian deformation, but that the cleavage and folds were superimposed on all rocks during the Appalachian orogeny. The formation of slaty cleavage in all rocks in the area at the same time was suggested by Lowry (1957). Thus, if we subtract minor structures of the post-Ordovician rocks from the Martinsburg, we are left with very little. The slaty cleavage will be gone from the Martinsburg, as well as the slip cleavage. What remains is a northwest-dipping slightly warped sequence of beds that constitutes the upright limb of the nappe that has been mapped to the southeast, and the Portland fault. It is true that there is more variation in trends of cleavage in the Martinsburg than in overlying units, but this may be expected because the variations, folding of cleavage, and development of a second (slip) cleavage increases in the Martinsburg to the southeast toward the center of the orogen.

Moench (1970) suggested that slaty cleavage developed in the Rangeley area, Maine, by tectonic dewatering and mechanical reorientation of mineral grains in rapidly deposited eugeosynclinal rocks during down-to-basin faulting. He presented the following mechanism for eastern Pennsylvania as an alternative to the mode of cleavage generation I presented earlier (Epstein and Epstein, 1969): the cleavage in the Martinsburg developed during the Taconic orogeny by basinward mass movement, and the cleavage in younger rocks developed later by the same mechanism (sliding basinward on the Blue Mountain décollement). Similar cleavage orientations in the two sequences would then be due to similar directions of mass sliding controlled by similar basin geometries. This is a most attractive hypothesis, but it suggests that cleavage in rocks younger than the Martinsburg developed by the dewatering mechanism, which Maxwell (1962) originally discounted. Moench's hypothesis, however, meets with several objections. First, it means that stress was taken up in post-Martinsburg rocks with little or no effect on the Martinsburg itself (i.e., nearly complete "dermal" tectonics). I have considered this possibility, but discounted it because folds in at least one locality (in the Bushkill quadrangle mentioned previously) pass from one lithotectonic unit into the other. Therefore, there has not been completely independent folding of the two sequences. Secondly, a basin with rapidly deposited muds requisite for Moench's thesis is not supported by post-Martinsburg paleogeographic interpretations as discussed under environments of deposition.

The tacit acceptance of two orogenies led Broughton (1946) to believe that the slaty cleavage in the Martinsburg of New Jersey was a product of Taconic tectonism and that the slip cleavage was formed during the later Appalachian orogeny, although he suggested that "These structures might well be explained as the result of two peaks in the stress cycle of one period . . . " (p. 17). Because both slaty cleavage and slip cleavage are found in all rocks in the Stroudsburg area, they are herein believed to have formed during the same continuing period of orogeny. This same interpretation has recently been accepted in the Harrisburg area by Root (1970). The idea that the Martinsburg was severely cleaved during the Taconic orogeny led Stevens (1966) to conclude that it was Taconic metamorphism that produced anthraxolite in the Martinsburg, although he noted (p. 111) that "It is a curious coincidence that the westward diminution of Taconic metamorphism in the Martinsburg conforms to the pattern of later metamorphism for the Pennsylvanian coals."

No unoriented slate fragments have been found in basal Shawangunk beds. Argillite intraclasts in the basal Shawangunk, especially at Lehigh Gap, have cleavage that is parallel to one of two cleavages present in the beds above. Moreover, X-ray analyses indicate that these fragments are similar to argillites interbedded with coarser Shawangunk clastics and not similar to slates in the Martinsburg.

The coincidental folding of both the Shawangunk and Martinsburg in the Portland and Bushkill quadrangles several miles northeast of Delaware Water Gap mentioned previously, and the cleavage in the Martinsburg that is parallel to the axial plane of the fold, is also evidence that the folds and cleavage were produced during post-Shawangunk deformation, the Appalachian orogeny (evidence for the Acadian orogeny in this area is scanty).

The sequence of events that can be attributed to Appalachian deformation are still problematical. I presented some of the possibilities in the discussion of lithotectonic unit 2. The general order of events suggested for most units is: (1) uplift and folding by flexural slip; (2) northwest translation of the lithotectonic units down the regional slope, on décollements, with continued folding and development of cleavage; (3) continued slippage in lithotectonic unit 2 with production of bedding slips, wedging, and dragging of cleavage (movement on the décollement zones probably ceased when folds become too tight, for there is no evidence that has been recognized to show that the tight folds in lithotectonic units 2 or 3 are faulted); (4) rotation of some of the folds and cleavage, especially in the Martinsburg and older rocks southeast of the Stroudsburg quadrangle and in younger rocks in the Lehigh Gap area, and production of slip cleavage that may be parallel to axial planes of cleavage arches, and small thrusts parallel to the slip cleavage, especially in the Martinsburg. This proposed sequence is only a suggestion gleaned from the field data. Probably all events overlapped to some degree, and the order may have varied depending on local stress conditions. Possibly these events occurred sequentially from southeast to northwest, so that intensity of deformation decreases to the northwest and stages 3 and 4 are not represented in lithotectonic unit 4 and stage 4 is not recognized in lithotectonic unit 3, but is known to the southwest in the Lehigh Gap area where recumbent folds with doubly overturned limbs have been described (Epstein and Epstein, 1967, 1969). Effects of differences in lithology were probably a strong contributing factor to heterogeneity in deformation from place to place. More detailed petrofabric work would shed much light on the problem.

Finally, elsewhere in eastern Pennsylvania there is evidence for wholesale subaqueous gravity sliding like the sliding that produced nappes in the Taconic area of New England. Many of the regional effects of the Taconic and Appalachian orogenies in eastern Pennsylvania are still unresolved. Many geologists are presently involved with the problem, and hopefully the tectonic interpretations presented here, if correct, will fit into the overall structural synthesis.

GEOMORPHOLOGY

Numerous and extensive investigations of wind and water gaps in the Appalachians have contributed to the controversies regarding Appalachian geomorphic evolution. Many geologists believe that after the Appalachian orogeny the drainage divide between streams that flowed southeastward into the Atlantic and those that flowed toward the continental interior was located either in the crystalline highlands southeast of the present Great Valley or in the Valley and Ridge province. The divide has since shifted westward to its present position in the Appalachian Plateau. The location of the original divide, the means by which the divide migrated, and the process or processes by which the numerous wind and water gaps were formed are problems that need to be considered in any hypothesis that attempts to explain the drainage development of the Appalachians.

Johnson (1931) believed that the original drainage lines were obliterated during a Cretaceous marine transgression and that the present drainage pattern is mainly the result of superposition from a coastal-plain cover. The location of a gap was purely by chance and is not systematically related to any weakness in the ridge, although there may have been local adjustment to structure.

Meyerhoff and Olmstead (1936) believed that the present drainage descended from the pattern that was established in Permian time which was controlled by structure and topography produced during the Appalachian orogeny. Hence gaps are found along transverse structures or in the northwest limbs of overturned folds.

Thompson (1949) argued that the original divide, which lay on crystalline rocks along the Blue Ridge-Reading Prong axis, was unstable because the southeastward-flowing streams had shorter courses than those that flowed northwestward. As a result, the divide shifted northwestward by normal stream erosion (headward piracy), and the gaps in Kittatinny and Blue Mountains are located at points of rock weakness.

Strahler (1945), who favored Johnson's hypothesis, stressed that the main test substantiating superposition was to show lack of coincidence of gaps and sites of structural weakness (specifically, transverse faults).

Structural characteristics and features other than transverse faults, however, may influence the resistance to erosion of hard-rock ridges. These include, among others: (1) changes in outcrop width, owing to changes of dip; (2) abrupt changes in strike, due to dying out of folds; (3) local weakness of otherwise resistant rocks as a result of the overturning of beds and accompanying shearing; (4) closely spaced joints and strong folding resulting from intense local stress; (5) cross folds and attendant fracturing; (6) thinning of resistant units, which reflects the original processes of sedimentation; (7) thinning or elimination of resistant strata by strike faults; and (8) change in facies.

Detailed structural data from gaps in the Stroudsburg area, presented by previous investigators, generally have been scanty. Detailed mapping of Blue and Kittatinny Mountains and of ridges to the north has shown that there is a correlation of gaps with one or more of the following conditions: (1) steep dips of beds and narrow outcrop widths of resistant units; (2) dying out of folds within short distances; and (3) more intense folding locally than nearby. The parallelism of the gaps is controlled by prominent southeast-trending cross-joint sets present throughout the area (fig. 84).

Gaps in Blue and Kittatinny Mountains

Blue and Kittatinny Mountains, parts of a single ridge supported by the Shawangunk Formation, are cut by the following gaps in the study area: Delaware Water Gap, Totts Gap, Fox Gap, and Wind Gap. Figure 107 shows the locations of the gaps and other major physiographic features. Figure 108 shows the distribution of geologic formations and the structural geology in the area, and demonstrates the correlation of gap location with the three structural conditions mentioned above.

Delaware Water Gap

Many early observers of Delaware Water Gap believed that it was the result of a violent cataclysm. Interesting excerpts of these early discussions are reported by Miller and others (1939, p. 139-

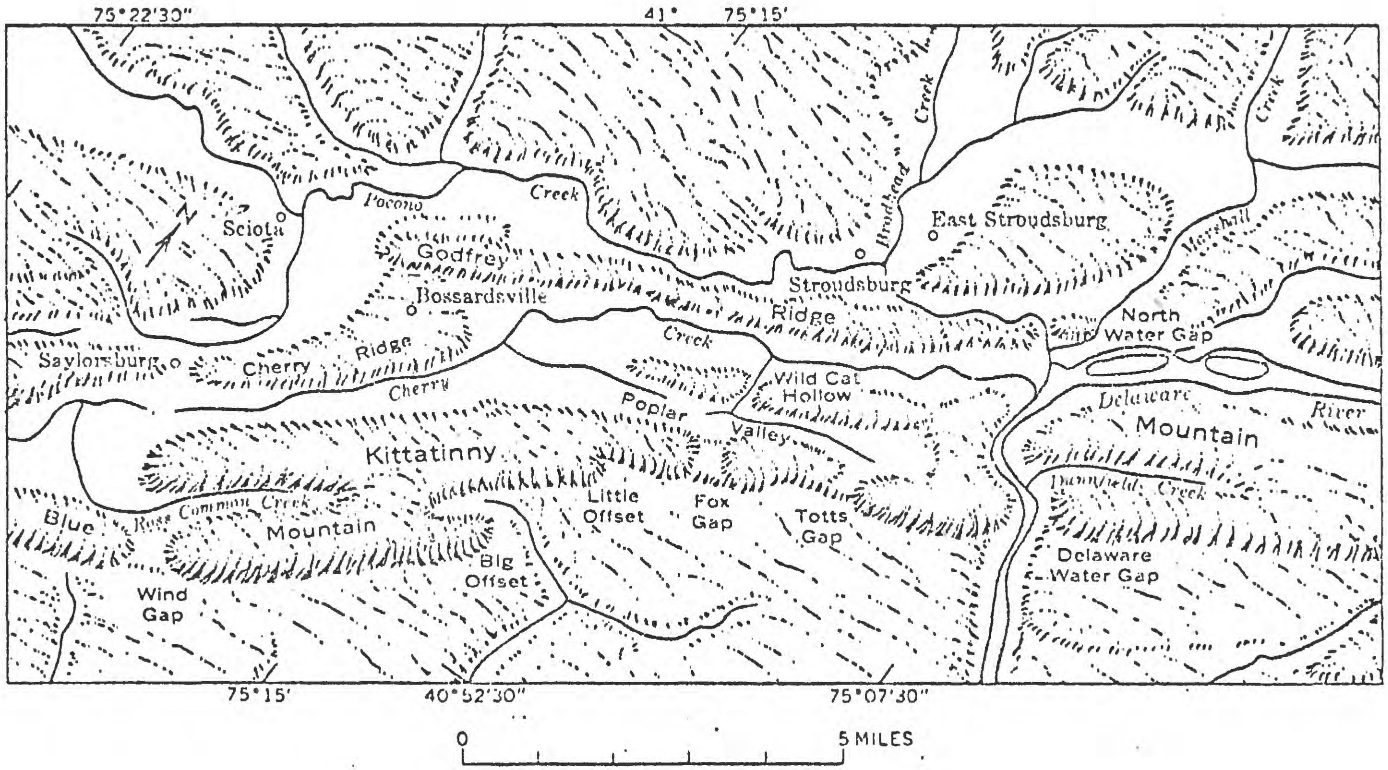


Figure 107. Physiographic diagram of the Stroudsburg area, Pennsylvania and New Jersey.

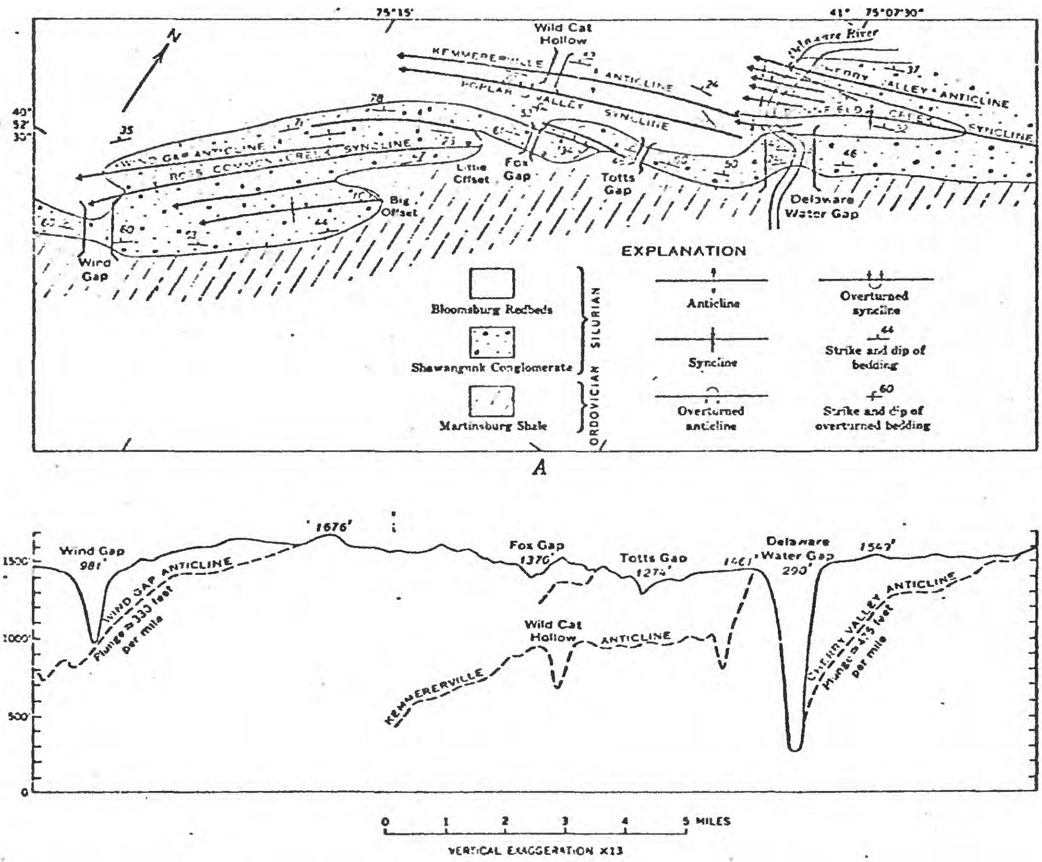


Figure 108. A, Geologic map of the Stroudsburg area, Pennsylvania and New Jersey. B, Projected longitudinal topographic profile, showing relation of geologic structure to location of gaps in Blue and Kittatinny Mountains. Profile viewed from the southeast. Dashed lines indicate topography behind main ridge and correspond approximately to crests of major anticlines. Several small folds north of Wind Gap, similar to those in Delaware Water Gap, are not shown; their extent is not well known because outcrops are poor. Topography from Wind Gap 15-minute quadrangle, Pa.-N.J., and Portland $7\frac{1}{2}$-minute quadrangle, N.J.-Pa.

142). Rogers (1858, v. 1, p. 283, v. 2, p. 896) noted that the ridge crest is offset 700 feet at the gap. He attributed the displacement to a transverse fault, as did Ashley (1935, p. 1406) and Willard (1938, p. 23). Chance (1882, p. 338), Johnson and others (1933, p. 26), Miller and others (1939, p. 144), and Strahler (1945, p. 58-59) believed that the ridge is offset by a slight flexure. Thompson (1949, p. 56, 59) found many small faults which he suggested might be offshoots of a major transverse fault, and attempted to show that the gap is structurally controlled.

During the present study no cross fault could be found at Delaware Water Gap. The Shawangunk consists of three Members that match at river level and have contacts that are not displaced (pl I). The bedding dips 35° to 45° to the northwest on both sides of the river at the bottom of the gap. At the top of the ridge on the New Jersey side, at Mt. Tammany, the dip is about 50°, whereas on the Pennsylvania side the dip decreases upward toward Mt. Minsi, being less than 25° at a place half-way up the mountain. Clearly, there is a small flexure at the gap; the beds on the New Jersey side dip more steeply than those in Pennsylvania, and the ridge crest in New Jersey lies about 700 feet northwest of the axis of the crest on the Pennsylvania side. The flexure can be seen by looking west from the New Jersey bank. Consideration of the structural geometry (fig. 109) reveals that there was an abrupt change in strike of the beds that formerly occupied the

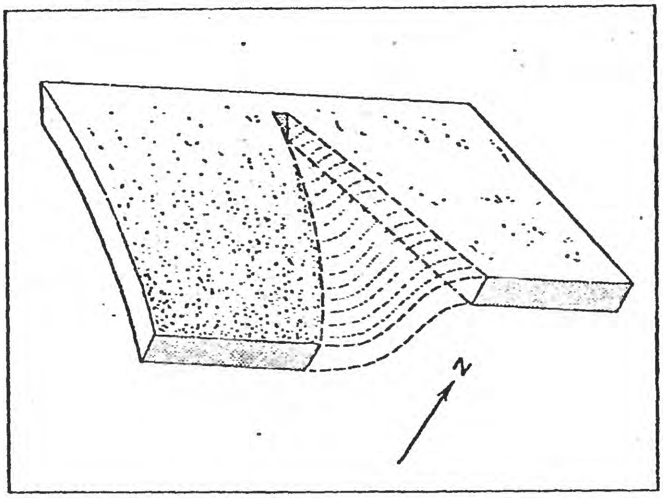


Figure 109. Diagram showing reconstructed flexure at Delaware Water Gap. Dashed lines show form of bed before gap was cut. Presence of flexure accounts for the topographic offset of the ridge and suggests extensive fracturing of the Shawangunk Formation at the gap site in the flexure zone.

site of the gap. As a consequence the brittle Shawangunk must have been weakened by extensive fracturing in the flexure zone. Structural control is therefore thought to have determined the location of the gap.

A series of folds in the Bloomsburg Red Beds along the course of the Delaware River north of the gap dies out to the southwest within a short distance (fig. 108). Probably the rocks are more highly sheared here, and resistance to erosion is less than in the areas between gaps where similar folds were not observed.

Perhaps equally important in controlling the location of Delaware Water Gap is the narrow width of outcrop of the Shawangunk Formation at the gap site than to the northeast where the formation is repeated in the southwest-plunging Cherry Valley anticline. The river now flows on the Shawangunk where it crosses the anticline, but undoubtedly it flowed on the weaker Bloomsburg Red Beds earlier in its history before cutting down into the Shawangunk. This is an example of local superposition.

<u>Totts Gap</u>

The beds at Totts Gap are more strongly overturned than elsewhere along the ridge crest in the area of study, and it seems likely that the rocks here are weakened more than in adjacent areas. Moreover, the Shawangunk Formation has a narrow outcrop width at Totts Gap. Thompson (1949, p. 58) observed that between Totts Gap and Delaware Water Gap the ridge crest is lower where joints are more closely spaced than elsewhere, and that at Totts Gap, the lowest point along this stretch, the joints are most closely spaced.

Whether this reflects greater stress, or whether it is due to chance exposure of different beds in the Shawangunk that possess different structural characteristics, is difficult to determine.

Fox Gap

Fox Gap is located where two southwest-plunging folds die out over a short distance, much as they do at Delaware Water Gap. Also, the beds are strongly overturned, and the outcrop width is narrow.

Wind Gap

Geologic structures in Wind Gap duplicate those in the Delaware Water Gap area. Two major folds plunge out north of the gap. The Shawangunk Formation is not repeated to the northwest because the Wind Gap anticline plunges to the southwest. There is a 15° difference in strike in beds in the ridge crest on either side of the gap, indicative of a flexure similar to that at Delaware Water Gap. In addition, several small folds in the Bloomsburg Red Beds are similar to those in the Bloomsburg at Delaware Water Gap. These folds were not included in figure 108A because outcrops are too few to permit tracing of their trends. Thinning of the outcrop width of the Shawangunk at the gap is evident on figure 108A. This is indicative of near-vertical dips which can be seen in cuts along the highway where it passes through the gap.

Gaps in Godfrey Ridge

Godfrey Ridge lies about 2.5 miles north of Kittatinny Mountain and is supported by complexly folded Upper Silurian and Lower Devonian limestone, shale, sandstone, and conglomerate. Silty shale and sandstone of the Esopus Formation and Oriskany Group support the higher parts of the ridge (pl. III). Small folds are numerous and die out rapidly. Sags in the ridge crest are numerous, but it is difficult to relate structural features to them. The two largest gaps in Godfrey Ridge, the gap of Brodhead Creek and North Water Gap, are located about 2.5 miles north-northwest of Delaware Water Gap.

Gap of Brodhead Creek

Brodhead Creek cuts through Godfrey Ridge at an altitude of about 300 feet. No rock crops out in the creek bottom, but bedrock is exposed in the creek bed about 1 mile upstream. Therefore, bedrock cannot be far below creek level in the gap. Folding at the gap is so complex that Willard (1938, p. 23) believed that the gap is the site of a north-south tear fault. Rather, there are four overturned folds in the southwestern part of the ridge near Brodhead Creek, two of which die out and are absent in the northeastern part. The abrupt dying out of folds is well illustrated by sections C-C' and D-D' in plate III. Change in strike of the beds that formerly occupied the site of the gap is inferred, as it is at Delaware Water Gap.

North Water Gap

North Water Gap is located where Marshall Creek cuts through Godfrey Ridge, about half a mile northeast of the gap of Brodhead Creek. It is almost as deep as the latter, but bedrock is not exposed in the creek floor. Glacial debris, which may be of great thickness[1], is found along the course of the creek in the gap. Clearly, North Water Gap was much deeper in preglacial times.

The structure at North Water Gap is similar to the structure at the gap of Brodhead Creek. Two folds trending toward the gap from the northeast die out within the valley, and do not reappear in the ridge to the southwest (compare sections B-B' and C-C' in pl. III). The two gaps are therefore located at sites where folds plunge out abruptly, and implication of structural control is clear. Moreover, because of near-vertical dips, the Oriskany and Esopus, which together make up the main ridge support, have a narrow outcrop width.

Stream Capture

Structural relations in the Stroudsburg area are believed to have controlled not only the locations but also the history of the gaps. For example, Wind Gap was cut by a stream that was later captured north of Blue Mountain by tributaries of either the Lehigh River to the west or the Delaware River to the east (Wright,

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[1] Bedrock was penetrated at a depth of 296 feet in a water well near the west bank of the Delaware River at an altitude of about 300 feet and approximately 2,000 feet southeast of the mouth of the gap, as reported by a local resident.

1896; Ver Steeg, 1930; Willard, in Miller and others, 1939; Mackin, 1941). Mackin showed that the drainage changes in the Wind Gap area were exceedingly complex and implied that evidence of the original captor of the Wind Gap River may be gone. Nevertheless, it seems likely that on the basis of structural considerations, the tributaries of the Delaware were more agressive than those of the Lehigh, and that a tributary of the Delaware captured the headwaters of Wind Gap River. Why was Wind Gap River, rather than the Delaware River tributary, beheaded? Mackin speculated that the present Delaware may have captured a stream that flowed through Culvers Gap in Kittatinny Mountain, 23 miles to the northeast, and greatly increased its own advantage, at that time, by this addition to its volume. Study of figure 108B suggests the following alternative explanation.

The Wind Gap River was captured just after it had cut down to an altitude of about 980 feet, the present altitude of the floor of the gap. At that level the stream had reached the resistant Shawangunk Formation in the Wind Gap anticline at about 980 feet, just northwest of the present gap, and its downcutting was retarded. The Delaware River, if it was at a similar altitude at that time, as seems likely, was still cutting down through weaker Bloomsburg Red Beds in the Cherry Valley anticline where the top of the Shawangunk is several hundred feet lower. The lower altitude of the top of the Shawangunk at Delaware Water Gap is explained by the difference in plunge of the folds: the Cherry Valley anticline plunges about 475 feet per mile while the Wind Gap anticline plunges about 330 feet per mile. Later, after the Delaware had captured the headwaters of Wind Gap River and cut through the Bloomsburg, it was superimposed on the Shawangunk in the Cherry Valley anticline and slipped down the plunge of the fold in a curving course. The curve was accentuated when it migrated downstream and reached the steeply dipping Shawangunk quartzites and conglomerates just west of the gap.

APPENDIX

Measured Sections

Section 1

Shawangunk Formation along Interstate Highway 80, Delaware Water Gap, Portland quadrangle, New Jersey. Beds generally dip moderately northwest but are interrupted by two small folds. Measurement begins within an estimated 3 feet of the covered contact between the Shawangunk Formation and Martinsburg Formation and ends at the contact between the Shawangunk Formation and Bloomsburg Red Beds.

Shawangunk Formation:	Thickness (feet)
Tammany Member:	
65. Quartzite and quartz-pebble conglomerate, medium-gray to medium-dark-gray, limonitic; quartz pebbles as much as 1.0 in. long; dark-gray argillite clasts as much as 2.0 in. long; beds as much as 12.0 ft. thick; crossbedded and planar-bedded; uppermost few feet consists of reddish-medium-gray fine- to medium-grained quartzite and conglomeratic quartzite with angular pebbles as much as 1.0 in. in diameter; top of unit forms dip slope in contact with red sandstone and siltstone of the Bloomsburg Formation; thickness of unit approximate; basal contact gradational...	241.0
64. Quartzite, medium-gray to medium-dark-gray, fine-grained, hematitic; crossbedded; massive and in beds as much as 5.0 ft. thick; some interbedded dark-gray argillite..................	125.0
63. Argillite, dark-gray; thins up-dip; basal contact abrupt...	3.2
62. Quartzite, medium-gray, fine-grained, limonitic; massive; basal contact gradational...............	4.8
61. Quartzite and argillite. Medium-gray to medium-dark-gray, fine-grained, quartzite interbedded with dark-gray argillite. Beds about 3.0 in.	

Tammany Member--Continued

	Thickness (feet)
thick. Unit forms base of steep cliff at an elevation of 660 ft. Dark-gray argillite abruptly overlies dense massive quartzite at base..	5.8
60. Quartzite, medium-gray to medium-dark-gray, fine- to medium-grained, limonitic; massive; few interbeds of dark-gray argillite; basal contact concealed....................................	69.1
59. Covered..	7.0
58. Quartzite, shaly siltstone, and silty shale. Medium-gray to medium-dark-gray, fine- to medium-grained, conglomeratic, limonitic, massive, crossbedded and planar-bedded quartzite in beds as much as 5 ft. thick interbedded with dark-gray lenticular argillite in beds as much as 2 ft. thick and argillite intraclasts as much as 5 in. long. Unit is more conglomeratic towards top. Basal contact abrupt............................	295.0
57. Shaly siltstone, dark-gray, laminated; thins and pinches out 50 ft. up-dip; basal contact abrupt..	1.5
56. Quartzite, very fine to very coarse grained, medium-light-gray to dark-gray, crossbedded and planar-bedded, with quartz pebbles as much as 2.0 in. long. Scattered beds of dark-gray siltstone and siltstone pebbles as much as 3 in. long. Basal contact abrupt and disconformable................	2.9
55. Argillite and quartzite. Dark-gray, quartzitic, arenaceous, limonitic, laminated shaly siltstone interbedded with medium-gray fine-grained quartzite. Unit thins up-dip as dark-gray argillite pinches out. Basal contact abrupt and disconformable..............................	3.5
54. Quartzite and silty shale. Medium-gray to medium-dark-gray, fine- to medium-grained, partly conglomeratic, massive, crossbedded and planar-bedded quartzite with quartz pebbles as much as $\frac{1}{2}$ in. long and dark-gray argillite pebbles as much as 2 in. long interbedded with dark-gray argillite as much as 6 in. thick which thin up-dip. Pyrite cubes scattered throughout. Basal contact abrupt..	25.4

Tammany Member--Continued

	Thickness (feet)
53. Shaly siltstone, dark-gray with pyrite cubes approximately 1 mm. long, medium- to coarse-grained, massive, crossbedded and planar-bedded, conglomeratic quartzite bed 11 in. thick in middle of unit separated from an overlying fine- to medium-grained quartzite 7 in. thick by a 2 in. siltstone bed. Unit thins up-dip. Basal contact abrupt..............................	5.7
52. Quartzite and argillite. Medium-gray to medium-dark-gray, fine- to coarse-grained, conglomeratic (angular to rounded quartz pebbles as much as ½ in. long and dark-gray angular to discoidal argillite pebbles as much as 3 in. long), crossbedded and planar-bedded, massive quartzite with lenticular interbeds of dark-gray shaly siltstone as much as 4 in. thick. Unit more conglomeratic towards top. Basal contact gradational..	14.8
51. Quartzite, medium-gray to medium-dark-gray, fine- to medium-grained, limonitic; crossbedded, planar-bedded, massive, in beds averaging 1.5 ft.; conglomeratic in uppermost foot; small pyrite cubes scattered throughout unit, especially in upper part; a few dark-gray burrow-mottled shaly siltstone and siltstone beds as much as 3 in. thick which pinch out within a few tens of feet are scattered throughout unit; basal contact abrupt..................	11.1
Total thickness of Tammany Member..........	815.8

Clinton Member:

50. Quartzite, dark- to medium-gray, very fine to fine-grained, silty, argillaceous; with dark-gray discoidal silty shale clasts as much as 2 in. long; unevenly bedded; basal contact gradational.	3.4
49. Silty shale, dark-gray, alternating with medium-gray fine-grained limonitic quartzite in uneven beds less than 1 in. to 8 in. thick. Basal contact consists of dark-gray argillite lying abruptly on massive quartzite......................	5.3
48. Quartzite, medium-gray, fine-grained, with scattered limonite flecks and dark-gray argillite	

Thickness (feet)

Clinton Member--Continued

pebbles averaging about ½ in. in length; massive; vaguely parallel bedded to structureless; ripples with 3-in. wavelengths 1.5 ft. below top; beds less than 1 to 15 in. thick; a few thin interbeds of dark-gray silty shale; basal contact irregular and gradational.................................... 6.8

47. Quartzite, shaly siltstone, and silty shale. Dark-gray, siliceous very unevenly bedded and lenticular shaly siltstone and silty shale beds as much as 5 ft. thick with thin lenses and beds of quartzite interbedded with medium-gray to dark-gray, fine-grained, massive, lenticular, partly crossbedded, locally very limonitic (limonite specks as much as ¼ in. in diameter), partly conglomeratic (intraclasts of dark-gray silty mudstone derived from underlying beds range in length from less than ¼ in. to as much as 2 in.). Quartzite in beds 1-18 in. thick. Many bedding planes contorted and show flow structures, channeling, some load casts, flaser bedding, and burrow mottling. One thin quartzite is boudinaged. Some beds rippled. Basal contact consists of dark-gray silty mudstone in disconformable contact with massive quartzite. Some quartzite beds contain phosphatic intraclasts as much as 1 in. long. Base of unit has small scattered phosphatic intraclasts.. 46.9

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

Shawangunk Formation--Continued

Clinton Member--Continued

	Thickness (feet)
45. Silty shale, shaly siltstone, and silty quartzite, medium- to dark-gray, fine-grained, partly limonitic; weathers pale-yellowish orange to light brown; laminated but appears massive in part; partly burrow mottled. Vertical burrows in upper 6 ft. of unit; basal contact abrupt........	10.1
44. Quartzite, medium-dark-gray, fine-grained, partly limonitic; weathers light gray; massive; some beds contain dark-gray silty shale clasts as much as 1 in. long; bedding characteristic--crossbedded and planar-bedded. Basal contact abrupt.........	4.4
43. Shaly siltstone, silty shale, and quartzite. Dark-gray arenaceous shale and siltstone interbedded and interlensed with thin quartzite in upper half of unit. Light- to medium-gray, partly silty, laminated, crossbedded, and massive quartzite with a few thin interbeds of dark-gray mudstone in beds as much as 5 in. thick make up lower half of unit. A 3-in.-thick bed of fine-grained convoluted quartzite 2.5 ft. below top of unit. Convolutions of laminated medium-light-gray to medium-gray very fine grained quartzite and medium-dark-gray siltstone. Basal contact abrupt......................................	7.2
42. Quartzite and silty shale. Medium-light-gray to medium-gray, fine-grained, massive, crossbedded quartzite containing dark-gray argillite fragments as much as 1 in. long. Quartzites are rippled and occur in beds 2-15 in. thick and are unevenly interbedded and interlaminated with very dark gray shaly siltstone. Unit partly burrow mottled. Silty shale makes up 12 percent of unit. Basal contact consists of quartzite abruptly overlying dark-gray silty shale.................	6.2
41. Quartzite and shaly siltstone. Dark-gray, laminated shaly siltstone interbedded with dark-gray fine-grained to very fine grained silty crossbedded quartzite with clasts of siltstone as much as ½ in. long. Unit partly burrow mottled at top with shale-filled burrows. Unit faulted at road level and repeated 50 ft. to northwest on northwest limb of small anticline. Basal contact abrupt......................................	2.3

Clinton Member--Continued

	Thickness (feet)
40. Quartzite, medium-gray, fine-grained; massive; a few intercalations of dark-gray silty shale; crossbedded and planar-bedded, massive; basal contact abrupt..................................	4.3
39. Quartzite, crossbedded and planar-bedded, light-olive-gray to medium-dark-gray, fine-grained, silty above basal foot and becoming very limonitic towards top of unit; basal foot consists of medium-gray quartzite resting disconformably on dark-gray shaly siltstone and silty shale of unit 38. Quartzite-filled, limonitic burrows in upper half (approximately $\frac{1}{4}$ in. in diameter and as much as 10 in. long) occur in silty fine-grained quartzite. Very conspicuous vertical burrows in upper 7 ft. Overlying units folded and faulted. Contact between units 39 and 40 is abrupt and is repeated 50 ft. to northwest.....................	9.2
38. Shaly siltstone and shale, dark-gray, laminated, alternating with light-olive-gray and medium-gray, fine-grained limonitic, crossbedded quartzite with dark-gray shale and clasts as much as 1 in. long. Beds from less than $\frac{1}{2}$ to 12 in. thick. Upper 3 ft. consists predominantly of laminated dark-gray argillite. Basal contact abrupt..................	8.1
37. Quartzite, medium-gray, fine-grained, limonitic, crossbedded, a few thin intercalations of dark-gray silty shale comprise about 5 percent of unit; beds 4-20 in. thick; basal contact abrupt and disconformable................................	5.9
36. Silty shale and shaly siltstone, dark-gray, in uneven laminae and beds (beds as much as 3 in. thick) interbedded with light-olive-gray, fine-grained, limonitic, thin-bedded quartzite which comprises about 15 percent of unit. Many sand-filled burrows parallel to bedding. Basal contact abrupt and disconformable................	7.4
35. Quartzite, moderate-brown and medium-gray, fine-grained, very limonitic with limonite concretions as much as 1 in. in diameter; unevenly bedded; bedding plane 1 ft. above base has ripple marks with amplitude of about $\frac{1}{2}$ in. and wavelength of about 3.5 in.; basal contact abrupt and disconformable.......................	1.5

Shawangunk Formation--Continued

Clinton Member--Continued

	Thickness (feet)
34. Shaly siltstone and silty shale, dark-gray, with spherical limonitic concretions averaging about 1 in. in diameter, unevenly interbedded with light-olive-gray to medium-gray fine-grained limonitic thin-bedded quartzite containing dark-gray argillite pebbles as much as 1 in. long. Upper 3/4 ft. is a light-gray fine-grained quartzite with dark-gray argillite pebbles as much as 1 in. long. Basal contact is abrupt and undulatory with many limonite concretions at or near the contact..	7.1
33. Silty shale, shaly siltstone, and quartzite. Siltstone contains some clay clasts $\frac{1}{4}$ in. in diameter and is partly burrow mottled. Medium-gray to medium-light-gray, fine-grained limonitic crossbedded even-bedded quartzite makes up 50 percent of unit and is interbedded with dark-gray partly silty shale. A 3-in. thick, laterally discontinuous quartzite bed, 4 ft. above base of unit, contains thin (.1 to $1\frac{1}{4}$ in.) branching argillite-filled burrows about 1 in. long. The finer grained quartzites are ripple topped. Ripples have wavelengths of 3 in.	8.7
32. Quartzite, medium-gray, fine-grained, limonite flecks; massive, crossbedded, laminated. Basal contact abrupt and disconformable................	5.8
31. Quartzite, medium-gray to medium-light-gray, fine- to medium-grained, limonitic, massive, partly rippled, with minor shale clasts as much as 1 in. long, in beds 4 in. to 2.5 ft. thick; alternating with dark-gray silty shale, partly burrowed, in beds 1 in. to 1 ft. thick. Basal contact abrupt..	13.6
30. Siltstone, shaly, dark-gray, with fine-sand-filled burrows and fine-sand lenses; basal contact abrupt..	1.3
29. Quartzite, medium-gray, fine-grained, crossbedded, with $\frac{1}{2}$-in.-long clay galls alternating with dark-gray, limonitic silty shale and shaly siltstone in beds as much as 2 in. thick which comprises less than 20 percent of unit. Basal contact abrupt and consists of a 2-ft. quartzite abruptly overlooking dark-gray argillite.........	7.6
28. Quartzite, medium-gray, fine-grained, crossbedded, unevenly bedded quartzite with rare clay galls as	

Clinton Member--Continued

	Thickness (feet)
much as 1 in. long, comprising 70 percent of unit, alternating with dark-gray burrow-mottled silty shale and shaly siltstone. Basal contact gradational..	7.0
27. Quartzite, medium-gray, fine- to medium-grained, limonitic, crossbedded, massive; basal contact abrupt and disconformable........................	5.8
26. Quartzite, medium-dark-gray, fine-grained, thin-bedded to laminated, crossbedded, alternating with dark-gray silty shale and shaly siltstone. Beds $\frac{1}{2}$ in. to 3 in. thick. Basal contact abrupt......	4.0
25. Quartzite, muddy siltstone to silty mudstone, medium-dark-gray, limonitic (limonite flecks about .1 in. in diameter scattered throughout), massive, unevenly bedded; with scattered dark-gray argillite clasts as much as 2 in. long, in beds 1-11 in. thick and comprising more than 90 percent of unit; and thin interbeds of dark-gray, partly burrow mottled, shaly siltstone. Graphite grains as much as .1 in. long scattered throughout..............	3.8
24. Quartzite, and silty claystone, light-olive-gray, fine-grained, laminated, partly limonitic, evenly bedded, crossbedded quartzite alternating with dark-gray, silty, slabby, burrow-mottled, shale which comprises about 65 percent of unit. Beds 1-8 in. thick. Basal contact gradational................	4.8
23. Quartzite and shaly siltstone. Medium-light-gray, medium- to fine-grained, limonitic, crossbedded quartzite with scattered dark-gray argillite clasts as much as 1 in. long in beds 1 to 19 in. thick and making up about 60 percent of unit. Quartzites interbedded with medium-dark-gray to dark-gray shaly siltstone with minor amounts of silty shale. Unit unevenly laminated to evenly bedded. Widely scattered irregular grains of graphite as much as .1 in. long. Some fine- to medium-grained sand-filled burrows $\frac{1}{4}$ in. in diameter. Basal contact covered..	16.0
22. Quartzite and shaly siltstone interbedded, in beds 1 in. to 3 ft. thick. Covered at road level but exposed in gully above............................	30.0

Clinton Member--Continued	Thickness (feet)
21. Covered. Probably consists mostly of siltstone and shale......................................	23.0
Total thickness of Clinton Member.............	273.0

Minsi Member:

20. Quartzite, light- to medium-gray, medium-grained to conglomeratic, with quartz pebbles as much as ½ in. long, massive, crossbedded and planar-bedded; uppermost bed is massive conglomerate about 2 ft. thick and is exposed in culvert on east side of road; 1 in.-thick medium-greenish-gray siltstone 5.3 ft. above base. Basal contact gradational....	12.8
19. Siltstone, shaly, dark-gray, finely laminated, interbedded with medium-dark-gray, conglomeratic, silty, fine-grained quartzite; basal contact abrupt..	1.5
18. Quartzite, medium-gray, fine- to medium-grained, limonitic; scattered angular quartz and chert pebbles as much as ½ in. long; crossbedded and planar-bedded; massive; a few interbedded dark-gray shaly siltstone beds 1 in. thick or less; basal contact abrupt and disconformable..........	11.5
17. Siltstone and silty shale, dark-gray, comprise about 65 percent of unit, interbedded with medium-gray, medium-grained, crossbedded quartzite and quartz- and chert-pebble conglomerate. Basal contact abrupt..	3.7
16. Quartzite, light-olive-gray to light-gray, medium-grained, partly conglomeratic (angular to subrounded quartz pebbles as much as ½ in. long and shale clasts as much as 1 in. long), local ripples; lenticular, interbedded with dark-gray, laminated shaly siltstone in beds 1 in. to 8 in. thick and comprising about 10 percent of unit. Basal contact abrupt....	37.8
15. Siltstone, shaly, dark-gray, interbedded with light-olive-gray and medium-dark-gray, medium-grained, limonitic, crossbedded quartzite. Unit from top to bottom consists of:	

Shawangunk Formation--Continued

Minsi Member--Continued

Thickness (feet)

Siltstone............ 0.8
Quartzite............ 5.3
Siltstone............ 2.2

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

14. Conglomerate and quartzite. Light-olive-gray to medium-dark-gray conglomerate with clasts as much as 3/4 in. long composed predominantly of quartz but with scattered dark-gray shale pebbles as much as 1 in. long alternating medium-gray to dark-gray, medium- to coarse-grained quartzite. Unit massively bedded and crossbedded. Basal $\frac{1}{2}$ ft. is a conglomerate bed which locally grades into underlying light-gray quartzite.................. 24.3

13. Quartzite, light-gray to light-olive-gray, fine- to medium-grained, planar-bedded; weathers to a lighter color than units above and below; few thin lenses of darker gray quartzite; basal contact gradational.................................... 8.0

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

11. Siltstone, shaly, arenaceous, dark-gray, siliceous, laminated, alternating with light-olive-gray and moderate-dark-gray, medium- to coarse-grained, partially conglomeratic (pebbles no more than $\frac{1}{4}$ in. long) quartzite. Basal contact abrupt and disconformable.................................. 4.8

10. Quartzite and conglomerate, light-olive-gray and medium-dark-gray, fine- to medium-grained; conglomerate comprises about 10 percent of unit; massively bedded; crossbedded; a few thin intercalations and channel fillings of dark-gray siltstone comprising about 4 percent of unit; basal contact abrupt and disconformable......................... 31.8

9. Conglomerate and quartzite; light-olive-gray to medium-dark-gray, crossbedded and planar-bedded, quartzitic conglomerate with clasts as much as

Minsi Member--Continued

Thickness (feet)

3/4 in. in diameter and scattered silty shale clasts as much as 4 in. long interbedded with dark-gray, fine-grained, argillaceous quartzite and siltstone. At road level are 4 dark-gray siltstone beds which range up to 1 ft. in thickness; these beds thicken and thin laterally. Conglomerates and quartzites between the siltstones are lenticular. This unit is persistant for at least 100 ft. up-dip. Mudcracks found up-dip at edge of cliff, approximately 60 ft. above road level. Basal contact abrupt and disconformable.................. 7.2

8. Quartzite, alternating medium-gray and light-olive-gray to light-gray, fine- to medium-grained; planar-bedded beds 2 in. to 3 ft. thick; basal contact gradational................................ 4.7

7. Conglomerate and conglomeratic quartzite, light-olive-gray to medium-dark-gray; crossbedded and planar-bedded; clasts as much as 1 in. long in a matrix of medium-grained quartzite, comprise basal 2.5 ft. and grades up into medium-gray, medium-grained laminated to fine-bedded quartzite; basal contact abrupt.................................... 6.0

6. Quartzite, light-olive-gray, fine- to medium-grained; a few scattered pebbles about $\frac{1}{4}$ in. long; basal few feet contains lenses of medium-dark-gray medium- to coarse-grained quartzite; upper half of unit crossbedded; basal half of unit planar bedded; basal contact abrupt.................................... 9.5

5. Quartzite, light-olive-gray, medium-gray to medium-dark-gray, predominantly medium grained, partly coarse grained; a few scattered angular pebbles as much as $\frac{1}{2}$ in. long; crossbedded. Basal contact abrupt.. 8.2

4. Conglomerate and quartzite, light-olive-gray and light-gray to medium-gray, medium- to coarse-grained, limonitic, partly crossbedded, lenticular. Pebbles of angular quartz and dark-gray chert as much as 2 in. in diameter and averaging $\frac{1}{2}$ in. in diameter. Base of many conglomerate beds disconformable with channels about $\frac{1}{2}$ ft. deep. There are 6 pronounced conformable contacts within this unit at road levels. Conglomerate grades up into or is interbedded with

Minsi Member--Continued

	Thickness (feet)
finer quartzite. Conglomerate beds 1 in. to 1 ft. thick. A few light-olive-gray shaly siltstone lenses averaging about 2 in. in length scattered throughout unit. Basal contact abrupt..	11.3
3. Quartzite and conglomeratic quartzite, angular pebbles of milky quartz predominate with scattered dark-gray chert and argillite pebbles as much as 1 in. long in a matrix of medium-dark-gray, medium- to coarse-grained quartzite; conglomeratic and feldspathic at base becoming finer grained toward top of unit; unevenly bedded; conglomeratic beds lenticular; basal contact gradational........	1.8
2. Quartzite, light-olive-gray and medium-light-gray to medium-gray, fine-grained to conglomeratic; crossbedded to planar-bedded partially limonitic; angular to rounded quartz pebbles with a few dark-gray to grayish-black chert pebbles approximately $\frac{1}{2}$ in. long; irregular bedded and crossbedded; conglomeratic, medium- to coarse-grained, and fine-grained quartzite beds 1 in. to 1 ft. thick alternate; thin lenses of light-olive-gray shaly siltstone not more than 1 in. thick and as much as 10 ft. long; limonitic concretions, 1-1$\frac{1}{2}$ in. in diameter are scattered throughout but occur in zones along bedding planes; basal contact covered..	18.4
1. Covered; contact between Shawangunk and Martinsburg Formations covered by colluvium; covered interval about 2 ft. thick................................	2.0
Approximate thickness of Minsi Member.........	302.6
Total thickness of Shawangunk Formation	1391.2

Section 2

Upper part of the Tammany Member of the Shawangunk Formation and lower part of the Bloomsburg Red Beds, Delaware Water Gap, Stroudsburg quadrangle, Pennsylvania. Traverse begins 100 feet east of the southern contact between the Shawangunk Formation and Bloomsburg Red Beds, extends 2,380 feet northwest along U.S. Highway 611A, rises up the cliff face, and then to the St. Marks Church in the village of Delaware Water Gap. [Units 101 to 119 and 123 are tongues of the Shawangunk Formation within the Bloomsburg Red Beds. For convenience, their thickness, totaling 129.9 feet, is included within the measurements for the Bloomsburg.]

Bloomsburg Red Beds (part):		Thickness (feet)
123.	Siltstone, greenish-gray; traverse down dip slope ends 200 ft. in a direction N. 60° W. where road near St. Marks Church is intersected; to the northwest of this point the beds rise in an anticline	3.0
122.	Siltstone, shaly greenish-gray with pale- to grayish-red-purple mottles; upper 3 in. grayish-red-purple siltstone; upper contact concealed, traverse continues to top of hill then down dip slope of unit 122 for 625 ft. in a N. 60° W. direction	2.0
121.	Sandstone, shaly, alternating greenish-gray and grayish-red-purple	15.0
120.	Siltstone, arenaceous grayish-red-purple	10.1
119.	Covered	10.0
118.	Siltstone, dark-gray, interbedded with medium-gray, very fine grained, argillaceous sandstone; unit exposed in ledges in slope above bluff; top of unit 118 forms dip slope on northwest side of hill; traverse continues N. 50° W. down dip slope of unit 118 for 350 ft. to base of next bluff	4.8
117.	Covered	5.0
116.	Quartzite, dark-gray, very fine grained, limonitic; and dark-gray siltstone; unit forms top of bluff	8.7
115.	Sandstone, medium-dark-gray, very fine grained, argillaceous	1.7
114.	Siltstone, dark-gray	1.4

Bloomsburg Red Beds (part)--Continued

		Thickness (feet)
113.	Sandstone, medium-dark-gray, very fine grained; basal contact abrupt and irregular..................	4.0
112.	Siltstone, dark-gray; basal contact gradational......	1.0
111.	Sandstone, medium-dark-gray; very fine grained; basal contact gradational..................................	2.7
110.	Siltstone, dark-gray................................	3.6
109.	Sandstone, dark-gray, very fine grained, siliceous...	2.3
108.	Siltstone, dark-gray................................	5.1
107.	Siltstone, dark-gray, interbedded with medium-gray and olive-greenish-gray, very fine to medium-grained sandstone. Unit evenly bedded with beds 2-15 in. thick..	6.5
106.	Partially exposed; a few ledges of medium-gray, fine-grained, argillaceous, limonitic sandstone....	30.0
105.	Sandstone, medium-gray, and dark-gray siltstone; traverse continues north along Appalachian Trail for 540 ft. to a subsidiary trail which leads N. 50° W. away from main trail. Top of unit 104 is 50 ft. up subsidiary trail. Top of unit 105 is 200 ft. along subsidiary trail from top of unit 104. Traverse continues up knoll N. 70° W. from top of unit 105 and crosses dirt road....................	20.0
104.	Sandstone, medium-gray, medium-grained, limonitic.....	2.7
103.	Sandstone, greenish-gray, medium-grained, limonitic at base and grades up into argillaceous sandstone...	7.0
102.	Sandstone, greenish-gray, fine-grained................	5.4
101.	Sandstone, greenish-gray, fine-grained................	5.0
100.	Sandstone, greenish-gray, argillaceous, grades up into grayish-red-purple silty shale......................	4.7
99.	Sandstone, greenish-gray, fine-grained................	2.4
98.	Siltstone, grayish-purple, arenaceous.................	2.7
97.	Quartzite, gray, fine-grained.........................	1.3
96.	Shale, grayish-purple.................................	0.3

Bloomsburg Red Beds (part)--Continued	Thickness (feet)
95. Sandstone, greenish-gray, fine-grained..................	1.9
94. Quartzite, greenish-gray, fine-grained.................	1.0
93. Siltstone, greenish-gray, arenaceous...................	0.5
92. Quartzite, gray, fine-grained..........................	0.8
91. Quartzite, greenish-gray, fine-grained, with pale-red-purple to grayish-red-purple mottles; interbedded with greenish-gray arenaceous silty shale with pale-red-purple to grayish-red-purple mottles.................	5.0
90. Shale, silty, pale-red-purple to grayish-red-purple....	1.3
89. Sandstone, greenish-gray, fine-grained.................	0.7
88. Shale, silty, pale-red-purple to grayish-red-purple....	0.9
87. Quartzite, gray, medium-grained, limonitic.............	4.3
86. Sandstone, greenish-gray, medium-grained...............	1.0
85. Quartzite, gray, fine-grained, limonitic...............	3.3
84. Shale, silty, pale-red-purple to grayish-red-purple....	3.3
83. Quartzite, gray, fine- to medium-grained, grades up into greenish-gray shaly siltstone in upper half of unit. Basal contact gradational....................	4.7
82. Siltstone to medium-grained sandstone, pale-red-purple to grayish-red-purple................................	15.0
81. Sandstone, medium-gray, medium-grained, limonitic......	3.1
80. Siltstone and fine-grained sandstone, pale-red-purple to grayish-red-purple................................	4.5
79. Sandstone, medium-gray and greenish-gray, fine- to medium-grained..	6.0
78. Siltstone, shaly pale-red-purple to grayish-red-purple.	3.5
77. Sandstone, medium-gray and greenish-gray, medium-grained, limonitic..................................	3.1
76. Siltstone, arenaceous and fine-grained silty sandstone, pale-red-purple to grayish-red-purple; basal contact gradational..	2.7

		Thickness (feet)
75.	Sandstone, medium-gray and greenish-gray, medium-grained, limonitic	6.0
74.	Shaly siltstone and interbedded fine-grained sandstone, pale-red-purple to grayish-red-purple	4.0
73.	Sandstone, medium-gray, medium-grained, limonitic; grades up into pale-red-purple to grayish-red-purple sandstone	2.6
72.	Quartzite, sandstone, and siltstone. Basal foot is medium-gray, medium-grained quartzite which grades up into pale-red-purple to grayish-red-purple, fine-grained sandstone and shaly siltstone	7.2
71.	Shaly siltstone and interbedded fine-grained sandstone, pale-red-purple to grayish-red-purple	4.1
70.	Quartzite, medium-gray, medium-grained, limonitic	2.0
69.	Shaly siltstone and interbedded fine-grained sandstone, pale-red-purple to grayish-red-purple	12.0
68.	Covered	2.0
67.	Quartzite, medium-gray to greenish-gray, conglomeratic (pebbles as much as $\frac{1}{2}$ in. in diameter); crossbedded; channeled into unit below; a few thin streaks of greenish-gray silty shale; basal contact abrupt. Unit traced to north for 550 ft. through series of folds and then measurement continues up cliff	7.0
66.	Quartzite, pale-red-purple to grayish-red-purple, medium- to coarse-grained conglomeratic, crossbedded; grades up into interbedded pale-red-purple to grayish-red-purple fine- to medium-grained quartzite and arenaceous siltstone; many red beds grade laterally into greenish-gray beds northward; basal contact gradational	13.8
65.	Quartzite, medium-gray to greenish-gray, medium- to coarse-grained, conglomeratic; a few quartz pebbles as much as $\frac{1}{2}$ in. long; crossbedded	5.5
64.	Quartzite, grayish-red-purple to pale-red-purple, very fine grained to medium-grained, argillaceous, crossbedded. Middle of unit contains interbeds of greenish-gray, medium-grained quartzite	26.0
63.	Quartzite, medium-gray to greenish-gray, fine- to medium-grained, conglomeratic (pebbles as much as $\frac{1}{4}$ in. long); crossbedded; channeled at base; grades	

	Thickness (feet)
laterally into pale-red-purple to grayish-red-purple beds of same lithic type interbedded with greenish-gray, fine-grained, limonitic, crossbedded quartzite....................................	6.8
62. Quartzite, medium-gray, medium-grained, conglomeratic, limonitic, crossbedded; grades up into fine-grained quartzite which in turn becomes greenish-gray and limonitic upwards..................................	6.3
61. Siltstone, shaly, greenish-gray, limonitic; basal contact gradational.................................	0.7
60. Quartzite, grayish-red-purple to pale-red-purple, and greenish-gray to medium-gray fine-grained, interbedded with pale-red-purple to grayish-red-purple, medium-grained partially limonitic and conglomeratic quartzite and arenaceous siltstone..................	71.0
59. Siltstone, shaly, grayish-red-purple to pale-red-purple, poorly exposed, grades up into grayish-red-purple and pale-red-purple, very fine grained, argillaceous quartzite which in turn grades up into medium-gray, coarse-grained quartzite...........................	15.0
58. Quartzite, greenish-gray, fine-grained, limonitic; grades up into medium-gray, coarse-grained quartzite.	5.1
57. Sandstone, greenish-gray, argillaceous.................	0.8
56. Quartzite, greenish-gray, fine- to medium-grained; grades up into grayish-red-purple, fine-grained quartzite..	4.2
55. Quartzite, medium-gray to greenish-gray, medium- to coarse-grained; massive; channeled into beds below...	3.0
54. Quartzite, grayish-red-purple, partially limonitic, crossbedded, with interbeds of pale-red-purple arenaceous shaly siltstone and scattered interbeds of greenish-gray sandstone and siltstone............	33.0
53. Quartzite, grayish-red-purple and greenish-gray, fine-grained, channeled into beds below, grades laterally and vertically into pale-red-purple to grayish-red-purple arenaceous siltstone.............	14.5
52. Quartzite, medium-gray, fine-grained, limonitic, massive, grades up into greenish-gray quartzite and pale-red-purple to grayish-red-purple, crossbedded,	

Bloomsburg Red Beds (part)--Continued

		Thickness (feet)
	argillaceous quartzite which grades up into greenish-gray argillaceous sandstone	12.4
51.	Siltstone, grayish-red-purple, quartzitic	4.5
50.	Quartzite, grayish-red-purple, fine-grained	2.8
49.	Quartzite, grayish-red-purple, silty, and grayish-red-purple quartzitic siltstone	3.4
48.	Quartzite, medium-gray, fine-grained, hematitic	1.2
47.	Quartzite, pale-red-purple, pale-red to grayish-red, silty, limonitic; and quartzitic and shaly siltstone	25.0
46.	Quartzite, medium-gray and greenish-gray, fine-grained, limonitic	0.3
45.	Siltstone, pale-red-purple to grayish-red-purple, quartzitic, shaly	8.7
44.	Quartzite, fine-grained, medium-gray grading up into grayish-red-purple, very fine grained quartzite	0.6
43.	Quartzite, medium-gray and greenish-gray, fine- to coarse-grained, partially conglomeratic; scattered 1 in.-thick mudstone intercalations	3.1
42.	Siltstone, greenish-gray	0.4
41.	Quartzite, medium-dark-gray, fine-grained, limonitic	1.7
40.	Shale, silty light-green	0.2
39.	Quartzite, medium-gray, fine-grained, limonitic	2.8
38.	Quartzite, grayish-red-purple, fine- to medium-grained, limonitic, crossbedded; and grayish-red-purple to pale-red-purple quartzitic siltstone	9.9
37.	Shale, silty pale-red-purple to grayish-red-purple	0.4
36.	Quartzite, grayish-red-purple, fine-grained, hematitic	0.5
35.	Shale, silty, grayish-red-purple to greenish-gray	0.2
34.	Quartzite, grayish-red-purple, fine- to coarse-grained, conglomeratic; crossbedded	1.5

	Thickness (feet)
33. Siltstone, quartzitic, pale-red-purple to grayish-red-purple and fine-grained, silty quartzite........	9.9
32. Quartzite, grayish-red-purple to pale-red-purple, medium-grained to coarse-grained, limonitic; crossbedded.......................................	7.3
31. Quartzite, grayish-red-purple, fine- to coarse-grained, conglomeratic; crossbedded...........................	2.2
30. Siltstone, greenish-gray, interbedded with medium-gray fine-grained quartzite............................	0.7
29. Quartzite, medium-gray and grayish-red-purple, fine-grained to coarse-grained, limonitic.................	4.0
28. Siltstone, shaly, grayish-red-purple to pale-red-purple; interbedded with grayish-red-purple, fine-grained, silty quartzite....................................	11.6
27. Conglomerate, grayish-red-purple; angular to subrounded milky quartz and jasper pebbles as much as ½ in. long..	0.4
26. Conglomerate, quartzite and siltstone. Conglomerate with angular to subrounded milky quartz and pale-red-purple jasper pebbles comprise basal 2 in.; grades up into grayish-red-purple, medium-grained conglomeratic quartzite, shaly siltstone. Basal contact abrupt and disconformable......................................	9.4
25. Quartzite, silty, grayish-red-purple, fine- to medium-grained, partly conglomeratic (angular to subrounded pebbles as much as ½ in. long), partially crossbedded; interbedded with grayish-red-purple siltstone.........	15.1
24. Quartzite, grayish-red-purple, fine-grained, grades up into pale-red-purple to grayish-red-purple silty quartzite..	7.0
23. Quartzite, grayish-red-purple, fine- to medium-grained, partially conglomeratic (subrounded quartz pebbles as much as 0.4 in. long); crossbedded; basal contact abrupt and disconformable....................	1.9
22. Quartzite, grayish-red-purple to pale-red-purple, fine- to medium-grained, limonitic; interbedded with pale-red-purple to grayish-red-purple quartzitic siltstone.	11.1
21. Siltstone, grayish-red-purple, quartzitic...............	3.8

	Thickness (feet)
20. Quartzite, grayish-red-purple, conglomeratic with quartz and jasper pebbles as much as $\frac{1}{4}$ in. long, crossbedded; basal contact abrupt and disconformable	1.4
19. Quartzite, grayish-red-purple, silty	2.6
18. Quartzite, medium-gray grading upward to greenish-gray, limonitic; crossbedded	6.1
17. Quartzite, pale-red-purple to grayish-red-purple, fine- to coarse-grained, medium gray near base, partly limonitic, crossbedded; interbedded with pale-red-purple to grayish-red-purple siltstone and shaly siltstone	25.9
16. Quartzite, silty, grayish-red-purple, massive; interbedded with grayish-red-purple quartzitic siltstone	3.0
15. Siltstone, light-brownish-gray to pale-red-purple and grayish-red-purple, quartzitic, partly shaly; cleavage limited to argillaceous beds; basal contact with Shawangunk Formation gradational within a 1-ft. interval and consists of greenish-gray silty quartzite (Shawangunk Formation) in contact with pale-red-purple to grayish-red-purple quartzitic siltstone (Bloomsburg Red Beds); color contact oblique to bedding	10.2
Incomplete thickness of Bloomsburg Red Beds...	700.8

Shawangunk Formation (part):

Tammany Member (part):

14. Siltstone, greenish-gray, shaly, grades up into medium-gray, fine-grained, silty quartzite which in turn grades up into medium-gray, fine-grained quartzite	3.1
13. Quartzite, medium-dark-gray, fine-grained	3.4
12. Siltstone, greenish-gray, shaly	1.0
11. Quartzite, medium-dark-gray, fine- to medium-grained.	3.0
10. Shale, silty, medium-gray to light-olive-gray	1.1

Shawangunk Formation (part)--Continued

Tammany Member (part)--Continued

	Thickness (feet)
9. Quartzite, medium-dark-gray, fine-grained, partly conglomeratic, micaceous	5.7
8. Siltstone, greenish-gray, quartzitic, limonitic	1.3
7. Quartzite, medium- to medium-dark-gray, fine-grained, partly hematitic and silty; beds as much as 7 ft. thick	14.9
6. Shale, medium-dark-gray	0.6
5. Quartzite, medium-gray to medium-dark-gray to greenish-gray, fine- to medium-grained partly silty, limonitic, crossbedded; beds 3-4 in. thick	30.5
4. Quartzite, fine-grained, light-olive-gray to medium-gray, silty; unit thickens up-dip	2.0
3. Quartzite, medium-gray to light-olive-gray, fine- to medium-grained, partly silty, hematitic; beds as much as 3 ft. thick	6.5
2. Siltstone, medium-gray to light-olive-gray, shaly and quartzitic	3.8
1. Quartzite, medium-gray to medium-dark-gray, fine- to medium-grained, massive; beds as much as 3 ft. thick; basal contact concealed	5.9
Incomplete thickness of Tammany Member	82.8
Incomplete thickness of Shawangunk Formation	82.8

Section 3

Coeymans and Rondout Formations, along southeast bank of Brodhead Creek, approximately 1,000 feet above dam and 3,000 feet southwest of Minisink Hills, Stroudsburg quadrangle, Pennsylvania. Beds vertical.

Coeymans Formation (part):

Stormville Member (thickness not measured)

Shawnee Island Member:

8. Limestone, arenaceous and argillaceous, finely to moderately crystalline, medium-dark-gray to medium-gray; weathers medium to light-medium gray; irregularly bedded; about 5-10 percent nodular

Shawnee Island Member--Continued

Thickness (feet)

dark-gray chert; a continuous chert bed ½-1 ft. thick 4 ft. below top; thin sand lenses occur as low as 5 ft. below top of unit; crinoid columnals and Gypidula coeymanensis abundant; upper contact disconformable; lower contact sharp and placed at first appearance of dark-gray chert................ 16.5

7. Limestone, arenaceous and argillaceous, finely to moderately crystalline, medium-dark-gray to medium-gray; weathers light-medium gray, limonitic; irregularly bedded; fossils abundant and include Gypidula coeymanensis, Leptaena rhomboidalis, stropheodontid brachiopods, fenestellid and trepostome bryozoans, tabulate and rugose corals; lower contact transitional......................... 18.5

Total thickness of Shawnee Island Member........ 35.0

Peters Valley Member:

6. Limestone, very arenaceous and argillaceous with scattered quartz pebbles up to ¼ in. in diameter, medium-gray, finely to moderately crystalline; weathers light-medium gray; occurs in beds 1½ ft. thick; partly crossbedded; abundantly fossiliferous; Gypidula coeymanensis and favositids especially abundant; lower contact transitional............... 5.0

Total thickness Peters Valley Member............ 5.0

Depue Limestone Member:

5. Limestone, slightly arenaceous, medium-to dark-gray; weathers medium gray; limonitic; very thin argillaceous limestone partings produce a ribbony character; basal 1-2 ft. of unit consists of crossbedded sandy limestone; stropheodontid brachiopods and ostracodes abundant; lower contact abrupt.. 18.0

Total thickness Depue Limestone Member........... 18.0

Incomplete thickness Coeymans Formation......... 58.0

Rondout Formation:

	Thickness (feet)
Mashipacong Member:	
4. Calcareous shale and argillaceous limestone; medium-gray; weathers medium-yellow gray; laminated and mudcracked; unfossiliferous; lower contact abrupt..	8.0
Total thickness Mashipacong Member.............	8.0
Whiteport Member:	
3. Dolomite, very finely crystalline, medium-gray; weathers brownish orange; laminated and deeply mudcracked; laminae are alternations of pure dolomite and slightly argillaceous dolomite with argillite weathering a lighter color; dark-gray calcareous shale partings between mudcrack polygons; unit unfossiliferous; lower contact abrupt..........	9.0
Total thickness Whiteport Member................	9.0
Duttonville Member:	
2. Limestone, slightly argillaceous, finely crystalline, medium-gray; weathers medium gray; beds 1 ft. thick; ribbony; ribbons due to alternations of purer limestone and more argillaceous limestone. Basal foot consists of a biostrome of fragmented horn and colonial corals and brachiopods; 1 ft. 3 in. above base are numerous smooth-shelled ostracodes covering all bedding planes to top of unit; the more argillaceous ribbons contain fewer numbers of ostracodes; lower contact abrupt, placed at base of biostrome..	4.5
1. Limestone, very argillaceous, very finely crystalline, medium-gray; weathers yellowish gray; weathers into thin layers from 1 in. to $\frac{1}{4}$ in. thick; unit laminated and mudcracked; mudcracks begin 1 ft. above contact with Decker; mudcracks $1\frac{1}{2}$ to 4 in. wide and well defined; unit unfossiliferous; lower contact abrupt.	7.0
Total thickness Duttonville Member..............	11.5
Total thickness Rondout Formation...............	28.5

Decker Formation (thickness not measured)

Section 4

Stormville and Shawnee Island Members of the Coeymans Formation in a series of ledges on hillside above house on south side of Cherry Valley Road, 1,000 feet east of intersection with Route 191, Stroudsburg quadrangle, Pennsylvania. Beds dip gently northeast.

Coeymans Formation (in part):	Thickness (feet)
Stormville Member:	
7. Sandstone, calcareous, fine- to medium-grained, light- to medium-gray; and finely to coarsely crystalline arenaceous limestone; upper contact concealed, but beds believed to be at top of member; lower contact concealed..........................	2.0
6. Covered..	2.0
5. Sandstone, pebbly and coarse-grained, quartz-pebble conglomerate; sandier lenses crossbedded; medium- to light gray; weathers tan gray; forms ledge; 7-8 ft. above base is conglomerate (quartz pebbles subrounded to well rounded and up to 1 in. long) which is immediately overlain by a fossil hash of brachiopods (<u>Gypidula coeymanensis</u>) and disarticulated crinoid columnals up to 1/8 in. in diameter; upper ½ ft. is a coarse-grained quartz-pebble conglomerate with crinoid columnals; lower contact disconformable.	11.6
4. Limestone, arenaceous, medium-gray, finely crystalline; and calcareous sandstone and medium- to fine-grained quartz-pebble conglomerate; basal foot is a quartz-pebble conglomerate; many scattered crinoid columnals; basal contact disconformable........................	5.0
3. Sandy limestone and calcareous sandstone; medium-gray; weathers tan gray; 1-2 ft. above base occurs first crossbedded sandstone; 2-3 ft. above base blue-black chert pods up to ½ ft. long and 0.3 ft. thick; 3-4 ft. above base crossbedded sandstone and medium-grained conglomerate; scattered crinoid columnals; lower contact concealed..........................	6.0
Total thickness Stormville Member...............	26.6
Shawnee Island Member:	
2. Covered..	4.5
1. Limestone, arenaceous and argillaceous, moderately crystalline, medium-gray, weathers tan gray; unit	

Coeymans Formation (part)--Continued

	Thickness (feet)
Shawnee Island Member--Continued	
forms ledge; crinoid columnals and _Gypidula coeymanensis_; base concealed........................	6.0
Incomplete thickness of Shawnee Island Member...	6.0

Section 5

Stormville and Shawnee Island Members of the Coeymans Formation at Hartman's Cave, altitude of 650 feet on the southeast slope of Godfrey Ridge, 0.85 mile northeast of the Stormville Church, at crest of overturned anticline, Stroudsburg quadrangle, Pennsylvania.

Coeymans Formation (part):

Stormville Member:

11. Conglomerate, medium-light-gray, calcareous, slightly limonitic; well-rounded to subrounded milky quartz pebbles; weathers light-tannish gray; scattered crinoid columnals and _Gypidula coeymanensis_; basal contact disconformable...........................	0.5
10. Sandstone, medium-light-gray, calcareous, medium-grained; weathers light-tannish gray; juxtaposed with medium-gray fine-grained arenaceous and argillaceous limestone which weathers medium light gray; abundant crinoid columnals; basal contact abrupt..................................	1.7
9. Sandstone, medium-light-gray, coarse-grained, calcareous; weathers light-tannish gray; thin quartz-pebble conglomerate at base; crossbedded; abundant crinoid columnals as much as 1/8 in. in diameter; basal contact disconformable.........	1.0
8. Sandstone and limestone. Sandstone is medium-light-gray, medium-grained, argillaceous, calcareous; weathers tannish gray. Limestone is medium gray, fine grained, arenaceous and argillaceous; weathers medium-light gray; 30-40 percent quartz sand. Basal 1.5 ft. medium- to coarse-grained sandstone; basal contact disconformable.................................	5.7
7. Limestone, medium-gray, fine-grained, arenaceous and argillaceous; weathers medium-light gray; abundant crinoid columnals; basal contact abrupt...........	2.8
6. Chert, dark-gray, bedded; basal contact abrupt......	.2

Coeymans Formation (part)--Continued

Stormville Member--Continued

	Thickness (feet)
5. Limestone; similar to unit 7; about 20 percent quartz sand; weak fracture cleavage; irregularly bedded; basal foot contains nodules of dark-gray chert; brachiopods and crinoid columnals abundant; basal contact disconformable...........................	8.1
4. Conglomerate, medium-light-gray; rounded to subrounded milky quartz pebbles, calcareous; weathers light-tannish gray; basal contact disconformable.........	.4
3. Limestone; similar to unit 7; about 30 percent quartz sand; weak fracture cleavage; irregularly bedded; 3-in. siltstone bed 2 ft. above base; upper 0.4 ft. dark-gray chert band; basal contact disconformable..	4.0
2. Conglomerate; similar to unit 4; basal contact disconformable......................................	.3
Total thickness of Stormville Member............	24.7

Shawnee Island Member (part):

1. Limestone, medium-gray, fine- to medium-grained, argillaceous and arenaceous; weathers medium-light-tannish gray; irregularly bedded; weak fracture cleavage; slightly limonitic; abundant valves of Gypidula coeymanensis; basal contact concealed.....	13.5
Incomplete thickness of Shawnee Island Member..	13.5
Incomplete thickness of Coeymans Formation.....	38.2

Section 6

Minisink Limestone, New Scotland Formation, and Coeymans Formation, northeast bank of Brodhead Creek at Minisink Hills, Stroudsburg quadrangle, Pennsylvania. Section begins just southeast of collapsed bridge. Bedding dips 40° NW., on the average.

Minisink Limestone (part):

13. Limestone, medium-gray, fine- to medium-grained, argillaceous; weathers medium-light gray; irregularly bedded; weak fracture cleavage; fossils abundant and include brachiopods, bryozoans, and coral fragments; basal and upper contacts concealed..................	7.0
Incomplete thickness Minisink Limestone.........	7.0

New Scotland Formation:

	Thickness (feet)
Maskenozha Member:	
12. Covered..	10.0
11. Shale, dark-gray, slightly calcareous and siliceous; weathers medium gray; scattered pods of medium-dark-gray dense argillaceous limestone in upper 10 ft.; a few beds of purer limestone in upper 10 ft; laminated; conspicuous fracture cleavage; basal 12 ft. contain about 10 percent beds and lenses of medium-gray fine-grained argillaceous fossiliferous limestone; fossils abundant and include Macropleura macropleura, Leptaena "rhomboidalis" and other brachiopods, trilobites, bryozoans, corals, ostracodes, and crinoid columnals; basal contact abrupt and placed at top of first downward appearance of dark-gray chert......................	33.0
Total thickness of Maskenozha Member...........	43.0
Flatbrookville Member:	
10. Shale, dark-gray, slightly calcareous and siliceous; weathers medium gray to medium-light gray; about 10-15 percent lenses and nodules of dark-gray chert; about 10 percent lenses, nodules, and beds of medium-dark-gray fine-grained argillaceous fossiliferous limestone; unit abundantly fossiliferous, having Macropleura macropleura, Leptaena "rhomboidalis," and other brachiopods, bryozoans, trilobites, ostracodes, and crinoid columnals; lenses of fine quartz sand as much as 0.5 ft. wide and 1-2 in. thick at upper contact; basal contact concealed............................	17.0
9. Covered..	7.5
8. Shale, similar to unit 10; basal contact concealed...	5.5
7. Covered..	3.0
Total thickness of Flatbrookville Member.........	33.0
Total thickness of New Scotland Formation........	76.0

Coeymans Formation (part):	Thickness (feet)
Stormville Member:	
6. Sandstone, medium-light-gray, fine- to coarse-grained, calcareous; weathers light tannish gray to orange gray; crossbedded; massive; basal contact concealed...........................	1.9
5. Covered..	11.0
4. Sandstone, conglomerate, and arenaceous limestone lenses juxtaposed, medium-light-gray to medium-gray; weathers light tannish gray; crossbedded; sand and conglomerate stand out in relief upon weathering; scattered crinoid columnals and _Gypidula coeymanensis_; basal contact disconformable..	3.8
Total thickness of Stormville Member..........	16.7
Shawnee Island Member (part):	
3. Limestone, medium-gray, fine-grained, arenaceous and argillaceous; weathers medium light gray; irregularly bedded; unit consists of about 20 percent quartz sand; fossils abundant, crinoid columnals and _Gypidula coeymanensis_; basal contact abrupt...	2.0
2. Limestone; similar to unit 3, but scattered nodules of dark-gray chert make up about 5 percent of unit; basal contact abrupt.............................	2.0
1. Chert, dark-gray, lenticular, 0.5-1 ft thick.........	1.0
Incomplete thickness of Shawnee Island Member.	5.0
Incomplete thickness of Coeymans Formation....	21.7

Section 7

Ridgeley Sandstone and Shriver Chert of the Oriskany Group, Port Ewen Shale, and Minisink Limestone, in roadcut on southwest side of U.S. Interstate Highway 80, approximately 0.4 mile southwest of Minisink Hills, Stroudsburg quadrangle, Pennsylvania. Section begins at road level in the upper beds of the Maskenozha Member of the New Scotland Formation and continues uphill along a construction bench to the top of the Oriskany Group. Section lies along an overturned syncline.

	Thickness (feet)
Oriskany Group:	
Ridgeley Sandstone:	
28. Sandstone, light-gray, fine- to medium-grained, calcareous; weathers brownish orange; grains well rounded to subrounded; leached; brachiopods abundant; basal contact disconformable..............	7.0
27. Conglomerate and sandstone, light-gray, calcareous; weathers orange gray; grains subangular to rounded; milky quartz pebbles as much as 0.5 in. long; unit coarser toward top; massively bedded; low-angle crossbedding; forms ledge at top of roadcut and weathers into large blocks; scattered brachiopod fragments; basal contact gradational................	3.6
26. Sandstone, medium- to light-gray, fine- to coarse-grained, calcareous; weathers orange gray; basal contact abrupt.................................	1.5
25. Sandstone, light-gray, coarse-grained, calcareous; weathers orange gray; grains subangular to rounded; limonitic; scattered dark-gray chert nodules; low-angle crossbedding and horizontal laminations; brachiopod fragments; basal contact disconformable..	1.9
24. Sandstone, medium-gray, fine-grained, silty, calcareous; weathers light-tannish gray to orange gray; massive; sparingly fossiliferous; basal contact gradational................................	1.3
23. Conglomerate, light-gray, fine-grained, calcareous; weathers orange gray; basal contact disconformable..	.6
Total thickness of Ridgeley Sandstone...........	15.9

Oriskany Group--Continued

	Thickness (feet)
Shriver Chert:	
22. Limestone, medium-gray, fine-grained, arenaceous and argillaceous; weathers tannish gray; nodules and lenses of dark-gray chert; sparingly fossiliferous; basal contact disconformable........................	1.3
21. Conglomerate and sandstone; similar to unit 27; basal contact disconformable........................	.3
20. Chert, dark-gray; scattered lenses of medium-gray fine-grained argillaceous limestone; basal contact disconformable....................................	.6
19. Conglomerate and sandstone; similar to unit 27; basal contact disconformable........................	.3
18. Chert, dark-gray; lenses of medium-gray fine-grained argillaceous fossiliferous limestone and sandstone; partly burrowed; basal contact disconformable......	6.3
17. Conglomerate and sandstone; similar to unit 27; milky quartz pebbles as much as 0.5 in. long; horizontally bedded to low-angle crossbedding; detrital chert; basal contact disconformable........................	.5
16. Chert, dark-gray; brachiopod shell hashes, dominantly spiriferid brachiopods, shell material composed of coarse-grained calcite which leaches upon weathering leaving numerous molds; coarse-grained calcareous sandstone as much as 0.6 ft. thick; unit contains detrital chert; laminations in fine-grained sandstone; basal contact disconformable................	5.6
15. Chert, dark-gray; basal contact disconformable.......	.8
14. Sandstone and conglomerate. Sandstone coarse-grained; conglomerate calcareous. Unit become finer grained toward top; low-angle crossbedding; basal contact disconformable....................................	.5
13. Chert, dark-gray, massive; nodules and lenses of medium-dark-gray fine-grained siliceous limestone; unit poorly fossiliferous; burrow mottles in limestone and chert; basal contact disconformable......	12.7

Shriver Chert--Continued

	Thickness (feet)
12. Sandstone and conglomerate. Sandstone coarse grained; conglomerate fine grained, calcareous. Grains subangular to rounded. Horizontally bedded to low-angle cross-stratification. Unit variable in thickness; fossils rare; basal contact disconformable..	1.7
11. Chert and calcisiltite. Chert is dark gray and occurs as irregular beds and pods; spiriferid brachiopod hashes. Calcisiltite is medium-dark gray, fine grained, siliceous. A 5-in. thick coarse to very coarse sandstone occurs near top of unit. Many burrow mottles in fine-grained beds; basal contact at base of fossil hash..............................	10.6
10. Limestone, medium-dark-gray, fine-grained, silty, siliceous; weathers light gray to medium gray; massively bedded; nodules and lenses of dark-gray chert; trilobites locally abundant; very fossiliferous; abundant burrow mottles; basal contact placed at top of brachiopod hash........................	23.7
9. Limestone, medium-dark-gray, fine-grained, argillaceous, silty, siliceous; weathers light-tannish gray; irregularly bedded; burrow mottled; chert intraclasts; many spiriferid brachiopods; basal contact placed at base of brachiopod hash..........	10.7
8. Chert, dark-gray; about 40 percent dark-gray siliceous shale with pockets of dark-gray fine-grained poorly fossiliferous limestone; burrow mottled; basal contact gradational.................	6.8
7. Chert, dark-gray; nodules and lenses of medium-dark-gray fine-grained siliceous and argillaceous limestone and calcareous shale; poorly fossiliferous; basal contact sharp, placed at first appearance of dark-gray chert..	2.3
Total thickness of Shriver Chert...............	84.7
Total thickness of Oriskany Group..............	100.6

	Thickness (feet)
Port Ewen Shale:	
6. Shale, calcareous, silty, siliceous, medium-dark-gray; weathers light-tannish gray; slightly pyritic; irregularly bedded; conspicuous cleavage; fossiliferous, having corals, brachiopods, ostracodes, trilobites, and crinoid columnals; more calcareous beds contain abundant small burrows (about $\frac{1}{4}$ in. in diameter); basal contact gradational and marked by increase in silt..............	44.5
5. Shale, medium-dark-gray, silty, calcareous; weathers light-tannish gray; pyritic; conspicuous cleavage; massively bedded; scattered brachiopods and corals; unit contains fewer silty laminae than underlying unit; basal contact gradational...................	44.7
4. Shale, medium-dark-gray, silty, calcareous; weathers light-tannish gray; slightly pyritic; irregularly laminated, because of alternations of silty and less silty beds; poorly fossiliferous; fossils disrupted by cleavage; more calcareous beds have rare burrows; basal contact at 1-ft.-wide calcite-filled fault zone, displacement probably not more than a few feet...	43.5
3. Shale, medium-dark-gray, silty, calcareous; weathers light-tannish gray; irregularly laminated, owing to alternations of silty and less silty beds; poorly fossiliferous; basal contact abrupt................	18.0
Total thickness of Port Ewen Shale.............	150.7
Minisink Limestone:	
2. Limestone, medium-gray, fine-grained argillaceous; weathers light-tannish gray; irregularly bedded; beds as much as 3 ft. thick; thin interbeds of calcareous shale; fracture cleavage; fossils mostly fragmental and include corals, bryozoans (mainly fenestellids), brachiopods, and crinoid columnals; basal contact sharp..............................	14.0
Total thickness of Minisink Limestone..........	14.0

New Scotland Formation (thickness not measured):

Thickness (feet)

Maskenozha Member (thickness not measured):

1. Shale, dark-gray, calcareous and siliceous; weathers medium-light-tannish gray; laminated; poorly exposed.

Section 8

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 south.

Buttermilk Falls Limestone (part):

Foxtown Member (part):

5. Limestone, medium-gray, silty, containing large crinoid columnals as much as 1 in. in diameter; weathers light gray and buff. Irregular chert lenses and pods as much as 5 in. long concentrated in more calcareous beds. Irregular wavy-bedded and interbedded calcarenite (as much as 5 in. thick) and calcilutite. Calcilutite is the minor component (approximately 25 percent of unit) and occurs as thin lenses, laminae, and beds as much as 1 in. thick. Burrow mottled. Chert, dark-gray; calcarenite, medium-gray, weathers medium-light gray to light gray; calcilutite, medium-dark-gray, weathers medium gray. Chert makes up about 5 percent of unit near base. Chert replaces limestone; fossils and burrows are within chert. Chert forms halo around more calcareous segregations. Basal contact abrupt and is about 5 ft. above road level at culvert.. 25.0

Incomplete thickness of Foxtown Member of the Buttermilk Falls Limestone................ 25.0

Schoharie Formation:

4. Siltstone, calcareous, massive, evenly bedded. Contains scattered dark-gray 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 to grayish-black, fossiliferous (brachiopods), irregularly bedded, shaly siltstone. Lowest bed contains a 2-in.-thick grayish-black chert lens which is about 3 ft. long and about

	Thickness (feet)
4 in. above the base of unit; chert is more abundant above 31 ft. above base of unit. Above 51 ft. above base of unit 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. Fossiliferous. Irregular lenses, beds, and pods of more calcareous calcisiltite somewhat burrow mottled with vertical shale-filled burrows approximately $\frac{1}{2}$ in. in diameter and 1-2 in. long. More extensively burrow mottled and less laminated toward top of unit. Contains scattered shale chips (inclined about 45° to the horizontal) is as much as 2 in. long..................	66.0
3. Siltstone, calcareous, massive, evenly bedded; beds range from about 4 in. to 16 in. thick; fossiliferous.......	7.0
2. Siltstone, calcareous, dark-gray, massive, laminated; in beds from a few inches to as much as 3 ft. thick; contains minor interbedded calcareous shaly siltstone; contact with Esopus is gradational. Base of Schoharie is placed at the first massive siltstone encountered going up section; cleavage is not as well developed as in the Esopus; when hit with a hammer the Schoharie yields a "firmer" ring as compared to duller sound of the Esopus; no chert; fairly well developed cleavage. Abundant _Taonurus caudigalli_. Unit becomes more unevenly bedded and laminated and more calcareous toward top with interlensings of more calcareous coarser grained calcisiltite and less calcareous calcisiltite. Becomes slightly burrow mottled toward top. Most burrowing is horizontal..................	30.0
Thickness of Schoharie Formation.................	103.0

Esopus Formation (part, thickness not measured):

1. Dark-gray, highly cleaved shaly, laminated siltstone; calcareous locally and containing _Taonurus caudigalli_.

Section 9

Schoharie Formation and Foxtown, McMichael, and Stroudsburg Members of the Buttermilk Falls Limestone in railroad cut of the Erie-Lackawanna Railroad, 1 mile south of the East Stroudsburg post office, Stroudsburg quadrangle, Pennsylvania. The center of the cut is in the Schoharie Formation and in the crest of an overturned anticline. Beds of the Buttermilk Falls Limestone to the north are overturned as much as 55° to the southeast.

Buttermilk Falls Limestone:

	Thickness (feet)
Stroudsburg Member:	
6. Limestone, medium-dark-gray, fine- to medium-crystalline, medium-light-gray to light-gray-weathering, irregularly interbedded and lenticular, fossiliferous; and grayish-black to dark-gray chert. Beds and lenses about 1 in. to 1 ft. thick. Chert and limestone in about equal proportions. Upper 15 ft. contains three beds that are 3 in. to 6 in. thick of medium-gray to medium-light-gray, light-gray-weathering, medium- to very coarsely crystalline limestone with abundant brachiopod debris. Contact with overlying Union Springs Member of the Marcellus Shale not exposed but is probably close	90.0
5. Shale, calcareous, medium-gray, silty, with some medium-gray to medium-light-gray, light-gray-weathering, fine- to medium-crystalline limestone pods up to 2 in. in diameter	3.0
4. Limestone, medium-gray to medium-dark-gray, light-gray to medium-light-gray-weathering, finely to medium-crystalline, locally argillaceous and fossiliferous; in irregular beds, lenses, and pods 1 in. to 1 ft. thick, and dark-gray to grayish-black chert in irregular pods, lenses, and discontinuous beds ¼ in. to 8 in. thick	56.0
Thickness of Stroudsburg Member	149.0
McMichael Member:	
3. Shale, medium-gray to medium-dark-gray, medium-gray-weathering, calcareous, partly silty, evenly bedded to lenticular, fossiliferous; in beds 2 in. to 1 ft. thick; interbedded with medium-gray finely crystalline 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 appearance of chert and disappearance of argillaceous beds	41.0
Total thickness of McMichael Member	41.0
Foxtown Member:	
2. Limestone, medium-gray to medium-dark-gray, light-gray to medium-light-gray-weathering, finely to very coarsely crystalline, irregularly bedded to lenticular, in beds 1 in. to 2 ft. thick, interbedded	

Buttermilk Falls Limestone--Continued

Thickness (feet)

Foxtown Member--Continued

with medium-dark-gray, calcareous, evenly bedded shale and siltstone in beds 1 in. to 1 ft. thick, and grayish-black to dark-gray chert. Chert in lower half occurs as irregular nodules $\frac{1}{2}$ in. to 6 in. in diameter. Chert becomes more abundant in upper half where it makes up more than 50 percent of unit and contains interbeds of calcareous argillite 1-2 in. thick and limestone pods 2-6 in. in diameter. Large crinoid columnals with cross-sectional diameters up to 1 in. are conspicuous in lower half. Abundant ostracodes. Base marked by 1-ft.-thick, medium-gray, light-gray-weathering, medium- to very coarse grained limestone in abrupt contact with underlying Schoharie. Contact with overlying McMichael Member transitional over 4-ft. interval.................................... 82.0

Total thickness of Foxtown Member................ 82.0

Total thickness of Buttermilk Falls Limestone.... 272.0

Schoharie Formation (part):

1. Siltstone, medium-gray to medium-dark-gray, finely sandy to argillaceous, calcareous to noncalcareous; in beds up to 5 ft. thick. Becomes sandier towards top. Base not exposed.............................. 58.0

Incomplete thickness of Schoharie Formation.... 58.0

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