STRUCTURE AND STRATIGRAPHY ABOVE, BELOW, AND WITHIN THE TACONIC UNCONFORMITY, SOUTHEASTERN NEW YORK

By

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INTRODUCTION

In the early Paleozoic, carbonate banks lay along the east coast of the ancient North American continent. In Ordovician time, plate convergence commenced the closing of the ancient proto-Atlantic ocean (Iapetus) and a deep basin developed into which thick muds and dirty sands were deposited. These were later to harden and become the Martinsburg Formation. Later still, with continued compression, the sediments were folded and faulted during the complex deformation of the Taconic Orogeny. In the field trip area the trend of these folds and faults is about N. 20° E. These structures become less intense westward. Following Taconic deformation, mountains rose to the east and coarse sediments were transported westward and deposited as sandstones and conglomerates of the Shawangunk Formation across beveled folds of the Martinsburg Formation. However, a thin diamictite with exotic pebbles records a heretofore unreported geologic episode which occurred during the Taconic hiatus. As the mountains were worn down, finer clastic sediments and carbonates were deposited more or less continuously through the Middle Devonian. Clastic influx during the Middle Devonian records a later orogeny, the Acadian. It is probable that the structural effects of this orogeny did not extend as far west as this field trip area; the limit of Acadian folds, faults, and igneous intrusions lies to the east. Finally, near the end of the Paleozoic, continental collision deformed all rocks, down to and below the Martinsburg. The trends of these later (Alleghanian) structures are more northeasterly.

On this field trip we will develop new interpretations of Ordovician and Silurian stratigraphy, demonstrate structural zones at the limits of Taconic deformation, investigate the relative effects of Taconic, Acadian, and Alleghanian deformation in southeastern New York, and discuss the strange goings-on in a thin enigmatic unit at the unconformity between the Martinsburg and Shawangunk Formations. We will see a variety of complex structures within three Taconic tectonic zones (Stops 1, 2, 5, 6, 7, and 8), examine the nature of, and deposits at, the Taconic unconformity (Stops 2, 5, and 8), review some of the proposed facies relationships in Silurian rocks (Stops 3, 7, and 8), and, weather permitting, look out over the regional geology from high atop the Shawangunk Mountains during lunch (Stop 4).

In the case of disastrous weather, alternate Stops 1A and/or 1B may be substituted for Stop 1. These stops would allow a brief look at a melange zone of Taconic age, albeit not as spectacular as at Stop 1, and a thrust fault zone of Alleghanian age, both in the Martinsburg Formation.

STRATIGRAPHY

A generalized description of the stratigraphic units in the field trip area is given in table 1. Because we will concentrate on rocks just above and below, as well as "within" the Taconic unconformity, certain details of these rocks are described below.

Table 1. Generalized stratigraphy in field trip area. Please note that stratigraphic terminology for rocks above the Onondaga Limestone is not well established in this area (see Rickard, 1964).

PLATTEKILL FORMATION of Fletcher (1962) (Middle Devonian): Red and gray shale, siltstone and sandstone. 500+ feet thick.

ASHOKAN FORMATION (Middle Devonian): Thin- to thick-bedded, olive-gray sandstone, and minor siltstone and shale. 500-700 feet thick.

MOUNT MARION FORMATION (Middle Devonian): Olive-gray to dark-gray, platy, very fine- to medium-grained, sandstone, siltstone, and shale. Probably more than 1000 feet thick.

BAKOVEN SHALE (Middle Devonian): Dark-gray shale. 200-300 feet thick.

ONONDAGA LIMESTONE (Middle Devonian): Cherty fossiliferous limestone. From top to bottom, Moorehouse, Nedrow, and Edgecliff Members. 100 feet thick.

SCHOHARIE FORMATION (Lower Devonian): Thin- to medium-bedded, calcareous mudstone and limestone; more calcareous upwards. From top to bottom, Saugerties, Aquetuck, and Carlisle Center Members as redefined by Johnsen and Southard (1962). 180-215 feet thick.

ESOPUS FORMATION (Lower Devonian): Dark, laminated and massive, non-calcareous, siliceous, argillaceous siltstone and silty shale. 200 feet thick; thickens to southwest.

GLENERIE FORMATION of Chadwick (1908) (Lower Devonian): Siliceous limestone, chert, and shale, thin- to medium-bedded. 50-80 feet thick.

CONNELLY CONGLOMERATE (Lower Devonian): Dark, thin- to thick-bedded pebble conglomerate, quartz arenite, shale, and chert. 0-20 feet thick.

PORT EWEN FORMATION (Lower Devonian): Dark, fine- to medium-grained, sparsely fossiliferous, calcareous, partly cherty, irregularly bedded mudstone and limestone. 70-125? feet thick; 180 feet thick near Port Jervis, N. Y.

ALSEN LIMESTONE (Lower Devonian): Fine- to coarse-grained, irregularly bedded, thin- to medium-bedded, argillaceous and partly cherty limestone. 20 feet thick.

BECRAFT LIMESTONE (Lower Devonian): Massive, very light- to dark-gray and pink, coarse-grained, crinoidal limestone, with thin-bedded limestone with shaly partings near the bottom in places. 30-50 feet thick; thins towards High Falls; 3 feet thick near Port Jervis, N. Y.

NEW SCOTLAND FORMATION (Lower Devonian): Calcareous mudstone and silty, fine- to medium-grained, thin- to medium-bedded limestone. May contain some chert. 100 feet thick.

KALKBERG LIMESTONE (Lower Devonian): Thin- to medium-bedded, moderately irregularly bedded limestone, finer grained than Coeymans Formation below, with abundant beds and nodules of chert and interbedded calcareous and argillaceous shales. 70 feet thick.

RAVENA LIMESTONE MEMBER OF THE COEYMANS FORMATION (Lower Devonian): Wavy bedded, fine- to medium-grained and occasionally coarse-grained, limestone with abundant thin shaly partings. 15-20 feet thick.

THACHER MEMBER OF THE MANLIUS LIMESTONE (Lower Devonian): Laminated to thin-bedded, fine-grained, cross-laminated, graded, microchanneled, mudcracked, locally biostromal limestone with shale partings. 40-55 feet thick.

RONDOUT FORMATION (Lower Devonian and Upper Silurian): Fossiliferous, fine- to coarse-grained, thin- to thick-bedded limestone and barren, laminated, argillaceous dolomite: Limestone lentils come and go, and the more persistent ones have been named (from top to bottom): Whiteport Dolomite, Glasco Limestone, and Rosendale Members. 30-50 feet thick.

BINNEWATER SANDSTONE of Hartnagel (1905) (Upper Silurian): Fine-grained, thin- to thick-bedded, crossbedded and planar-bedded, rippled quartz arenite , with gray shale and shaly carbonate. Probably grades southwestwardly into the Poxono Island Formation. 0-35 feet thick.

POXONO ISLAND FORMATION (Upper Silurian): Poorly exposed gray and greenish dolomite and shale, possibly with red shales in the lower part. 0-500 feet thick.

HIGH FALLS SHALE (Upper Silurian): Red and green, laminated to massive, calcareous shale and siltstone, occasional thin argillaceous limestone and dolostone. Ripple marks, dessication cracks. 0-80 feet thick.

BLOOMSBURG RED BEDS (Upper Silurian): Grayish-red and gray shale, siltstone, and sandstone. 0-700 feet thick.

TONGUE OF THE BLOOMSBURG RED BEDS: Grayish-red siltstone and shale and slightly conglomeratic, partly crossbedded sandstone with pebbles of milky quartz, jasper, and rock fragments, and gray sandstone. 0-300 feet thick.

SHAWANGUNK FORMATION (Middle Silurian): Crossbedded and planar-bedded, channeled, quartz-pebble conglomerate (rose quartz conspicuous in upper part), quartzite, minor gray, shale and siltstone, and lesser red to green shale. Lower contact unconformable. 0-1,400 feet thick.

TONGUE OF THE SHAWANGUNK FORMATION: Crossbedded, cross-laminated (distinctive very-light and medium-dark-gray laminae), and planar bedded, thin- to thick-bedded, medium-grained quartzite and conglomerate with quartz pebbles as much as 2 in long and greenish-gray silty shale and siltstone. 0-350+ feet thick.

"WEIRD ROCKS" (Lower Silurian or Upper Ordovician): Diamictite (colluvium and shale-chip gravel with exotic pebbles) and fault gouge of sheared clay and quartz veins. Lower contact unconformable. Less than 1 foot thick.

MARTINSBURG FORMATION (Upper and Middle Ordovician): Greater than 10,000 feet thick.

SHALE AND GRAYWACKE AT MAMAKATING: Dominantly thick sequences of thin- to medium- bedded, medium dark gray shale interbedded with very thin to thick-bedded graywacke (as much as 6 ft thick) alternating with thinner sequences of medium-bedded graywacke interbedded with less thin- to medium- bedded shale. Grades downward and laterally into the sandstone at Pine Bush.

SANDSTONE AT PINE BUSH: *Medium-grained, medium- to thick-bedded, medium gray, speckled light-olive-gray- and light-olive-brown-weathering quartzitic sandstone interbedded with, and containing rip-ups of, thin- to medium-bedded, medium-dark-gray, greenish gray-weathering shale and fine-grained siltstone. Lower contact with Bushkill Member is interpreted to be conformable, but in many places it is marked by a thrust fault. Grades upward and laterally in the shale and graywacke at Mamakating.*

BUSHKILL MEMBER: *Laminated to thin-bedded shale and slate containing fine-grained graywacke siltstone. Bed thickness of shales does not exceed 2 in and bed thickness of graywackes rarely exceeds 12 in. Lower contact conformable with underlying Balmville Limestone of Holzwasser (1926), but often disrupted by thrust faulting.*

Ordovician Rocks
(Rocks below the Taconic unconformity)

There has been, and continues to be, a great deal of confusion when dealing with the Ordovician clastic sediments of southeastern New York State. A brief (and by no means exhaustive) review highlighting some of the earlier work in these rocks is helpful to emphasize the complex history of names, and establish proper correlation of units. The rocks that we concentrate on in this guidebook, all of which are considered to be members of the Martinsburg Formation, underlie the Wallkill Valley from south of Rosendale, New York, to the New Jersey border (fig. 1).

In the Wallkill Valley, a thick section of glacial deposits covers much of the bedrock. In so far as this makes structural analysis of the rocks in places difficult, if not impossible, this has a definite influence on resolving the stratigraphy. The tracing of faults and sometimes folds in the Ordovician rocks is extremely difficult, which explains why we and other geologists such as Vollmer (1981) and Kalaka and Waines (1986) have chosen to divide map areas into structural domains that can be defined in general descriptive terms. Added to this is the century-old problem regarding which Ordovician clastics in the Hudson Valley region are part of the far-traveled Taconic allochthon and which are part of the parautochthonous flysch that rests conformably on Middle Ordovician carbonates of the North American shelf. This is a problem which seems to be satisfactorily resolved to the southwest in New Jersey and Pennsylvania (Lash and Drake, 1984; Lash, 1985; Perissoratis and others, 1979; Lash, Lyttle, and Epstein, 1984) but remains a critical problem in parts of southern New York State, particularly along the Hudson River. There is an irony to this, since the existence of the far-travelled rocks was recognized much later in Pennsylvania (Stose, 1946) than in New York.

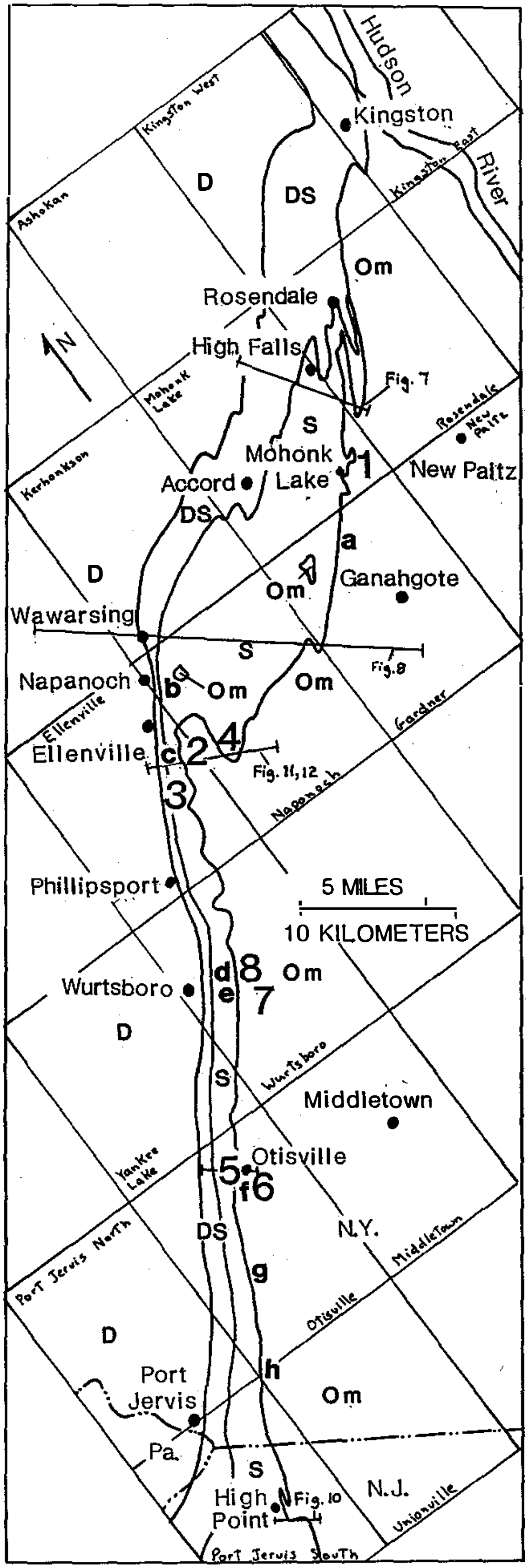


Figure 1. Generalized geologic map of part of southeastern New York showing field trip stop numbers, localities where the unconformable contact between the Martinsburg and Shawangunk Formations have been studied (small letters), location of cross sections, and 7.5-minute-quadrangle coverage.

a. Trapps
b. Napanoch
c. Mt. Meenahga
d. N.Y. Route 17
e. Abandoned railroad tunnel
f. Otisville
g. Guymard prospect
h. Interstate 84

D Rocks of the Hamilton Group (Plattekill, Ashokan, Mount Marion, and Bakoven Formations) and younger

DS Rocks between the Onondaga Limestone and Binnewater Sandstone-Poxono Island Formation

S High Falls Shale, Shawangunk Formation, Bloomsburg Red Beds, and tongues of the Shawangunk and Bloomsburg

Om Martinsburg Formation

Mather (1840) first proposed the name "Hudson River slate group" for rocks that he had previously referred to as "transition argillite" (1839). Subsequently, this name has seen at least 7 variants including Hudson River Series, Hudson River Group, and Hudson River Formation. In addition to the variations in the name, the use of these names has been extended north into Canada and as far west as Wisconsin. Holzwasser (1926) gives a useful account of the tortured history of Hudson River nomenclature; unfortunately, she also decided to use the name Hudson River formation for the shales and graywackes of the Newburgh Quadrangle. Although the name has generally been abandoned since Ruedemann's work in the beginning of this century, it is still loosely used and misused in a variety of publications to this day. Ruedemann (1901, p. 561) first used the name Normanskill Shale for rocks in the gorge of the Normans Kill near Kenwood, New York. This type locality turns out to be one of the more spectacular exposures of melange in the northern Appalachians, as attested to by the extremely detailed mapping of the structures by Vollmer (1981). It should not be too surprising, therefore, that there has also been considerable confusion in the use of this geologic name. Later, when mapping the Catskill quadrangle, Ruedemann (1942) recognized two belts of rock that he included in the Normanskill Shale. The western "grit belt" was named the Austin Glen Member and the eastern "chert belt" was named the Mount Merino Member. Most geologists today would agree that both of the type localities for these members are within the Taconic allochthon (sensu stricto); that is, the rocks are part of the far-traveled slope-rise sequence. The name Snake Hill Shale was first used by Ulrich (1911), although he based his discussion on the work of Ruedemann who later published a number of papers using this name (1912, for example). The type locality for this unit is on the east side of Saratoga Lake. Berry (1963) suggested abandoning the name because restudy of this region showed that what was mapped as Snake Hill contains three different lithic units all of which contain elements of the distinctive fauna which Ruedemann used as the unit's diagnostic feature. This points to yet another problem in the nomenclature of the clastics of the Hudson Valley region. Ruedemann and others often failed to discriminate between biostratigraphic and lithostratigraphic units, making it extremely difficult for later workers to fully appreciate the problems inherent in using a particular name.

More recently, Fisher (1962) and Offield (1967) have used the names Mount Merino Shale, Austin Glen Graywacke, and Snake Hill Shale for the lower, middle and upper units of the parautochthonous Middle and Upper Ordovician shales and graywackes that are found west of the Hudson River in the Wallkill Valley. Later, Fisher (1969; 1977; in Fisher and others, 1970) made a number of modifications to the mapping and naming of Ordovician clastic units in the vicinity of the Hudson River at the latitude of our field trip, but very little new work closer to the unconformable contact with the Silurian Shawangunk to the west has been published. For a summary of the most recent work near the Hudson River, particularly in the region underlying Marlboro and Illinois Mountains, see Waines (1986).

Offield (1967) produced a wealth of new stratigraphic and structural information in the Goshen 15-minute quadrangle (Middletown, Goshen, Warwick, and Pine Island 7.5-minute quadrangles) and recognized that his units might correlate with Behre's (1933) tripartite subdivision of the Martinsburg Formation in Pennsylvania. This subdivision was later refined by Drake and Epstein (1967) who recognized a lower thin-bedded slate unit called the Bushkill Member, a middle graywacke-rich unit called the Ramseyburg Member, and an upper thick-bedded slate unit called the Pen Argyl Member. Berry (1970) was one of several people to recognize significant similarities between the Delaware Valley sequence of Drake and Epstein and the sequence of rocks in the Wallkill Valley (Fisher, 1962; Offield, 1967). We feel that all of the names that Offield (1967) chose for the units of what he refers to as "the shale sequence" in the Wallkill Valley should be discontinued. One reason to do this is to avoid unnecessary confusion with the Normanskill Shale and its members that are clearly part of the far-traveled Taconic allochthon. Another reason, which is even more important, is that a better correlation can be made with units mapped in Pennsylvania and New Jersey. We have not done all of the detailed mapping that is necessary to establish these correlations in detail, but we feel confident that the correlations proposed herein are correct overall.

We believe that it is appropriate to refer to all of the parautochthonous Ordovician clastics in the Wallkill Valley as the Martinsburg Formation of Middle to Upper Ordovician age. Virtually all of the Ordovician clastics in the Great Valley from eastern Pennsylvania through northern New Jersey to the New York State border have been mapped in detail (1:24,000 scale) in the last 20 years, and much of it in the last 10 years. The parautochthonous sequence west and southwest of Albany, New York, is not contiguous with the rocks of the Wallkill Valley; nor has the stratigraphy of the rocks near Albany been done in sufficient detail to warrant using the names established for that area in the Wallkill Valley.

There has been debate in eastern Pennsylvania over whether the Martinsburg is a tripartite sequence with a lower slate member, a middle graywacke member, and an upper slate member, or a bipartite sequence with an upper graywacke member and a lower slate member (see Lash, Lyttle, and Epstein, 1984, for a summary of this debate). We feel strongly that the published detailed mapping, which ultimately must answer all questions of this sort, supports the tripartite subdivision first discussed by Behre (1933) and later named along the Delaware Valley by Drake and Epstein (1967). The question that must now be answered, is how far away from the Delaware Valley can the three members of the Martinsburg be mapped? The upper Pen Argyl Member, which contains thick-bedded slates (up to 25 ft thick), has been extensively quarried in Pennsylvania from the New Ringgold 7.5-minute quadrangle in the west to the Stroudsburg 7.5-minute quadrangle in the east where it disappears beneath the Silurian Shawangunk Formation. Based on our mapping and that of other geologists, it is not found in northern New Jersey and southern New York. However, the Pen Argyl correlates in part with rocks that we have mapped in the western Wallkill Valley unconformably beneath the Shawangunk, and that we are herein informally naming the shale and graywacke at Mamakating, subsequently called the Mamakating (fig. 2, table 1, and the discussion at Stop 7). The Mamakating represents the upper part of the Martinsburg in the western Wallkill Valley and is named for the excellent exposure seen at Stop 7 along Route 17 (just east of Wurtsboro exit) in the eastern part of the Mamakating Township.The Mamakating first appears from beneath the Shawangunk in the Otisville 7.5-minute quadrangle, New York and extends northeastward. All of the Martinsburg we shall be seeing on this field trip is within the Mamakating. The Ramseyburg Member extends from the New Tripoli, 7.5-minute quadrangle, Pennsylvania to the Middletown 7.5-minute quadrangle, New York. To the northeast it correlates for the most part with a unit that we are herein informally calling the sandstone at Pine Bush, subsequently called the Pine Bush (fig. 2, table 1). The sandstone at Pine Bush extends from the High Point area of New Jersey through the Middletown and Pine Bush 7.5-minute quadrangles, New York, where it is thickest, and appears to die out somewhere in the vicinity of the southwest corner of the Gardiner 7.5-minute quadrangle. There are excellent exposures of the Pine Bush along Route 17K that underlie the unnamed hills 1.6 miles west of Montgomery, New York, in the Pine Bush 7.5-minute quadrangle. Since the details of the facies changes in the middle and upper Martinsburg have not been sufficiently mapped in southern New York State, it is safest to say that the combined Ramseyburg and Pen Argyl correlates with the combined Pine Bush and Mamakating. It may eventually be determined that the Pen Argyl correlates with all of the Mamakating and the uppermost Pine Bush. The lower Bushkill Member of the Martinsburg has, by far, the greatest areal extent of the three members of Drake and Epstein (1969). It extends as far southwest as Reading, Pennsylvania (and probably considerably farther) and northeast at least as far as the Newburgh, New York area. We have not done sufficient detailed mapping in the central part of the Wallkill Valley to confidently work out precise stratigraphic relations of the Mamakating and the Pine Bush, nor do we know in detail how these units correlate with the Pen Argyl and Ramseyburg Members of the Martinsburg. Figure 2 portrays our current state of understanding.

The Mamakating is everywhere unconformably overlain by the Shawangunk Formation. It grades conformably downward and laterally into the Pine Bush, and the contact is arbitrarily put where beds of medium-grained, clean protoquartzite make up more than 5% and are thicker than 2 inches. In most places in the Wallkill Valley the Pine Bush grades upward into the Mamakating,

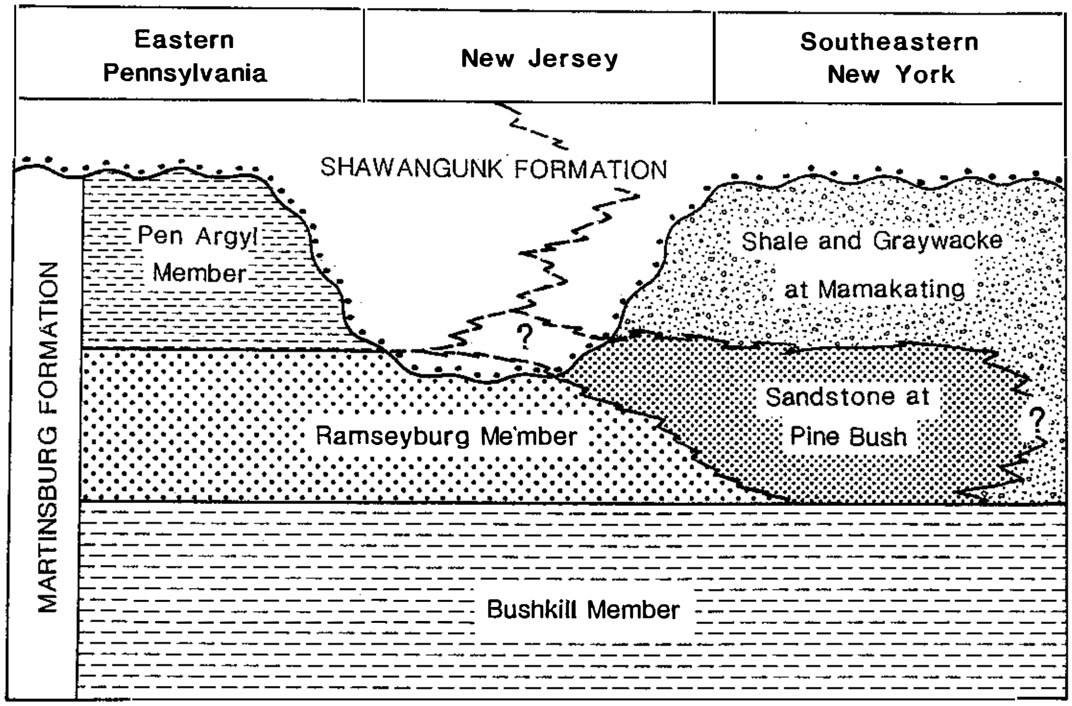


Figure 2. Preliminary correlation diagram showing members of the Martinsburg Formation of Ordovician age from eastern Pennsylvania to southern New York. The shale and graywacke at Mamakating and the sandstone at Pine Bush are named informally for the first time in this guidebook. Evidence for the facies relations between the Pen Argyl and Ramseyburg Members to the southwest and the Mamakating and Pine Bush to the northeast has been removed by erosion beneath the Taconic unconformity or may lie beneath the Shawangunk Formation to the northwest of the outcrop area of the Martinsburg. These inferred relations are shown by dashed lines.

but to the southwest near High Point, New Jersey, it is unconformably overlain by the Shawangunk Formation. We have not done enough detailed mapping in the Pine Bush, Walden, and Gardiner 7.5-minute quadrangles, New York, to resolve what happens to the Pine Bush to the northeast. From reconnaissance, it would appear to pinch out and grade laterally into the Mamakating somewhere near the northeast corner of the Pine Bush quadrangle.

Several very general points can be made about the Martinsburg Formation. From eastern Pennsylvania to the field trip area in southern New York, the composite thickness of the Martinsburg appears to remain fairly constant with ranges estimating from about 8,000 to 12,800 feet. It is possible that the thickness decreases going towards the northeast, perhaps by as much as 3,000 feet. All thickness estimates may be on the generous side, because of the large number of thrust faults that duplicate portions of the unit, particularly the lower Bushkill Member.

The sedimentology of the lower part, or Bushkill Member, of the Martinsburg remains remarkably constant along strike from eastern Pennsylvania through southern New York. However, the middle part of the Martinsburg shows considerable facies variation along strike. To the southwest in Pennsylvania, the Ramseyburg Member rarely contains more than 20% medium- to very thick bedded graywacke beds. Also going up-section in the Ramseyburg, the thickness of slate beds increases dramatically near the contact with the Pen Argyl. From High Point, New Jersey northward, the Pine Bush commonly contains up to 50% clean, medium- to very thick bedded sandstone, and as best as we can tell from reconnaissance, the thickness of shale beds does not increase going up in section. Both of these factors would appear to suggest that the middle part of the Martinsburg is becoming more proximal to the northeast. The upper part of the Martinsburg also shows dramatic facies changes along strike. Although this part of the section is dominated by shales or slate everywhere, in eastern Pennsylvania, slate beds in the Pen Argyl Member are commonly 12 feet thick, and can be as thick as 25 feet. In New York, the shale beds in the Mamakating rarely exceed 3 inches in thickness.

Silurian Rocks

(Rocks above the Taconic unconformity)

The stratigraphic relations of Silurian rocks, especially in the lower part,in southeastern New York, especially in the lower part, have been poorly understood (Fisher, 1959, Rickard, 1962,). The presently accepted sequence is, from the base upwards, the Shawangunk Formation, High Falls Shale, Binnewater Sandstone of Hartnagel (1905), and Rondout Formation (See Table 1 for a general description of these rocks). The stratigraphic identification and regional relations of rocks between the

Rondout Formation and Onondaga Limestone are fairly well known. The sequence of Shawangunk-High Falls-Binnewater in the northern part of the field trip area is firmly established. However, our recent mapping suggests that the facies mosaic of most of the Silurian rocks is a bit more complex than previously envisioned, and a revision of some stratigraphic interpretations is necessary. Figure 3 shows the present stratigraphic interpretation. Work is still in progress, so some details will most certainly be changed.

Regionally, the Silurian sequence thins dramatically between eastern Pennsylvania and southeastern New York, (fig. 4). The Shawangunk Formation of eastern Pennsylvania consists of three quartzite-conglomerate units (Weiders, Minsi, and Tammany Members) and a unit containing appreciable shale and some red beds (Lizard Creek Member) (Epstein and Epstein, 1972). Farther southwest, only a basal quartzite (Tuscarora Sandstone) and shale-sandstone sequence (Clinton Fomration) can be recognized (Lyttle, Lash, and Epstein, 1986). In New Jersey, the shales of the Lizard Creek become less abundant and the unit can no longer be mapped in the middle of the state, but scattered beds and intervals of shale persist into southeastern New York. These shales are generally not mappable and appear to be present at various levels within the Shawangunk (fig. 3). Recent mapping in the Ellenville and Naponoch area has allowed us to divide the quartzites and conglomerates of the Shawangunk into lower and upper units, separated by a "shale" unit about 100 feet thick. Actually this unit contains more sandstone and siltstone than shale, but it is distinctive and mappable. It thins to the northeast to where it is generally unmappable. Locally it may contain red beds, just as in the Lizard Creek Member in eastern Pennsylvania. Friedman (1957) divided the Shawangunk in the Ellenville area into three members. Our "shale" unit may be his Minnewaska member, separating his Mohonk conglomerate below from his Ellenville member above. The exact relation between his and our units is uncertain, however. It is possible that his Ellenville member may contain some rocks that we place in the tongue of the Bloomsburg and the tongue of the Shawangunk. Some shales in the Shawangunk were believed by Swartz and Swartz (1931) to be abundant enough near Otisville that they named the interval the "Otisville Shale". The "Otisville Shale", however, fails the test of mappability. In the type area, which we shall see near Stop 5, the Shawangunk consists predominantly of quartzites and conglomerates with scattered interbedded shale. Nowhere are the shales concentrated enough to form a separate mappable unit. As a matter of fact, Clarke (1907) measured the Shawangunk in great detail west of Otisville, and of the 420 feet measured, less than three percent were shale, and these beds were scattered throughout the sequence.

The Bloomsburg Red Beds overlies the Shawangunk in eastern Pennsylvania and New Jersey (fig. 4). The contact is transitional, in places through about 700 feet of rock, as at Delaware Water Gap at the New Jersey-Pennsylvania border

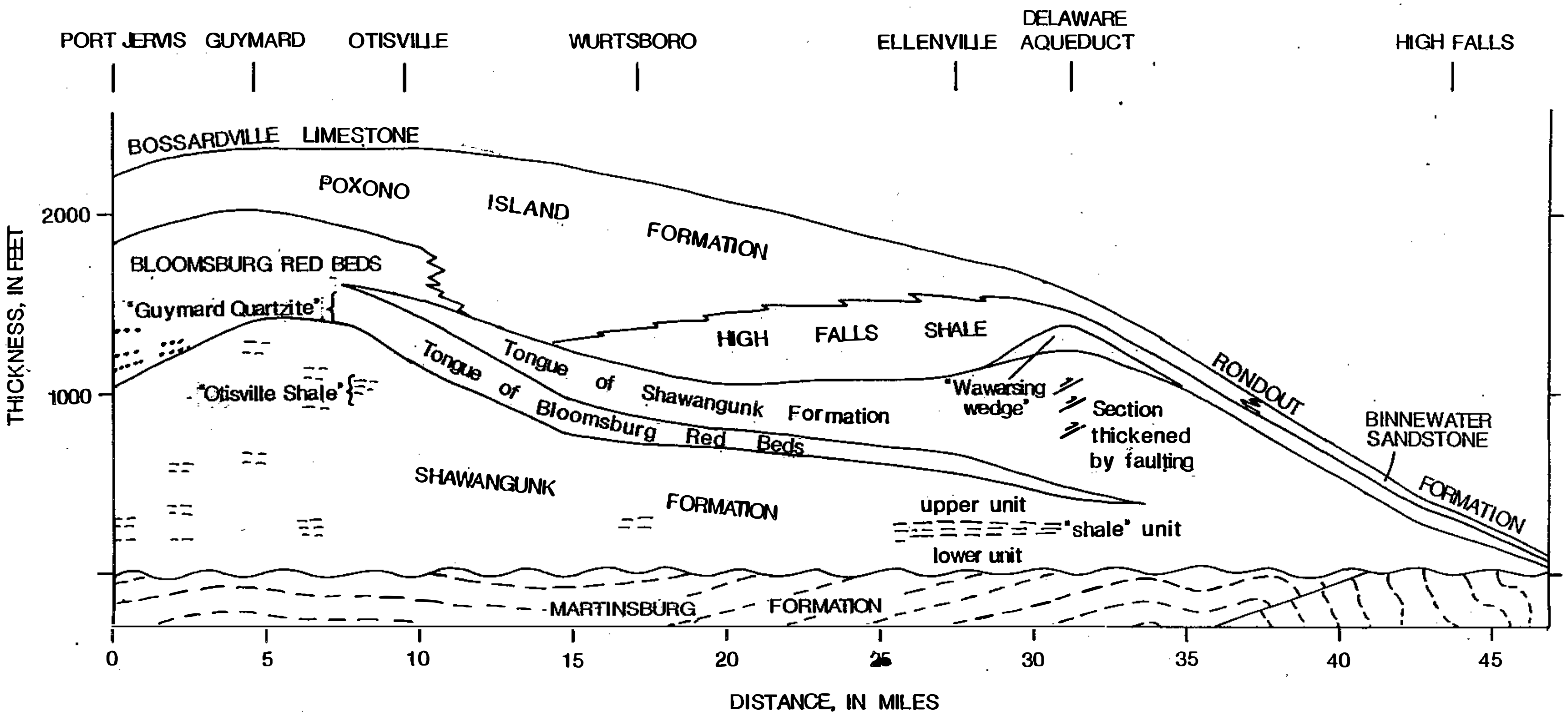


Figure 3. Preliminary stratigraphic section of Silurian rocks from the Poxono Island Formation and Binnewater Sandstone of Hartnagel (1905) to the Shawangunk Formation in southeastern New York.

(Epstein, 1973). The contact has been traced without complication to Guymard, N.Y. Between Wurtsboro and Ellenville redbeds followed by gray sandstone and shale overlie the Shawangunk. Because of a similar sequence of red and gray rocks at High Falls, several workers have identified these rocks as the High Falls and Binnewater, respectively (Darton, 1894; Sims and Hotz, 1951, Friedman, 1957, Gray, 1961, Smith, 1967). Younger rocks are not generally exposed. Detailed and reconnaissance examination suggests, on the contrary, that the red bed sequence between Wurtsboro and Ellenville is a tongue of the Bloomsburg, and not the High Falls, and the overlying gray sandstone and shale are a tongue of the Shawangunk, and not the Binnewater. The High Falls, which is very poorly exposed, crops out above both of these units near Wurtsboro (roadlog milage 99.0). Future detailed investigations will allow redefinition of these mappable units. The tongue of the Bloomsburg disappears northeastward by gradual change in color of the rocks from grayish red, through olive gray, into gray. This lateral change in color is similar to the changes seen along the transitional contact at Delaware Water Gap. The name "Guymard Quartzite" was applied to a portion of the tongue of the Bloomsburg between Guymard and Otisville by van Ingen (Bryant, 1926, p. 259). We feel that this name, like the "Otisville Shale", should not be used to define the stratigraphy of these rocks.

The rocks in the tongue of the Shawangunk are somewhat different from those in the main part of the formation in that they contain quartzites that are more distinctly crossbedded (seen along U.S. 44, roadlog mileage 33.8; north of Ellenville, mileage 41.5; and along N.Y. Rte 17 just south of Wurtsboro, mileage 98.5), and contains scattered red beds and polymictic conglomerates. Some of the conglomerates are similar to those in the Green Pond Conglomerate of the Green Pond outlier, about 25 miles to the southeast. One can easily envision a stratigraphic section between the main outcrop belt and the outlier that shows the Shawangunk tongue becoming thicker and encompassing more of the lower part of the section going eastward. In the outlier most of the Green Pond Conglomerate would be included in the tongue.

The High Falls Shale at High Falls not only contains red shales, similar to those of the Bloomsburg, but also abundant dolomite, fine-grained limestone, and green shales. Ripple marks and desiccation cracks are abundant. In the Delaware Aqueduct Bird (1941) reported 95 feet of gray limestone between the Shawangunk and his "High Falls". He named this unit the "Wawarsing wedge", alluding to the fact that the longitudinal shape of the unit must be wedge-like--it is not seen in exposures to the northeast or southwest. In all likelihood, it is predominantly dolomite, similar to the "powerhouse limestone" within the High Falls Shale at High Falls (Rickard, 1962, p. 129). The dolomite, green and red shale, limestone, and sandstone within the High Falls interval are very similar to rocks within the Poxono Island Formation of eastern

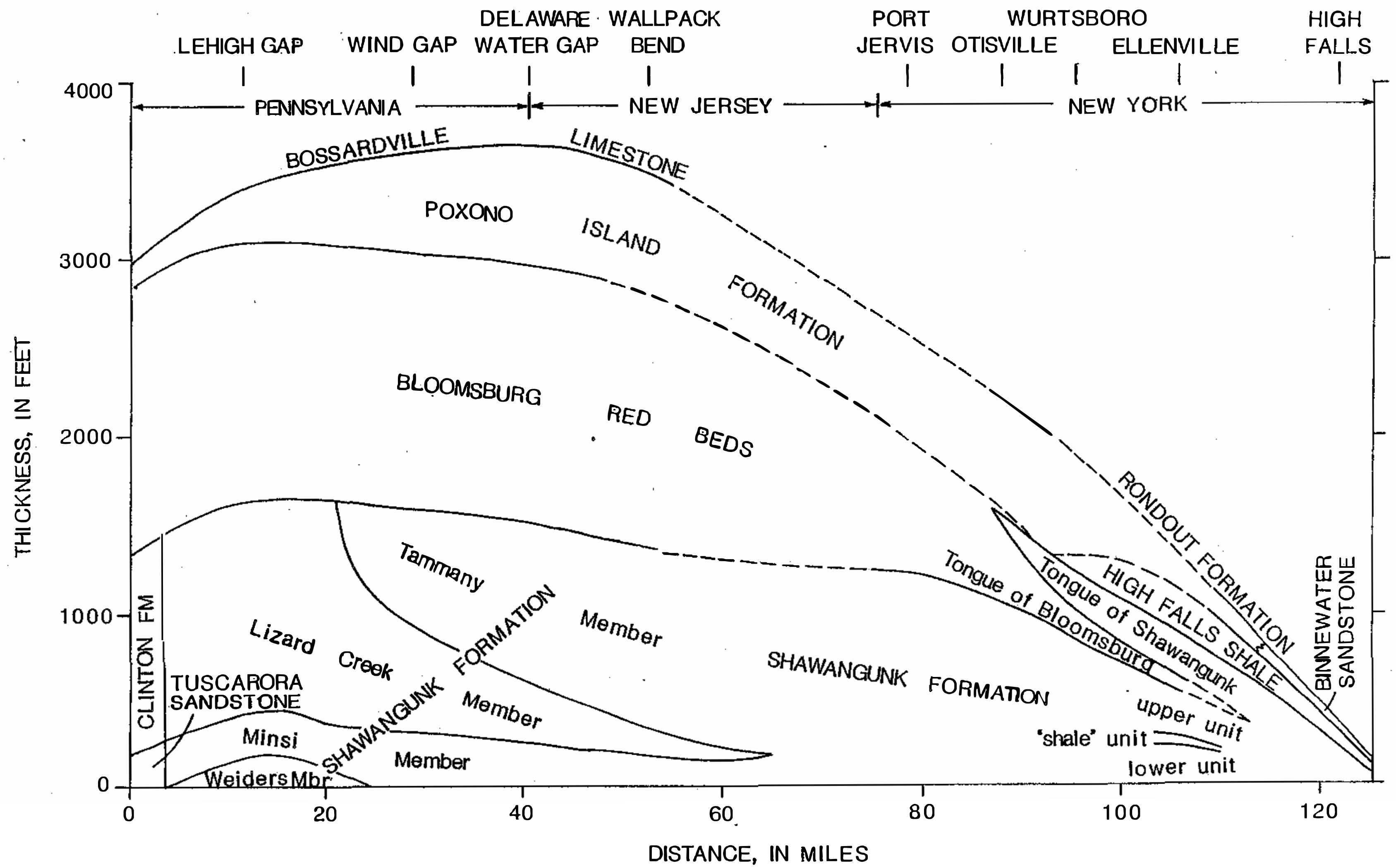


Figure 4. Generalized stratigraphic section of Middle and Lower Silurian rocks from Lehigh Gap, Pennsylvania, to High Falls, New York.

Pennsylvania. As a matter of fact, in the Delaware Aqueduct Fluhr and Terenzio (1984, p. 73) referred to the Wawarsing wedge of Bird (1941) as the "Wawarsing Limestone in Poxino Island Shales". (Note that "Poxino" has been misspelled by several authors ever since the original error by Wilmarth, 1957, p. 1724). For this reason the Poxono Island and High Falls are shown to grade into each other in figure 3. These rock units are generally not exposed and the location of the contact between them is speculative. This contact has not been defined, but a logical choice for its location would be where redbeds exceed a certain percentage, perhaps 50 percent (High Falls), and where they are less abundant (Poxono Island). The Binnewater Sandstone, which consists predominantly of crossbedded sandstone, at and north of High Falls, loses its character to the southwest (Rickard, 1962, Waines, 1976), becoming more dolomitic and shaly, so that at Accord, Fisher (1959) named the interval the "Accord Shales". This shows that even the Binnewater takes part in the complex carbonate-clastic facies mosaic of the Poxono Island-High Falls interval.

The complex Silurian sequence in southeastern New York described above is capped by the Bossardville Limestone near Otisville (Epstein and others, 1967), but somewhere to the northeast that unit disappears under glacial cover and the Binnewater is overlain by the Rondout Formation.

The consequence of these studies has been to better define the stratigraphic variations in Silurian rocks in southeastern New York. It demonstrates that the name "High Falls Shale", shown on the New Jersey State geologic map (Lewis and Kummel (1912), should not be used for rocks that should be referred to as the Bloomsburg Red Beds.

Weird Rocks
(Rocks "within" the Taconic unconformity)

The uppermost rocks of the Martinsburg Formation are near the Middle and Late Ordovician boundary in age, and the lowest rocks in the Shawangunk Formation are probably Middle Silurian in age. Thus, the Taconic hiatus in southeastern New York is about 20 to 30 million years, nearly as long as the entire Silurian Period itself. An interesting question is, what went on during that long period of time?

At the contact between the Martinsburg and Shawangunk Formations in the field trip area there is an interval, generally less than one foot thick, of diamictite (nongenetic term for a poorly sorted terrigenous deposit), clay, and at one locality, a deposit of Martinsburg shale fragments, which resembles a mass-wasting, terrestrial deposit (shale-chip gravel). The diamictite is interpreted to be a colluvial deposit. The clay with its slickensided quartz veins is believed to be tectonic (fault gouge). The deposit of shale fragments resembles a mass-wasting, terrestrial deposit (shale-chip gravel).

Some aspects of these rocks have been discussed before and alternative interpretations made. Waines and Sanders (1968) believed that the clay at the contact is a paleosol. Lukas, Rutstein, and Waines (1977) and Waines and others (1983) interpreted the clay as a hydrothermally altered Silurian shale and certain structures at the base of the Shawangunk as runnels produced by backflow on a beach. As discussed below, we believe that these structures are tectonic in origin. In eastern Pennsylvania, a similar clay layer is found between the Martinsburg and Shawangunk. Liebling and Scherp (1982) believe that this layer in Pennsylvania is a separate stratigraphic unit, in contradiction to the fault gouge hypothesis of Epstein and others (1974).

The diamictite is dark yellowish orange and consists of a variety of clasts in a sand-silt matrix. The clasts consist of fragments of the underlying Martinsburg, quartz pebbles (similar to those found in the overlying Shawangunk), and exotic rounded to subangular pebbles (dissimilar to rock types immediately above or below the unconformity). Sorting is poor (fig. 5A). There is a sharp contact with the Shawangunk above and also a sharp contact with the Martinsburg below. In places, such as at Otisville (Stop 5), it appears that parts of the Martinsburg have been bodily lifted from the underlying bedrock and incorporated in this diamictite. We do not believe that this deposit is a fault breccia, because there does not appear to be a foliation in it, although it may have been affected by movement to some degree. It looks more like a product of mass wasting, that is, a colluvium. Moreover, it contains a large variety of pebbles, which could have only been brought in as a sedimentary deposit.

The exotic pebbles are rounded to subangular and as much as 4 inches long. They consist of graywacke, orthoquartzite, feldspathic and chloritic sandstone, cross-laminated feldspathic conglomeratic quartzite, red fine-grained sandstone and siltstone, vein quartz, coarse-grained quartzite with pyrite, graywacke, medium-gray siliceous siltstone, laminated micaceous siltstone, and medium dark-gray shale. The pebbles are found at the Taconic unconformity near Otisville (Stop 5), Wurtsboro (Stop 8), and Otisville.

Martinsburg fragments are also found within the colluvium and consist of angular fragments derived from the immediate underlying bedrock, and rounded clasts that were transported for some distance. Angular Martinsburg fragments are also found in the gouge, presumably incorporated during fault movement.

Many pebbles are rounded and have weathering rinds a few millimeters thick. A few laminated samples have small ridges weathered out in relief. The oblate shape of others appears to have formed by erosion in running water. Clearly, these cobbles were exposed to the air, weathered, and incoporated in the diamictite, which we believe to be a colluvium.

We have collected samples for petrographic analysis from sedimentary rocks that may have been the source for the exotic pebbles. The work is still in progress, but we can make some guesses. The graywacke pebbles could have been derived from the Martinsburg. The pebbles of quartzite are similar to quartzites fairly high up in the Shawangunk, but obviously the Shawangunk could not have been the source of the pebbles. The dirtier sandstones, red sandstone and siltstone, as well as the quartzite pebbles, may have come from the Quassaic Formation of Waines (1986) of the Marlboro Mountains, presently 5-15 miles east of the Taconic unconformity. The age of the Quassaic is somewhat speculative, but it probably ranges from lower Martinsburg through the Upper Ordovician (Waines, 1986), so some of it, at least, could have supplied the pebbles and cobbles to the colluvium. Similar rocks are found in Little Mountain in the Friedensburg quadrangle of eastern Pennsylvania, between the Susquehanna and Lehigh Rivers, as well as possibly at the Spitzenberg a bit farther northeast. Some of the sandstone could have been derived from the sandstone at Pine Bush (informally named in this report). Some possible problems remain: (1) the shape of the pebbles suggests short transport, but similar rocks are not presently found in the Martinsburg immediately below; (2) the possible source terrane for these pebbles was probably not similar to the one which supplied the graywacke sandstone presently in the Martinsburg; and (3) few (if any) of the pebbles like those described are found in the conglomerates of the immediately overlying Shawangunk Formation.

The occurrence of angular slickensided vein quartz fragments that are oriented in all directions within the colluvial diamictite presents a problem in interpretation. The fact that the gouge and quartz veins are found uniquely at the Martinsburg-Shawangunk contact suggests that the movement is post-Taconic, probably Alleghanian, in age. The colluvium with exotic rounded pebbles unconformably overlies the Martinsburg and unconformably underlies the Shawangunk. It is therefore post-Martinsburg and pre-Shawangunk in age, a product of Taconic uplitt. The problem is that angular fragments of vein quartz (Alleghanian ?) is incorporated within the colluvium of Taconic age. The resolution to this dilema may be that there has been multiple movement along the fault at the Shawangunk-Martinsburg contact, and that the "weird rocks" is a composite deposit, made up of both Taconic colluvium and fault breccia. Therefore, the angular fragments of vein quartz were incorporated in the colluvium during later fault movement. Alternatively, the fragments of vein quartz could have been derived from vein quartz produced during Taconic faulting and incorporated in the colluvium as sedimentary clasts.

The clay within the zone between the Martinsburg and Shawangunk occurs as discontinuous light bluish-gray layers that have been weathered to moderate red and grayish orange. The clay

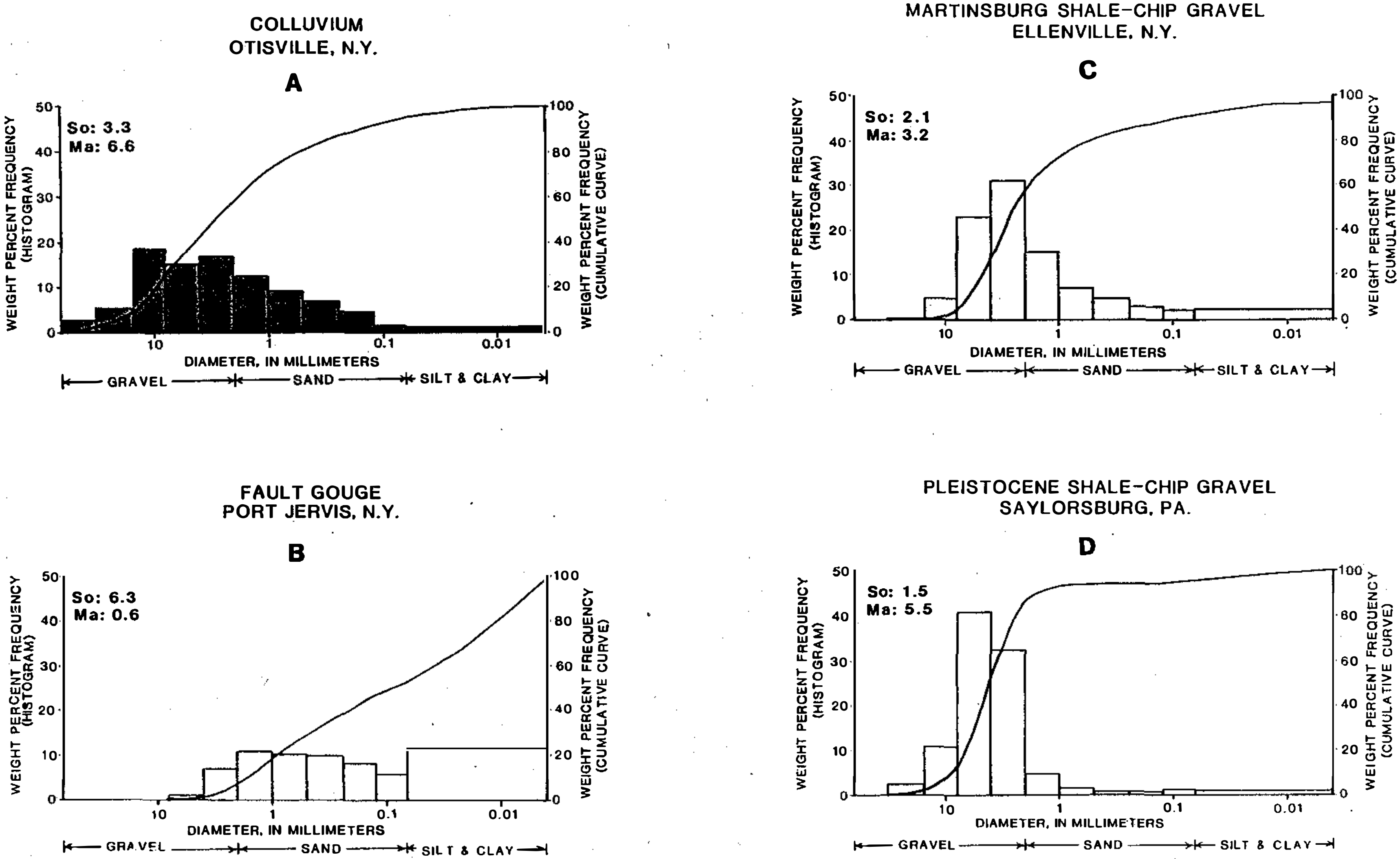


Figure 5. Histograms and cumulative curves for deposits between the Martinsburg and Shawangunk Formations. These deposits are interpreted to be colluvium (A), fault gouge (B), and shale-chip gravel (C). A Pleistocene shale-chip gravel is shown in D for comparison with C. So, coefficient of sorting; Ma, median diameter, in mm.

is internally folded and contains both continuous and disrupted quartz veins. In places, closely spaced fractures extend down from the clay into the underlying bedrock. In other places the lowest few millimeters of the Shawangunk is sheared. At Stop 8 the upper few inches of the Martinsburg is rotated. The clay is clearly a fault gouge. The vein fragments are slickensided, indicating repeated movement along the zone.

One question that needs to be asked is why the clay in the fault gouge has remained a sticky clay, whereas surrounding rocks have been lithified? The answer may be that the contact is a zone of alteration. This area of the Shawangunk Mountains contains several abandoned lead-zinc mines and there are many prospects and mineralized localities throughout the area. The lower few inches of the Shawangunk here at Otisville is similarly altered.

The shale-chip gravel just below the Shawangunk Formation and above solid Martinsburg bedrock at Ellenville (see description for Stop 2) is remarkably similar in appearance to Pleistocene shale-chip gravels elsewhere in the northern Appalachians. Figure 5 compares a size distribution analysis of the gravel at Ellenville (fig. 5C) with a Pleistocene shale-chip gravel in eastern Pennsylvania (fig. 5D). The coefficient of sorting, So, of the Ellenville gravel is 2.1, indicating a very well sorted sediment, similar to sorting found in alluvial sands. This suggests water washing of the sediment. The mean grain size, Ma, is 3.2 mm. The Pleistocene shale-chip gravel is remarkably similar, both in sorting and mean grain size, suggesting a similar origin. On the other hand, colluvium between the Martinsburg and Shawangunk at Otisville, New York (Fig. 5A), which we will see at Stop 5, is much more poorly sorted. Fault gouge between the Martinsburg and Shawangunk, such as at Port Jervis, New York, is even more poorly sorted and contains a much larger percentage of silt and clay (fig. 5B).

These data add an interesting hitherto unrecognized chapter to Late Ordovician paleogeography in the central Appalachians. It seems likely that following the deposition of the marine Martinsburg shales and graywackes, the Martinsburg was uplifted during the Taconic orogeny. But later as the Martinsburg surface was subaerially exposed, diamictic colluvium and shale-chip gravels were spread out on the exposed surfaces, and exotic pebbles and cobbles were incorporated in the diamictite. Much of this material was subsequently removed during pre-Shawangunk erosion and only scattered occurrences remain. The clasts were derived from a source that is no longer exposed nearby. The only evidence for that source is from the few pebbles that we have found. It might be suggested that thrusts brought these exotic rocks close to the site of deposition, and that thrusts sheets were subsequently eroded. If this is true, these thrusts must have been Taconic in age. These deposits were later covered by conglomerates and sandstones of the Shawangunk Formation during Middle Silurian time.

Therefore, these "weird rocks" indicate a fairly complex geologic history that has not been previously suggested. We welcome your comments.

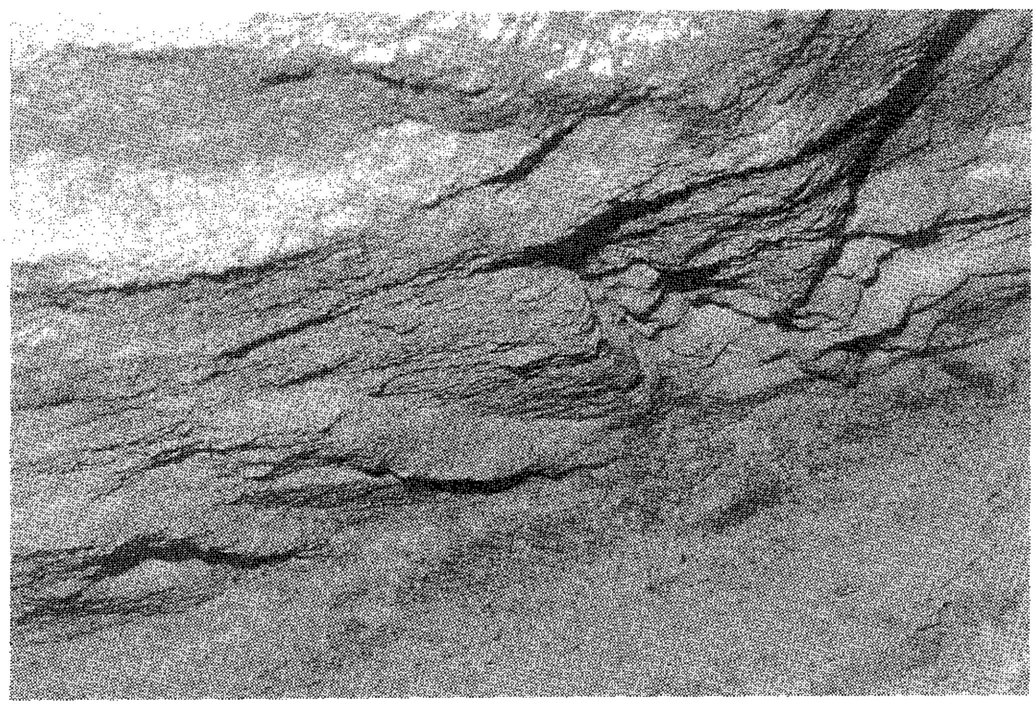
Mullions at the base of the Shawangunk

"Mullion" is an architectural term borrowed by structural geologists to describe elongate fold-like or prism-like forms developed at the boundary between rocks of different mechanical properties. They may be very regular in spacing and geometry and extend for considerable distances, or they may be irregular and short. They may originate by differential folding of rocks of contrasting properties or by disruption of competent rocks along foliation that is well developed in surrounding less competent rocks. They may be either parallel or perpendicular to the structural transport direction. These characteristics are discussed in many structural geology texts.

Mullions were seen at the base of Shawangunk Formation at seven localities in southeastern New York. These are Interstate 84 south of Port Jervis, in a prospect near Guymard, at the abandoned railroad cut in Otisville (Stop 5), along NY Route 17 south of Wurtsboro (Stop 8), in the abandoned railroad tunnel just south of Route 17, along the creek just east of the prison at Wawarsing, and a few hundred feet south of NY 55-US46 (the "Trapps", Waines and others, 1983).

The mullions are straight to slightly irregular downward-projecting structures at the base of the Shawangunk (fig. 6). They tend to have an asymmetrical wave-like form, and extend about two inches below the Shawangunk contact. The mullions trend subparallel to the strike of the Shawangunk. In a few places faint slickenlines trend about perpendicular to the trend of the mullions. At the creek behind the prison at Naponoch, the mullions bow down the slightly sheared bedding in the upper few inches of weathered Martinsburg, suggesting that they were not eroded into the underlying shales, but are a tectonic loading feature. We do not believe that they are "runnels" formed on a beach face (Waines and others, 1983) because they are found only at the Martinsburg-Shawangunk contact, a boundary of extreme mechanical disharmony (they are not seen at the bases of beds elsewhere in the Shawangunk) and their trend is not parallel to current directions indicated by trough crossbedding (see fig. 15). We interpret the Shawangunk as a fluvial (braided stream) deposit, not a beach deposit.

A



B

Figure 6. Mullions at the base of the Shawangunk Formation at Otisville, Stop 5 (A), and the Guymard prospect (B). The mullions are 1-2 in deep and asymmetrical. They vary from straight (left side of B), to irregular (right side of B). At Otisville, fragments of Martinsburg bedrock and exotic pebbles can be seen in the diamictite between the Shawangunk and Martinsburg.

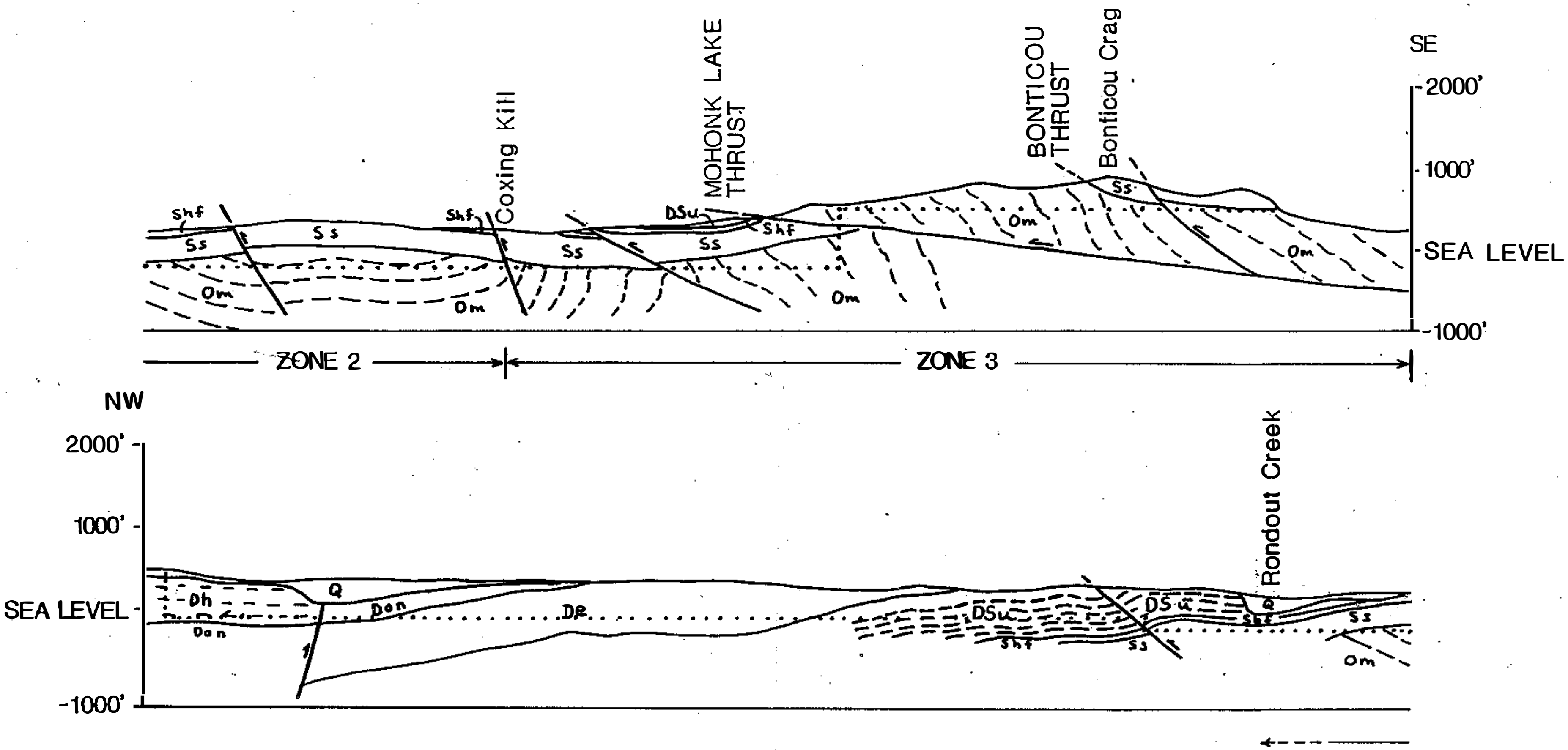


Figure 7. Cross section through Bonticou Crag showing location of Taconic tectonic zones. See figure 1 for location.

Q, Quaternary surficial deposits; Dh, Hamilton Group; Don, Onondaga Limestone; De, Schoharie and Esopus Formations; DSu, Glenerie Formation through Binnewater Sandstone; Shf, High Falls Shale; Ss, Shawangunk Formation; Om, Martinsburg Formation.

From surface mapping and data modified from New York City Water Board, unpublished data of the Catskill Aqueduct. Compare with Berkey (1911, fig. 22) and Brown (1914, fig. 2). Dotted line is the position of the aqueduct tunnel, in places projected into the line of section.

STRUCTURAL GEOLOGY

Both Ordovician and younger rocks <u>in the field trip area</u> are more highly faulted and tightly folded in the eastern part of the area than to the west. Timing and degree of deformation of these rocks has been the subject of considerable long-standing debate.

The three most important problems are: (1) what is the geographic distribution of Taconic structures in pre-Silurian rocks; (2) what are the intensities of Taconic and post-Taconic deformations in pre-Silurian rocks (and what is the age of the folds, faults, melange, and cleavage in these rocks); and (3) is the post-Taconic deformation Acadian or Alleghanian, or both?

On this field trip we will suggest that (1) zones of Taconic deformation can be recognized which decrease in intensity from east to west; (2) west of "Ruedemann's Line" the Ordovician rocks were more severly affected by post-Taconic deformation than by Taconic deformation; (3) the age of the later deformation is Alleghanian, (4) Alleghanian deformation along the Taconic unconformity decreases in intensity from Pennsylvania into southeastern New York, 5) the regional slaty cleavage in this area, where present, is Alleghanian in age, (6) more intense, later, Alleghanian deformation overlaps the earlier Alleghanian deformation in the eastern part of the area, and (7) the strike of Taconic structures is more northerly (by as much as 20^{o}) than Alleghanian structures.

<u>Taconic Tectonic Zones</u>

Compilation of geology in the Delaware and Catskill aqueduct tunnels, and comparison with surface exposures in southeastern New York, allows us to identify tectonic zones of Taconic age. (figs. 7 and 8). These zones strike about N. 10-20^{o} E. and progressively emerge to the southwest along the contact with the overlying Shawangunk Formation. The structure is more complex to the east. The zones are, from west to east: (1) zone 1 which has broad open folds in slight angular unconformity with the overlying Shawangunk Formation, (2) zone 2 that is a belt of less severe folds and faults with bedding in high angularity with overlying Silurian rocks; and (3) zone 3 with thrusts, steep dips, overturned folds, and melange. Many melanges have been mapped in the Ordovician rocks of the Hudson Valley, such as one on Rondout Creek near Rosendale, New York. These structures are definitely Taconic because in places the Silurian rocks truncate the scaly cleavage in them. The Taconic thrust faults that produced these melanges are abundant to the southeast of the unconformity and appear to become rarer as the unconformity is approached. The contact between zones 1 and 2 may be the extension of Ruedemann's Line which trends southerly and is overlapped by Silurian rocks southwest of Albany (Bosworth and Vollmer, 1981). This line passes under the Catskill Plateau and

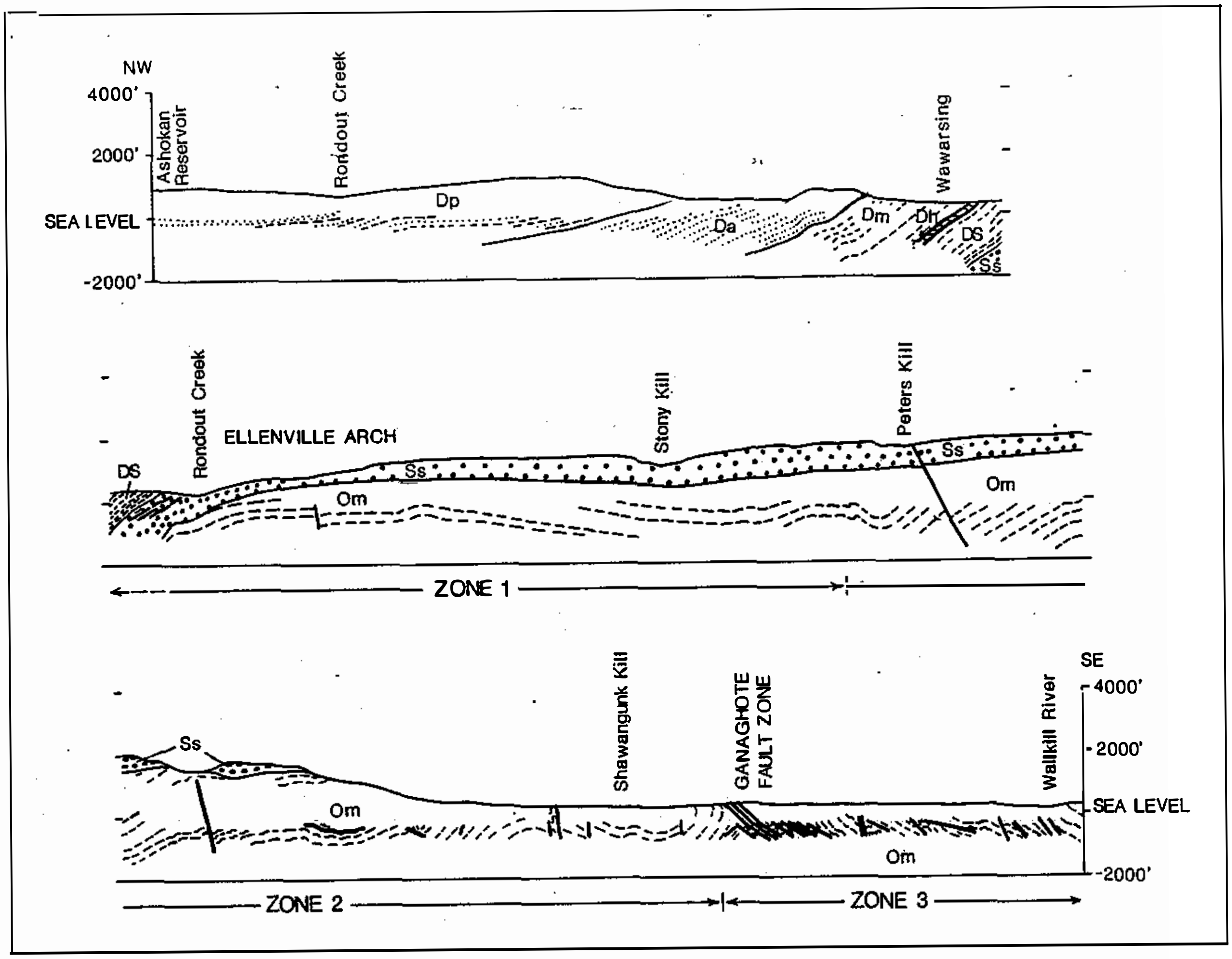


Figure 8. Cross section along the Delaware Aqueduct from the Ashokan Reservoir, through Wawarsing, to the Wallkill River (see Figure 1 for location), showing location of the Taconic tectonic zones and the Ellenville arch.

Dp, Plattekill Formation; Da, Ashokan Formation; Dm, Mount Marion Formation; Dh, shales and siltstones of the Hamilton Group; DS, Onondaga Limestone through the Binnewater Sandstone; Ss, High Falls Shale, Shawangunk Formation, and tongues of the Shawangunk Formation and Bloomsburg Red Beds; Om, Martinsburg Formation.

From surface mapping and underground data modified from the Delaware Aqueduct (New York City Water Board, unpub. data, 1945).

emerges from beneath the Shawangunk Mountains about 5 miles east of Ellenville (fig. 9). To the east of zone 1 lie the complex structural terrane of the Taconic klippen. To the west of zone 3, such as in central Pennsylvania, angular unconformity gives way to a conformable Ordovician-Silurian sequence, and orogenic uplift is reflected only by the Taconic clastic wedge.

Ignoring for the moment all faults and folds of Taconic age, the structure of the Martinsburg belt in eastern Pennsylvania can be characterized as a northwest-dipping sequence. The oldest member is always on the south side of the Great Valley and the youngest on the north side. Lyttle and Epstein (1987) show that this monoclinal sequence is actually the north limb of a very broad anticline that involves rocks as far south as the Pennsylvania Piedmont and that this structure is probably Alleghanian in age. Going northeastward into New Jersey the middle member of the Martinsburg is found in the trough of several smaller scale synclines, but still the very broad and general structure is one of a northwestward-dipping monocline. In southern New York State, the Wallkill Valley has long been recognized as a very broad open anticline (e.g., Offield, 1967; Kalaka and Waines, 1986). This anticline is highly faulted in the Mohonk Lake area (figs. 1 and 7). Many of these faults cut Silurian rocks and we interpret them to be Alleghanian in age.

Post-Taconic structures
Relative effects of Alleghanian and Taconic deformation

The tectonic effects in rocks above and below the Taconic unconformity in the central Appalachians has been the subject of considerable discussion and debate ever since the unconformity was recognized by H. D. Rogers in 1838. We have been mapping selected areas along 120 miles (200 km) of the unconformity from eastern Pennsylvania through New Jersey, and into southeastern New York (fig. 10). We have chosen areas where exposures are abundant enough to be able to determine structural relations in rocks on both sides of the contact. In general, going from Pennsylvania to New York, structures become simpler, from highly faulted and folded at Hawk Mountain, where the Tuscarora Formation rests on both the Martinsburg Formation and rocks of the Hamburg klippe, to overturned and faulted rocks at Lehigh Gap, to oversteepened folds at Delaware Water Gap, and upright to slightly overturned folds at High Point, New Jersey, and finally into a fairly simple arch at Ellenville, New York. Slaty cleavage in both Ordovician and younger rocks is common, particularly in the southwestern part of the study area.

The geology of the area near Ellenville, where Alleghanian and Taconic structures are relatively simple, is an excellent place to distinguish the effects of Taconic and later deformations. The Ellenville arch is a northeast-plunging fold with a half wavelength of about 4.2 miles (6.8 km). Folded rocks include the Martinsburg in the Great Valley, the Shawangunk in

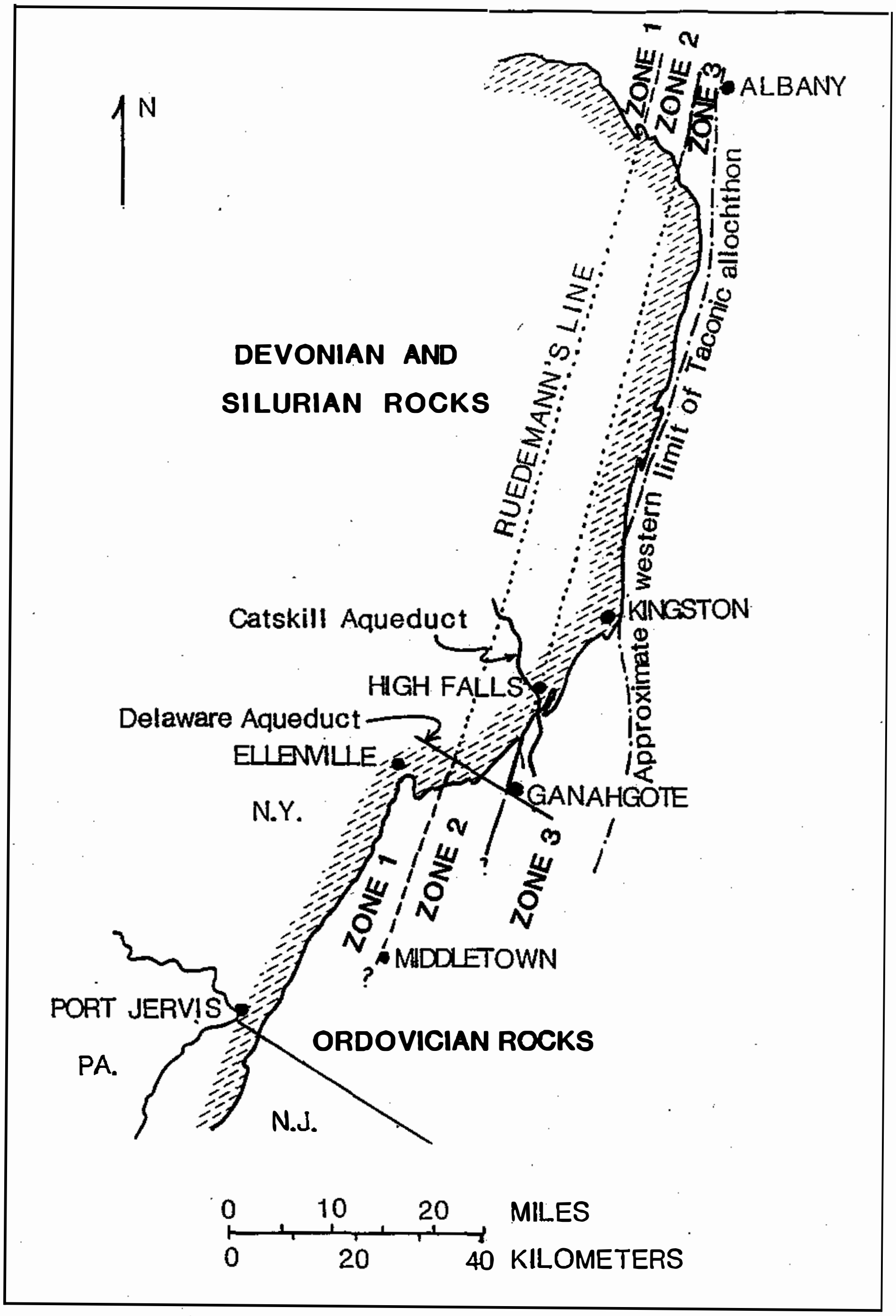


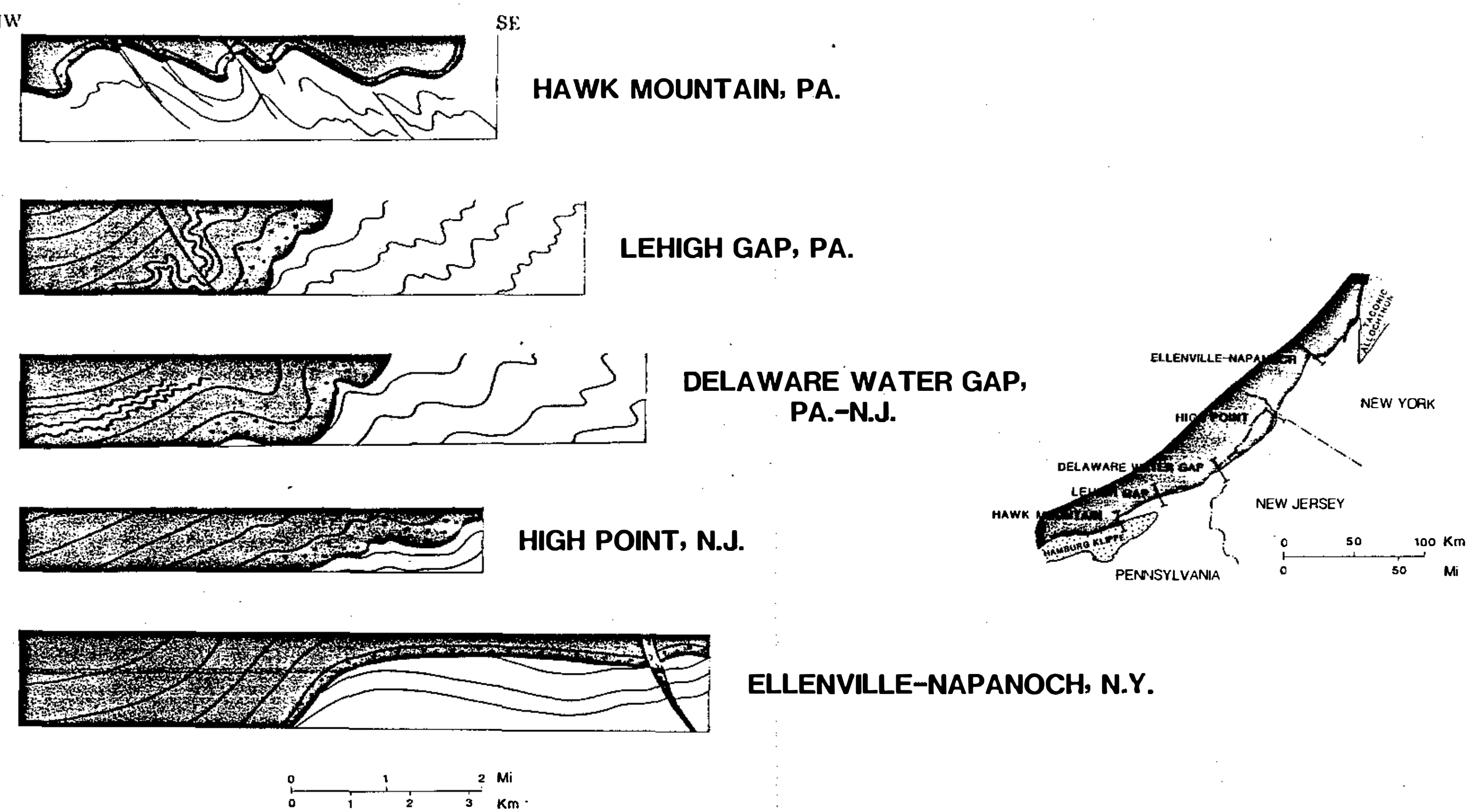
Figure 9. Map of southeastern New York showing the Taconic tectonic zones within the parautochthonous flysch, the boundary of overlapping Devonian and Silurian rocks, and the approximate western limit of allochthonous rocks of the Taconic allochthon. The zone boundaries are dotted beneath the Devonian and Silurian rocks. ZONE 1, broad open folds; ZONE 2, tight folds and thrust faults; ZONE 3, overturned folds, thrust faults, and melanges. Faults and some overturned folds are found in zone 1, and some areas of open folds are found in zone 3. Zones in the Albany area are from Vollmer (1981) and Bosworth and Vollmer (1981).

the Shawangunk Mountains, and rocks of Silurian and Devonian age in the Rondout Valley and Catskill Plateau (fig. 8). The broad arch is prominent in exposed cliffs of the Shawangunk Formation in the Ellenville area. The shales and graywackes of the Martinsburg are fairly well exposed in this area. The Martinsburg rarely exhibits slaty cleavage in this area. We are therefore able to draw an accurate cross section which shows that the crest of the arch differs in position in the Martinsburg and in the Shawangunk (fig. 11). It is clear that this geometry is the result of the folding of an unconformable sequence. If we unfold the folds in the Shawangunk, we can reconstruct the pre-Alleghanian folds in the Martinsburg on the bottom of the diagram. Note that the Ellenville arch has been eliminated and we are left with only a broad syncline, Taconic in age.

We have also done a similar reconstruction by rotating bedding in the Shawangunk back to horizontal using a stereo net and determining the retrodeformed Taconic attitudes in the Martinsburg. Figure 12 shows the position of the Alleghanian Ellenville arch. The heavy lines are isogons showing angles of dip and dip directions in the Shawangunk. These isogons were used to determine the amount of rotation necessary for the Martinsburg structural readings. The dips shown in the Martinsburg are these retrodeformed dips, that is, the Alleghanian folding has been eliminated. Therefore, this is a composite map, showing Alleghanian structure in the Shawangunk and Taconic structure in the Martinsburg. Note that the rotated beds in the Martinsburg dip consistently and gently to the southeast in the western part of the area and that the Ellenville arch has disappeared. The fold axes in the Martinsburg are thus Taconic in age. Also note that east of the Lake Awosting deformed zone, beds in the Shawangunk, shown by the isogons, strike ENE (average N. 76° E.), but that the Martinsburg underneath strikes more northerly by about 16° (averages N. 60° E.).

Using the data shown in the map, a cross section that is similar to the one shown in figure 11 was constructed (section A-A′, fig. 12). The solid line is a cross section showing bedding derived from our stereographically rotated Martinsburg. Note that it agrees almost perfectly with the pattern derived from the simple unfolding of the cross section shown in figure 11, the dashed line. It seems clear that Taconic folds in this area are broad and open, and the Ellenville arch is a later structure superimposed on the Taconic folds.

Figure 13 shows equal area plots of bedding in the Shawangunk, in the Martinsburg, and in the stereographically rotated Martinsburg. The girdle in the Shawangunk defines a fold whose axis plunges 5° N. 32° E. The Martinsburg trends, as we see them now, are more northerly, by about 10°, than trends in the Shawangunk. Interestingly, when the retrodeformed Martinsburg bedding is plotted, the Taconic folds plunge to the southwest. Therefore, we conclude that Taconic folds trend more



CROSS SECTIONS OF THE TACONIC UNCONFORMITY

Figure 10. Taconic unconformity study area between Hawk Mountain, Pennsylvania, and Napanoch, New York, showing decreasing Alleghanian deformation in the Shawangunk Formation and younger rocks (dark area) from southwest to northeast, and refolding of open Taconic folds (zone 1) in the Martinsburg Formation (light area).

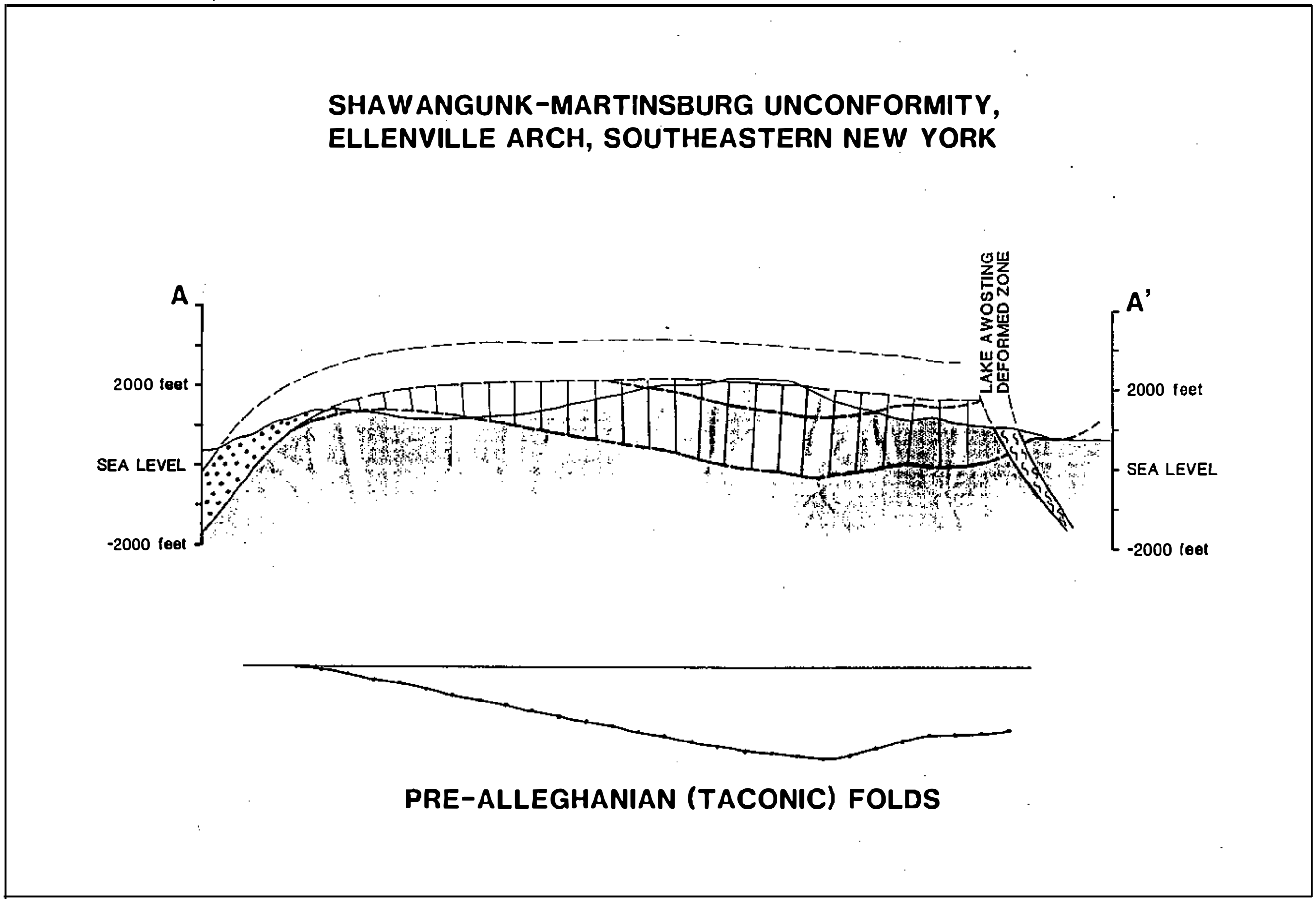


Figure 11. Cross section through the Ellenville arch east of Ellenville, showing the angular unconformity between the Shawangunk Formation (dotted) and the Martinsburg Formation (shaded), and the different position of the fold crest in the two units. By measuring the orthogonal distance between the base of the Shawangunk and a marker bed in the Martinsburg (near vertical lines), we can reconstruct the configuration of Taconic folds in the Martinsburg, shown on the lower part of the diagram. See figure 1 for location of cross section.

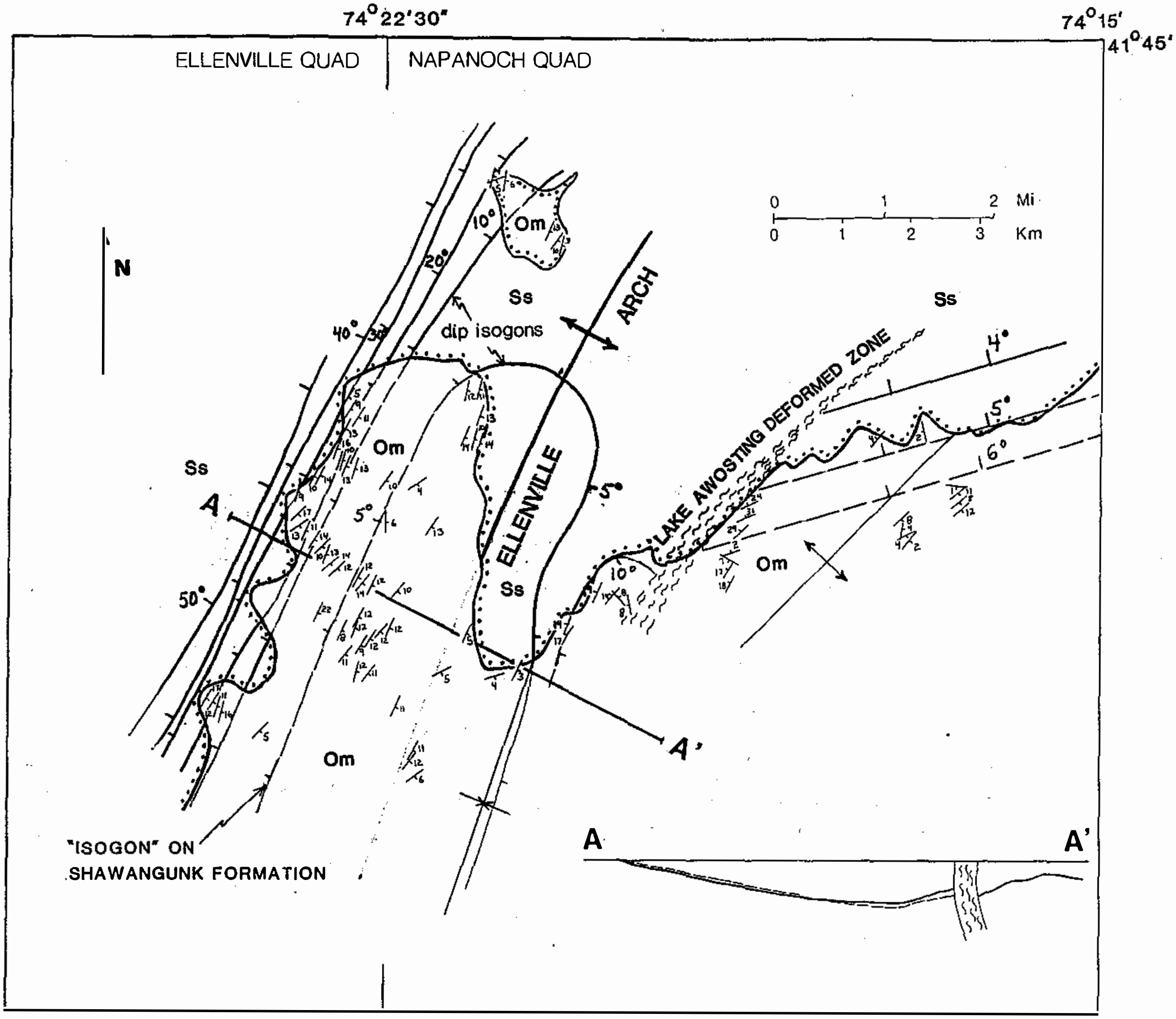


Figure 12. Geologic map of parts of the Ellenville and Napanoch 7.5-minute quadrangles showing the unconformable contact between the Shawangunk Formation (Ss) and the Martinsburg Formation (Om), lines of equal dip (dip isogons) in the Shawangunk (solid lines), and areas where the Shawangunk has been removed by erosion (dashed lines), dips in the Martinsburg that have been rotated to eliminate Alleghanian folding shown by the dip isogons, and the position of the reconstructed Taconic folds in the Martinsburg. The cross section A-A' compares the retrodeformed Taconic structures derived from the construction from the map (solid line) and from the exercise in figure 11 (dashed line).

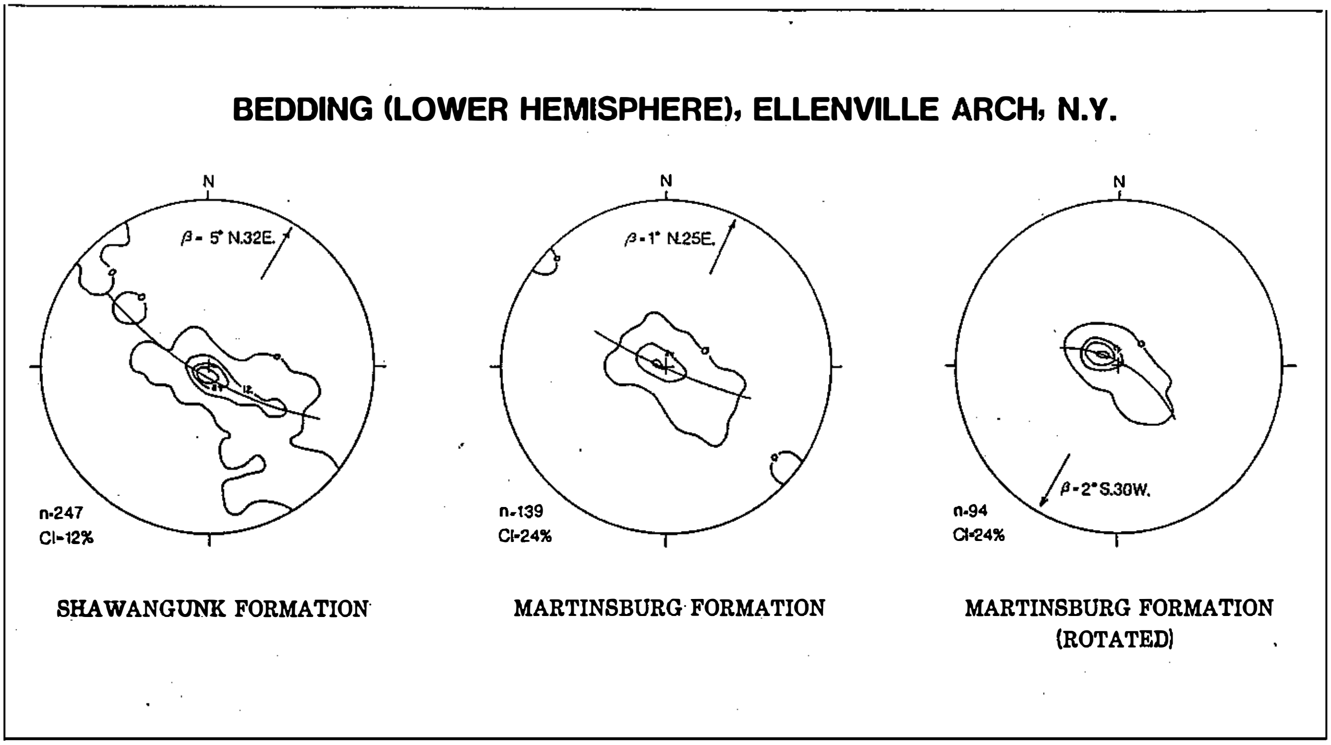


Figure 13. Equal-area projections (lower hemisphere) of the present attitudes of bedding in the Shawangunk and Martinsburg Formations in the area shown in figure 12, and the bedding in the Martinsburg that has been rotated so as to eliminate the effects of the Ellenville arch.

northerly than Alleghanian folds in this area, and plunge in the opposite direction. Thus, in the Ellenville area, we have been able to distinguish Taconic from Alleghanian folds, both in amplitude and trend.

From the data presented above, and from other considerations (Epstein and Lyttle, 1986), we draw the following conclusions for the area from Ellenville to northeastern Pennsylvania <u>near the Taconic unconformity</u>:

1. With only a few exceptions, the Shawangunk and equivalent Tuscarora Formation overlie the Martinsburg Formation with an angular unconformity that ranges between an angle that is barely discernible, to about 15°.

2. The dominant regional folding in all rocks along the contact is Alleghanian in age.

3. The regional slaty cleavage is Alleghanian in age.

4. Taconic folds in the Martinsburg Formation below the unconformity are mostly broad and open along the entire 120 mile length of the contact that we have studied southwest of Ellenville. To the north in zones 2 and 3 the structures become more intense and the angular disparity between beds above and below the unconformity is greater.

5. The strike of Taconic structures trend a bit more northerly (by about 3-20^{o}) than later structures.

Age of post-Taconic deformation

Was the entire sequence of rocks exposed in the field trip area affected by Acadian or Alleghanian deformation, or both? Marshak (1986, p. 366) gives a succinct summary of the controversy. An Acadian age was favored by Woodward (1957), Ratcliffe and others (1975), and Murphy and others (1980), based on the age of the youngest rock that has been deformed. Structures in Early Devonian and Upper Silurian rocks were believed to be Acadian in age by Chadwick (1944) and Woodward (1957) because these structures were thought to be different in style and trend from structures known to be Alleghanian in age in Pennsylvania. On the other hand, Schuchert (1930), Sanders (1969), and Geiser and Engelder (1983) argued that secondary structures could be traced from Pennsylvania into New York, and the structures in the Hudson Valley area are Alleghanian in age. An Acadian age was inferred by Ratcliffe and others (1975) and Sutter and others (1985) from dating of cleavages east of the Hudson River. We favor an Alleghanian age for the following reasons:

1. The Ellenville arch is a structure at the northeast end of a series of structures that extend from tight folds with abundant faults in east-central Pennsylvania, through tight folds with less-abundant faults in easternmost Pennsylvania, through upright folds in New Jersey, and into simple folds and monoclinal dips in southeastern New York (fig. 10). Since these folds in Pennsylvania involve rocks of Pennsylvanian age, the Ellenville arch is therefore believed to be Alleghanian in age. In New York rocks at least as young as the Plattekill Formation of Middle Devonian age are affected by the arch. Possibly even younger rocks, now eroded away, were involved in the folding. To the east in New England the age of Acadian intrusion and deformation is generally believed to be Middle Devonian in age (Naylor, 1971). Clearly the Ellenville arch is a post-Acadian structure.

2. The structures of the Hudson Valley trend in the Silurian and Devonian rocks in the Kingston area (Marshak, 1986) may extend southwest into structures that we have mapped in the Shawangunk Mountains of the field trip area. We believe that these structures cross cut and post-date the Alleghanian

Ellenville arch, and therefore formed during a later Alleghanian event. A possible example of one of these later structures in the field trip area is the Bonticou thrust (fig. 7).

3. Many workers have suggested that the youngest rocks that have been folded or faulted are in the Hamilton Group, thus limiting the time of deformation to Middle Devonian (the Acadian orogeny). Two such fault zones, one in the Bakoven Shale and one in slightly younger rocks of the Mount Marion Formation, are discussed at roadlog mileage 0.3. Slickenlines and verging of folds at these localities indicates northwestward translation along these faults. Similar faults have been reported in equivalent rocks in central New York as much as 100 miles west of Albany (Schneider, 1905; Long, 1922, Rickard, 1952, Bosworth, 1984a, b). Thus, there is evidence for detachment within Middle Devonian shales under the rocks of the Catskill Plateau. Bosworth (1984b) suggested that this movement may be linked to detachment in Salina salt under the Appalachian Plateau of central New York and Pennsylvania, described earlier by Prucha (1968) and Frey (1973). Bosworth placed no age constraints on the age of this movement, except to say that it is post-Middle Devonian, and could be Acadian or Alleghanian. If it is linked to the Salina horizon, and all the rocks of the Catskill Plateau have moved on this decollement, then an Alleghanian age would be indicated.

Similar fault horizons are found in rocks even higher than the Middle Devonian shale interval. For example, one such fault was discussed by Pedersen and others (1976, p. B-4-16). It is in the Plattekill Formation, located in the Woodstock 7.5-minute quadrangle, along NY Route 28, 7 miles west of Kingston. The fault zone is a duplex about two feet thick in which slickenlines, the verging of folds, and overlapping of structural blocks indicates translation of the overlying beds towards N. 23° W. Well-developed cleavage is found just below the fault. All these data suggest that there has been movement of rocks of the Catskill Plateau above the Hamilton shale horizon as well as within younger rocks. Perhaps many more similar faults zones are waiting to be discovered. If the structures within the Hamilton shales really mark the limit of Acadian deformation, as a number of geologists have suggested, then younger rocks should lie on the Hamilton with angular unconformity. So far as we know, no evidence for such an unconformity has ever been presented. If one recognizes structures such as small thrust zones or detachment horizons within the Hamilton shales, and does not see this sort of structure in any overlying unit, it is meaningless to say that the Hamilton is the youngest unit affected by these structures. There is plenty of evidence to suggest that these structures formed when the rocks were at least partially lithified. Therefore, some rocks younger than the affected beds <u>must</u> have been present and were transported to the west in the overlying block or thrust sheet. Therefore, we feel it is very important to examine the type of structure being discussed when important generalizations about the ages of regional deformations are being made.

4. Lineaments, which have a trend of about N. 20° E., are very apparent on radar imagery and topographic maps. They extend northward into rocks as young as the Plattekill Formation of Middle Devonian age and probably extend into the Oneonta Formation of Late Devonian age. They also parallel faults that we have mapped in the Shawangunk Mountains to the south. In the Catskill Plateau, they are aligned along valleys (seen from mileage 1.3 and Stop 3), which preliminary investigations suggest are controlled by minor faulting and very closely spaced joints. The structures that cause these lineaments are post-Acadian in age, since they cut Upper Devonian rocks. The parallelism with the faults in the Shawangunk Mountains suggests, but does not prove, an age equivalence.

5. Finally, the Acadian orogeny in New England involved deformation, metamorphism, pluton emplacement, and uplift. Dating of the late orogenic plutons places a minimum date of 380 million years (middle Middle Devonian) for the orogeny (Naylor, 1971). Therefore, Acadian deformation ceased by at least the time that the basal part of the Hamilton Group (Bakoven Shale) was being deposited, if not sooner. Thus, the response in the field trip area to Acadian deformation going on to the east was subsidence to form a basin in which Hamilton sediments were deposited. This was followed by shoaling and finally terrestrial deposition ("Catskill Formation") as the Acadian mountains to the east were uplifted. Acadian folding may never have extended as far west as the field trip area! Faill (1985) likewise suggested that evidence for Acadian deformation of rocks in the Catskill depositional basin are either absent or ambiguous, at best. Catskill sediments are the result of Acadian orogenic uplift, and were not deformed during Acadian tectonism. Faulting in the Plattekill and Hamilton must therefore be the result of later (Alleghanian) deformation. This suggests that the flat-lying and gently dipping rocks of the Catskill Plateau may lie with fault contact on the highly deformed Upper Silurian and lower Middle Devonian rocks of the Hudson Valley. Alternatively, the severe deformation of these Silurian and Devonian rocks may not have extended as far west as the present Catskill front (Marshak, 1986, p. 366).

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is internally folded and contains both continuous and disrupted quartz veins. In places, closely spaced fractures extend down from the clay into the underlying bedrock. In other places the lowest few millimeters of the Shawangunk is sheared. At Stop 8 the upper few inches of the Martinsburg is rotated. The clay is clearly a fault gouge. The vein fragments are slickensided, indicating repeated movement along the zone.

One question that needs to be asked is why the clay in the fault gouge has remained a sticky clay, whereas surrounding rocks have been lithified? The answer may be that the contact is a zone of alteration. This area of the Shawangunk Mountains contains several abandoned lead-zinc mines and there are many prospects and mineralized localities throughout the area. The lower few inches of the Shawangunk here at Otisville is similarly altered.

The shale-chip gravel just below the Shawangunk Formation and above solid Martinsburg bedrock at Ellenville (see description for Stop 2) is remarkably similar in appearance to Pleistocene shale-chip gravels elsewhere in the northern Appalachians. Figure 5 compares a size distribution analysis of the gravel at Ellenville (fig. 5C) with a Pleistocene shale-chip gravel in eastern Pennsylvania (fig. 5D). The coefficient of sorting, So, of the Ellenville gravel is 2.1, indicating a very well sorted sediment, similar to sorting found in alluvial sands. This suggests water washing of the sediment. The mean grain size, Ma, is 3.2 mm. The Pleistocene shale-chip gravel is remarkably similar, both in sorting and mean grain size, suggesting a similar origin. On the other hand, colluvium between the Martinsburg and Shawangunk at Otisville, New York (Fig. 5A), which we will see at Stop 5, is much more poorly sorted. Fault gouge between the Martinsburg and Shawangunk, such as at Port Jervis, New York, is even more poorly sorted and contains a much larger percentage of silt and clay (fig. 5B).

These data add an interesting hitherto unrecognized chapter to Late Ordovician paleogeography in the central Appalachians. It seems likely that following the deposition of the marine Martinsburg shales and graywackes, the Martinsburg was uplifted during the Taconic orogeny. But later as the Martinsburg surface was subaerially exposed, diamictic colluvium and shale-chip gravels were spread out on the exposed surfaces, and exotic pebbles and cobbles were incorporated in the diamictite. Much of this material was subsequently removed during pre-Shawangunk erosion and only scattered occurrences remain. The clasts were derived from a source that is no longer exposed nearby. The only evidence for that source is from the few pebbles that we have found. It might be suggested that thrusts brought these exotic rocks close to the site of deposition, and that thrusts sheets were subsequently eroded. If this is true, these thrusts must have been Taconic in age. These deposits were later covered by conglomerates and sandstones of the Shawangunk Formation during Middle Silurian time.

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ROAD LOG AND STOP DESCRIPTIONS

Total Miles	Miles Between Stops	
0.0		Leave parking lot of Ramada Inn Motel. Locality is on blacktop of Holocene age, unconformably overlying stream and lake-bed deposits of Pleistocene (Woodfordian) age, unconformably overlying either the Onondaga Limestone or Bakoven Shale of Middle Devonian age. Turn right at traffic light heading west on NY 28.
0.3	0.3	Turn right onto US 209 South towards Ellenville. About one-third mile straight ahead on the north side of NY 28 is a fault in the Bakoven Shale (noted by Pedersen and others, 1976, p. B-4-21). The fault zone is about 5 feet thick and consists of crumpled and slickensided black shale with abundant quartz veins. The slickenlines and verging of the folds indicate that the overriding beds moved to the northwest. Some workers believe that these are the youngest rocks deformed in the area and therefore date the folding in Silurian and Lower Devonian rocks as Acadian. However, we believe that there is evidence to suggest that this deformation is Alleghanian (see section on Age of Deformation). 2.1 miles northeast of the fault in the Bakoven is a fault duplex about 5 feet thick, slightly higher in the section in the Mount Marion Formation. Slickensides in the duplex indicate that the overriding beds moved N. 70° W. Pedersen and others (1976, p. B-4-6, 7, 22,23) consider these structures to be soft-rock "pull aparts". However, a 1-foot-thick sandstone bed is deformed into mullions and is surrounded by slickensided surfaces and sheared shale. Tectonic shortening is estimated to be 50-60 percent, judging from the overlapping of the mullions.
0.6	0.3	Fault in Bakoven Shale described above can be seen to right. For the next 8 miles we will be riding along a flat plain underlain by floodplain and stream-terrace deposits of Esopus Creek and glacial lake-bed sediments of Pleistocene Lake Stone Ridge (Dineen and Duskin, 1987).

1.3	0.7	The hills in foreground to right are underlain by shales and sandstones of the Mount Marion Formation. In the hills above are sandstones of the Ashokan Formation. Valleys which trend N. 20° E. are parallel to lineaments that are very apparent on radar imagery and topographic maps. The valleys, seen for the next two miles, are controlled by very closely spaced joints and minor faulting. The lineaments extend northward up into rocks as young as the Plattekill Formation of Middle Devonian age and may extend into the Oneonta Formation of Late Devonian age. Southward, these lineaments parallel faults that have been mapped in the Shawangunk Formation of Silurian age. This is one of the reasons for suggesting that the deformation in the area is Alleghanian, rather than Acadian, in age.
1.8	0.5	Cross Esopus Creek. For the next several miles we will see scattered exposures of the Onondaga Limestone poking through glacial cover.
4.7	2.9	Entering Marbletown.
8.9	4.2	Traffic light. Continue straight on US 209 South.
9.6	0.7	Junction with NY 213 West. Continue straight on US 209 South and NY 213 East.
10.4	0.8	Turn left on NY 213 East.
11.0	0.6	View of Mohonk Lake tower on Shawangunk Mountain at 2 o'clock. The tower affords an excellent view of the Catskill Mountains, Walkill Valley, and surrounding region. It overlooks a gorgeous lake at the Mohonk Mountain House which is situated at the crest of a faulted anticline.
11.3	0.3	Enter town of High Falls.
11.5	0.2	Outcrops of the Schoharie Formation.
11.6	0.1	Traffic light. Continue straight.
11.7	0.1	Cross Rondout Creek. Classic section of High Falls Shale, Binnewater Sandstone, and Rondout Formation to left.
12.1	0.4	Exposures of uppermost Shawangunk Formation in low cliff one block ahead. Turn right onto Bruceville Road (Ulster County 6A) between antique store and pizzeria.

12.2	0.1	Canal Museum on left.
12.3	0.1	Continue straight on Hill Road.
13.1	0.8	"Y" in road. Bear left.
13.4	0.3	Cross Coxing Kill.
13.7	0.3	"Y" in road. Continue right on Ulster Co. 6A.
14.0	0.3	Exposure of High Falls Shale, Binnewater Sandstone, and Rondout Formation in steep slope to left.
15.0	1.0	Intersection with Clove Road. Continue straight.
15.4	0.4	Mossy Brook Road on right. If you hike about 0.5 mile down this road, which is on private land belonging to the Mohonk Mountain House, you will find an old log cabin. Nearby, the Mohonk Lake thrust fault is beautifully exposed in Mossy Brook. This gently southeast dipping fault carries Ordovician Martinsburg Formation northwestward over the Silurian Shawangunk.
15.6	0.2	Exposure of red beds of High Falls Shale on right.
15.7	0.1	Exposure of Shawangunk on right.
15.8	0.1	Cross Mohonk Lake thrust fault, which carries shales of the Martinsburg Formation, here dipping moderately to steeply towards the southeast, northwestward over quartzites and conglomerates of the more gently southeast dipping Shawangunk Formation. This fault is not exposed where it crosses the highway.
16.0	0.2	For the next 0.7 mile we pass outcrops of the Martinsburg, consisting of thin-bedded shale, minor siltstone, and very rusty weathering, fossiliferous, fine-grained graywacke in beds up to 3 inches thick. Cleavage is poorly developed.
16.9	0.9	Pass through one-lane underpass, then immediately turn to right at gatehouse.
17.0	0.1	Stop sign at gate house.

ROUTE TO ALTERNATE STOP 1A (If it is raining hard, we may choose to take the bus to this stop instead of walking to Stop 1.):

0.0	0.0	Stop sign at gate house. Turn right on Huguenot Drive heading towards main entrance of Mohonk Mountain House.
0.1	0.1	Exposures of slumped Martinsburg on left. View of Catskill Mountains on right.
0.8	0.7	Road intersection at Woodland Bridge. Straight ahead, and following the stream valley, is the Kleine Kill thrust fault. To the right are exposures of deformed Shawangunk and the slope to the left is underlain by deformed Martinsburg.
		Make abrupt left turn on Terrace Road heading back towards gate house.
0.9	0.1	Martinsburg in bank on right. For most of this outcrop the southeast dipping shales and graywackes are right side up; however, there are several zones about 3 feet wide that are very tightly folded. The azimuth of these folds vary from N-S to N. 10° E. and they plunge gently to both the north and south.
1.0	0.1	Turn right into shale pit.

ALTERNATE STOP 1A.

FAULT ZONE IN FOSSILIFEROUS MARTINSBURG

The Martinsburg in this outcrop is dominantly medium dark-gray shale interbedded with fine grained graywacke. The graywacke beds are commonly less than 5 inches thick, and exhibit graded bedding, and parallel and cross laminations. The graywackes are fossiliferous (mostly brachiopods and crinoids) and contain a fair amount of pyrite. The fossils are most easily seen in the very rusty weathering pyrite-bearing graywacke beds. A cleavage is poorly to moderately well developed in the shales, although not enough to call these rocks slates.

The Martinsburg in this shale pit contains fault-related structures interpreted to be of two different ages. A melange or broken formation, best seen at the far north end of the pit (at least at the time of this writing), is part of the same melange zone seen at Stop 1. The melange zone is Taconic in age and has a strike of N. 5-10° E. It has been carried westward over the Silurian Shawangunk in the hanging wall of the younger Kleine Kill thrust (fig. 14). Most of the small faults and slickensided

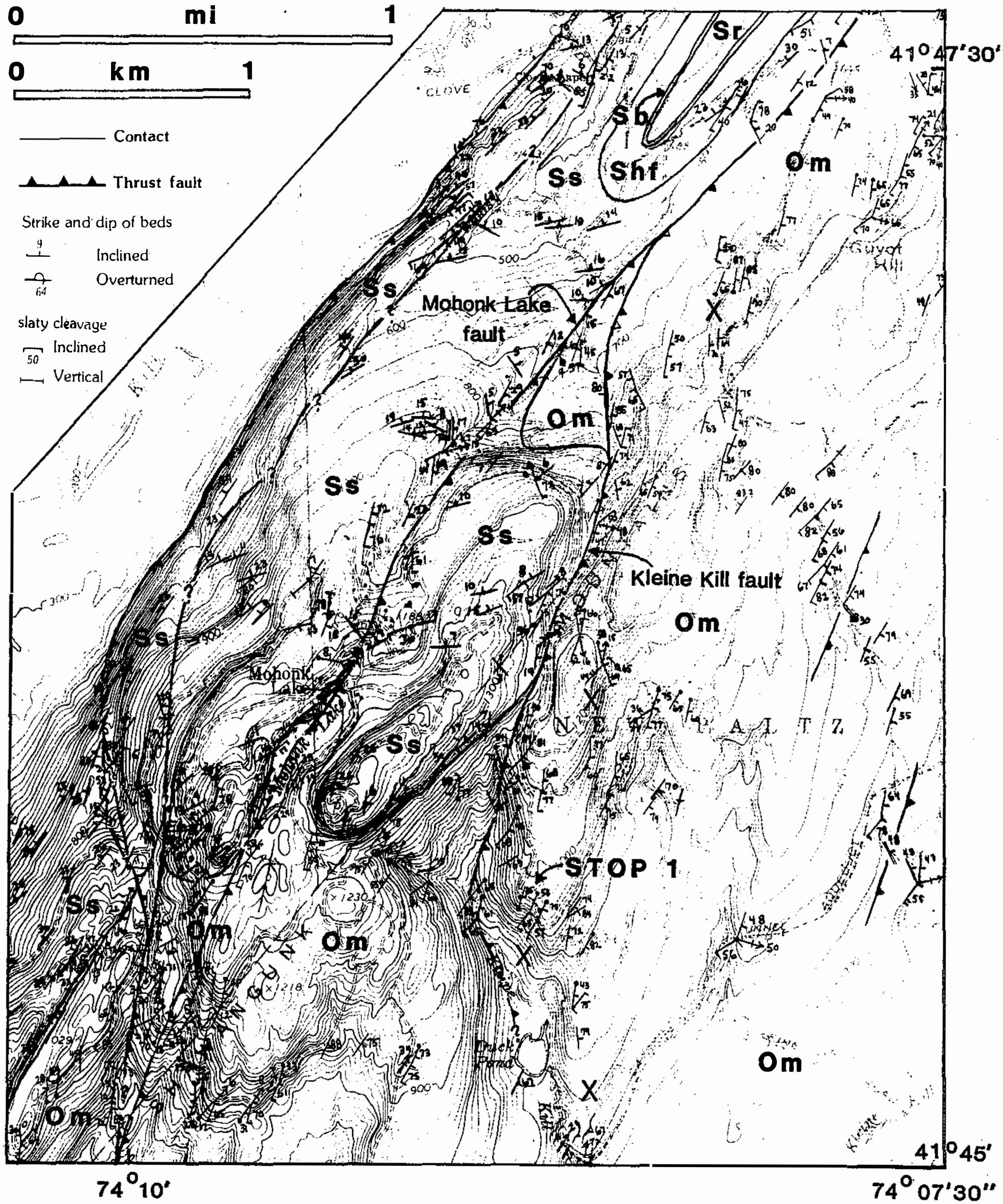

Figure 14. Preliminary geologic map of the Mohonk Lake area, N.Y.

Sr, Rondout Formation; Sb, Binnewater Sandstone; Shf, High Falls Shale; Ss, Shawangunk Formation; Om, Martinsburg Formation. X marks exposures of melange.

surfaces that are common in this pit are probably related to this younger thrust fault. The trace of the Kleine Kill thrust nearby has a strike of N. 15° E., and is interpreted to be Alleghanian in age.

Based on our mapping, several generalizations can be made about Taconic and Alleghanian fault-related structures. The fault zones in the Martinsburg which clearly do not cut Silurian and younger rocks generally have: a) a trend more northerly than the northeast-trending folds and faults in the Silurian rocks, b) a diagnostic scaly cleavage (see Stop 1 for a fuller discussion), c) tightly folded "floating" knockers of graywacke whose axes plunge predominantly to the northeast with variable azimuth, and 4) very little, if any, vein quartz. The faults that definitely cut both the Ordovician Martinsburg and the Silurian Shawangunk, and which we interpret to be Alleghanian in age, generally have: a) a slightly more easterly strike, b) well-developed "pencils" in the shales formed by the intersection of bedding and cleavage, and c) vein quartz parallel to bedding and/or cleavage that commonly contains shale fragments.

An example of a good Taconic melange can be seen at Stop 1, and an example of an excellent Alleghanian fault zone can be seen at Alternate Stop 1b.

		Reboard bus, leave shale pit, turn right toward gate house.
1.4	0.4	View of Wallkill Valley to right (southeast).
1.8	0.4	Rejoin roadlog at Milage 17.0.

17.0	0.1	Stop sign at gate house. (NOTE: THIS IS PRIVATE PROPERTY; ACCESS CAN ONLY BE GAINED BY CONTACTING DAN SMILEY AT THE MOHONK MOUNTAIN HOUSE). Drive a few feet past the gatehouse and turn left down Lenape Lane (a dirt road) past the "Do Not Enter" sign.
17.9	0.9	Excellent exposures of Martinsburg shales to right and at bend in road. Thin-bedded, graphitic shale interbedded with thin- to medium-bedded, parallel-laminated, fine-grained, pyritiferous graywacke. Cleavage is poorly to moderately well developed and oriented nearly parallel to bedding.
18.2	0.3	STOP 1. Park on right and disembark. Climb hill along dirt road with switch back. After walking approximately 1,000 feet you will reach the intersection of Forest Drive and Oakwood Drive; continue straight ahead on Oakwood Drive. Between here and Stop 1 Oakwood Drive marks the boundary between the lands of the

Mohonk Mountain House and the Mohonk Preserve, which is also a hunting boundary.

PLEASE BE AWARE THAT BOW AND ARROW HUNTERS MAY BE LURKING IN THE WOODS. NO DEER IMITATIONS ALLOWED.

After about 1,800 feet you will cross Kleine Kill Road. Continue another 50 feet on Oakwood Drive and follow it around a sharp bend to the right (northwest). For the next 750 feet until we reach Stop 1, pay attention to the outcrops of Martinsburg on the right. You should be able to find tight folds, overturned bedding, slickensided fault surfaces with and without vein quartz, and tension gashes in sandstone beds. We will not spend much time discussing these rocks until we reach Stop 1.

STOP 1

MARTINSBURG MELANGE

At this stop we will see a good example of a tectonic melange within the Martinsburg Formation. As there are no identified "exotic" blocks in this melange, it perhaps should be called a broken formation (Hsu, 1968). As you can see by looking to the northeast, we are very close to the Shawangunk cliffs beneath Skytop Tower. Although there are no exposed contacts showing unfaulted Shawangunk resting unconformably on Martinsburg melange in the field trip area, there are several localities in the Rosendale quadrangle to the east where Silurian rocks directly on strike with Martinsburg melange zones show no comparable deformation or offset. In addition, mapping by Vollmer (1981) just southwest of Albany, New York (fig. 9) documents a beautiful exposure of unfaulted Rondout Formation resting unconformably on top of Taconic melange in the Normanskill Shale. For these reasons we feel that this melange zone, as well as similar ones nearby in the Martinsburg, must be Taconic in age. In the Kleine Kill valley down the hill and less than 1,000 feet to the west of Stop 1, is the main trace of the Kleine Kill thrust fault, which a short distance to the north offsets and folds the Shawangunk. This fault is part of an imbricate splay, or perhaps a duplex (fig. 14). It would appear that the melange zone seen at Stop 1 and several other places along strike is always contained in the hanging wall of the Kleine Kill thrust fault. Since there are thrust faults that postdate and transport these melange zones, it is particularly important to document structures that appear to be diagnostic for the melanges. The most important feature which can be seen at this stop is a scaly, anastomosing, phacoidal cleavage that commonly exhibits shiny and smeared surfaces. In addition, bedding is very disrupted and many tight folds are rootless and "floating" in the phacoidally cleaved shale and siltstone. Both of these features are most easily seen by examining the two to six inch graywacke beds. As one might expect, the hinge lines of the rootless folds show a significant range in orientation; however, they generally plunge moderately to steeply to the NNE. By carefully examining small scale structures such as asymmetric folds, minor offsets, and slickensides, it is possible to determine the sense of movement on some of the faults. What is difficult, if not impossible, to prove is whether an individual fault formed during the Taconic melange-forming episode or is related to the later, probably Alleghanian thrust system. It is possible, however, to show that although most small-scale structures show an east-over-west sense of rotation and a west-northwest transport direction, there are quite a few examples of thrusts with the opposite sense of movement.

There are two good exposures of the Kleine Kill thrust fault in the bed of the Kleine Kill just west of this stop. These outcrops are remarkably different from the melange seen here. They show sharp, planar, knife-edge faults with minor brecciation but no wholesale bedding disruption. They also contain many quartz slickensided surfaces. Most of these slickensides show an east-over-west thrust sense; however, a number of slickenlines are subhorizontal and suggest that there is a component of strike-slip displacement. The sense of movement is ambiguous, but appears to be left lateral. The shales near the fault commonly show an excellent cleavage (they are almost slates) and are beautifully pencilled.

		Return to bus, continue straight on Lenape Lane.
20.3	2.1	Turn right on Butterville Road. Excellent view to right of cliffs of the Shawangunk Formation and the Mohonk Tower. The hills in the middleground are underlain by shales and graywackes of the Martinsburg Formation, trending northerly with angular discordance under the Shawangunk.
20.6	0.3	Turn right on NY 299 heading west.
21.6	1.0	Overturned shales and thin graywackes of the Martinsburg Formation on right. There are a number of narrow fault zones with vein quartz. This outcrop is roughly on strike with Alternate Stop 1B.
22.0	0.4	World-renowned New York State orchards.
22.4	0.4	Steeply dipping and overturned Martinsburg shales and thin graywackes on right. View of the Shawangunk cliffs at the Trapps straight ahead.

22.9	0.5	Martinsburg with 2.5 ft graywackes on right. Bedding appears to be right-side-up, however, the poorly developed cleavage in the shales dips steeply to the west suggesting that both bedding and cleavage have been rotated by faulting.
24.2	1.3	Stop sign. Intersection with US 44-NY 55. Turn right, heading west.

ROUTE TO ALTERNATE STOP 1B

0.0	0.0	Stop sign. Turn left on US 44- NY 55 heading east.
2.2	2.2	Benton Corners. Intersection with Libertyville Road. Continue straight on US44-NY55.
3.2	1.0	Exposures of Martinsburg Formation of Alternate Stop 1B to left.
3.4	0.2	Park on shoulder at intersection. Walk west, back to outcrop of Martinsburg Formation.

ALTERNATE STOP 1B

FAULT ZONE AT GANAHGOTE--MARTINSBURG FORMATION

The shales and graywackes of the Martinsburg in this long roadcut have been severely faulted. This locality was chosen as an alternate stop in order to show the small-scale structures related to what we and others (Kalaka and Waines, 1986) interpret as a major thrust fault of Alleghanian age. Several difficulties arise when trying to document this age: 1) The extent and thickness of glacial materials in the Wallkill Valley prevents the reliable tracing of structures over great distances. 2) This locality contains no rocks younger than the Martinsburg of Ordovician age. Therefore, at this specific locality it is impossible to prove the fault is younger than Taconic. This fault was first referred to by Kalaka and Waines (1986) and they will probably visit this locality on Trip H (this guidebook).

There are at least two ages of quartz slickensides at this stop. The oldest slickensides are parallel to bedding, show movement to the northwest, and were later folded by the tight folds produced during faulting. Unfolded slickensides also formed along these late faults and again show east-over-west movement. In addition, vein quartz found along faults can contain broken pieces of shale. The faults vary in strike from N. 10^{o} E. to N. 50^{o} E. and dip gently to moderately to the southeast. Cleavage, though present throughout the outcrop, is more intensely developed near the NE-trending thrust faults. It is in these localities that the rock is intensely pencilled.

Based on our mapping in this region, the best examples of pencil shales occur near the younger faults that cut both Ordovician and Silurian rocks. At this outcrop it is common to find bedding and folds abruptly truncated by faults, but the total disruption common to the melange seen at Stop 1 is missing. While one can find smearing along cleavage planes and some anastomosing fabrics at this outcrop, the pervasive scaly cleavage so beautifully developed at Stop 1 is also missing.

About 0.5 mile southwest of Stop 1B along the Shawangunk Kill are a series of excellent exposures of the middle part of the Martinsburg that we are informally calling the sandstone at Pine Bush (see section on Ordovician stratigraphy). For a distance of at least 2,000 feet along Shawangunk Kill the entire section is overturned. These outcrops appear to be in the footwall of the thrust fault seen at this stop. However, the total width of the fault zone is not known and there appears to be some faulting at the west end of the Shawangunk Kill exposures. In addition, data from the nearby Delaware aqueduct suggests that the 2,000 feet of overturned Pine Bush might be a sliver caught in the fault zone (see fig. 7). About 3.2 miles to the north of Stop 1B on Route 299 (Roadlog mileage 21.6 to 22.4) a minimum of 4,000 feet (perhaps as much as 6,000 feet) of Martinsburg is overturned or close to vertical. Also, it would appear that the thrust is cutting up section towards the north since it is approaching the contact with the overlying Shawangunk Formation. It is most likely that this fault is the same as the Mohonk Lake thrust fault (see figs. 7 and 14). They both have minimum offsets of several thousand feet. In the Mohonk Lake area, the stiff and thick-bedded Pine Bush is virtually absent and the thinner bedded shales and graywackes of the upper Martinsburg (Mamakating) do not appear to be regionally overturned. Locally, for distances of a few tens of feet the rocks may be tightly folded and overturned.

		Return to bus, reverse direction heading west on US44-NY55.
5.5	2.1	View of Shawangunk Formation on cliff face straight ahead.
6.7	1.2	Intersection with NY 299. Pick up road log at 24.2

24.2	1.3	Stop sign. Intersection with US 44-NY 55. Turn right, heading west. For the next mile we will be climbing to the top of the Shawangunk Mountains.
24.4	0.2	Martinsburg on left

24.8	0.4	From here to the unconformable contact with the Shawangunk near the top of the mountain the Martinsburg is well exposed. The rocks are predominantly shale interbedded with thin-bedded (up to 5 in), crossbedded to planar laminated siltstone, and minor fine-grained sandstone. Soft-sediment slump folds are common in the siltstones. Cleavage is absent or very poorly developed, except near tight folds and narrow fault zones. Most of these folds and faults do not affect the overlying Shawangunk and must be Taconic in age. They trend from N. 5° E. to N. 20° E., while structures in the overlying Shawangunk trend moreeasterly.
25.2	0.4	To the left is a turn off with a nice view of Wallkill Valley.
25.3	0.1	Buried contact of Martinsburg and Shawangunk. This area of the "gunks" is very popular with rock climbers, often as "thick as pigeons" (R. Waines, oral commun., 1983). The contact is exposed at two spots about 400 feet southwest of the road at the base of the cliffs. Fairly regular and linear mullions are seen in the basal Shawangunk at the contact.
25.4	0.1	Pass under Trapps bridge. Conglomerates and quartzites of the Shawangunk dipping moderately to the west.
26.6	1.2	Cross Coxing Kill. Here the Coxing Kill valley coincides with the trough of a broad open syncline that plunges gently to the northeast. It is also the site of much nude bathing. For the next 0.5 mile we will begin to cross a broad open anticline that exposes a window of Martinsburg that is approximately 2 miles long.
27.1	0.5	Poor exposure of Martinsburg to left.
27.4	0.3	Exposure of basal Shawangunk to right with unconformably underlying shales of the Martinsburg exposed about 40 feet away. Dips in both units are very gentle and the angle of unconformity is as little as 2°. However, the divergence in strike is as much as 38°, with the strike in the Martinsburg being more northerly. The Martinsburg here is in the broad open-fold Taconic tectonic zone (zone 3, fig. 9).
28.0	0.6	Cross Peters Kill.

28.5	0.5	Entrance to Lake Minnewaska State Park on left.
28.7	0.2	Parking lot on left; entrance to trail leading to Lake Awosting.
29.4	0.7	Cross Sanders Kill.
30.4	1.0	Upturned beds in Shawangunk mark a fault here.
30.5	0.1	Overview on right of Rondout Valley, underlain by Upper Silurian through Middle Devonian rocks which are buried by a variety of glacial sediments, and the Catskill Mountains, underlain by Middle and Upper Devonian clastic rocks of the "Catskill Formation". Moderately dipping quartzites and conglomerates of the upper part of the Shawangunk on left.
31.5	1.0	Cross Stony Kill
33.8	2.3	Roadcut in tongue of the Shawangunk (figs. 3 and 4) consisting of distinctive light- and dark-gray, crossbedded, slightly conglomeratic quartzite.
34.2	0.4	Cross Rondout Creek.
34.3	0.1	Stop sign. Intersection with US 209. Turn left. U.S. 209 follows the Rondout Valley, here underlain by rocks from the uppermost part of the Shawangunk Formation, then through a sequence of Upper Silurian through Middle Devonian limestones, shales, sandstones, and siltstones. Exposures are poor because of cover by glacial drift.
36.5	2.2	Enter Town of Wawarsing.
37.1	0.6	Cross Vernooy Kill.
37.4	0.3	Gravel pits in glacial delta to right and lake clays of glacial Lake Wawarsing under flat plain to left (Rich, 1934; Heroy, 1974). Glacial Lake Wawarsing was dammed in the Rondout Valley between the recessional moraine at Phillipsport (mileage 65.2) and the retreating ice front. The top of the deltaic deposits are at approximately 600 feet altitude, showing that the lake was about 300 feet deep here. The lake enlarged during recession, it dropped as lower outlets were uncovered, and finally drained as the ice retreated past the northeast end of the Shawangunk Mountains near Rosendale.

37.9	0.5	Sand and gravel pit to right.
38.1	0.2	Eastern New York Correction Facility, a maximum security prison, servicing many gentlemen from the New York City area, to left. There is an excellent exposure of the Martinsburg-Shawangunk contact, about 20 feet long, at an altitude of 600 feet. The angular discordance between the two formations is 4°; the Martinsburg here is in Taconic tectonic zone 3 (fig. 9). The Shawangunk dips 22° NW. in the northwest limb of the Ellenville arch. Mullions are prominent on the basal Shawangunk surface, and there is a shear fabric in both the Martinsburg and Shawangunk.
38.4	0.3	View of the Shawangunk Mountains in the northwest-dipping limb of the Ellenville arch to left.
38.8	0.4	Cross Rondout Creek.
39.2	0.4	Exposures of shaly siltstone to very fine-grained sandstone of the Mount Marion Formation, dipping 56° NW., to right. Field to left covered by glacial deposits except for one exposure of Onondaga at airfield.
39.8	0.6	Enter Village of Ellenville.
40.4	0.6	Cross Beer Kill. A fine example of a slump deposit with disrupted bedding in the Mount Marion Formation is exposed 800 feet up the creek to the right. This outcrop may be within the Alcove Conglomerate of Wolff (1977).
40.5	0.1	Turn left on Liberty Street. View of North Gulley in Shawangunk Mountain straight ahead.
40.6	0.1	Stop sign. Turn left on Canal Street.
40.9	0.3	Cross Sandburg Creek.
41.1	0.2	Pass Berme Road. The Ellenville zinc-lead mine and a rock quarry in the tongue of the Shawangunk are located at the base of the mountain to the left. See Sims and Hotz (1951) and Rutstein (1987, p. 116) for descriptions.
41.5	0.4	Cross North Gully, joining NY 52. Exposures of the tongue of the Shawangunk in roadcuts and tongue of the Bloomsburg in the creek bed of North Gully to the left (fig. 3).

41.8	0.3	Turn left on blacktop road towards Mt. Meenahga.
42.0	0.2	Red beds of tongue of the Bloomsburg to left. Till and moderately NW-dipping Shawangunk higher along road towards Mt. Meenahga.
42.2	0.2	View to right of the valley of Sandburg Creek, the Nevele Country Club, and the Catskill Mountains.
42.6	0.4	Turn left. Conglomerates of basal Shawangunk on left. (Bus will return to this spot after letting group off at top).
42.7	0.1	Uppermost Martinsburg on left.
42.9	0.2	Contact between Martinsburg and Shawangunk at base of low cliff on left.
43.0	0.1	Pull into parking area of abandoned ski slope. Disembark. Bus will return to mileage 42.6.

STOP 2

CONTACT OF MARTINSBURG AND SHAWANGUNK; SHALE-CHIP GRAVEL AT TACONIC UNCONFORMITY; UPPERMOST MARTINSBURG IN TACONIC OPEN-FOLD FRONTAL ZONE; CLEAVAGE IN SHAWANGUNK

Take a peek to the northwest through the bushes at the broad glacial valley of Sandburg Creek and the Catskill Mountains beyond. The valley is underlain by glacial lake sediments, deposited in glacial lake Wawarsing between the morainal dam at Phillipsport, 5 miles to the southwest, and the receeding ice front. Also note the graffiti-covered, unevenly and planar bedded conglomerates with low-amplitude channels in the lower Shawangunk Formation. The contact with the underlying Martinsburg Formation is near the base of the low cliff. In this area the strike of the two formations is similar, but the Martinsburg dips 10 to 15 degrees less than the Shawangunk.

Locality A:

Walk 300 feet down the road to the exposed contact of the Martinsburg and Shawangunk.

The Shawangunk consists of planar bedded, quartz-pebble conglomerate with rounded to subangular vein quartz pebbles as much as 2.5 inches long, and planar bedded and crossbedded, conglomeratic, medium- to coarse-grained, feldspathic quartzite. Chert pebbles are rare. There are no pebbles derived from the underlying shales and graywackes of the Martinsburg Formation.

The Shawangunk forms a two-foot overhang above the underlying rock, which is at least 1.5 feet thick and consists of a mass of shale chips with an openwork texture. The chips are up to about 1 inch long and form a crude foliation approximately parallel to the overlying contact with the Shawangunk, although this foliation is interrupted in places. It might be suggested that these rocks were jammed by man under the Shawangunk, but the unit below the Shawangunk is clearly in place. The only explanation for this unit that we can think of is that it is a shale-chip gravel, deposited on and derived from a sloping Martinsburg surface. The shale chips are flat and generally equidimensional on their flat surface. There is no secondary cleavage in the chips, as far as we can tell. This suggests that cleavage was not imposed upon the Martinsburg prior to the deposition of the gravel. Thus, slaty cleavage at this locality did not form during Taconic deformation.

The gravels in the Martinsburg are remarkably similar to Pleistocene shale-chip gravels derived from Paleozoic shales in the central Appalachians, both in physical appearance and size-distribution characteristics (see section on "Weird rocks" and fig. 5 C,D).

If this is indeed a colluvial deposit, the geologic relations in this area indicate that the Martinsburg was gently folded during Taconic deformation, it was uplifted and exposed with a steep enough slope to develop a colluvial shale-chip gravel, and was later covered by conglomerates (believed to be fluvial) of the Shawangunk Formation.

Locality B

Walk another 700 feet down the road to exposures of uppermost Martinsburg bedrock.

The Martinsburg here consists of thin-bedded grayish black shale with some thin beds of olive-gray, very fine grained, crossbedded graywacke, capped by thin Pleistocene till. Note the lack of cleavage in the shales. The Shawangunk 40 feet above has the same strike, but dips 10^{o} more steeply. This gentle angular discordance between the two units is typical not only for the Ellenville area, but for many miles to the northeast (to Ruedemann's Line, fig. 9) and to the southwest through New Jersey into eastern Pennsylvania (Epstein and Lyttle, 1987). This relationship is typical of the open-fold Taconic frontal zone (fig. 9).

Locality C

Walk another 600 feet downhill to the road intersection and the Shawangunk outcrop.

Bedding in the Shawangunk dips 40^{o} NW here, getting steeper as we head farther northwestward into the steep limb of the Ellenville arch. The conglomerates in Shawangunk contains closely spaced fractures cutting through the quartz pebbles and sand matrix. In places a residual thin film of mica and opaque minerals along the cleavage folia shows that it is a pressure-solution phenomenon. This type of cleavage is common in the Shawangunk in New Jersey and New York. Because bedding-plane slickensides are not common in this area, it is hypothesized that shortening during folding of the Shawangunk was taken up by development of cleavage. In eastern Pennsylvania, where folding is tighter and there has been much accomodation by bedding-plane slippage, there is little cleavage in the conglomerates and quartzites.

43.4	0.4	Reboard bus and retrace route back to NY 52.
44.2	0.8	Stop sign. Turn left on NY 52.
44.3	0.1	Tongue of the Bloomsburg Redbeds on left. The road follows this unit for several hundred feet.
44.8	0.5	Outcrops of uppermost Shawangunk in flatirons on northwest limb of Ellenville arch.
44.9	0.1	Cross South Gully.
45.6	0.7	Site of Stop 3 on left.
45.7	0.1	Pull off on shoulder to right. Cross road and walk 0.1 mile down to Stop 3.
		CAUTION--WALK ONLY ON SHOULDER. THIS ROAD IS HEAVILY TRAVELLED! NO REFUNDS IF YOU ARE HIT.

STOP 3

STRATIGRAPHY AND SEDIMENTATION OF THE SHAWANGUNK FORMATION

The upper half of the Shawangunk Formation is exposed here and consists of crossbedded and planar-bedded conglomeratic quartzite and pea-gravel conglomerates, with minor thin, lenticular light-olive-gray shale. Channels are abundant and many beds pinch out along strike. Shale drapes in crossbeds are common. Flattened silty shale balls up to 8 inches long are seen on the lower exposed bedding surface. Crossbed trends throughout the area of this field trip are to the northwest (fig. 15). The sedimentary structures, current trends, and petrographic characteristics suggest a fluvial, braided stream environment of deposition, similar to the interpretation for the Shawangunk in eastern Pennsylvania (Epstein and Epstein, 1972).

We will discuss some of the regional stratigraphic correlation shown in fig. 3.

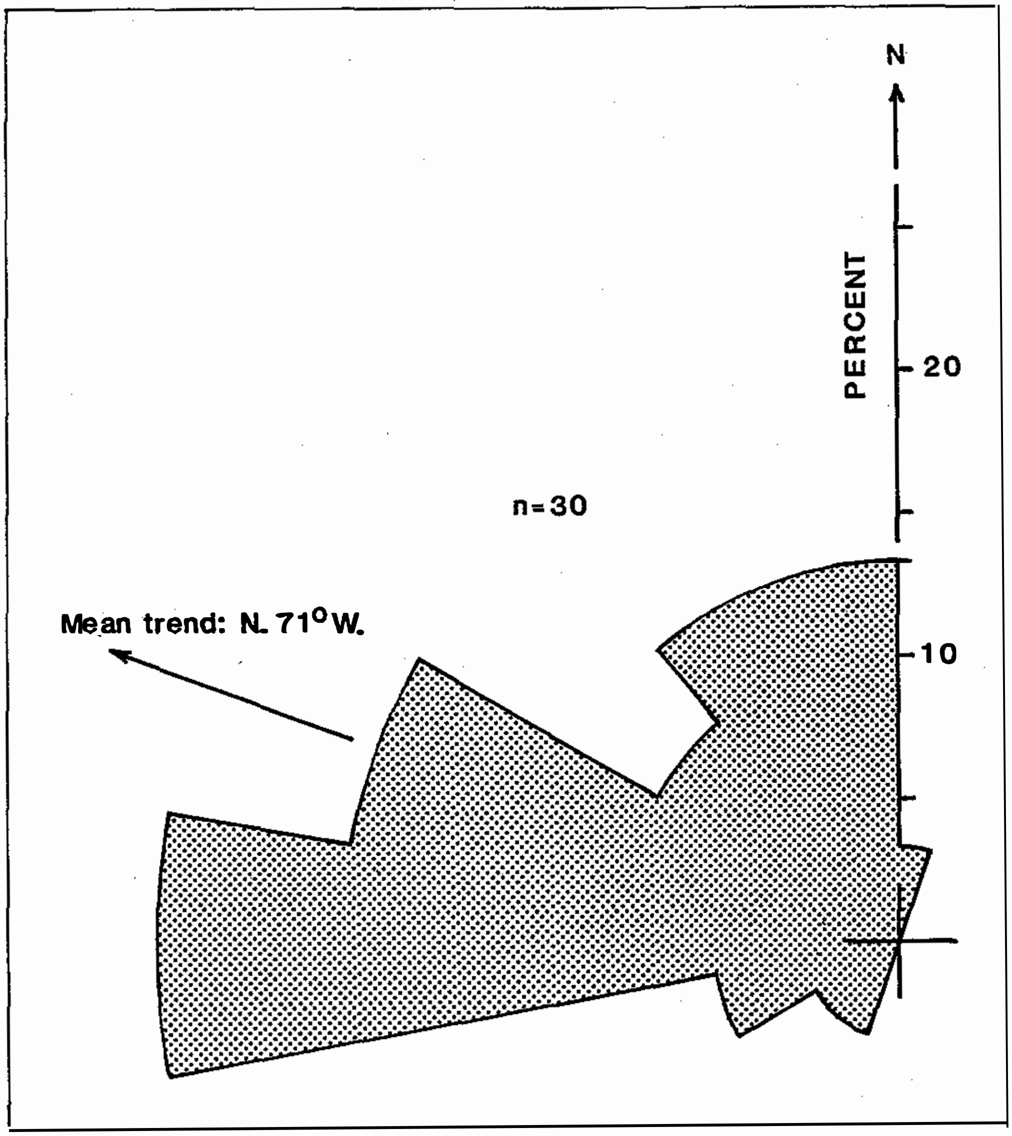

Figure 15. Histogram showing current trends from axes of trough crossbedding in the Shawangunk Formation, southeastern New York. Grouped in 20 percent intervals.

The beds dip about 45° NW. They are interupted by a kink fold whose axis trends 18° S. 56° W., a more easterly trend than the regional strike of the beds. This fold, and scattered others in this part of the Appalachians, may represent a later stage of Alleghanian folding.

If the leaves are off the trees, you may be able to see the linear valleys in the Catskill Mountains to the north. These are discussed under "Age of post-Taconic Deformation".

If parking of the bus for this stop does not work at this locality, proceed to mileage 46.8 for alternate Stop 3.

Return to bus and continue uphill on NY 52.

45.9	0.2	Small thrusts in Shawangunk to left. These have a strike similar to the kink axis at Stop 3 and may also be later structures.
46.2	0.3	Upper quartzite member of Shawangunk. Launch site for hang gliders straight ahead.
46.5	0.3	Shale unit of Shawangunk on left.
46.6	0.1	Back into overlying quartzite unit.
46.8	0.2	Shale unit of Shawangunk to left, nice view at turn off to right. Pull off for Alternate Stop 3.

ALTERNATE STOP 3

To the right (northwest) is the flat-floored valley of Sandburg Creek underlain by glacial lake clays. In the far distance to the north the hills are underlain by sandstones of the Ashokan Formation, and in the far distance to the north are the higher Catskill Mountains underlain by Middle and Upper Devonian rocks of the "Catskill Formation". The valleys in the Catskills are aligned along linears that are presumably controlled by structural weakness (see section on age of deformation).

CAREFULLY CROSS THE ROAD

In this area we have been able to divide the Shawangunk into lower and upper units (fig. 3), separated by a shale-bearing sequence about 100 feet thick. The shale unit underlies topographic lows, generally allowing for easy mapping. This unit can be seen at the base of the exposed section, and consists of more than 80 feet of interbedded, laminated, ripple laminated, olive-gray silty shale and moderate-brown and light-olive-gray very fine to medium-grained, crossbedded, lenticular sandstone, slightly conglomeratic in places. Many of the sandstones have sharp channeled bases and some are ripple-topped.

The shale unit is overlain by several hundred feet of thin- to medium-bedded, medium-grained, partly conglomeratic, partly feldspathic, crossbedded, channeled quartzite with scattered thin and lenticular olive gray shale. The quartzites appear to be evenly bedded from a distance, but closer scrutiny shows that they are channeled, lenticular, and unevenly bedded.

Return to buses and continue uphill along NY 52.

47.9	1.1	Turn left on road to Cragsmoor and Ice Caves Mountain. Between here and the next stop, the road will be mostly on glacial till, with a few scattered exposures of the Martinsburg.
48.3	0.4	Village of Cragsmoor. Bear right at Post Office.
48.4	0.1	Turn right on Sams Point Road following signs to Ice Caves Mountain.
48.6	0.2	Cragsmoor Fire Dept. on right. Martinsburg exposure on left. This exposure and a few more up the road are in the Taconic tectonic zone of broad open folds. Views of continuous cliffs of the Shawangunk Formation in the broad top of the Ellenville arch may be seen at several places along this road.
48.7	0.1	Borrow pit on right in Martinsburg.
49.7	1.0	Entrance to Ice Caves Mountain National Landmark. Stop sign. Continue straight ahead on loop road to left. If you are quick you might read the educational (??) signs as the bus proceeds. It is possible that we will not drive to the top of the mountain at Sam's Point. If so, pick up a lunch and take a liesurly 15-minute stroll to Sam's Point along the road to the right. The basal Shawangunk is nicely exposed near the end of the journey.
49.8	0.1	Slot Rock, a crevasse in the Shawangunk, on your right.
50.0	0.2	Martinsburg on right. At this locality the Martinsburg dips 5° more steeply to the southeast than the Shawangunk exposed in the low cliffs above.
50.5	0.5	Cross Martinsburg-Shawangunk contact.

50.7	0.2	Microwave tower on left. Lake Marentanza on right. Many of the Shawangunk surfaces contain glacial striae.
51.1	0.4	Lake Maratanza, partly dammed by till in a structural depression, on right.
51.3	0.2	Sign: "There are no fish in this lake. This is Lake Marentanza. It is the water supply for Ellenville. There are no fish because the rocky bottom does not grow plant life to give off enough oxygen to support fish life. It is a mystery where the water comes from since the lake is on a mountaintop. What do you think?"
51.7	0.4	Road to Ice caves on left. Continue straight.
52.1	0.4	Turn right to Sam's Point.
52.2	0.1	Park in lot and walk out to Sam's Point.

STOP 4

SAM'S POINT
REGIONAL OVERVIEW
BASAL SHAWANGUNK; TROUGH CROSS BEDDING
GLACIAL STRIAE
ICE CAVES AND JOINTS
LUNCH

The highest point in the Shawangunk Mountains (2,289 ft) lies 2,000 feet north of this point. From southeast (left) to north (right), you can see (if the day is clear), the New York Highlands underlain by Precambrian rocks thrust on top of Cambrian and Ordovician carbonates and shales of the Wallkill Valley. In front of the Highlands are Schunnemunk and Bellvale Mountains underlain by conglomerates and sandstones of the Middle Devonian Schunnemunk Conglomerate in the Green Pond outlier. The rocks of the outlier are in fault and sedimentary contact with the Precambrian. The details of these structures are far from fully known. Shawangunk and Kittatinny Mountains, held up by the Shawangunk Formation, upon which we stand, next wiggle to the southwest with Tristates Monument marking the highest elevation in New Jersey at High Point (1,803 ft). We already know about the glaciated valley northwest of the mountain. The large white buildings 17 miles due west near Monticello make up the Concord Hotel, the site of several past GSA meetings. Beyond that are the Pocono Mountains of Pennsylvania that blend into the Catskill Mountains of New York to the northeast, underlain by flat-lying rocks of the "Catskill Formation".

The Shawangunk at Sam's Point dips very gently to the northeast, near the broad crest of the Ellenville Arch. Trough crossbedded is well exposed. These indicate current trends ranging between S.80°W. and N.70°W. Glacial striae with chatter marks on the bedding surfaces show that the Wisconsinan glacier flowed over the mountain moving S. 16° W.

The lower 80 feet of the Shawangunk here consists of medium- to thick-bedded conglomerate with quartz pebbles as much as 2 inches long. Channeled bases are common. Nowhere do we see any pebbles from the underlying Martinsburg, a peculiarity that exists throughout New York, New Jersey, and eastern Pennsylvania, and one which eludes a good sedimentologic explanation.

The Shawangunk is separated into huge blocks tens of feet wide. These have moved apart along the soft shales of the underlying Martinsburg, probably forced apart by frost action and wedging of boulders that fall into the cracks, producing a "moveoutite". This process has gone to a joyous extreme at the Ice Caves, one-half mile to the east, where the joints parallel the cliff face of the mountain. Cold air is trapped in the maze of blocks, and snow may persist throughout the summer, hence their name.

		Return to bus. Turn right out of parking lot and proceed down over cliff of Shawangunk conglomerates, crossing buried contact with Martinsburg Formation.
52.4	0.2	Note the breaking away of large blocks of the Shawangunk along joints.
52.8	0.4	Entrance to park. Retrace route back to Ellenville.
54.2	1.4	Post Office in Cragsmoor. Bear left downhill.
55.7	1.5	Stop sign. Turn right on NY 52 towards Ellenville.
57.2	1.5	At 11 o'clock are linear valleys in the Catskill Mountains that mark lineaments seen on radar imagery and described under mileage 1.3.
59.7	2.5	Bear left on Center Street.
60.5	0.8	Stop light. Intersection with US 209. Turn left.
61.3	0.8	Moderately northwest dipping gray shale, siltstone, and sandstone of the Mount Marion Formation. We will be paralleling these rocks for the next 18 miles. On the left are lake deposits of Lake Wawarsing. This lake was dammed by the moraine at Phillipsport, four

		miles to the southwest.
64.4	3.1	Bear Hill to left in Ellenville arch.
64.8	0.4	Cross Sandburg Creek.
65.1	0.3	Cross Homowack Kill. Leave Ulster County; enter Sullivan County.
65.2	0.1	Moraine at Phillipsport on left.
68.5	3.3	Leave moraine.
69.6	1.1	Parking area on right from which to see gliders on lazy summer days.
70.1	0.5	Wurtsboro airport on left. Shawangunk mine (zinc-lead) on top of Mountain to left (Ingham, 1940; Gray, 1961).
71.8	1.7	Enter Village of Wurtsboro.
72.4	0.6	Stop light. Danny's Restaurant on left is excellent place for pastrami and corned beef sandwiches. Continue straight on US 209.
73.6	1.2	Overpass with NY 17. Continue straight on US 209. Exposures of Mount Marion to right.
78.8	5.2	Entering Village of Westbrookville.
79.1	0.3	Turn left on Otisville Road (Sullivan Co. Rt 163).
79.2	0.1	Enter Orange Co (Orange Co. Rt 61).
79.5	0.3	Cross Basher Kill.
79.7	0.2	Large erratics of Catskill sandstone on left.
80.0	0.3	Quarry in New Scotland Formation on left.
81.0	1.0	Beginning of exposures of Shawangunk Formation on left.
81.2	0.2	Stop sign. Intersection with NY 211. Turn left. Northwest dipping Shawangunk straight ahead. In quarry to left are thin shales interbedded with typical Shawangunk quartzites and conglomerates. These are on line with exposures 1.2 miles to the southwest to which Swartz and Swartz (1931) applied the name "Otisville Shale Member of the Shawangunk Formation". This unit is out to lunch, that is,

it is poorly defined, it is unmappable, and should be discarded. Clarke (1907) measured the rocks in the quarry and showed that shale makes up less than 3 percent of the section.

Turn immediately right onto dirt road of abandoned railroad track. Walk to stop 5.

STOP 5

TACONIC UNCONFORMITY AT OTISVILLE

This is a classic exposure, discussed by many geologists in the past (Clarke, 1907, Schuchert, 1916, others), and visited by the 34th Meeting of the NYSGA (Fink and others, 1962). All have recognized the angular discordance in bedding between the Martinsburg (N.16°E., 44°N.W.) and Shawangunk (N.36°E., 28°N.W.). In this area we are in the broad open-fold zone of Taconic deformation, although these gentle structures are interrupted locally by a faulted overturned fold, seen at the next stop (fig. 16).

The basal Shawangunk conglomerates contain quartz pebbles as much as 2 inches long. No pebbles from the underlying Martinsburg were seen. The lowest few inches is pyritized. The Martinsburg comprises shale with minor thin graywacke siltstones and contains no obvious secondary cleavage.

The basal surface of the Shawangunk is irregular, with downward-projecting mullions that have a relief of about one inch and are about 3 inches to two feet apart. These have a general trend of N. 32° E., about parallel to the strike of the beds and perpendicular to the regional transport direction. Note that these mullions are found only at the Martinsburg-Shawangunk contact and are not found on any surface higher up in the section. Some of the lowest Shawangunk is sheared parallel to bedding.

Between the solid Martinsburg bedrock and the Shawangunk there is an unusual zone, as much as one foot thick, containing light-gray to light-bluish gray clay gouge with slickensided quartz veins. This gouge, and the associated mullions in the overlying conglomerates, are typical of most Martinsburg--Shawangunk contacts exposed in southeastern New York (fig. 1) and shows that the unconformity is also a plane of movement, the displacement along which is not known.

Also in this zone is a poorly sorted and vaguely bedded diamictite (a nongenetic term referring to a poorly sorted sedimentary rock with a wide range of particle sizes) containing angular to rounded pebbles of exotic types, as well as clasts from the Martinsburg, in a clay-silt matrix. Bedding is generally poor, but some samples collected from the northeast

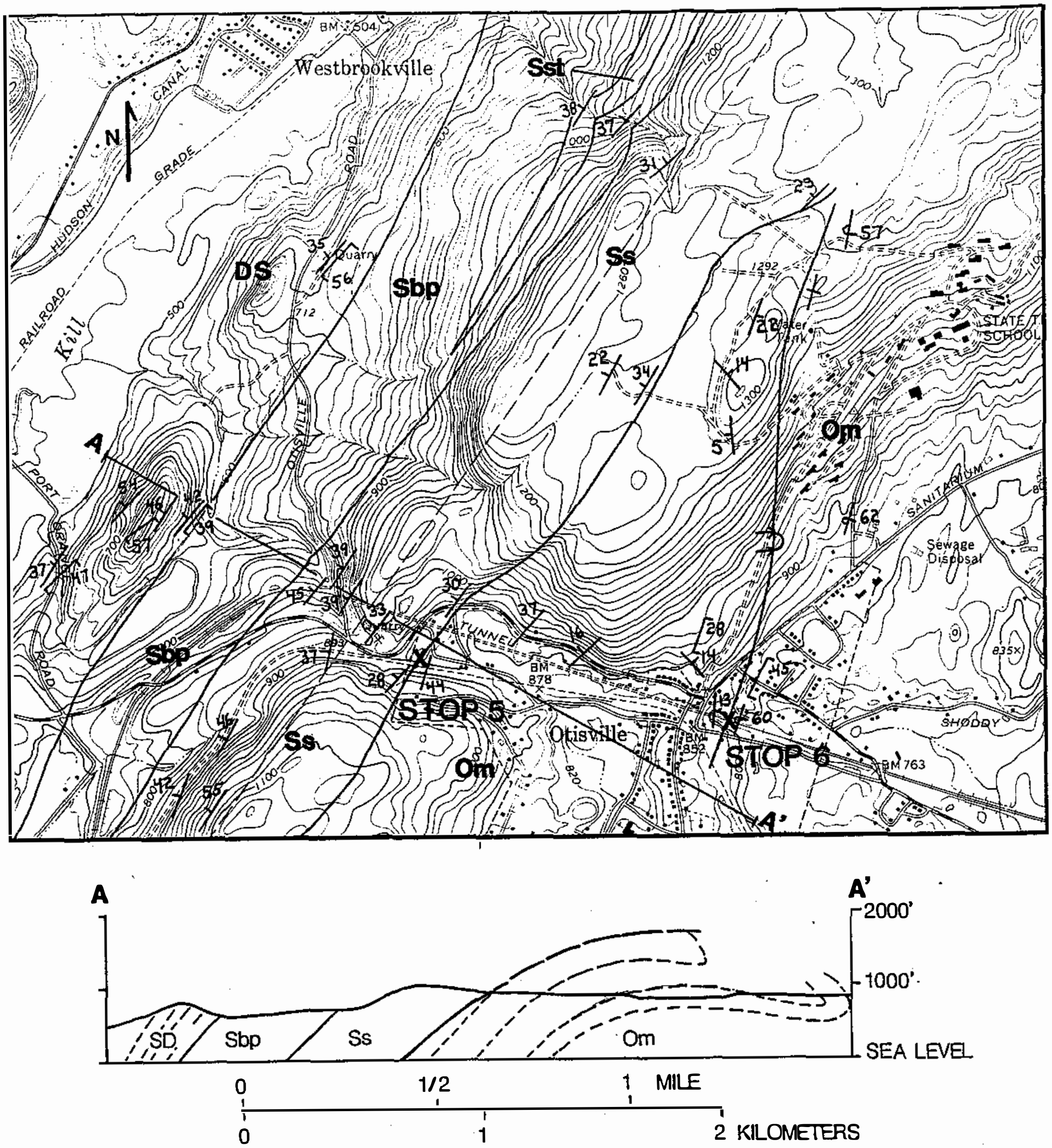

Figure 16. Preliminary geologic map and section of the Otisville, N.Y. area showing the angular unconformity between the Shawangunk and Martinsburg Formations, the overturned syncline overlapped by the Taconic unconformity, and location of stops 5 and 6. Standard structure symbols used for bedding, cleavage, and axial trace of syncline. DS, Schoharie Formation through Bossardville Limestone; Sbp, Poxono Island Formation and Bloomsburg Red Beds; Ss, Shawangunk Formation; Om, Martinsburg Formation. Base from U.S. Geological Survey topographic quadrangle: Otisville, N.Y., 1969.

side of the cut show reasonably decent bedding. There is a sharp contact with the Shawangunk above and also a sharp contact with the Martinsburg below; both are unconformable. In places it appears that parts of the Martinsburg have been bodily lifted from the underlying bedrock and incorporated in this diamictite. There are several possibilities for the origin of this unit. We do not believe that it is fault related, because there is no foliation in it. It looks more like a product of mass wasting, and is interpreted to be a colluvial gravel.

The pebbles include types foreign to the immediately underlying bedrock. They are composed of fairly clean quartzite, some of which are pyritic, fine-grained protoquartzite and subgraywacke, red siltstone, medium-gray siliceous siltstone, laminated micaceous siltstone, medium dark-gray shale, graywacke, and vein quartz. Many are rounded, some have a thin weathering rind, and others have surfaces that are weathered in relief. Clearly, these cobbles were exposed to the air, weathered, and incoporated in the diamictite.

One question that needs to be asked is why the clay has remained a sticky clay, whereas surrounding rocks have been lithified? The answer may be that the contact is a zone of alteration. This area of the Shawangunk Mountains contains several abandoned lead-zinc mines and there are many prospects and mineralized localities throughout the area. The lower few inches of the Shawangunk here at Otisville is similarly altered.

Another puzzlement is that the colluvium contains many disoriented clasts of slickensided vein quartz. This indicates fault movement prior to incorporation in the colluvium. Possibly the Martinsburg nearby was faulted and slickensided during Taconic deformation and the slickensided fragments were later incorporated in the colluvium. Another possibility is that the diamictite is a fault gouge and not a colluvium, and there has been several periods of movement, the latest one of which fractured earlier slickensided rocks. The problem with this interpretation is that it does not account for the exotic pebbles nor does it explain the lack of foliation in the diamictite.

WHAT DO YOU THINK?

		Return to bus, turn right, and continue east on NY 211 towards Otisville.
81.4	0.2	Enter Village of Otisville.
81.5	0.1	Covered contact of Martinsburg and Shawangunk.
81.8	0.3	Exposures of Martinsburg shale and graywacke on left, dipping moderately northwest.
82.2	0.4	Turn right on Kelly Hill Road. Follow road to left paralleling railroad tracks..

82.6 0.4 Stop on right shoulder. Cross over to railroad tracks and walk westward to Stop 6.

STOP 6

OVERTURNED TACONIC FOLD IN MARTINSBURG FORMATION

The Martinsburg in the Otisville area is generally within the open-fold Taconic frontal zone. However, this locality is complicated by a faulted overturned fold (fig. 17). The Martinsburg here consists of shale and interbedded thin- to thick-bedded graywacke. Sole marks (grooves, flutes, and loads) are prominent on the undersurfaces of bedding in the overturned limb. Cleavage is well developed and is axial-planar to the fold. The axis of the fold trends about N.10°E. and is overlapped by the Shawangunk about 1.3 miles to the north. Beacuse the Shawangunk does not appear to be folded at the unconformity, the fold, faults, and cleavage in the Martinsburg at this locality must be Taconic in age. Outside the area of this fold, cleavage is generally not developed. While the map is believed to be accurate, critical parts lie within the boundaries of both a State and a Federal maximum security prison. These areas have not as yet been mapped. The criminal instincts of the senior author of this guidebook may allow him to set up residence here in the near future in order to complete the mapping.

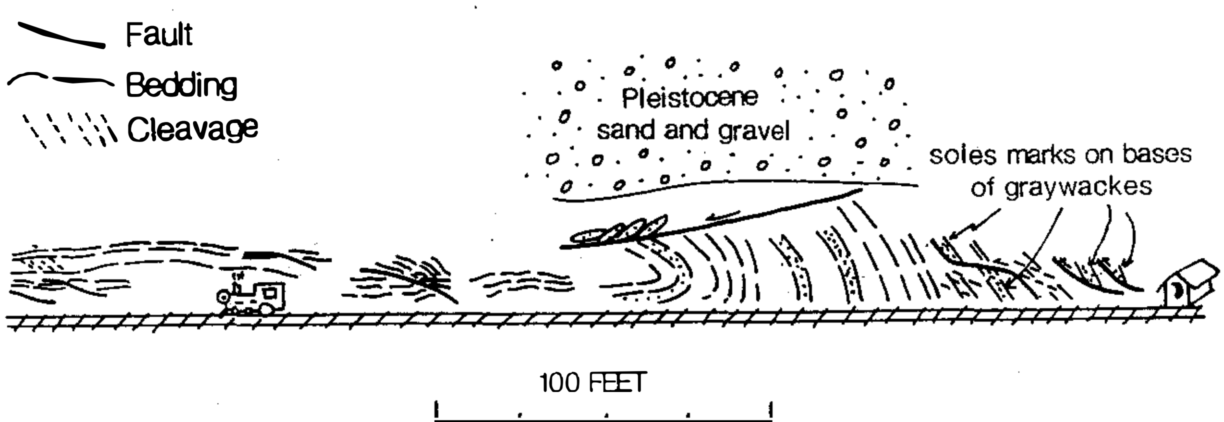

Figure 17. Field sketch (looking north) of faulted overturned syncline along Erie-Lackawanna Railroad, Otisville, New York. Stop 6.

		Reboard bus and continue straight ahead.
83.2	0.6	Stop sign. Turn left on N.Y. 211, passing under railroad bridge.
84.3	1.1	Stop sign. Turn right on Sanitorium Avenue (Orange Co. Rt 90).
84.4	0.1	Road to Federal Correctional Institution to left.
84.6	0.2	Otisville Correctional Facility of the New York State Department of Correctional Services to left. At this point, all those who have disagreed with the interpretations presented on this field trip will be dispatched.
86.3	1.7	Graywackes of the Martinsburg Formation on left.
87.1	0.8	Entering Sullivan County. Continue straight on Sullivan Co. Rt 65.
87.5	0.4	Continue straight on Sullivan Co. Rt 65.
88.3	0.8	Continue straight on Sanitorium Road towards High View.
88.7	0.4	Bear left at "Y" on Mountain Road.
89.4	0.7	Lake Altemont on left; gently dipping Martinsburg shales on right.
92.0	2.6	Stop sign. Turn left on Rt 17K.
92.2	0.2	Thick bedded graywacke and shale of the Martinsburg on left.
92.3	0.1	Turn left just before overpass of Rt 17 towards High View Terrace.
92.4	0.1	Martinsburg graywacke and shale on right.
92.5	0.1	Stop sign. Turn right.
92.6	0.1	Do not turn left; pull into parking area straight ahead.
		Walk out to overlook above NY Rt 17.

STOP 7

ROUTE 17 ROADCUT: STRATIGRAPHY AND STRUCTURE OF THE UPPERMOST MARTINSBURG, THE TACONIC UNCONFORMITY, AND LOWERMOST SHAWANGUNK.

CAUTION. DO NOT FALL OFF ROADCUT.
DEATH WILL RESULT

A fine view may be seen from this point. Far to the east (right) are the Schunnemunk and Bellvale Mountains, underlain by the Schunnemunk Conglomerate of Middle Devonian age in the Green Pond outlier. The lowland immediately to the east is the Walkill Valley, underlain by carbonate rocks of Cambrian and Ordovician age, as well as the Martinsburg Formation. Directly under us is a marvellous 3000-foot-long exposure demonstrating the stratigraphy and structure within the Martinsburg. To the west (left) you can see the overlying Shawangunk conglomerate (STOP 8), as well as the tongue of the Bloomsburg and overlying tongue of the Shawangunk. Beyond the bend in the road, and not seen, is the High Falls Shale. Off in the distance are the Catskill Mountains with rocks as young as the Plattekill Formation of Middle Devonian age.

This outcrop offers the best look at the uppermost 600 feet of the shale and graywacke at Mamakating of the Martinsburg exposed anywhere in the Wallkill Valley. Some of the more interesting sedimentologic and structural features are described below and located on figure 18, so that at some future date the field tripper can return and look at the outcrop at his or her leisure. As mentioned in the section on Ordovician stratigraphy, the Mamakating in southern New York differs from both the Ramseyburg and Pen Argyl Members of the Martinsburg that have been mapped in eastern Pennsylvania and northern New Jersey. The Mamakating consists dominantly of thick sequences (hundreds of feet) of medium dark-gray, thin-bedded shale interbedded with with very thin to medium-bedded (1/4 to 15 in), very fine to fine-grained, graywacke. These thick sequences alternate with thinner sequences (generally less than 100 feet) of thin-bedded shale interbedded with medium- to thick-bedded (up to 6 ft), fine-grained graywacke. Locally in both sequences, graywacke makes up more than 50 percent of the outcrop, but a more common average would be less than 25 percent. Only seen at this outcrop, but probably present elsewhere in the Mamakating, is a 40 foot thick olistostrome (fig. 19, near location B, specifically all rocks at ground level between station 50 and 300; fig. 18) with slump folds, flute casts, randomly oriented fissile shale chips, and imbricately stacked thin graywacke beds in a dominantly shale matrix, all of which suggest westward flowing currents. The olistostrome is dominantly shale, but contains some coherent graywacke beds which have incorporated some folded shale rip-ups. Perhaps earthquakes triggered slurries of slump deposits which were then immediately followed

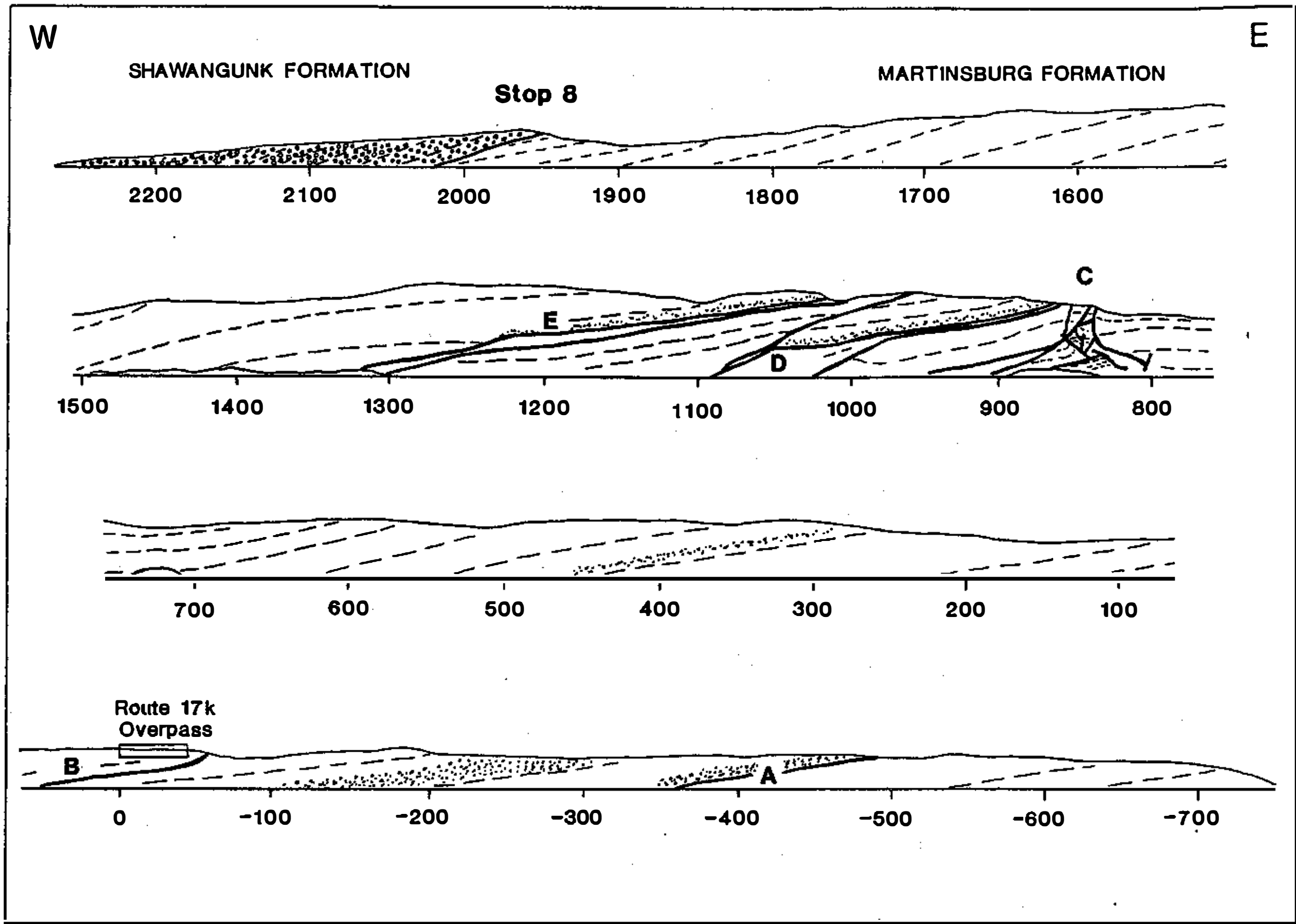

Figure 18. Field sketch from photographs of the 3,000 foot long roadcut along N.Y. Route 17 seen at Stop 7. Numbers beneath sketch indicate distance in feet. Pacing was arbitrarily begun directly beneath the west side of the Route 17K overpass; all distances to the east are shown as negetive numbers and to the west as positive numbers. See Stop 7 for detailed descriptions of structures marked by letters A-E. This long roadcut exposes the uppermost Martinsburg Formation exposed in southeastern New York State and the unconformable contact with the overlying Shawangunk Formation (Stop 8).

Figure 19. Olistostromal deposits within the shales and graywackes at Mamakating of the Martinsburg Formation at Stop 7. Picture location is directly under the west side of the Route 17K overpass on the south side of Route 17 roadcut (see fig. 18, locality B). To the right of the hammer handle is a good example of tightly slump-folded graywacke in a shale matrix. To the left of the hammer and above the foot-thick graywacke lens are imbricately stacked and broken thin graywackes. At the top of the picture is a thick graywacke turbidite which contains folded shale rip-ups near its base. Not visible are randomly oriented fissile shale intraclasts in the shale matrix.

by turbidites which ripped up the shale. This olistostrome appears to be in the hanging wall of a back thrust of unknown displacement. A return to this exposure at a later date would be well worth the effort.

Near locality A on Figure 18 is a minor 2 inch thick bedding plane fault at the base of a foot thick graywacke bed. Another 60 feet east (at station 480 on fig. 18) is a graywacke bed with breccia at its base. The breccia contains quartz and calcite crystals and slickensides at its base. The upper block appears to have moved to the southeast.

The most obvious features seen from this vantage point are a number of faults (fig. 18, location C) directly across the highway. All of these structures trend in a more northerly direction than bedding in the overlying Shawangunk, and comparable disruption is not seen in the Shawangunk. Therefore, it seems most probable that these structures are Taconic in age. The thrust fault on the east (right) side of this tepee-like structure has an east-over-west sense of motion, and has produced an excellent cleavage in the gently arched adjacent rocks of the hanging wall. This is all the more evident because cleavage is not well developed, if at all, at Stop 7, except near faults. It is difficult to prove, but this fault is probably the one with the greatest displacement. Framing the west side of this tepee-like structure is a back thrust with unknown, but probably less, displacement. This back thrust cuts a bedding plane fault that probably has had minor movement with most of the strain taken up in little buckle folds, narrow breccia zones, and fractures. In between the two are a host of accommodation faults, which are trying heroically to solve the room problem. With a little patience it is possible for the field tripper to work out a chronology of movement among the many little faults in this area.

About 250 feet to the west (fig. 18, location D) is a complex area with faults of three different ages. From our vantage point across the road it is impossible to see these details, but it is worth discussing. The earliest movement is parallel to bedding and produces quartz slickensides. These slickenlines plunge N. 60° W. and show that the upper block moved northwest. The bedding plane faults are cut by a very steep fault oriented N. 83° E., 80° SE. which has a 6-12 inch gouge. Down-dip slickenlines show that the south block moved up in this case. This steep fault is in turn cut by a third fault oriented approximately N. 70° E., 50° NW. This cross structure may be a much later Alleghanian feature similar to the late kinks seen at Stop 3. Movement on this youngest fault folds the second steep fault and shows down-to-the-northwest movement.

At the 1,175 foot marker on Figure 18 (near location E) are beautiful fractures filled with calcite, brecciated shale fragments, quartz, and a brownish-orange carbonate mineral (probably ankerite). These vertical fractures, seen at road level, are oriented N. 11° E. and appear to be caught up in a fault zone about 20 to 25 feet above road level. This fault reaches road level at station 1,300 on Figure 18. We interpret this thrust fault as a backthrust, based on folding of bedding in the upper block (presumed hanging wall) and the sense of rotation of the vertical fractures. Some of these fractures were the locus of later movement as evinced by slickenlines oriented 11° N. 11° E.

From station 1300 (fig. 18) west to the contact with the unconformable contact with the overlying Shawangunk at Stop 8, the Mamakating dips gently northwest and is devoid of any complex structures.

D. W. Fisher made three collections of graptolites from the Martinsburg shales of this outcrop, which were reported on by W. B. N. Berry (1970). The species reported by Berry are: Climacograptus spiniferus Ruedemann and Climacograptus typicalis Hall from 16 feet below the contact with the Shawangunk; Climacograptus sp., Dicranograptus nicholsoni var. minor Bulman, and Orthograptus quadrimucronatus var. approximatus (Ruedemann) from 49 feet below the contact with the Shawangunk; and Dicranograptus nicholsoni var. minor Bulman from 138 feet below the contact with the Shawangunk. These fossils are of critical importance to the dating of Taconic events (see section on Ordovician stratigraphy in text) and in establishing the length of the hiatus represented by the Taconic unconformity in southern New York State. Berry puts these graptolites in his upper subzone of zone 13, which suggests the rocks are late Middle Ordovician to early Late Ordovician in age.

Just to the south of where we are standing and approximately 240 feet beneath us is an old abandoned railroad tunnel that Russell Waines kindly suggested we visit. The southeastern 3,400 feet of this tunnel is in the Martinsburg, while the northwestern 400 feet offers excellent exposures of Shawangunk. The mineralized unconformable contact is especially well exposed (for details see Stop 8). Interestingly, a long section of the tunnel that is bricked over so that no rocks can be seen coincides with the most faulted section of the Martinsburg (fig. 18, between localities C and E). A thirty foot wide thrust fault zone (located about 400 feet in from the southeastern end of the tunnel) which, if projected along strike, would be located about 1,000 feet east of the long roadcut of Stop 7. For anyone enterprising enough to visit this tunnel, we would highly recommend a hard hat, and even more importantly, a pair of chest waders at least 5 feet tall; there is always a great deal of water in the north end of the tunnel.

Reboard buses and retrace route back to NY 17K.

92.8 0.2 Turn right on NY 17K.

93.8	1.0	Entering Bloomingburg.
94.3	0.5	Stop light. Continue straight.
94.7	0.4	Turn left on NY 17K towards Newburgh.
95.2	0.5	Turn left on NY 17 East towards Wurtsboro.
97.5	2.3	Beginning of long Martinsburg exposure described at Stop 7 on right.
97.7	0.2	Excellent exposure of olistostrome showing slump folds in thick graywacke on left beneath overpass.
98.0	0.3	Pull off on shoulder to right.

STOP 8

MARTINSBURG-SHAWANGUNK CONTACT STRATIGRAPHY OF THE SHAWANGUNK-BLOOMSBURG INTERVAL

BE VERY CAREFUL OF HIGH-SPEED TRAFFIC.

This is another fine exposure of the Taconic unconformity in southeastern New York. The rocks of the Martinsburg and Shawangunk are similar to those we have seen elsewhere. The basal foot of the Shawangunk contains much pyrite. The Martinsburg at the contact dips 16° to 31° NW., whereas the Shawangunk dips 25° NW. The angular discordance at eye level is 15°. No secondary cleavage is seen in the Martinsburg at this spot. Graptolites of Zone 13 age (late Middle to early Late Ordovician) were identified by Berry in the Martinsburg within 135 feet of the overlying Shawangunk (Offield, 1967, p. 53; Berry 1970; see Stop 7).

The character of the zone between the Martinsburg and Shawangunk varies from place to place. Near road level, the zone contains rotated shale fragments with some quartz veins. This is probably a shear zone. Also included in this zone are disrupted shale fragments and a medium dark-gray sticky clay, a fault gouge. To the southeast, where the contact rises to about 20 feet above road level, we found rounded to subangular pebbles and cobbles up to 4 inches long of graywacke, chloritic sandstone, crosslaminated feldspathic conglomeratic quartzite, and red very fine-grained sandstone. Small ribs on the surface of one pebble prove that the clast was weathered prior to emplacement, and is not a fault-breccia fragment. Several pebbles also have distinct weathering rinds. The shape of the pebbles suggest transport of short distances.

As indicated in the section on stratigraphy at the beginning of this guidebook, these findings suggest that there were a series of Upper Ordovician and possibly Lower Silurian rocks that were deposited upon the Martinsburg following Taconic uplift and folding. These were derived from source rocks that are now gone. The potential source areas are presently under investigation.

About 1,000 feet to the west we can see fine exposures of the tongue of the Bloomsburg (called High Falls by Gray, 1961, and Otisville Shale and High Falls by Smith, 1967), overlain by the tongue of the Shawangunk (called Binnewater by both Gray, 1961, and Smith, 1967). About 2,000 feet farther west are rocks which we believe to be part of the High Falls Shale. See the section on stratigraphy for an understanding of these interpretations. The conclusions were based on tracing the various facies in the Shawangunk and Bloomsburg eastward from New Jersey.

		Return to buses and continue north on NY 17
98.3	0.3	Uppermost Shawangunk on left.
98.5	0.2	Contact between tongue of the Bloomsburg Redbeds and tongue of the Shawangunk on right.
99.0	0.5	High Falls Shale dipping moderately northwest.
100.2	1.2	Turn off at Exit 113 towards US 209.
100.6	0.4	Stop sign. Turn right on US 209 North.
101.9	2.0	Stop light. Danny's Restaurant on right. Good place for pastrami and corned beef sandwiches. Continue straight on US 209 and retrace route back to Kingston.
103.7	1.8	Shawangunk Mine high on northwest slope of Shawangunk Mountain to right.
111.2	7.5	View of Ellenville Arch straight ahead.
113.8	2.6	Junction with NY 52 at traffic light in Ellenville. Continue straight on US 209 North.
115.1	1.3	Enter Naponoch.
115.7	0.6	View of eroded Ellenville arch producing flatirons in northwest limb of fold on right.
116.2	0.5	Eastern New York Correctional Facility to right.
116.9	0.7	Entering Wawarsing.
120.0	3.1	Junction with US 44 and NY 55. Continue straight on US 209.

120.8	0.8	Traffic light in Kerhonkson.
122.5	1.7	Granit Hotel to right and water tower at Minnewaska at top of Shawangunk.
124.8	2.3	Town of Accord.
129.4	4.6	Dark gray shales of Bakoven Shale on left.
130.4	1.0	Schoharie on left.
131.0	0.6	Entering Stone Ridge.
140.4	9.4	Turn right onto NY 28 East heading towards Kingston.
132.8	0.5	Turn left into Ramada Inn Parking lot.

END OF TRIP.

HAVE A SAFE JOURNEY HOME.