Trip B-3

EXAMPLES OF ALONG-STRIKE CHANGES IN FOLD-THRUST BELT ARCHITECTURE; STRUCTURAL GEOLOGY OF THE ROSENDALE NATURAL CEMENT REGION, ULSTER COUNTY, NEW YORK

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INTRODUCTION

It was necessary for the leaders of this trip to specify a set number of vehicles to obtain permission to visit several of the following stops. For this reason, personal cars will not be allowed to follow the field trip caravan.

Throughout much of the 19th century, the Rosendale natural cement region (Figure 1) was recognized worldwide as a center for the production of high-quality hydraulic cement. Although the industry collapsed in the early 1900s, the geology of this region continues to attract attention. The Rosendale area contains the northernmost portion of the central Appalachian foreland fold-thrust belt. This fold-thrust belt segment lies in the southern arm of the New York recess, a convex to the foreland, map-view curvature in the Appalachian orogen. Fold-thrust belt deformation across the New York recess involves a mechanically rigid strut of Late Silurian through Middle Devonian sedimentary strata (Figure 1; Wanless, 1921; Waines and Hoar, 1967; Rodgers, 1971; Marshak, 1986; Epstein and Lyttle, 1987; Marshak and Tabor, 1989; Marshak, 1990). This rigid strut is sandwiched between thick, relatively ductile units of Ordovician shale (below) and Middle Devonian shale (above). Near Rosendale, the Siluro-Devonian strut thins markedly from greater than 1000 m thick in central Pennsylvania to little more than 100 m thick north of Kingston. These contrasts in the pre-deformational stratigraphy of the affected units give rise to dramatic, along-strike transitions in the scale, style, and trend of structures in the fold-thrust belt across the New York recess. Preliminary balanced cross sections based on recent geologic mapping in the vicinity of Rosendale, combined with recently re-discovered historical photographs, are providing new insights into the structural relationships underlying these along-strike transitions in fold-thrust belt architecture. Specifically, the south to north thinning of the Siluro-Devonian rigid strut that takes place near Rosendale appears to trigger a south to north: 1) slight westward rotation of structural trends in the fold-thrust belt; 2) eastward migration of the pin line of deformation resulting in a narrower cross-strike fold-thrust belt width; 3) tightening of fold amplitudes and wavelengths; 4) decrease in the spacing between thrust faults and the development of lateral ramps; 5) northward dying out of thrust faults into fault-propagation folds, and 6) redistribution of regional detachment horizons.

The Rosendale natural cement region is ideally suited for the study of along-strike changes in the architecture of fold-thrust belts. In particular, the unique regional stratigraphy provides a basis for directly examining the role of changing mechanical stratigraphy in the development of along-strike changes in the internal architecture of these tectonic provinces. Further, the fold-thrust belt near Rosendale contains all of the structural complexities of regions like the Valley and Ridge Province of Pennsylvania, yet with a cross-strike width of little more than 2 to 8 km, it is possible to walk transects of the fold-thrust belt in one day. This excursion will focus on the following aspects of the Rosendale region's geology. The Rosendale region is an ideal place to examine: 1) fault mechanisms, including ramp-flat thrust fault geometries, accommodation faulting, and duplex structures; 2) fault-bend, fault-propagation, and detachment folding; 3) strain distribution in thrust sheets; and 4) the controls of rock type and structural relationships on cleavage morphology and intensity. In addition to structural relationships, the strata in the Rosendale region preserve an abundance of Early to Middle Devonian marine fossils, so we can examine examples of classic shallow-marine carbonate facies successions (Rickard, 1962; LaPorte, 1969), and outcrops of the region provide exposures of the Taconic angular unconformity (Rodgers, 1971; Toots, 1976; Epstein and Lyttle, 1987).

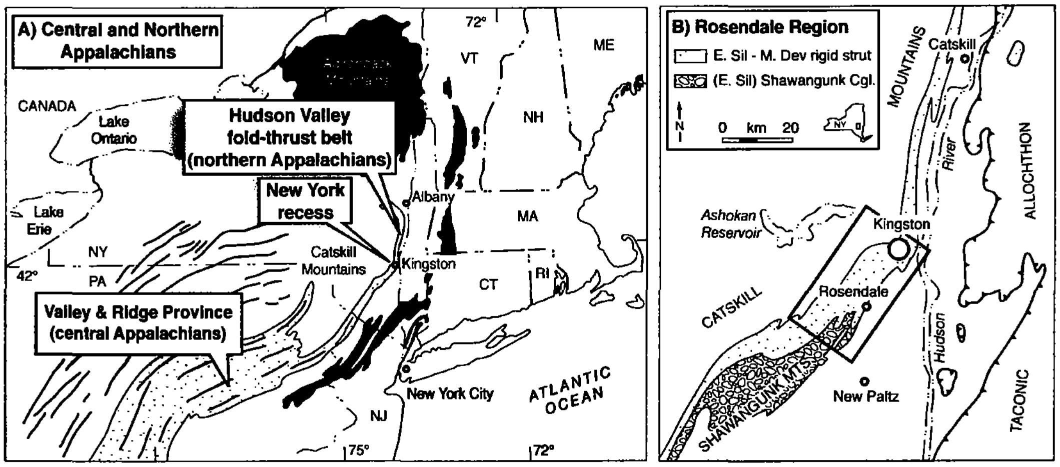


FIGURE 1: Regional map **(A)** showing: central (Valley and Ridge Province) and northern (Hudson Valley fold-thrust belt) segments of Appalachian fold-thrust belt; New York recess; and cities of New York, Kingston, and Albany. Blackened areas delineate exposures of Precambrian, crystalline basement rocks in hinterland of orogen. Location map **(B)** shows: Rosendale natural cement region (outlined by heavy black box); cities of Kingston and New Paltz; Hudson River; and westernmost Taconic thrust sheet. Patterns show distribution of Late Silurian to Middle Devonian strata involved in fold-thrust belt deformation across New York recess. Modified after Marshak and Tabor (1989).

HISTORY AND GEOLOGY AT ROSENDALE

From the 1820s through the early 1900s, the Rosendale natural cement region produced the highest-quality hydraulic cement in North America. For nearly a century following its discovery during the construction of the Delaware & Hudson Canal, miners in the Rosendale area quarried the Rosendale and Whiteport Members of the Rondout Formation, persistently following the beds around folds and across faults. The unique chemistry of these dolomitic strata required no further modification during the manufacture of cement, making them an ideal resource. Despite the dangers and arduous labor of cement mining, the abundance and quality of this resource in the Rosendale area sparked an explosion of local industry. So proficient was their pursuit of these rocks that the long-abandoned remains of their efforts are ubiquitous in the region's dark and overgrown corners. Thus, the history Rosendale region is deeply tied to its geology.

Fresh outcrops generated by Rosendale's nascent cement industry began drawing geologists as soon as they were uncovered. Notable early geologists, including Mather (1838, 1843), Darton (1893), Nason (1893), and van Ingen and Clark (1903), produced a series of comprehensive reports for the various publications of the New York State Museum. The natural cement industry collapsed during the early 1900s, leaving behind widespread quarry exposures. Although something of an environmental catastrophe, these abandoned quarries provide unique and otherwise inaccessible glimpses of structural relationships in the fold-thrust belt. For this reason, it is of little surprise that the Rosendale natural cement region has long served as a classroom for many colleges and universities teaching the basics of field geology, structure, stratigraphy, and sedimentology. Data collected by the countless field courses that pass through the Rosendale region represent a considerable and underappreciated legacy. Perhaps the most significant of these collections consists of a series of reports held by Princeton University. Gilbert van Ingen, a Professor of Geology at Princeton University, taught annual field courses in the Rosendale area between roughly 1915 and 1923. Van Ingen's students painstakingly compiled the results of their fieldwork into a series of impressive senior and master theses (Hamil, 1916; Cairnes, 1920; Wanless, 1920; 1921; Osborne, 1921; Wiggans, 1923). These reports contain: photographs illustrating fresh quarry faces – exposures that were destroyed long ago or are presently overgrown; detailed surveys of exposures in the walls of subsurface mines that are now unsafe to enter; and dozens of carefully measured stratigraphic sections. The field relationships recorded in these old photographs are an invaluable resource for delineating the structural complexities of this region.

GEOLOGIC SETTING

The Rosendale natural cement region lies along the western margin of the Hudson Valley, about 5 km southwest of the city of Kingston (Figure 1). The region encompasses the northernmost Shawangunk Mountains, the southern extent of the Helderberg Plateau, and portions of the Wallkill and Rondout-Esopus River Valleys. The Rosendale area is characterized by a series of northeast trending hills with rarely more than 50 to 100 m relief. This portion of the central Hudson Valley is underlain by a thick and strongly deformed sequence of Ordovician shale, siltstone, and greywacke (McBride, 1962; Waines et al., 1983; Vollmer and Bosworth, 1984; Kalaka and Waines, 1986; 1987). East of the Hudson River, these Ordovician strata form the footwall of the extensive thrust sheets of the Taconic allochthon. These thrust sheets include distal marine sedimentary strata that were thrust westwards over the North American passive margin during the Taconic Orogeny. The Ordovician rocks are separated from overlying strata by the regional Taconic angular unconformity (Rodgers, 1971).

The Rosendale region includes the northernmost portion of the central Appalachian foreland fold-thrust belt. Deformation associated with the fold-thrust belt at Rosendale occurs within a 2 to 8 km-wide, northeast trending zone and involves Ordovician through early Middle Devonian strata. The Helderberg Escarpment, a 20 to 40 m high cliff, forms the eastern mapable extent of the fold-thrust belt at Rosendale. The escarpment comprises the sequence of Late Silurian through Middle Devonian strata that directly overlie the Taconic unconformity. The western margin of the fold-thrust belt lies in the foothills of the Catskill Mountains, west of the Esopus River Valley. The Catskill Mountains contain a thick sequence of Middle Devonian shale, sandstone, and conglomerate shed westward during the Acadian Orogeny. Strata within the Catskill clastic wedge are un-deformed and were either deposited subsequent to fold-thrust belt deformation, or lie beyond the western extent of deformation.

The fold-thrust belt at Rosendale lies within the southern arm of the New York recess (Figure 1), a regional curvature in the Appalachian orogen centered in near Kingston. Southwest of Rosendale, the fold-thrust belt widens into the Valley and Ridge Province of Pennsylvania. These structures continue north of Kingston in the Hudson Valley fold-thrust belt, which can be traced along the western edge of the Hudson Valley to the city of Albany. North of Albany, erosion across the Mohawk Valley has removed the strata involved in the fold-thrust belt.

STRATIGRAPHY

Fold-thrust belt deformation in the central Hudson Valley region involves a sequence of Ordovician through Middle Devonian marine clastic and carbonate sedimentary strata (Figure 2; Waines and Hoar, 1967). Thick Ordovician turbidite sequences of the Austin Glen, Martinsburg, and Quassaic Formations underlie the lowlands of the Hudson Valley (Waines et al, 1983) and are separated from overlying strata by the Taconic angular unconformity (Rodgers, 1971). At Rosendale, the Taconic unconformity is overlain by a sequence of Late Silurian through Middle Devonian strata that form the highlands of the Shawangunk Mountains and the Helderberg Plateau. The base of this Siluro-Devonian sequence comprises a wedge of Late Silurian, near-shore marine strata. The stratigraphically lowest of the Silurian units near Rosendale is the Shawangunk Conglomerate, a massive, silica-cemented quartz pebble conglomerate, which is overlain by the High Falls Shale. The High Falls Shale contains red and green shale and siltstone with locally interbedded limestone and dolomite. The High Falls Shale passes upwards

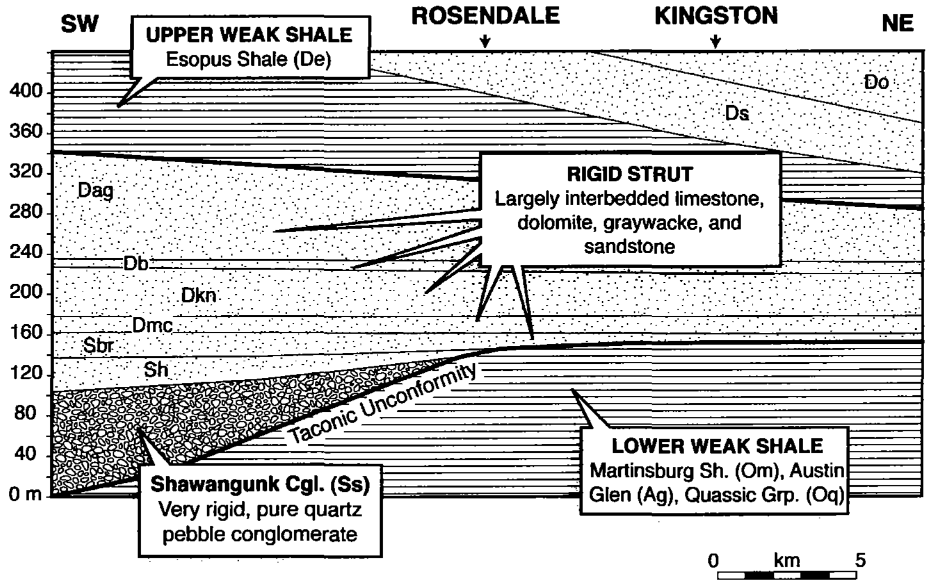


FIGURE 2: Schematic, along-strike stratigraphic chart showing the simplified relationships of Ordovician through Middle Devonian units in the vicinity of the Rosendale natural cement region. Note dramatic northward thinning of rigid stratigraphic strut of Siluro-Devonian strata. As units progressively pinch out, Late Silurian strata thin from nearly 150 m to roughly 10 m thick. The Shawangunk Conglomerate, a rigid quartz-rich unit, is stratigraphically lowest and mechanically most significant of Late Silurian units. Silurian strata are overlain by a roughly 125 m thick sequence of Early Devonian limestone, dolomite, and sandstone. The rigid strut is sandwiched between relatively ductile Ordovician Martinsburg Shale/Quassaic Group strata (below) and Esopus Shale (above). Abbreviated units are: High Falls Shale (Sh); Rondout and Binnewater formations (Sbr); Manlius and Coeymans formations (Dmc); Kalkberg and New Scotland formations (Dkn); Becraft Limestone (Db); Alsen through Glenerie formations (Dag); Schoharie Formation (Ds); and Onondaga Limestone (Do). Base line for stratigraphic section is top of Rondout Formation. Adapted from Waines and Hoar (1967).

into the Binnewater Sandstone, a thin to moderately bedded quartz arenite with abundant sedimentary structures. The Rondout Formation, a thickly bedded sequence of dolostone and moderately fossiliferous limestone, overlies the Binnewater Sandstone. The thickness of the Silurian wedge changes dramatically near Rosendale as the lower units progressively thin and pinch out northwards (Waines and Hoar, 1967). The thickness of the Shawangunk Conglomerate decreases sharply at the latitude of Rosendale, and is no longer present at Bloomington. The High Falls Shale and Binnewater Sandstone pinch out near Wilbur, leaving only the Rondout Formation north of Kingston. The Rondout Formation is present at the latitude of Catskill, where it is only 1 to 2 m thick.

Silurian strata are in turn overlain by the Early to Middle Devonian Helderberg and Tristates Groups, which record a series of transgressions in a shallow sea (Rickard, 1962; LaPorte, 1969; Sanders, 1969). The Helderberg Group contains two transgressive sequences. The first transgressive sequence begins with the near-shore tidal and beach facies of the thinly bedded Manlius Limestone and the wavy bedded, moderately fossiliferous, and locally cherty Coeymans Formation. These units are in turn overlain by the fossiliferous and increasingly argillaceous lime wackestone of the deeper-water facies of the Kalkberg and New Scotland Formations. The Becraft Formation overlies the New Scotland Formation. The Becraft Formation, the first unit in the second transgressive sequence of the Helderberg

Group, is a characteristically fossiliferous, near-shore, pinkish gray, coarse-grained lime grainstone, with locally interbedded green shale lenses. The Becraft Formation grades upwards into the progressively deeper-water argillaceous lime wackestone of the Alsen and Port Ewen Formations.

The Helderberg Group is overlain by the Tristates Group. The lower units in the Tristates Group are the Connelly Sandstone and the cherty limestone of the Glenerie Formation. The thick, black Esopus Shale overlies the Glenerie Formation, and grades upwards into the argillaceous limestone of the Schoharie Formation. The Schoharie Formation passes upwards into the reefal Onondaga Limestone, which contains abundant black nodular chert. The black, laminated shale of the Bakoven Member of the Union Springs Formation, abruptly overlie the Onondaga Limestone. The Union Springs Formation is the basal unit in the Hamilton Group, which is part of the Catskill clastic sequence.

STRUCTURAL FRAMEWORK

Deformation in the New York recess of the Appalachian foreland fold-thrust belt involves a mechanically rigid strut of Late Silurian through Middle Devonian sedimentary strata (Figure 2; Wanless, 1921; Waines and Hoar, 1967; Rodgers, 1971; Marshak, 1986; Epstein and Lyttle, 1987; Marshak and Tabor, 1989; Marshak, 1990). This strut thins rapidly northwards along the strike of the New York recess, from greater than 1000 m thick in central Pennsylvania to little more than 100 m thick in southeastern New York. The strut is sandwiched between thick, relatively ductile units of Ordovician shale (below) and Middle Devonian shale (above). Such contrasts in the pre-deformational, mechanical stratigraphy (stratigraphic sequence defined in terms of rock rheology) of affected rocks are known to give rise to dramatic, along-strike changes in the architecture of fold-thrust belts (McDowell, 1998; Turrini et al., 2001; Soto et al., 2002). Specifically, in the vast Valley-and-Ridge Province of Pennsylvania, folds have kilometer-scale amplitudes and wavelengths, and large subsurface duplex structures occur at depth. At the apex of the Valley-and-Ridge Province in central Pennsylvania, the cross-strike width of the fold-thrust belt exceeds 140 km. The architecture of the Hudson Valley fold-thrust belt in the northern arm of the New York recess is similar to Valley-and-Ridge Province, but contains folds with amplitudes and wavelengths measured in 10s to 100s of meters. As a result, the fold-thrust belt in the northern arm is often as little as 2 km wide – almost two orders of magnitude smaller than in the Valley-and-Ridge Province of Pennsylvania.

Stratigraphic changes along strike in the New York recess appear to cause changes in the architecture of the regional detachment faults within the fold-thrust belt. At least two regional detachments underlie the Siluro-Devonian strut in the Hudson Valley fold-thrust belt, north of the city of Kingston in the New York recess. The uppermost of these horizons, the Rondout detachment, lies within the base of the Siluro-Devonian strut (Marshak, 1986; Marshak and Engelder, 1987; Marshak and Tabor, 1989; Marshak, 1990). The Rondout detachment is folded in outcrops within the Hudson Valley, suggesting at least one additional detachment horizon at depth in the underlying Ordovician Martinsburg Formation (Marshak, 1986; Marshak and Engelder, 1987; Marshak and Tabor, 1898; Marshak, 1990). The exact number of detachment horizons in the Hudson Valley fold-thrust belt, however, is unclear since cross sections constructed in this region are unbalanced. Previously, the Rondout detachment was interpreted as extending south of the New York recess (Marshak, 1990). However, recent work suggests that a regional detachment fault does not occur at this stratigraphic position south of Kingston (Burmeister and Marshak, 2002). Therefore, shortening accommodated by the Rondout detachment north of Kingston is being redistributed to other faults as the Siluro-Devonian strut thickens southward through the New York recess, resulting in a fundamental change in the internal architecture of the fold-thrust belt.

ALONG-STRIKE CHANGES IN THE FOLD-THRUST BELT NEAR ROSENDALE

The first-order structural architecture of the fold-thrust belt near Rosendale comprises a series of north-northeast trending, kilometer-scale anticlinoria and synclinoria that are subsequently faulted and folded by smaller, second-order structures. Subsequent erosion carved the Hudson Valley into the core of one such anticlinoria; exposing the underlying Ordovician strata and separating the Silurian-Devonian strata of the Helderberg Plateau from outliers (Mount Ida and Becraft Mountain) on the east side of the Hudson River. Strain developed in the various units of the Siluro-Devonian strut by a variety of mechanisms, including folding, thrust faulting, pressure solution, and intracrystalline twinning.

Nowhere are the structural affects of along-strike stratigraphic changes to the rigid, Siluro-Devonian strut in the New York recess more apparent than in exposures near Rosendale. Recent geologic mapping of the fold-thrust belt in the Rosendale vicinity suggests changes in the mechanical stratigraphy profoundly influenced the architecture of the fold-thrust belt (Burmeister and Marshak, 2002). The northward thinning of the Shawangunk Conglomerate corresponds with a south to north: 1) slight westward rotation of structural trends in the fold-thrust belt; 2) eastward migration of the pin line of deformation resulting in a narrower cross-strike fold-thrust belt width; 3) tightening of fold amplitudes and wavelengths; 4) decrease in the spacing between thrust faults and the development of lateral ramps; 5) northward dying out of thrust faults into fault-propagation folds, and 6) redistribution of regional detachment horizons.

Perhaps the most visible change in the structural architecture of the fold-thrust belt occurs along the along the Helderberg Escarpment. The structures exposed in quarries along the Helderberg Escarpment between Bloomington (Stop 4 and Optional Stop B) and Rosendale include a series of left-stepping, northwest dipping thrusts faults that ramp out of the cores of tight synclines and laterally ramp up section to the south. In contrast, structures exposed in the escarpment at the latitude of Kingston (Stop 3, Hasbrouck Park) are extremely complex, involving stacks of horses in a large duplex structure (Marshak and Tabor, 1989; Marshak, 1990).

Preliminary balanced cross sections suggest that two regional-scale detachment horizons exist at depth in the Ordovician strata near Rosendale. The upper detachment lies roughly 10 to 20 m below the base of the rigid Siluro-Devonian stratigraphic strut and is deformed by structures developing on the lower detachment. The lower detachment is located a depth approximately 150 m further beneath the upper fault. A large fault roughly matching the estimated depth of the lower detachment crops out in the Ordovician strata at the base of the Helderberg Escarpment along the Rondout Creek at Creeklocks, about 1.0 km east of Rosendale. Preliminary balanced cross sections and field observations suggest that detachments also develop locally within several units in the Siluro-Devonian strut, including the Shawangunk, Rondout, Manlius-Coeymans, and Kalkberg Formations. Hanging-wall and/or footwall flat geometries in the Shawangunk Conglomerate are exposed in outcrop at High Falls, the south end of the Rosendale trestle, and in quarries east of Tillson. Where faulted, the Rondout Formation usually shows evidence of pervasive bedding-parallel slip, flat-on-flat fault geometries, or shallow thrust ramps. Although rarely visibly faulted in outcrop (except for at Stop C), faults generated near the contact between Manlius and Coeymans Formations usually form flats or low angle ramps. Preliminary balanced cross sections also suggest that localized detachments develop in the Kalkberg Formation, particularly within tight folds. Marshak (1990) describes similar faulting in the Kalkberg Formation in road cuts along State Route 23 near Catskill.

STOP LOCATIONS

Our excursion will follow an oblique, north to south transect across the fold-thrust belt in the vicinity of the Rosendale natural cement region. This route will allow us to observe several of the along-strike changes in the structural architecture of the fold-thrust belt occurring in the southern arm of the New York recess. Our excursion will begin west of Kingston in the foreland of the fold-thrust belt. We will make our first stop in the vicinity of Kingston, where we will examine structures characteristic of the Hudson Valley fold-thrust belt. Here, we will also observe the structural complexity of the belt along its eastern margin in the Helderberg Escarpment. We will then proceed south into the northernmost Appalachian fold-thrust belt along the Helderberg Escarpment, where will examine along-strike transitions in the structural architecture of the eastern margin of the belt. Near Rosendale, we will turn southwest towards High Falls, stopping a several locations in a roughly cross-strike transect of the fold-thrust belt. Finally, we will return to Kingston to examine deformation associated with the upper detachment along the western margin of the fold-thrust belt.

Stop 1: Folds exposed in road cuts along State Route 209 north of Kingston

During our drive east, we have passed from the foreland of the Appalachian orogen into the core of the Hudson Valley fold-thrust belt north of Kingston. Here, road cuts along State Route 209 expose large, slightly asymmetric open folds with no visible thrust faulting or mesoscopic folding. The geology of this stop was first described by McEachran (1985) and later used as a field trip stop by Marshak (1990). Five major, map-scale fold hinges cross State Route 209 between Routes 9W and 32. The most prominent of the folds at this stop is a large anticline (Figure 3) involving the upper Becraft Limestone, the Alsen Formation, and the Port Ewen Formation. Note the differential development of cleavage in these units. The Becraft Limestone contains little to no cleavage, while the Alsen and Port Ewen Formations clearly possess a strong, southeast-dipping cleavage. Marshak (1990) notes that these folds are characteristic of structural styles north of Kingston, in that they trend roughly 015° and lack structural complexity. Return to the vehicles and carefully merge back into traffic. As we proceed a short distance further to the east on State Route 209, notice the west-dipping beds of the Manlius through New Scotland Formations. **End.**

FIGURE 3 (STOP 1): Photograph of road cut exposure looking north showing first order anticline involving Becraft Limestone (Db), Alsen Formation (Da), and Port Ewen Formation (Dpe) along the north side of State Route 209/199, just east of intersection with State Route 32.

Stop 2: Laterally ramping thrust faults in road cut along Route 32 north of Kingston

Four major thrust faults duplicate the Rondout and Manlius Formations in a series of imbricate thrust sheets in the northern half of the long road cut along the west side of State Route 32 (Figure 4). The geology of this stop was first described in detail by Waines and Hoar (1967) and was further interpreted by McEachran (1985) and Marshak (1990). The major thrust faults in this outcrop strike roughly 040° and calcite slip fibers on these faults suggest a transport direction of 060°-070°. In places, these faults have a flat-on-flat geometry (i.e. the thrust faults are parallel bedding in both the hanging wall and footwall), suggesting large displacements. In places (particularly in the upper portion of fault block 6; Figure 4), thrust faults appear to cut down section. However, this is likely an artifact of the obliquity of the road cut face to the structures, where the hanging walls are thrust westward into the outcrop. These faults could not be traced west of the road cut, but may ramp laterally up-section and die out to the north. Return to vehicle and continue south on State Route 32 South. From here, we will proceed southeast towards the Helderberg Escarpment **End.**

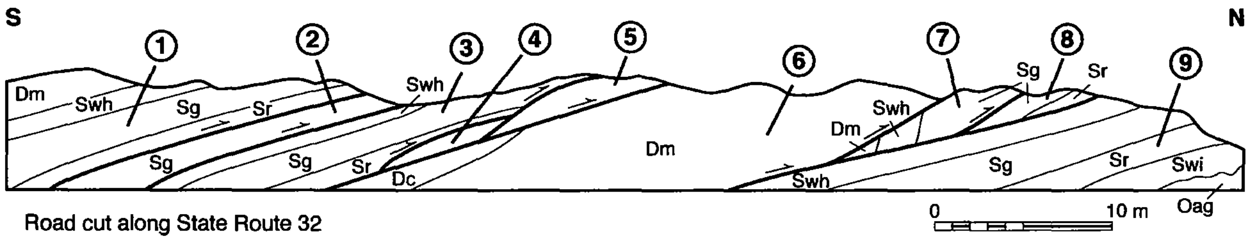


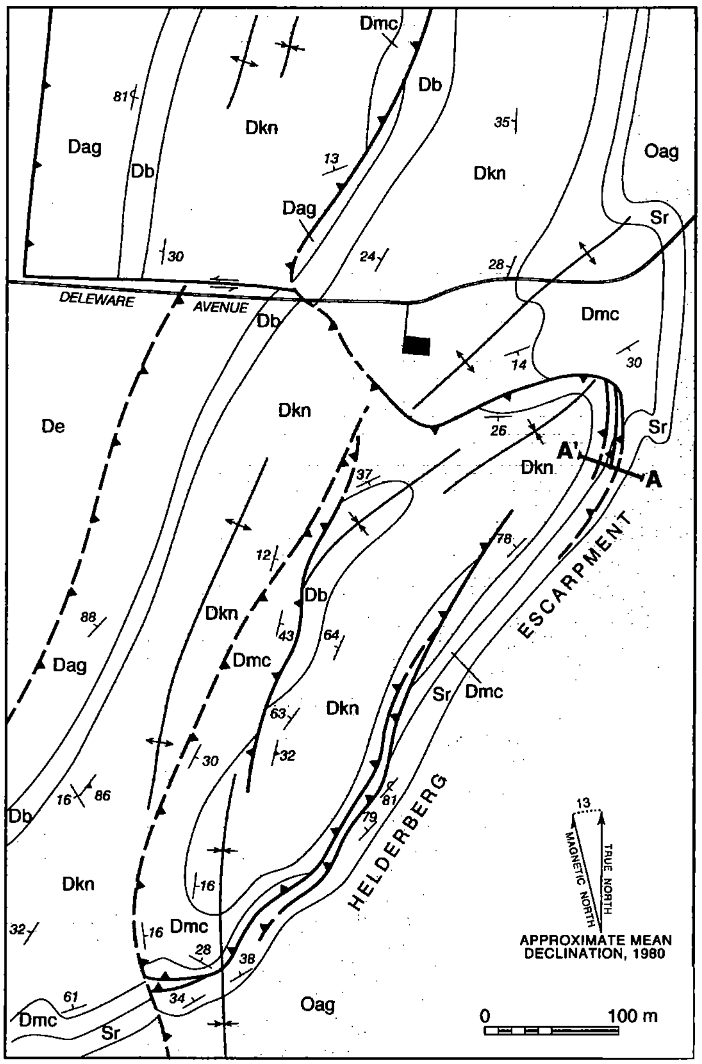
FIGURE 4 (STOP 2): Schematic cross section with slight vertical exaggeration of road cut exposure along west side of State Route 32 just south of intersection with State Route 199. Note duplication of Silurian and Devonian strata in series of imbricate thrust sheets and horses. The hanging wall **(1)** of the southernmost of these four major thrust faults contains Rosendale Member through Manlius Formation, which is thrust over a horse **(2)** of Glasco Member. These rocks are then thrust over a block **(3)** containing Rosendale through Whiteport Member rocks. Here, the Rosendale Member is thrust over two small horses **(4, 5)** of the Glasco Member, and over a block **(6)** containing rocks of the Manlius through Coeymans Formation. This block is then thrust over two small horses containing **(7)** Glasco Member through Manlius Formation and **(8)** Rosendale through Glasco Member, which are in turn trust over **(9)** a sequence of Austin Glen Formation through Whiteport Member strata. Austin Glen Formation (Oag), Rondout Formation [Wilbur Member (Swi), Rosendale Member (Sr), Glasco Member (Sg), Whiteport Member (Swh)], Manlius Limestone (Dm), and Coeymans Formation (Dc). Figure redrawn after Marshak (1990).

Stop 3: Complex structural relationships of Hasbrouck Park, east Kingston

Lock cars and follow the footpath at the east end of the parking lot for roughly 75 m as it descends around the nose of a small hill of Manlius, Coeymans and Kalkberg Formations south of the trail. At the foot of this slope is an abandoned adit cut into an extensively quarried face in the Helderberg Escarpment. The geology of the Helderberg Escarpment at Hasbrouck Park was fist described by Marshak and Tabor (1989; Figure 5) and later revisited as a field trip stop by Marshak (1990). This face provides a cross-sectional view through the leading edge of a duplex composed of a stack of horses involving Rondout through Kalkberg Formation strata (Figure 5B). The basal thrust fault in this duplex, the Hasbrouck thrust, cuts laterally up section along the sloping footpath we walked along (Figure 5C), and through the woods. The Hasbrouck thrust fault reappears on the north side of Delaware Avenue, where it places the Manlius Formation over the Alsen Formation, above extensive roof-and-pillar cement mines just east of Corporate Drive. A tear fault with a trace roughly coincident with Delaware Avenue may extend to the west of the lateral ramp. The complexity of these structural relationships amongst the

Silurian and Devonian strata in Hasbrouck Park is characteristic of the geology along the Helderberg Escarpment at the latitude of Kingston.

Return to main footpath and follow it further to the south, skirting along the base of the Helderberg Escarpment. Stay to the right at the first fork in the footpath and proceed up narrow ridge. From this locality, it is possible to observe steeply dipping to overturned beds exposed by quarrying of portions of the Rondout Formation. Retrace your path along the ridge back to the main footpath, return to the vehicles, and exit the park. We will now proceed south and examine some of the along-strike changes in structural architecture of the eastern margin of the northern Appalachian fold-thrust belt near Rosendale. **End.**



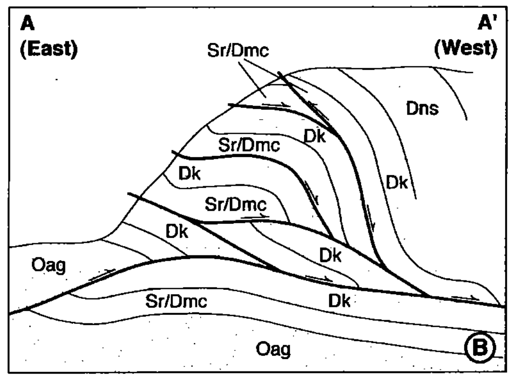


FIGURE 5 (STOP 3): Simplified geologic map of Hasbrouck Park (after Marshak and Tabor, 1989). Note complex structural relationships along eastern map margin. Line AA' **(B)** corresponds with schematic cross-section above (not to scale), which illustrates complex, imbricate thrust sheets along the Helderberg Escarpment. Photograph **(C)** shows a similar perspective of the same face. Map and cross-section after Marshak, 1990. Photo by G. van Ingen and reprinted from Cairnes, 1920.

FIGURE 6 (STOP 4): Photograph taken of eastern mine entrance at north end of Quarry Hill, looking south along mine cut in Rosendale Member (Sr) of the Rondout Formation. Eastern quarry wall is the gradational contact between Binnewater Sandstone (Sb) and Rondout Formation. Excavation removed all of Rosendale Member save support pillars; a thickness of nearly 4.5 m. Western quarry wall is the contact between the Rosendale Member and Glasco Member (Sg). Quarry affords an exceptional view of steeply dipping eastern limb and tight, west-verging hinge of a syncline.

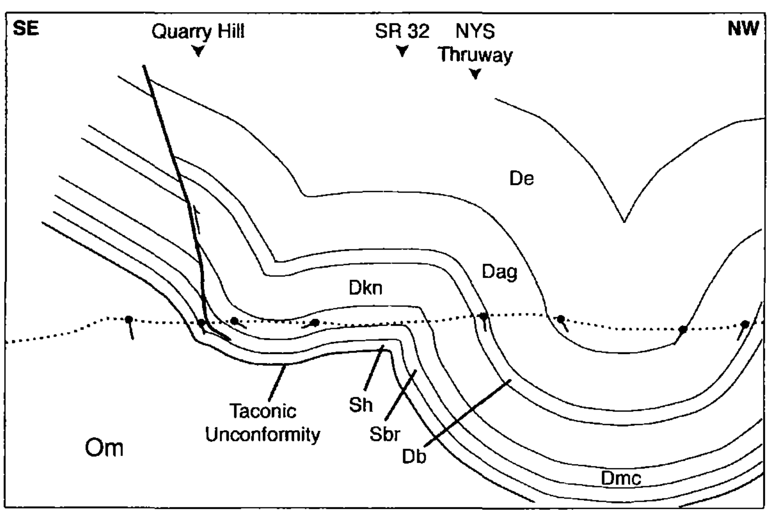


FIGURE 7 (STOP 4): Schematic and un-balanced cross-sectional sketch of structural relationships in Quarry Hill vicinity, Drawn along a line drawn roughly perpendicular to the structural grain and is based upon data obtained during recent geologic mapping. Note tight syncline and associated out-of-the-syncline thrust fault in the Siluro-Devonian strata along the Helderberg Escarpment at Quarry Hill.

Stop 4: North end of Quarry Hill, Bloomington

This stop is on private property. You must obtain permission to visit from the owners of the house near the garage before proceeding. Walk the short distance to the garage on the edge of the tree line just south of the parking lot. Upon reaching the tree line, you will notice two depressions just through the trees to the south. These are the northern end of a series of extensive abandoned cement quarries spanning the entire length of Quarry Hill. Please proceed with caution.

First, walk into the western quarry pit. Here, a small quarry exposes east-dipping strata of the Rosendale and Glasco Members of the Rondout Formation. Retrace your path back to the edge of the tree line, and circle back around to the eastern quarry opening. Watch your step as you descend into this quarry. The slope is uneven and littered with broken glass and scrap metal. Here, the Rosendale Member of the Rondout Formation was extensively mined (all that remain are support pillars) and affords a fantastic view to the south along the axis and steeply dipping eastern limb of a northwest-verging syncline (Figure 6). The eastern quarry wall contains the gradational contact between the Rosendale Member and the underlying Binnewater Sandstone. The base of the Glasco Member forms the western quarry wall.

Note the tight hinge of the syncline and recall the relationship observed in the smaller quarry to the west. A northwest dipping, out-of-the-syncline thrust fault that apparently ramps up section out of the Rondout Formation separates the two quarries at this location (Figure 7). Thus, strata exposed in the western quarry are in the hanging wall, and were thrust to the southeast over the strata in the eastern quarry. Consider the contrasts in structural style between this location and the complex duplexes and the stacking of imbricate thrust sheets near Kingston. The quarry exposures at this location afford an excellent view of the structural relationships that are characteristic along the Helderberg Escarpment between Bloomington and Rosendale. Here, the escarpment is defined by a series of left-stepping, thrust faults that cut up section to the east, out of the cores of large synclines. Return to vehicles. Turn left (west) out of Bloomington Fire Company parking lot onto Taylor Road. **End.**

Stop 5.1: Eastern limb of the Hickory Bush anticline, Rosendale Landfill

Lock vehicles and walk approximately 100 m northeast along Hickory Bush Road to the entrance of the Rosendale Landfill and Recycling Center. Proceed through gate and to the north corner of the facility. Recent excavation along the north wall created fresh exposures of an east-dipping sequence of strata (Figure 8). The north wall of the landfill contains Martinsburg Shale, the Taconic unconformity, Shawangunk Conglomerate, High Falls Shale, Binnewater Sandstone, Rondout Formation, and Manlius Limestone.

From a distance, the Martinsburg Shale appears un-deformed, but closer examination reveals that it is strongly deformed by complex brittle faulting. Above the Taconic unconformity, the Shawangunk Conglomerate is little more than a 5 to 10 cm thick lag deposit of the characteristic milky white quarts pebbles. Overlying the Shawangunk Conglomerate is a complete and apparently continuous sequence of High Falls Shale and Binnewater Sandstone. Both the Rosendale and Whiteport members of the Rondout Formation are quarried at this location. Separating the two quarries is the Glasco Member, which contains beautiful *Halycities* chain corals. At the eastern end of the north wall are exposures of the overlying Manlius Limestone, which are in faulted contact.

The east-dipping strata exposed in the Rosendale Landfill form the eastern limb of the Hickory Bush anticline. The involvement of Martinsburg Shale in core of the fold suggests this structure developed as the result of slip along a detachment at depth in the underlying Ordovician strata. The large scale of the Hickory Bush anticline suggests that the underlying thrust is a master fault in the fold-thrust belt at this latitude and ramps directly from the lower detachment horizon. The thrust fault exposed at the eastern end of the exposures along the north wall is the westernmost fault in a complex imbricate fan of thrusts that ramp out of the Rondout Formation and cut through Hickory Bush Hill (the large hill southeast of the landfill). Return to the vehicles. **End.**

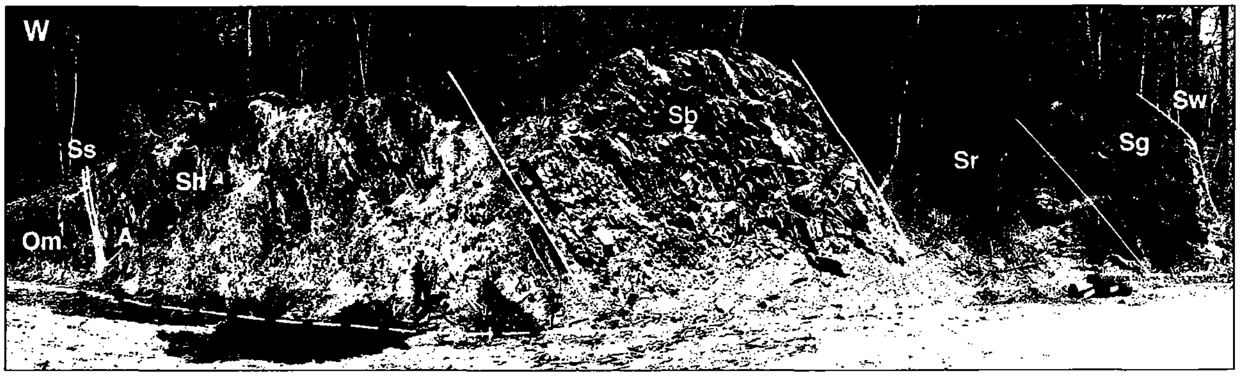


FIGURE 8 (STOP 5.1): Photograph of north wall of Rosendale Landfill at Hickory Bush showing southeast dipping Ordovician through Silurian strata in the eastern limb of the Hickory Bush anticline. Martinsburg Shale (Om) is in unconformable contact with Shawangunk Conglomerate (Ss), which is a 6.0 cm lag deposit of white quartz pebbles. High Falls Shale (Sh) and Binnewater Sandstone (Sb) are overlain by the Rondout Formation, out of which the Rosendale (Sr) and Whiteport (Sw) members were quarried leaving the Glasco Member (Sg). Dashed line denotes base of outcrop. Geologist for scale.

Stop 5.2: Western limb of the Hickory Bush anticline, rail cut near Fourth Lake

Walk southwest along the rail trail from the parking lot along Hickory Bush Road for roughly 350 m until you encounter a rail cut exposing moderately northwest dipping strata on both sides of the trail. The exposed sequence includes High Falls, Binnewater, Rondout, and Manlius Formations (Figure 9). Along the northwest side of the trail, the High Falls Shale is difficult to distinguish, but it is overlain by a complete thickness of the Binnewater Sandstone. Cross bedding, ripple marks, and graded bedding are clearly visible, as is a characteristic, roughly 10 cm thick shale horizon just below the contact with the overlying Rondout Formation. This shale layer is also present in an outcrop of the Binnewater sandstone at the Snyder Estate, where it is deformed. The Rosendale and Whiteport members of the Rondout Formation are quarried at this location. Notice how air circulating through the abandoned mines keeps this area noticeably cooler during the hot summer months.

Climb onto the embankment on the south side of the rail trail using the small path through the trees located just north of the northernmost quarry opening. The embankment was once a tramway that serviced the cement quarries in this area. Watch your step. Abandoned cement kilns and sunken shed foundations are scattered along this tramway and are often difficult to see. Proceed along tramway to the southeast, skirting along an exposure of the Binnewater Sandstone. When the tramway narrows and prevents further progress, drop down the slope to the next lower abandoned roadbed and continue to the southeast. After hiking approximately 150 m from the rail trail, you will reach and intersection with a dirt road. This road is part of the Perfume Trail on the Williams Lake Resort. Follow the dirt road to the right (southwest) and you will soon see a large mine entrance. Proceed about 10 m into the mine.

This mine was operated by the Lawrence Cement Company (Werner, personal communication, 2003) and is cut into the Rosendale Member of the Rondout Formation. The contact with the underlying Binnewater Sandstone forms the floor of the mine, and the contact with the overlying Glasco Member forms the ceiling (Figure 10). The quarry is in a large, asymmetric, open anticline. Note how the shallow dip of strata in the western limb of the fold gently increases to the southwest. Proceed southwest into the mine along the axis of the fold. Note the relatively rapidly increasing dip of the strata in the eastern limb of the fold. Quarrying of the eastern limb was most likely halted due to the proximity of a fault with a trace that roughly follows the path of the Perfume Trail a few meters further to the east.

FIGURE 9 (STOP 5.2): Photograph looking north at railroad cut (presently a rail trail) between Fourth Lake and Hickory Bush. Cut exposes northwest dipping Silurian and Devonian strata in the western limb of the Hickory Bush anticline: High Falls Shale (Sh), Binnewater Sandstone (Sb), Rondout Formation [Rosendale Member (Sr), Glasco Member (Sg), Whiteport Member (Sw)], and Manlius Limestone (Dm). Photo by G. van Ingen and reprinted from Osborne, 1921.

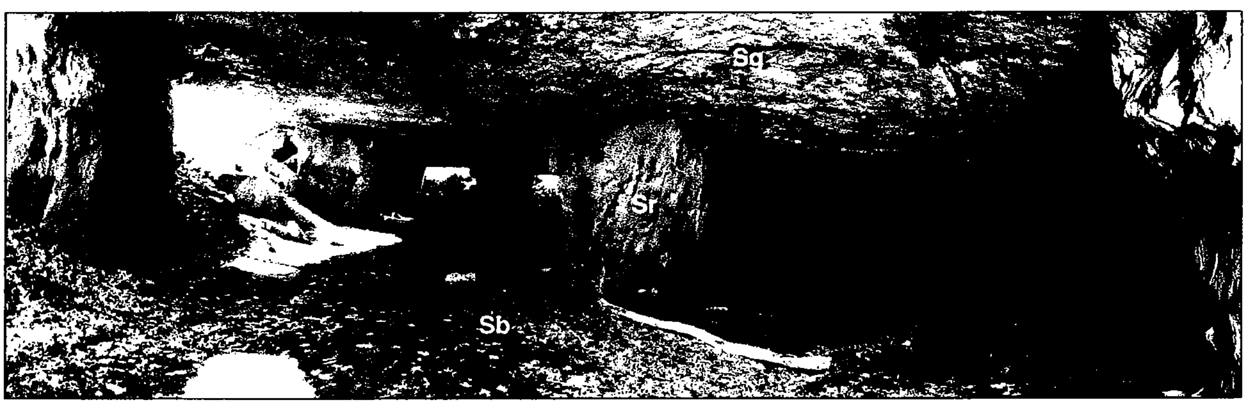


FIGURE 10 (STOP 5.2): Photograph looking south along the shallowly dipping, western limb of anticline exposed in Lawrence Cement Company quarry near Fourth Lake. Binnewater Sandstone (Sb), Rosendale Member (Sr), and Glasco Member (Sg).

Climb up and out of the mine through the opening left by the partial collapse of the roof at the southeast end of the quarry. As you climb out of the mine, pause to note the other portions of the quarried fold around the periphery of the collapsed area. It is unclear whether strata of the Whiteport Member above the quarried fold was removed by erosion or was stripped by quarrying. Follow the footpath path down to the Perfume Trail and continue to the south until you reach a intersection of several trails. Return to the vehicles by walking north along the rail trail (covered in black gravel) from this junction. Along the way, note the various quarries and outcrops as you pass through the Fourth Lake region. The Williams Lake Resort property around Fourth Lake contains some of the best exposures of structural relationships in the region, and has long been used to teach the methods of field geology. **End.**

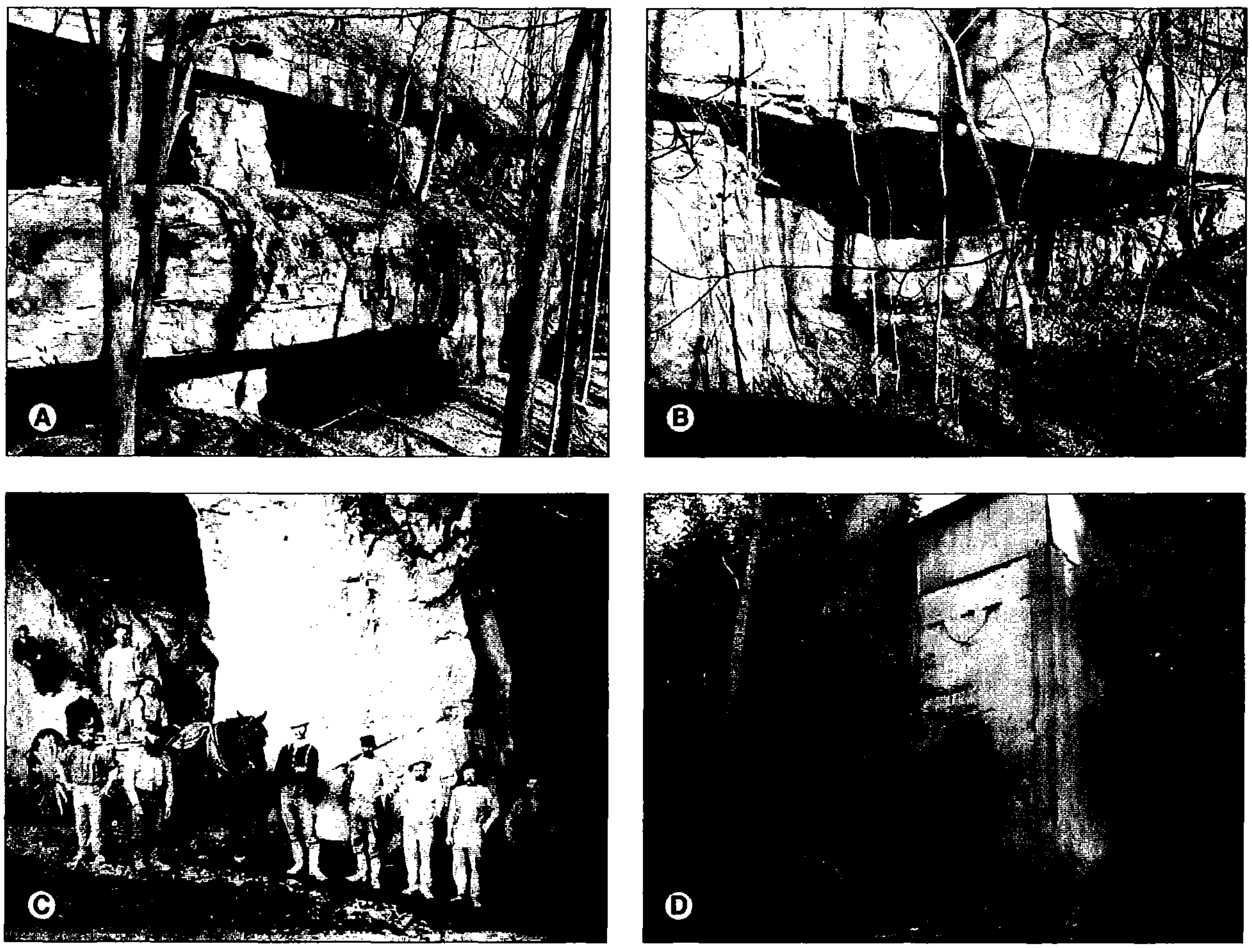


FIGURE 11 (STOP 6): Photograph of the Van Tassel's Quarry (A) on the Snyder Estate. Van Tassel's Quarry is in the footwall of the Century thrust fault (Optional Stop C). Mining of hydraulic cement was conducted using the room-and-pillar method in which a series of individual rooms (B) are quarried and eventually interconnected. The tenacity with which these mines were worked is apparent, and even more impressive considering that most quarries were worked entirely with hand tools and dynamite. Photograph (C) shows workers in front of the Widow Jane Mine, which is also on the Snyder Estate. The quarryman at center is holding star drills, which were driven into rock with sledgehammers to slowly carve out holes for black powder blasting charges. Rock collected in quarries was separated into cobble-sized fragments in screening house (D). Crushed rock was then burnt in cement kilns to remove CO_2 before being ground into the powdered final product. Photograph C courtesy of the Century House Historical Society.

Stop 6: The Snyder Estate

This land was originally owed by the Snyder family, who were central players in the local cement industry since its beginning during the construction of the Delaware & Hudson Canal (Werner, personal communication, 2003). The Century House Historical Society now maintains the Snyder property. This non-profit educational organization is dedicated to preserving the unique history of the Rosendale natural cement region. Leave cars and walk towards the battery of cement kilns at the east end of the lot. Continue eastward along the small trail leading down a small slope and through a small stand of trees. Proceed along the base of another battery of cement kilns to the driveway of the small, adjacent house. *This lot is private property. Please obtain permission from the owners before continuing along this route.* Use the flight of small stone steps directly behind the house to climb up to the abandoned tramway atop the embankment. Walk eastward along the abandoned tramway for several meters until you reach a set of small cuts. These cuts expose shallowly east-dipping beds of the uppermost Binnewater Sandstone. Note the characteristic shale horizon (previously seen at Stop 5.2) and examine the well-developed cleavage duplex that suggests some degree of bedding-parallel slip.

Continue eastward on the abandoned tramway to Van Tassels Quarry, a section of extensively mined Rondout Formation in the footwall of the Century thrust fault (Figure 11A). Van Tassels Quarry is an excellent example of the classic Rosendale natural cement quarry. Mines are cut into the Rosendale and Whiteport members, which were historically referred to as the upper and lower cements, respectively. The Glasco Member, historically known as the middle ledge, is left un-quarried between the cement layers. If time permits, follow the tramway north along the front of the quarries. The Rosendale Member is several feet thicker at the Snyder Estate than is to the north and south. Continue on the tramway to the northwest, further up onto the embankment behind the small house. Return to the vehicles in the parking lot of the Snyder Estate from the north, along the top of the embankment. Pause along the way to examine the screening house (Figure 11D) and other remnants of the cement industry, but be careful to stay away from the large openings atop the cement kilns.

As we leave the Snyder Estate, note the Brooklyn Bridge ornaments atop the gateposts. Over 100,000 barrels of Rosendale Natural Cement were used in the construction of the Brooklyn Bridge because of its unparalleled strength. Other famous landmarks built with locally produced cement include the pedestal of the Statue of Liberty and the Wings of the United States Capitol Building (Werner, personal communication, 2003). Turn right (west) onto State Route 213. **End.**

Stop 7: Bedding-parallel slip in Shawangunk Conglomerate, State Route 213 east of High Falls

Leave the cars and walk east along the south side of State Route 213. Here, steep, 4 to 5 m high cuts in the uppermost Shawangunk Conglomerate line both sides of the road. The contact with the overlying High Falls Shale is roughly at the top of the road cuts. The rocks exposed in this road cut are in the footwall of a thrust fault, which cuts roughly perpendicular to the road at the east end of these cuts. As you proceed eastward, note the next set of road cuts in the Shawangunk Conglomerate. The strata exposed in the cuts further to the east are in the hanging wall of the thrust fault.

When you have nearly reached the eastern end of the lower (westernmost) road cuts, stop and examine the exposure along the north side of the road, west of the sign announcing High Falls District. Note the distinct, bedding-parallel slip surface (Figure 12), then carefully cross the road and examine this horizon up close. The slip surface contains a cleavage duplex composed of powdered quartz that gives a top to the west sense of shear. However, the lack of piercing points prevents a quantification of the amount of slip that has occurred on this surface. For this reason, it is unclear if the slip on this surface was the result of flexural-slip folding (suggesting little lateral displacement between bedding layers) or if it is a segment of a thrust fault exhibiting a flat-on-flat geometry (suggesting large lateral displacement).

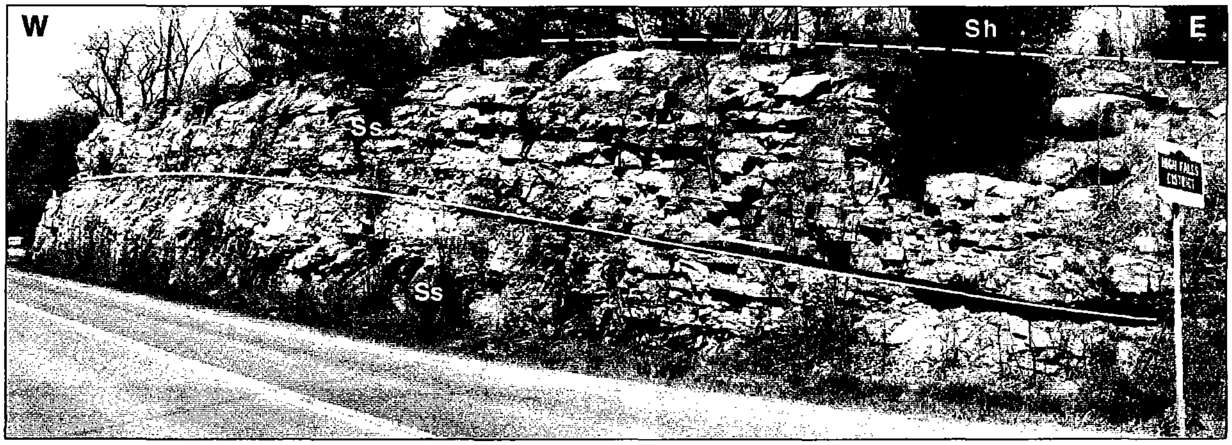


FIGURE 12 (STOP 7): Photograph of road cut in Shawangunk Conglomerate (Ss) along north side of State Route 213 just east of High Falls. Bedding-parallel slip surface is indicated by solid white line. Approximate contact with overlying High Falls Shale (Sh) indicated with dashed white line. Road sign is roughly 4.0 m tall.

FIGURE 13 (STOP 8): Panoramic photograph of outcrop along north bank of Rondout Creek at the High Falls Park/Central Hudson power plant in High Falls, NY. Note large detachment fold in Binnewater Sandstone (Sb) and High Falls Shale (Sh) at center, the westernmost mesoscopic structure in the Rosendale-High Falls vicinity. Strata to east are part of the moderately northwest-dipping west flank of an anticline that roughly parallels Bruceville Road. Outcrop at fold is approximately 30 m high.

Stop 8: Mesoscopic folding in Silurian strata, along the Rondout Creek at High Falls

Southwest of High Falls, the Rondout Creek flows roughly parallel to strike of the Rondout Formation and Manlius Limestone. At High Falls, the creek bends sharply to the east and begins cutting perpendicular to strike, down-section towards Rosendale. The highest falls are over an outcrop of the Rondout Formation. Downstream, smaller subsequent falls separated by shallow pools occur in the Binnewater Sandstone and High Falls Shale downstream followed by minor rapids caused by debris of the Shawangunk Conglomerate. As you follow the footpath past the High Falls power station northeast, note the shallowly northwest dipping beds of Binnewater Sandstone in the cut on the right. Once past the fenced-in are surrounding the power station, leave the trail and head north across the grassy area towards the wooded area long the creek. Stop to examine the millstones cut from Shawangunk Conglomerate placed as decoration in the grass. Also note the ruins of the stone building behind the cyclone fencing.

This was once the processing plant of the F.O. Norton Cement Company, which operated mines in High Falls and along Binnewater Road near Williams (Fifth) Lake (Werner, personal communication, 2003).

When you reach the waters edge, examine the asymmetric anticline in the Binnewater Sandstone and High Falls shale exposed along the north bank of the creek. This fold is the westernmost mesoscopic structure in the fold-thrust belt near Rosendale. What is unusual, however, is that the axial surface of the fold is dipping to the west, a sense of vergence opposite to the regional trend. The shape and scale of this fold suggest that it is a fault-propagation fold above a blind thrust fault. The fault underlying this structure is most likely a west dipping back thrust associated with the merger of two detachment horizons in the Ordovician strata at depth.

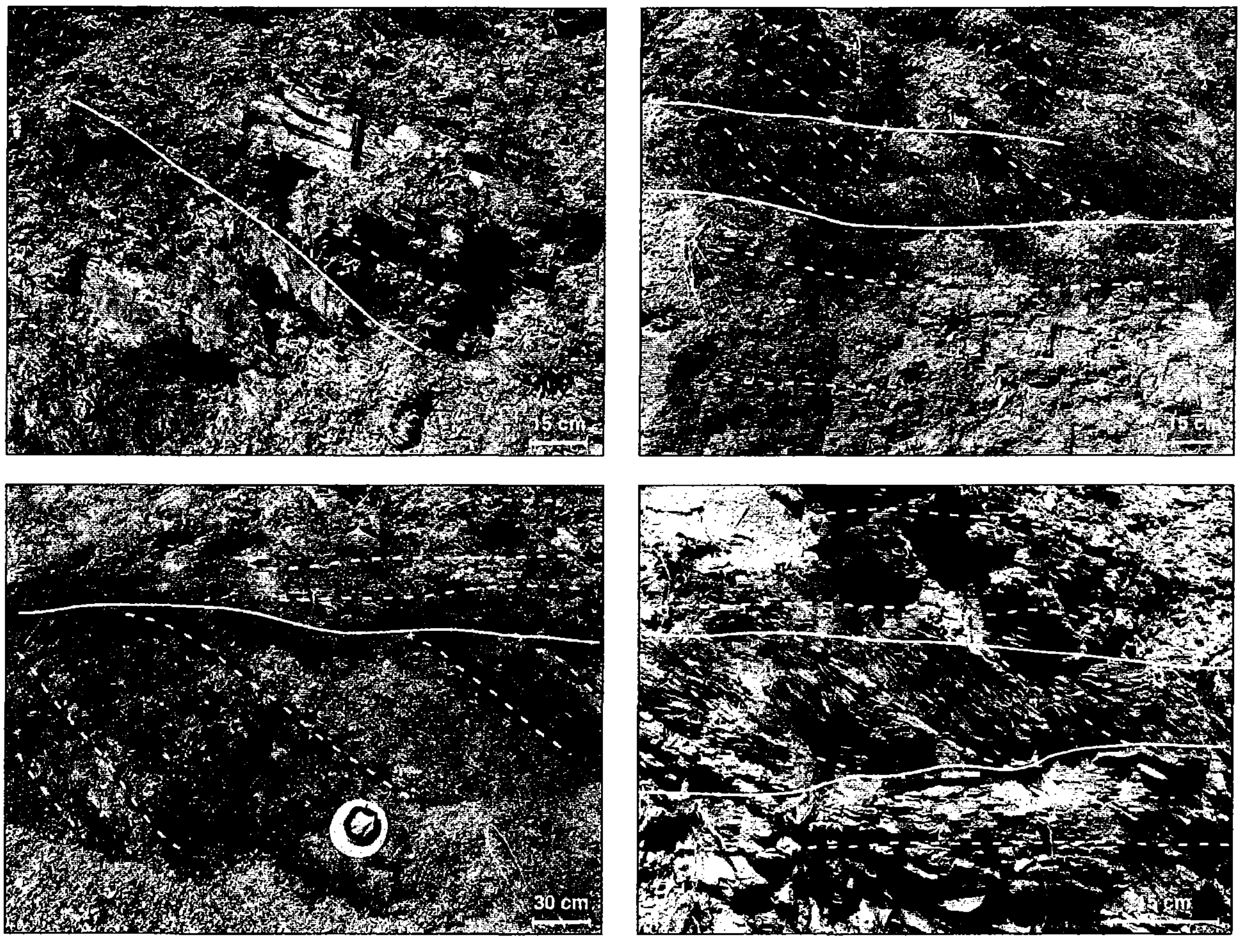


FIGURE 14 (STOP 9): Photographs of mesoscopic-scale cleavage duplex structures and shear zones in the Bakoven Member of the Union Springs Formation as described by Bosworth (1984) and Nickelson (1986). Duplex structures range between rough 10 cm and 1.0 m thick, and suggest the accommodation of blind thrust faulting of strata underlying this outcrop. All photographs are facing roughly north.

Stop 9: Cleavage duplexes in Bakoven Shale, road cut along State Route 28, west of Kingston

Our excursion has taken us full circle, returning to the foreland of the fold-thrust belt. Here we can see evidence of deformation associated with the upper detachment of the fold-thrust belt as deformation dies out westwards. The steep escarpment and road cut along City View Terrace, beneath the Skytop Motel, contains an exposure of the two lower members of the Union Springs Formation, which is the basal unit of the Hamilton Group. Here, the upper 10 m of the fissile black shale of the Bakoven Member grade upwards into the lower 23 m of the Stony Hollow Member, a sequence of the buff-weathering shale and siltstone (Ver Straeten and Brett, 1995). The structural relationships of this location have been described by Bosworth (1984) and Nickelson (1986). Numerous examples of mesoscopic-scale deformation are visible in the Bakoven Member along the road cut. These cleavage duplexes and shear zones (Figure 14), often less than 20 cm thick, suggest that blind thrusts cut the underlying strata.

OPTIONAL STOP LOCATIONS

Stop A: Road cut exposure of folds along Route 32, north of Rosendale

The road cut along the west side of State Route 32 at this locality exposes a tight, northwest verging anticline in the Kalkberg Formations. This structure is a continuation of the same series of folds exposed in the mines along Quarry Hill (Figure 7). The dip of the strata in the western limb of this fold continues to increase westward. Exposures of Becraft through Port Ewen Formations are steeply dipping to overturned in road cuts along the New York State Thruway. **End.**

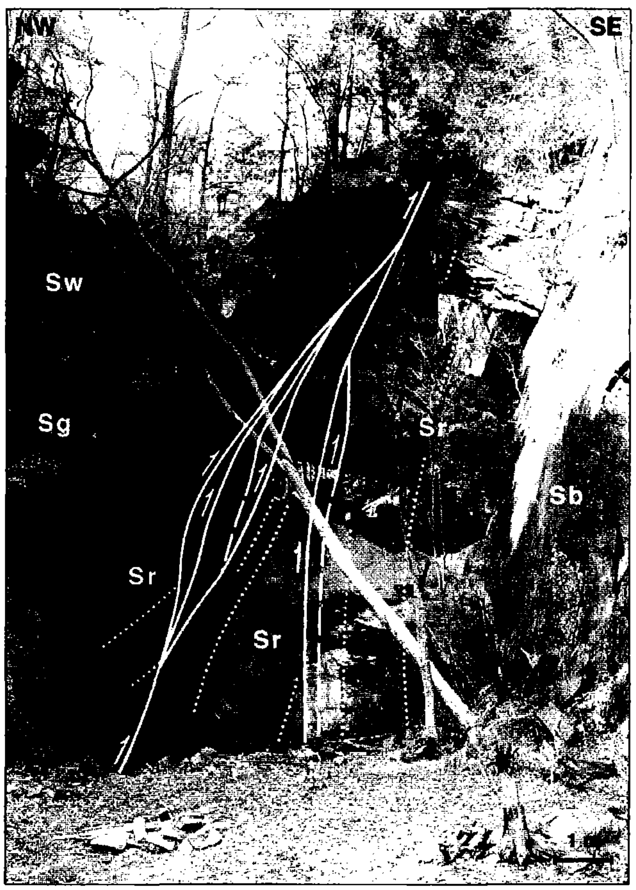


FIGURE 15 (STOP B): Photograph looking northeast of abandoned quarry in Rosendale (Sr) and Whiteport (Sw) members of the Rondout Formation at south end of Quarry Hill. Large excavation at center is quarried out of the Rosendale Member, which is duplicated by a series of northwest dipping, out-of-the-syncline thrust faults. Although, not continuous, these faults are similar to those seen at Stop 4. Binnewater Sandstone (Sb) forms the eastern quarry wall. This surface contains a beautiful set of non-coaxial slip fibers. A folded sequence of the Glasco (Sg) and Whiteport members of the Rondout Formation from the western quarry face. Heavy lines denote fault surfaces. Dotted lines highlight bedding.

Stop B: South end of Quarry Hill, Bloomington

This stop is on private property and permission to visit must be obtained in advance. Trespassers will be prosecuted. Walk north along the small dirt road located across from the house, keeping to the right as the road descends into the mouth of an abandoned cement quarry. The quarry at this locality is the southernmost of the Quarry Hill mines. Both the Rosendale and Whiteport Members of the Rondout Formation are extensively quarried at this location (Figure 15). Steeply dipping beds of the base of the Rosendale Member and the Binnewater sandstone form the eastern quarry wall. Moderately dipping beds of the Rondout through Manlius Formations form the western quarry face. The large, central quarry area exposes strata of the Rosendale Member that are repeated by two major thrust faults and extensively cut by a number of smaller thrusts. The easternmost of the two major thrust faults is steeply west dipping and exhibits a hanging wall ramp on footwall flat geometry. The western major thrust fault is moderately west dipping and also has a hanging wall ramp on footwall flat geometry. The western fault contains a horse of Rosendale Member. The two major thrust faults merge near the top of the quarry. The hanging wall of these faults is involved in a northwest-verging syncline, but is apparently not faulted. Some amount of bedding-parallel slip has also occurred along the eastern quarry wall. A close examination of this surface reveals a well-developed set of non-coaxial slip fibers. The faults exposed at this location are not continuous with those exposed at the north end of Quarry Hill (Stop 4). **End.**

Stop C: Century thrust fault, road cut along State Route 213 east of Rosendale

Portions of this stop are on private property and permission to visit must be obtained in advance. Trespassers will be prosecuted. Park vehicles out of the way of traffic in the lot and walk westward along the north side of State Route 213, keeping the guardrail between you and the traffic. The large quarried face to the north is the Butler's lock Quarry and includes a continuous sequence of Rondout though Kalkberg Formations. As you proceed along the road, note how the strata in the Butler's lock Quarry are folded into a small syncline. Once at the western end of the guardrail, very carefully cross to the south side of State Route 213 and quickly climb over the guardrail. Continue westward along the south side of State Route 213, again keeping the guardrail between you and traffic, until you reach the center of the large road cut along the north side of the road (Figure 16).

The road cut exposes the Century thrust fault, which places Binnewater Sandstone over Manlius Formation. The hanging wall contains a low-angle ramp which transitions into a hanging wall flat. Similar stair-step geometry of shallow ramps and flats in the Binnewater Sandstone can also be observed in a faulted sequence southwest of Tillson. The fault zone contains what is likely a horse of crushed Binnewater Sandstone and a sliver of Manlius Limestone. The footwall is a flat in the Manlius Limestone. The footwall is also cut by several minor thrust faults, the westernmost of which appears to be a wedge fault. Thus, the hanging wall of the Century Thrust contains the Butler's Lock Quarry. The footwall contains the Van Tassel's Quarry, which we will visit in Stop 6. Carefully return to the vehicles, and continue west on State Route 213. **End.**

Stop D: Lawrenceville anticline

Leave the vehicles and cross to the north side of State Route 213. Walk to the center of the bridge over the Rondout Creek and look to the west. Although it may be difficult to see during the spring and summer months, this position affords a good view of the Lawrenceville anticline. The anticline is the westernmost major, map-scale fold exposed in the Rosendale region. The Lawrenceville anticline appears in numerous photographs taken of the Delaware & Hudson Canal in this region (Figure 17). **End.**

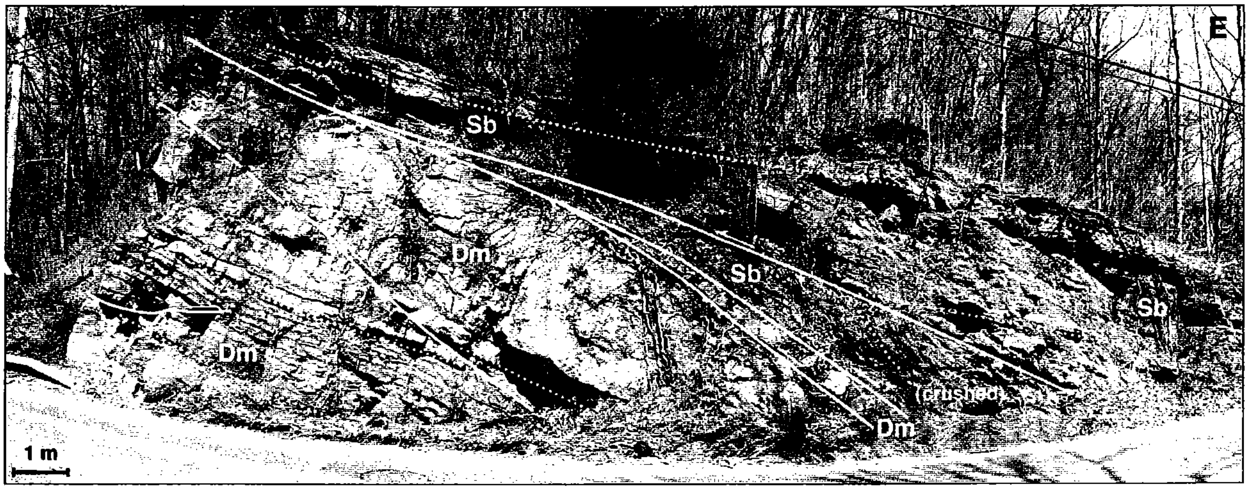


FIGURE 16 (STOP C): Photograph, looking north, of Century thrust fault exposed in a road cut along north side of State Route 213 between Butler's Lock Quarry (presently Turco Bros. Water Service) and Van Tassels Quarry on the Snyder Estate. Here, a hanging wall ramp and flat in Binnewater Sandstone (Sb) is thrust over a footwall flat of Manlius Limestone (Dm). Note horse of crushed Binnewater Sandstone and sliver of Manlius Limestone. Heavy lines denote fault surfaces. Dotted lines highlight bedding

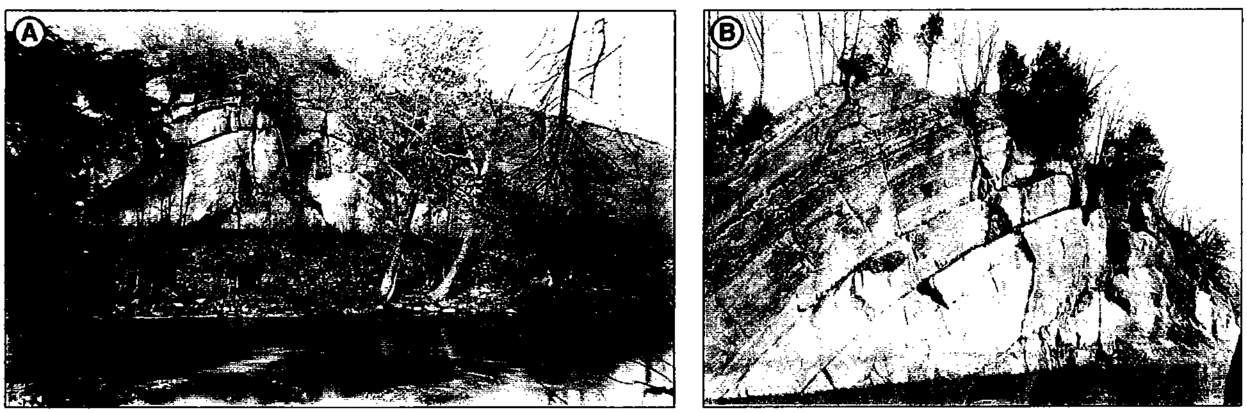


FIGURE 17 (STOP D): Two photographs of the best-exposed anticline at Lawrenceville, along the Rondout Creek, taken during the early 20th century. Today, the outcrop is badly overgrown and often difficult to see from State Route 213 except during the spring and summer months. This anticline involves Kalkberg and New Scotland formations, and was exposed by a cut made during the construction of the Delaware & Hudson Canal. Photograph **(A)** shows a partially obscured anticline when viewed looking from the south bank of Rondout Creek. Photograph **(B)** is also taken looking north, but from the towpath atop the canal retaining wall. Photograph (A) by Cairnes (1920), photograph (B) by G. van Ingen and reprinted from Osborne (1921).

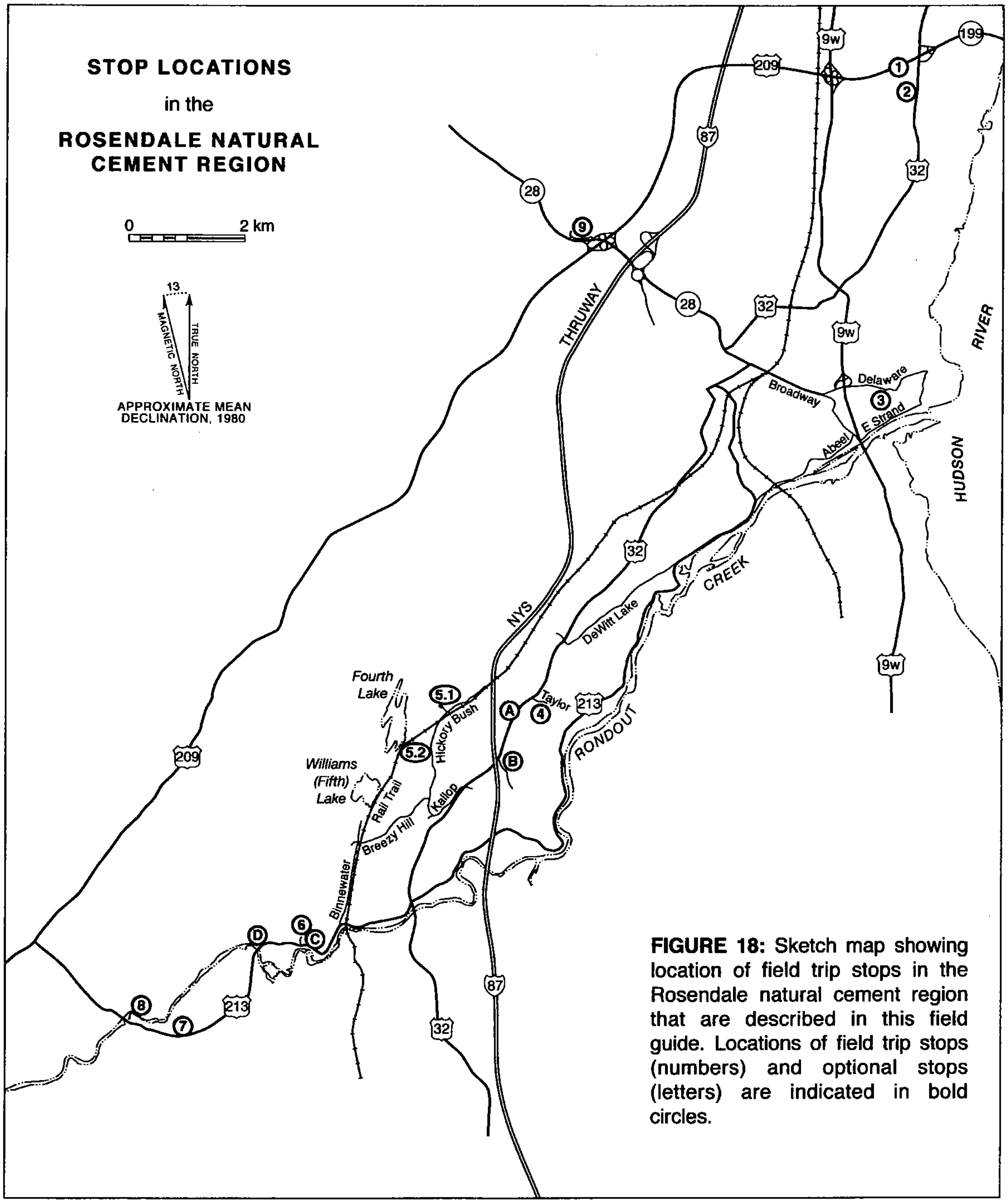


FIGURE 18: Sketch map showing location of field trip stops in the Rosendale natural cement region that are described in this field guide. Locations of field trip stops (numbers) and optional stops (letters) are indicated in bold circles.

ROAD LOG (Figure 18)

Cum	**Part**	
0.0	0.0	Road log mileage begins at the base of the exit ramp from State Route 28 East. Merge onto State Route 209 North heading towards Rhinecliff Bridge
0.1	0.1	*Road cut* exposures of shallowly west-dipping beds of the Union Springs Formation along the left (northwest) side of Route 209 North
2.4	2.3	*Bridge* over New York State Thruway
2.8	0.4	*Bridge* crossing Esopus Creek
3.6	0.8	*Underpass* for 9W, continue on State Route 209 N
3.8	0.2	*Road cut*: Broad, open anticline in Schoharie Formation and Onondaga Limestone.
4.3	0.5	**STOP 1:** *Pull off onto the shoulder of the road* and park in the adjacent grassy area.
4.6	0.3	Bridge over State Route 32, stay in right-hand lane.
4.7	0.1	*Exit for State Route 32*, turn right and proceed to the end of the ramp.
4.9	0.2	*Stop sign, turn left onto State Route 32 South* and proceed for a short distance. If your group is large, you may want to park in the small, unmarked gravel parking lot directly across from the base of the exit ramp and walk to Stop 2.
5.2	0.3	**STOP 2:** *Pull off onto the shoulder of the road* as far as possible, but use caution as the shoulder is low.
7.5	2.3	*Turn left* onto entrance ramp for Route 9W South (Frank Koenig Boulevard.)
8.5	1.0	*Turn right onto exit for Delaware Avenue*. Stay to the left as you proceed to end of ramp.
8.8	0.3	*Traffic light*, intersection of exit ramp and Delaware Avenue. Turn left onto Delaware Avenue, keeping to the right-hand side of the road as it crosses back over Route 9W
8.9	0.1	*Follow Delaware Avenue as it veers* to right, then back to the left before entering the historic district (caution 15 mph speed zone)
9.1	0.2	*Traffic light*, intersection with Murray Street
9.2	0.1	*Traffic light*, intersection with Corporate Drive
9.3	0.1	**STOP 3:** *Small, hidden lane between last two houses on right-hand (south) side* of road. Turn right onto entrance road to Hasbrouck Park just before Delaware Avenue begins to descend steeply over the Helderberg Escarpment. Park in small gravel lot on left (east) side of lane, across from schoolyard.
9.4	0.1	*Turn right at intersection onto Delaware Avenue*, and follow the road down the hill (caution - tight turn)
9.6	0.2	*Intersection with Abruyn Street* at base of hill, continue straight on Delaware Avenue. Note entrances to the abandoned Delaware Mine on left (west) side of road. This mine was most recently used by the Knaust Brothers to grow 'Fallout Proof' mushrooms during the 1950s.
9.7	0.1	*Stop sign*, intersection with Lindsley Avenue, continue Delaware Avenue
9.9	0.2	*Traffic light, turn right onto North Street.*

Cum	Part	
10.1	0.2	*Traffic light* at intersection with East Union Street. Note abandoned canal barge in tidal flats off to left (east).
10.3	0.2	*North Street bends to right and becomes East Strand Street.* Continue on East Strand Street.
11.0	0.7	*Pass under Route 9W Bridge.* East Strand Street bends sharply to the right and becomes Broadway. The Mansion House located on this corner was built in 1833 by Jervis McEntee, one of the engineers that pointed to Rosendale as a local source for hydraulic cement for construction of Delaware & Hudson Canal (Werner, personal communication, 2003).
11.1	0.1	*Intersection, turn left* onto Abeel Street
11.3	0.2	*Traffic light*, intersection with Wurtz Street, continue on Abeel Street
11.5	0.2	*Traffic light*, intersection with Dock/Ravine Streets, continue on Abeel Street
11.6	0.1	*Traffic light*, intersection with Hunter Street, continue on Abeel Street
12.2	0.6	*Pass under West Shore Railroad bridge.*
12.4	0.2	*Intersection* with Wilbur Avenue
12.5	0.1	*Traffic light*, intersection with State Route 213, continue on Abeel Street/ State Route 213 South. Note various ruins of cement kilns and associated buildings along next the road over the next kilometer.
13.6	1.1	*Veer right onto DeWitt Lake Road* (County Route 28), and head up the east flank of Vly Mountain. This road follows the path of what was originally a plank road and later the roadbed of the horse-drawn Hickory Bush-Eddyville railroad. A consortium of cement companies constructed and maintained this throughway to avoid the shipping fees charged by the Delaware & Hudson Canal for moving their product from Hickory Bush to Kingston (Werner, personal communication, 2003).
14.4	0.8	*Stop sign*, intersection with the road to Eddyville, continue on DeWitt Lake Road
14.8	0.4	Abandoned roadbed for Hickory Bush-Eddyville railroad diverges from course of DeWitt Lake Road and is visible in trees of to right (west)
15.1	0.3	*Intersection*, turn left onto State Route 32 South
15.9	0.8	**STOP 4:** *Turn left onto Taylor Street*, then immediately turn right into the parking lot of Bloomington Fire Company and proceed to back (southwest), gravel end of lot and park.
16.4	0.5	*Intersection, turn left* onto State Route 32 South
16.6	0.2	**OPTIONAL STOP A**: *Pull off highway and park in paved area along the road.* Please be sure to not block access to road that continues off to southwest.
16.8	0.2	Road cut exposures of the Manlius Formation containing karst dissolution features along left (east) side of road.
16.8	0.2	**OPTIONAL STOP B**: *Turn left onto private drive* just north of the bridge over the New York State Thruway. Proceed slowly down gravel road to the first house and park vehicles out of the way.
16.9	0.1	Bridge over New York State Thruway

Cum	Part	
17.7	0.8	*Turn right* onto Kallop (Corners) Road
17.9	0.2	*Veer right onto Hickory Bush Road* at three-way intersection
18.0	0.1	Intersection with Breezy Hill Road, continue straight (north) on Hickory Bush Road
18.5	0.5	Well-preserved cement kilns on left-hand (northwest) side of road
18.6	0.1	Entrance to the mines on right-hand side of road were once operated by the Lawrence Cement Company (Werner, personal communication, 2003), and are presently owed by Iron Mountain Incorporated as a future archival site.
18.8	0.2	Cement kiln ruins on right-hand (southeast) side of road
18.8	0.0	**STOPS 5.1 & 5.2:** Cross roadbed for Wallkill Valley Railroad (presently a rail trail maintained by John Rahl of Rosendale) and pull into dirt parking lot on left side of road
19.7	0.9	*Exit parking lot and turn right*, heading south on Hickory Bush Road.
20.1	0.4	*Stop sign*, turn right onto Breezy Hill Road.
20.6	0.5	*Stop sign*, turn left (south) onto Binnewater Road (County Route 7) heading towards Rosendale. Binnewater Road follows the trace of the axis of the Binnewater anticline.
21.1	0.5	The south quarries of the F.O. Norton Company in east-dipping units of the Rondout Formation located in the escarpment through trees on left (east) side of road.
21.2	0.1	The Beach Mine of the Lawrenceville Cement Company (Werner, personal communication, 2003) in west-dipping strata of the Rondout Formation along right (west) side of road. Iron Mountain Incorporated now uses these mines as a document storage facility.
21.4	0.2	The Hoffman Quarry of the Lawrence Cement Company located east of small Wallkill Valley RR trestle on left (east) side of road. A battery of abandoned cement kilns built by the Lawrenceville Cement Company is visible on the right (west) side of road (Werner, personal communication, 2003).
21.6	0.2	Stone reservoir along right (west) side of road. This pond was created in the late 1820's to ensure a constant reserve supply of water for a feeder stream that was used to replenish water levels in the Delaware & Hudson Canal (Werner, personal communication, 2003).
22.0	0.4	*Intersection, turn right (west) onto State Route 213.* Joppenbergh Hill is located immediately to the left (east) of this intersection. The hill is named after Jacob Rutsen, who became the first westerner to settle in the Rosendale vicinity in1680. The New York and Rosendale Cement Company extensively mined Joppenbergh Hill during the 1800's. Large sections of the resulting quarry faces began collapsing in 1899, and have continued to do so as recently as April 2003. Rosendale Bridge, built by the Wallkill Valley Railroad, spans Rondout Creek from the flank of Joppenbergh Hill. Locally, State Route 213 follows the northern bank of Rondout Creek, and coincides with the trace of the Delaware & Hudson Canal. A thick, east-dipping sequence of Shawangunk Conglomerate cropping out in the south banks of the creek is visible through the trees.
22.1	0.1	Butler's Lock Quarry once operated by the Rosendale Cement Company. This mine is presently used as a water reservoir for Turco Brothers Water Service.

Cum	Part	
22.1	0.0	**OPTIONAL STOP C:** *This is private property and permission must be secured in advance to park in this lot. Many aspects of this stop are extremely dangerous and should only be attempted by very small groups. Pull off State Route 213 into the parking lot* of the Butler's Lock Quarry and the Turco Brothers Water Service, and park out of the way. Beware that semi trucks hauling full-sized water tanks enter this lot at full speed and use portions of this space to turn around. Care must be taken when parking and walking about the lot.
22.2	0.1	Van Tassels Quarry visible through chain link fence along the right (north) side of road
22.3	0.1	**STOP 6:** *Turn right into the Snyder Estate*, and proceed up the driveway, across a small bridge, and park in the large, grass-covered parking lot on the right.
22.6	0.3	Note Shawangunk Conglomerate in road cut immediately adjacent to the driveway of the Snyder Estate along the right (north) side of road.
22.9	0.3	Bridge over Rondout Creek
23.0	0.1	**OPTIONAL STOP D**: *Pull off on small turnout on left (south) side of road.* It is possible to park vehicles here for a short amount of time. For longer stays, the public parking lot located just across Rondout Creek from this location should be used.
23.5	0.5	Note the outcropping of Shawangunk Conglomerate in escarpment across cornfield on left (east) side of road. These rocks are in the hanging wall of the Snyder thrust fault.
23.7	0.2	Intersection with Mossy Brook Road. Ruins of mill foundation along the creek behind the bed and breakfast inn is supposedly the site of one of the very first cement mills in this region (Werner, personal communication, 2003).
24.4	0.7	High Falls Motel on left (south) side of road
24.4	0.0	**STOP 7:** *Pull off on right-hand side of road at base of hill.* Caution, the road has a low shoulder and ground is usually fairly mucky. It is also possible to park around the corner to the north or to park for short amounts of time in parking lot on the south side of the street.
24.5	0.1	Intersection with Bruceville Road (north)/Mohonk Road (south). D&H Canal Museum is located about 0.1 mile south of State Route 213 on east side of Mohonk Road
24.6	0.1	Intersection with Second Street, Blacksmith Shop where local dolostone was first burnt for cement located a few meters north of this intersection
24.8	0.2	**STOP 8:** *Turn right into parking lot* of High Falls park/Central Hudson Power Station. Lock vehicles and proceed down footpath towards power station.
24.8	0.0	*Turn right (west) on State Route 213* from parking lot at High Falls park/Central Hudson Power Station
24.9	0.1	*Bridge* over Rondout Creek
25	0.1	*Traffic light*, intersection with County Route 1
26.1	1.1	Small road cut in gently west dipping strata of the Kalkberg/New Scotland Formations.
26.2	0.1	*Traffic light, turn right* onto State Route 209 North towards Stone Ridge

Cum	Part	
28.9	2.7	Intersection with Cottekill Road, continue on State Route 209 North
30.3	1.4	Old abandoned quarry in Onondaga Limestone in trees along left (west) side of road
33.8	3.5	Esopus Creek visible through trees on left (west) side of road. Onondaga Limestone underlies much of this portion of the valley
33.9	0.1	Intersection with road to Town of Hurley. It was here that the government of New York was temporarily relocated when the British sacked Kingston in 1777
34.7	0.8	Underpass
36.2	1.5	*Bridge* crossing Esopus Creek
36.4	0.2	*Merge from right-hand lane onto exit ramp* leading to State Route 28 West toward Pine Hill, and proceed over bridge as it crosses back over State Route 209
36.8	0.4	*Turn right onto Forrest Hill Drive*

36.8	0.0	**STOP 9:** Turn right onto City View Terrace Road, and pull off onto shoulder to park
37.0	0.2	*Pull back onto City View Terrace Road* and continue East
37.2	0.2	*Use parking lot of Potter Bros. Ski and Patio to turn around*, heading back to the west on City View Terrace Road.
37.2	0.0	*Stop sign, turn left* onto Forrest Hill Drive
37.2	0.0	*Traffic light, turn right onto State Rroute 28* West towards Pine Hill and return to Oneonta

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Workshop W-1

Hands-on Activities for Teaching about Earthquakes - an IRIS Workshop

Jeffrey S. Barker, Department of Geological and Environmental Sciences, Binghamton University, Binghamton NY 13902

Accurate and timely seismological data can serve as a basis for a number of hands-on, guided inquiry-based learning exercises at the college, high school, middle school and upper elementary school levels. Workshop participants will perform several activities related to earthquakes and seismology appropriate as labs in college Geology courses or as learning activities within high school Earth Science or Physics classes. Topics include earthquake location, cause, distribution, recurrence, and magnitude. This workshop is sponsored by IRIS (Incorporated Research Institutions for Seismology) which provides the data as well as a variety of supporting materials (maps, posters, handouts, etc). Workshop will run from 8:30 – 12:00.

Workshop W-2

Teaching Environmental Science in the Outdoors: Pine Lake Environmental Campus

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Environmental science is by its nature interdisciplinary. This workshop will focus on the use of Hartwick College's Pine Lake Environmental Campus to illustrate the interactions between geology, biology, and chemistry, with emphasis on how these factors control the water quality in Pine Lake. Although this region of New York experiences some of the most acidic rain in the US, the pH of Pine Lake water has remained nearly neutral. We will explore how geology, biology, and chemistry explain this phenomenon. Several hands on assignments previously used to teach courses such as Introduction to Environmental Science, Earth Cycles, and Environmental Geology will be distributed and discussed. We will all also experience one of these assignments for ourselves.