Structures of the Hudson-Valley Fold-Thrust Belt in the Appalachian Foreland of Eastern New York

Stephen Marshak[1], Kurtis C. Burmeister[2], Pragnyadipta Sen[1], Petr V. Yakovlev[3] and Yvette D. Kuiper[3]

[1]*Department of Geology, University of Illinois, Urbana, Illinois 61801*
[2]*Department of Geosciences, University of the Pacific, Stockton, California 95211*
[3]*Department of Geology and Geophysics, Boston College, Chestnut Hill, MA 02467*

TRIP OVERVIEW

Exposures of a thin-skinned, foreland fold-thrust belt crop out west of the Hudson River in the central Hudson Valley of New York State (Figure 1a, b). This Hudson Valley fold-thrust belt (HVB), which involves Middle Ordovician through lower Middle Devonian strata, is generally less than 4 km wide. Thus, first-order structures (e.g., fault-related folds, detachment faults and duplexes) of the belt are small enough to be seen in their entirety within individual outcrops. The small size of the belt also makes it possible to examine along-strike variations in fold-thrust belt structural architecture that reflect variations in the thickness and mechanical properties of pre-deformational strata and/or in the amount of shortening (Marshak, 1983; 1986a; Burmeister and Marshak, 2003; Burmeister, 2005). This field trip will visit selected exposures of structures in the HVB to examine the structures of the belt at all scales. The stops illustrate the relationships between deformation style and stratigraphy.

In addition to examples of fold-thrust belt structural architecture, stops on the trip will also provide: (1) exposures of the Taconic angular unconformity (Rodgers, 1971); (2) examples of tectonic cleavage, veins, and slip fibers (Marshak and Engelder, 1985); (3) classic Lower Devonian North American faunas (Chadwick, 1944; Goldring, 1943); (4) examples of shallow-marine carbonate facies (Rickard, 1962; LaPorte, 1969); (5) an example of an orocline (Marshak and Tabor, 1989; Marshak, 2004); and (6) a context for considering continuing debates concerning the timing (Alleghanian vs. Acadian) of regional orogeny in the New England Appalachians, and the nature of the transition between the central Appalachians and the northern Appalachians (Marshak, 1986a; Marshak and Tabor, 1989; Marshak and Bosworth, 1991).

This trip proceeds from north to south along the belt. Highlights include the Route 23 roadcuts near Catskill, evidence for overprinting of deformation features near Kingston, and structural complexities of the Helderberg escarpment. This guidebook is a modification of a one that the lead authors have prepared for earlier field trips sponsored by the Geological Society of America and NYSGA.

GEOLOGICAL CONTEXT

Introduction

The Hudson Valley fold-thrust belt (HVB) is a narrow band of thrust faults and folds that verge generally westwards, toward the foreland of the Appalachian orogen. First-order folds range up to about 100 m in amplitude and 250 m in wavelength. The HVB is clearly a post-Taconic feature, because its structures involve the post-Taconic unconformity (an angular unconformity that truncates folds involving Middle Ordovician turbidites) and the Silurian through lower Middle Devonian strata above. Because of erosion, all that remains of the HVB is a 2 to 4 km-wide miniature valley and ridge province that lies between the Hudson River on the east, and the foothills of the Catskill Mountains on the west. Outliers of Silurian/Lower Devonian strata exhibiting HVB deformation crop out east of the Hudson River (at Mt. Ida and Becraft Mountain), indicating that the belt once extended further to the east into the region of the Taconic Mountains. But because the HVB structures strike parallel to Taconic structures, HVB deformation cannot be identified in regions where only Middle Ordovician and older strata are exposed.

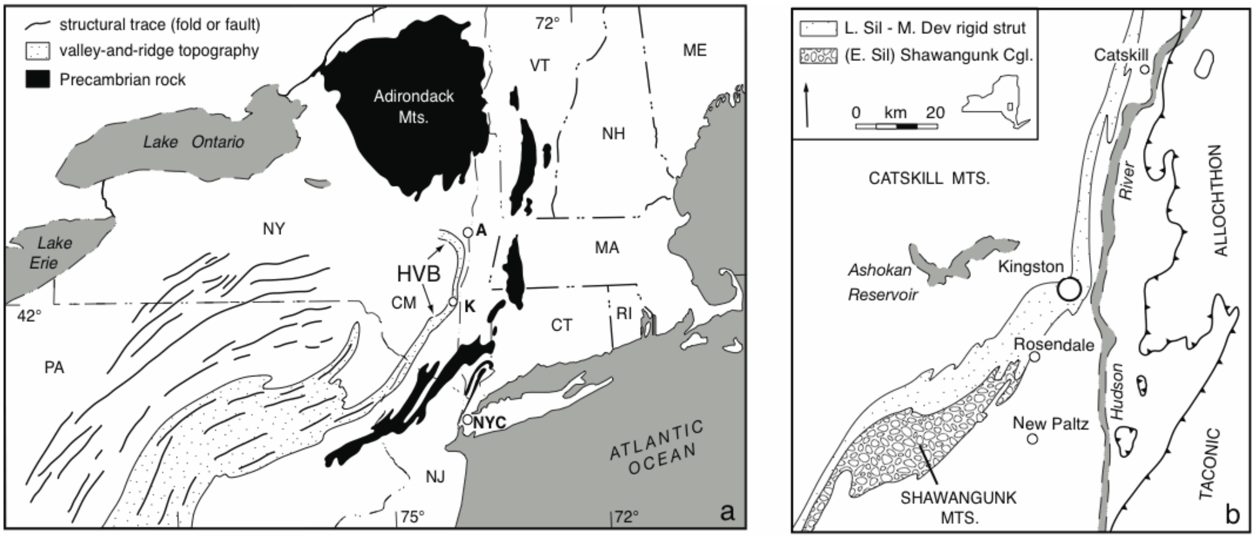

Figure 1. (a) A map of New York State showing the distribution of fold-thrust belt structures. The stippled belt represents the area of structurally controlled valley-and-ridge topography. Note that the broad Pennsylvania Valley and Ridge Province merges with the very narrow Hudson Valley fold-thrust belt, and that very gentle folds occur in the foreland of the Pennsylvania Valley and Ridge (in Pennsylvania and south-central New York), but not in the Catskill Mountains. HVB = Hudson Valley fold-thrust belt; K = Kingston; A = Albany. (b) Detail of the New Paltz to Catskill area, illustrating the pinch out of the Shawangunk Conglomerate, and the regional change in structural trends that takes place in Kingston.

In the region north of Kingston, structures of the HVB trend north-south to N10°E, whereas in the region south of Kingston, HVB structures trend about N30°E, and the belt becomes progressively wider as deformation propagates into the foreland (Figure 2). In New Jersey and Pennsylvania, the HVB merges with Pennsylvania Valley and Ridge Province. This map-view curve is one of the four major curves of the Appalachians (i.e., two salients and two recesses; Figure 3), and effectively marks the center of the syntaxes between the Northern Appalachians and the Central Appalachians. The change in trend within Kingston has been interpreted as an "intersection orocline" in which Alleghanian structures of the central Appalachian foreland overprint and rotate Acadian structures of the northern Appalachian foreland (Figure 4; Marshak and Tabor, 1989).

Structures of the HVB are significantly smaller than those of Pennsylvania Valley and Ridge or other foreland fold-thrust belts. This contrast is due to the thinness of the stratigraphic sequence involved in the HVB. In effect, the belt is a "fold-thrust belt in miniature". The scale of the HVB puzzled 19th century geologists-Davis (1882; 1883), who referred to the belt as the "Little Mountains," could not understand why strata in the HVB, a region in which elevations are less than 100 m, was so much more deformed than the Catskill Mountains, in which elevations reach 1200 m. Because of the proximity of the HVB to many colleges and universities, its outcrops are many student field trips and mapping projects every year. Several field guides to belt are available (e.g., Sanders, 1969; Marshak 1986b; 1989; 1990; Burmeister and Marshak, 2002).

Stratigraphy

The strata encountered on the field trip includes Middle Ordovician flysch as well as Late Silurian through lower Middle Devonian shallow marine strata (Figure 5a). At Rosendale, the Middle Ordovician Martinsburg Shale, a thick sequence of interbedded greywacke and shale, underlies the Taconic unconformity. Its correlative, the Austin Glen Formation, underlies the Taconic unconformity between Kingston and Catskill. This sequence represents an accumulation of turbidites deposited on the margin of North America just prior to collision with the offshore Taconic volcanic arc. Subsequent to the Taconic orogeny, which folded the Austin Glen and Martisburg strata, a long period of erosion produced the post-Taconic unconformity. A sequence of Late Silurian clastic and carbonate strata were deposited on the unconformity. Near Rosendale, this sequence includes the Late Silurian Shawangunk Conglomer-

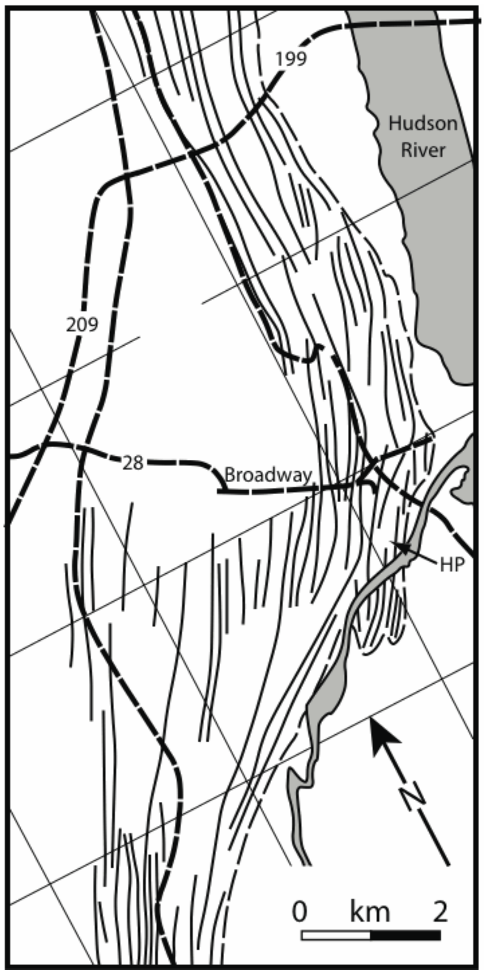

Figure 2. Sketch map of structural grain (fold and fault traces) in the Kingston area, showing the change in structural trend that occurs at Kingston (Marshak and Tabor, 1986). Note also that the belt gets wider south of Broadway Avenue. HP = Hasbrouck Park. 0: Figure 2. Sketch map of structural grain (fold and fault traces) in the Kingston area, showing the change in structural trend that occurs at Kingston (Marshak and Tabor, 1986). Note also that the belt gets wider south of Broadway Avenue. HP = Hasbrouck Park.

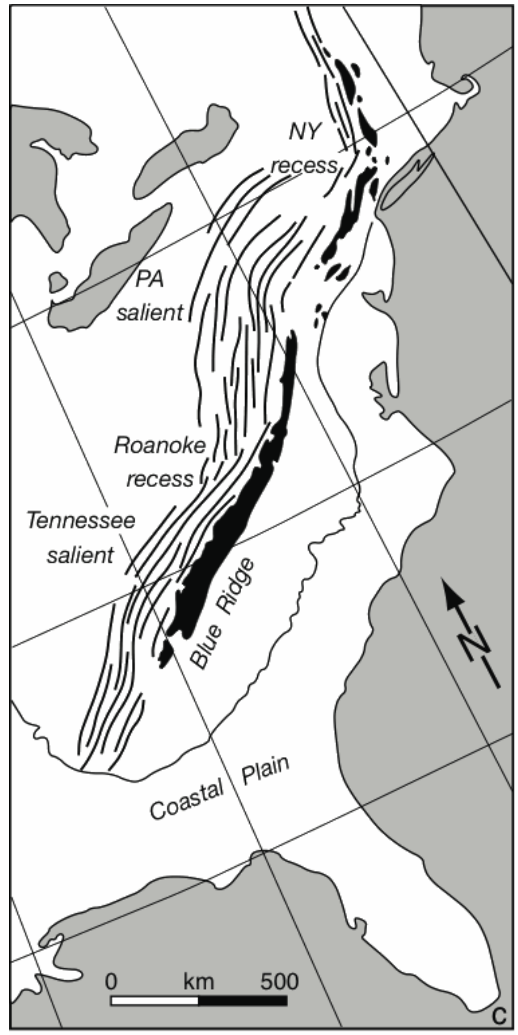

Figure 3. Sketch map of structural traces illustrating the salients and recesses of the Appalachian fold-thrust belt. The heavy lines are representative traces of folds and faults.

ate, the High Falls Shale, the Binnewater Sandstone, and the Rondout Formation (Waines and Hoar, 1967). Lower units in the Silurian section thin to the north and pinch out north of Rosendale, so that by the latitude of Kingston, only the Rondout Formation remains (Figure 5b). The Rondout Formation continues to thin northwards to Catskill, where it is represented by only 1 to 2 m of sandy, dolomitic limestone.

The Devonian Helderberg and Tristates Groups overlie the Rondout Formation. These groups include deposits indicative of successive transgressions of a shallow sea (Wanless, 1921; Waines and Hoar, 1967; Laporte, 1969; Sanders, 1969; Rodgers, 1971; Marshak, 1986a; Epstein and Lyttle, 1987; Marshak and Tabor, 1989; Marshak, 1990). The only significant non-carbonate unit in this sequence is the Esopus Shale. Above the Tristates Group lies the Onondaga Limestone, which is the youngest carbonate unit to be deposited prior to the deposition of the Catskill clastic wedge. Deformation features characteristic of the fold-thrust belt deformation in the Hudson Valley are visible in the Bakoven Shale and Mt. Marion Formation, units of the Hamilton Group that directly overlie the Onondaga Limestone, but cannot be found in younger units (Murphy and others, 1980).

Regional Structural Architecture of the HVB

Model cross sections of the HVB suggest that shortening in the fold-thrust belt occurred above regional-scale detachment faults (Marshak, 1986a; Burmeister and Marshak, 2002). From Kingston to the north, there appear to be four detachment horizons (Figure 6). Area balancing of cross sections suggests that the lowest of these, called the Austin Glen detachment, lies at a depth of about 500 m below ground level. This detachment may represent a reactivated Taconic thrust. Displacement on it resulted in folding of the post-Taconic unconformity, and the development of folds with amplitudes of tens of meters that are cored by Middle Ordovician strata. Ramps rising from this detachment locally place Ordovician strata over Silurian strata; examples cropped out in quarries north of Kingston. The next higher detachment, the Rondout detachment, lies just above the post-Taconi unconformity. Where exposed, this detachment is a zone of west-verging mesoscopic folding, intense cleavage development, and local duplexing in the Rondout Formation. Ramps rising from this detachment cut across Lower Devonian strata. Detachments, with associated deformation also occur at the base of the Esopus Shale, and in the Bakoven Shale. From Kingston to the south, there appear to be additional detachments below the Austin Glen detachment, and the Rondout detachment does not appear to exist. Deformation in the fold-thrust belt south of Kingston appears to be associated with two detachment faults within Ordovician strata. Thus, detachments in the HVB appear to ramp up section from east to west, and from south to north.

Deformation associated with the fold-thrust belt along the western margin of the Hudson Valley dies out westward. The occurrence of cleavage duplexes in the Bakoven Shale (Nickelsen, 1986) and of spaced cleavage in the Mount Marion Formation suggests that west-directed displacement associated with the HVB occurs at least a few kilometers west of the westernmost fold of the HVB (Marshak and Bosworth, 1991).

Stratigraphic units in the Hudson Valley can be categorized in terms of their mechanical character (Figure 3b). Specifically, the Late Silurian through Middle Devonian clastic and carbonate sedimentary rocks can be considered to be a mechanically rigid "strut" (Burmeister and Marshak, 2002; Burmeister and Marshak, 2003; Burmeister, et al., 2003; Burmeister, 2005). The Siluro-Devonian strut in the central Hudson Valley is roughly 150 m thick near Rosendale. (Of note, its along-strike equivalent in the Pennsylvanian Valley and Ridge Province to the south is more than 1000 m thick.) This strut thins northwards between Rosendale and Catskill. This strut is sandwiched between thick, relatively weak, shale sequences: the Middle Ordovician Martinsburg and Austin Glen Formations below, and the Middle Devonian Esopus Shale above. This distinct mechanical stratigraphy controls the dimensions of structures and the positions of detachments - as units thin, fold amplitude and thrust spa-

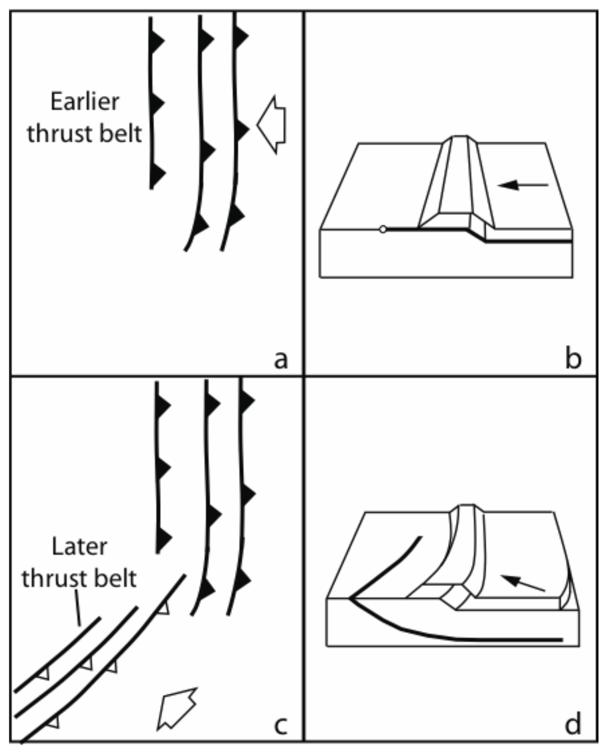

Figure 4. Block diagrams showing the concept of an intersection orocline. The NE-SW-trending thrust belt is younger than the N-S-trending thrust belt. Displacement on a younger thrust bends the structures in its hanging wall (Marshak and Tabor, 1986).

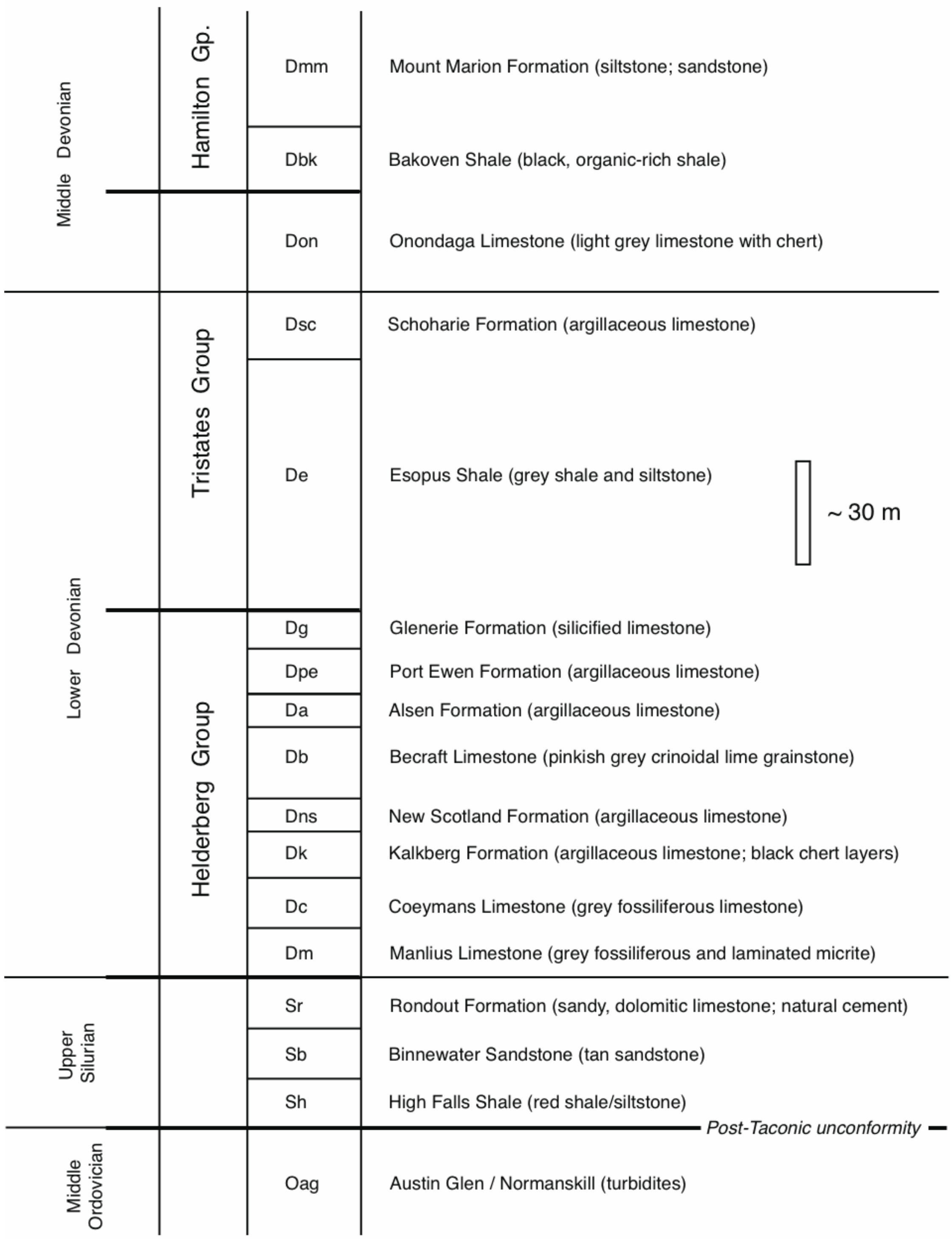

Figure 5. (continues)

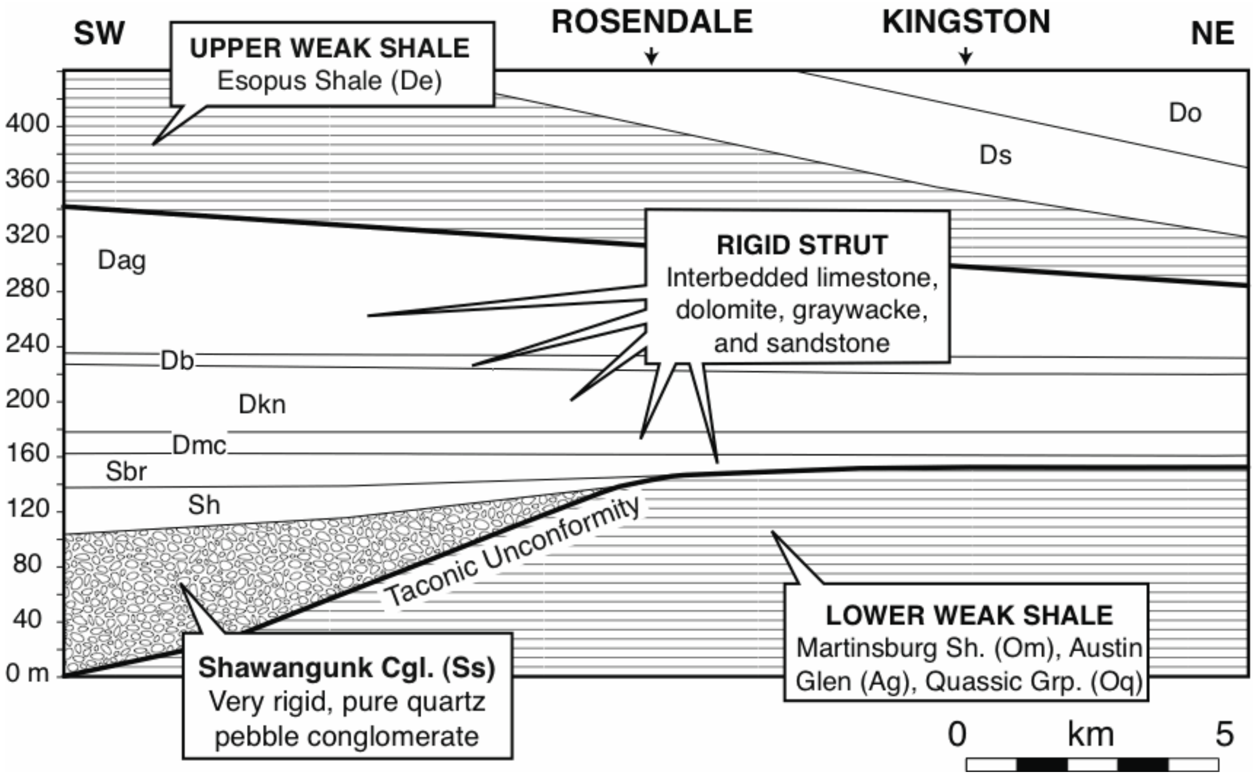

Figure 5. (continued) (a) Composite stratigraphic column of the Hudson Valley fold-thrust belt. Thicknesses are approximate. (b) Simplified north-south trending fence diagram, illustrating how Silurian strata thicken to the south starting at a latitude just north of Kingston (Burmeister, 2006).

cing decreases. Accomodation between different zones of the fold-thrust belt appears to take place by lateral ramping.

The age of deformation in the Hudson Valley remains enigmatic. It is possible that the belt is Acadian (Devonian), because of the location of the belt between the Acadian foreland basin, represented by redbeds of the Catskill Mountains, and the Acadian orogen of New England. However, the belt could also be Alleghanian (late Paleozoic), because of an apparent continuity with structures of the central Appalachians and the proximity of the belt to the foreland of a region that was remobilized during the Alleghanian orogen. Deformation age cannot be stratigraphically constrained because the belt involves Lower Devonian strata, but dies out to the east of the first exposures of Acadian foreland strata.

LIST OF STOPS

Optional Stop A - Abandoned Quarry near Fuerra Bush. Exposure of a duplex along the Rondout Detachment, and a large Ramp anticline. This stop provides excellent exposures of an impressive 10 m-high duplex involving the Rondout Formation and the Manlius Limestone along the Rondout Detachment. Within the duplex, there are numerous ramps spaced at 0.5 to 2 m. The duplex has a flat roof. The quarry also exposes of a first-order ramp anticline involving the Manlius Limestone, Coeymans Limestone, and Kalkberg Formation. The quarry has been cut into the Helderberg Escarpment, a 10 to 50 m-high cliff that marks the eastern limit of Siluro-Devonian strata in the HVB west of the Hudson River.

Stop 1 - Exposures along Route 23 Near Catskill: A cross section of the entire HVB. Stop 1 includes several roadcut exposures along State Route 23, approximately 2 km northwest of Catskill. The outcrops are numbered in succession from west to east (Figure 7); those containing the letter N border the north side of the road, and those containing the letter S border the south side. For logistic reasons, we start the trip at the east end of the fold-thrust belt and work our way westwards, toward the foreland. These exposures show the following:

Roadcut 1A exposes the post-Taconic angular unconformity and the Rondout detachment. The unconformity dips moderately westward, parallel to the strata above, and cuts across steeply dipping beds of Austin Glen Formation. Displacement on the detachment resulted in formation of west-verging (i.e., down-dip verging, in this outcrop) folds, and in cleavage that has rotated counter-clockwise, relative to bedding (Marshak, 1986a, b). A homoclinally dipping sequence of the lower Helderberg Group (Manlius, Coemans, and Kalkberg Formations) lies over the Rondout Formation. The Manlius contains small black ostracods, the top of the Manlius is a layer of thinly laminated micrite, the Coeymans contains the white, beaked brachiopod Gypidula coeymanensis, and the base of the Kalkberg is marked by a distinctive black chert layer.

Here, as throughout the Hudson Valley fold-thrust belt, development of cleavage is lithologically controlled; cleavage occurs primarily in rocks containing greater than 10 percent clay (Marshak, 1983). Also, slip fibers develop on bedding planes due to both detachment faulting and flexural slip. On the west limb of folds, slip due to flexural slip can be distinguished from that due to detachment faulting by the sense of slip indicated by imbrication of fiber sheets and by shear rotation of cleavage adjacent to slip surfaces. Flexural slip displacement is always "top-up." Slip on a west-verging, but now west dipping detachment, is "top-down" in its present (post-folding orientation).

Outcrop 1B provides another exposure of the lower Helderberg Group in the western limb of the Tollgate Syncline, a first-order fold that underlies State Route 23B between 1A and 1B. In this outcrop, the section was thickened as a result of movement on two well-exposed, out-of-the-syncline forethrusts (see Dahlstrom, 1970). The lower fault brings the Manlius Formation over the Kalkberg Formation.

Outcrops 1CN and 1CS provide additional exposures of the Taconic Unconformity and of the Helderberg Group

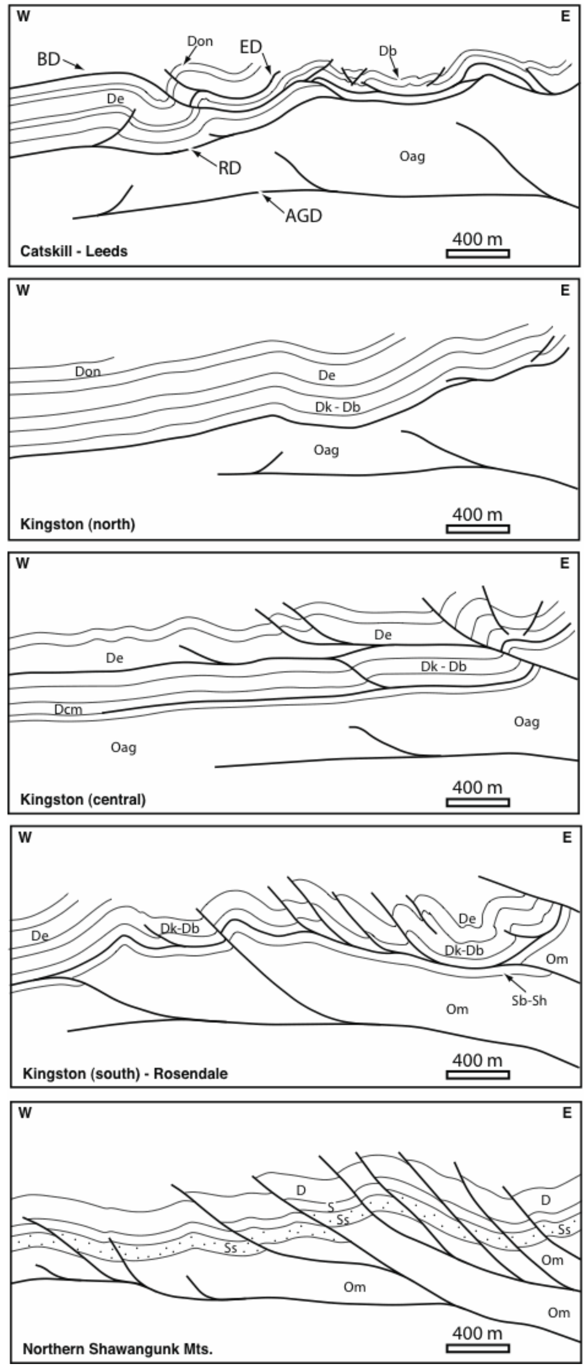

Figure 6. Model cross sections of the Hudson Valley fold-thrust belt at different latitudes (north at the top, to south at the bottom). Oag = Austin Glen; Om = Martinsburg; Sr = Rondout; Sb-Sh = Binnewater and High Falls; Dm-Dc = Manlius and Coeymans; Dk- Db = Kalkberg, New Scotland, and Becraft; De = Esopus; Don = Onondoga (Marshak and Tabor, 1986; Burmeister, 2006).

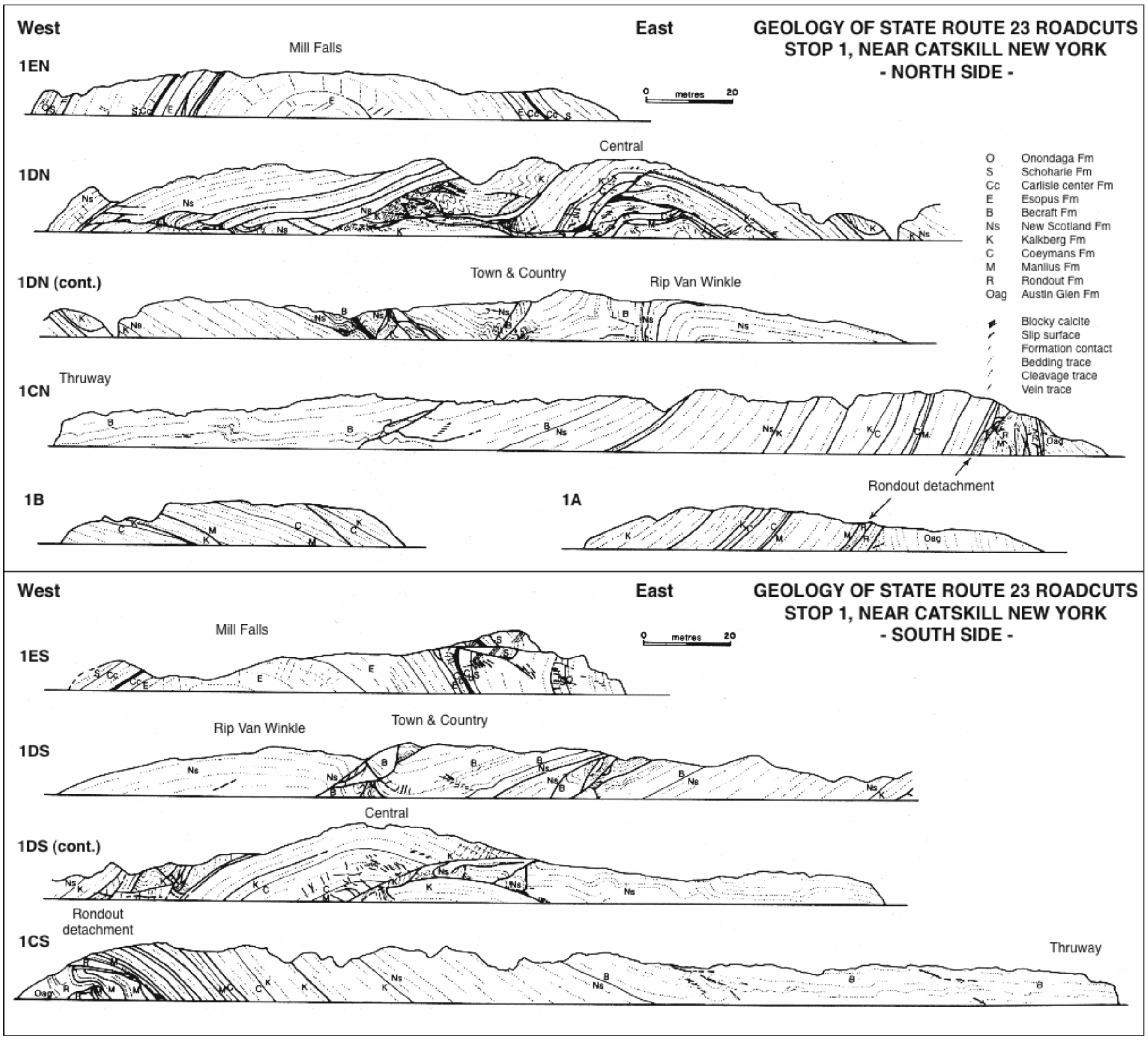

Figure 7. Sketches of the structures exposed in the Route 23 roadcuts, west of Catskill (Marshak, 1984). The major folds are named.

(through the Becraft Formation). Of particular note in these outcrops are the complex faults and folds in the Rondout and lower Manlius Formations, manifestations of movement on the Rondout detachment. Many bedding-plane slip surfaces, which developed during flexural-slip folding and are coated with sheets of calcite slip fibers, occur in outcrops 1CN and S3. In the Kalkberg Formation, some of these slip surfaces are bounded by zones of nearly slaty cleavage. At the northwest end of outcrop 1DN, numerous mesoscopic folds, as well as two back-thrusts, occur within the Becraft Limestone.

Outcrops 1DN and 1DS are the most spectacular of the State Route 23 outrcrops. Together, these exposures (which include rocks of the Manlius Formation through Becraft Limestone) display, from southeast to northwest, ramp faults with hanging wall anticlines (Rip van Winkle anticline), out-of-the-syncline forethrusts and backthrusts, folded ramps and flats (in the Central anticline), and zones of tectonic cleavage intensification (on the northwest limb of the Central anticline). Of particular note are the examples of fault bends (Suppe, 1983) at which bedding-parallel flats join cross-strata ramps. The Central anticline appears to be composed of a stack of fault-bounded horses (see Boyer and Elliott, 1982), one of which is internally deformed throughout by mesoscopic folds. Structures of outcrops 1DN and 1DS do not directly correlate across the highway, illustrating how rapidly structural geometry can change along strike in the HVB. The contrast in structural geometry between outcrops on opposite sides of the road may reflect the occurrence of a lateral ramp in the interval that was excavated during construction of the highway. We can also see variations in strain magnitude, indicated by cleavage intensity, as well as lithologic control on the degree of cleavage development. Studies of these rocks provide interesting constraints on the volume-constant vs. volume-loss models of cleavage development (Bhagat and Marshak, 1990).

Outcrops 1EN and 1ES expose the Esopus and Schoharie Formations, and the base of the Onondaga Limestone. These units are arched around the Mill Falls anticline. Nearly slaty cleavage occurs within the lower Esopus Shale. The upper few meters of the Esopus Shale are composed of beds of finely laminated mudstone and siltstone that have been crinkled into tiny folds. A sub-horizontal fault is present at the top of outcrop 1DS. Time permitting, we will visit the deformation front of the fold-thrust belt as it is exposed along Catskill Creek in the village of Leeds, approximately 1 km north of State Route 23.

Stop 2 - Roadcut along Route 23A, east of the Thruway Bridge: Exposure of the Esopus detachment. Stop 2 exposes disharmonic folds that formed in association with movement on a detachment fault between the Esopus and Glenerie Formations. This outcrop inspires considerable debate about the origin of the deformation. Is the structure tectonic, or is it a consequence of slumping that was penecontemporaneous with deposition? The association of fractures, cleavages, and shear zones with the folds suggests that the deformation is tectonic. Deformation likely occurred at this horizon because of the viscosity contrast between the Esopus and Glenerie Formations. The lowermost Esopus Shale is composed of alternating beds of siltstone and shale, and such a sequence is susceptible to buckling. The overlying Esopus Shale is more homogeneous and contains closely spaced to slaty cleavage. The detachment at the contact may reflect differential shortening between the Esopus and Glenerie Formations.

Optional Stop B - Roadcut on Route 209: Cleavage duplexes in the Bakoven Member of the Union Springs Formation. This stop exposes the Bakoven and Stony Hollow Members of the Union Springs Formation, the basal unit of the Hamilton Group, in the steep escarpment and road cut along City View Terrace, beneath the Skytop Motel. Mesoscopic-scale duplexes and shear zones in the upper 10 m of the Bakoven Member provides an opportun-

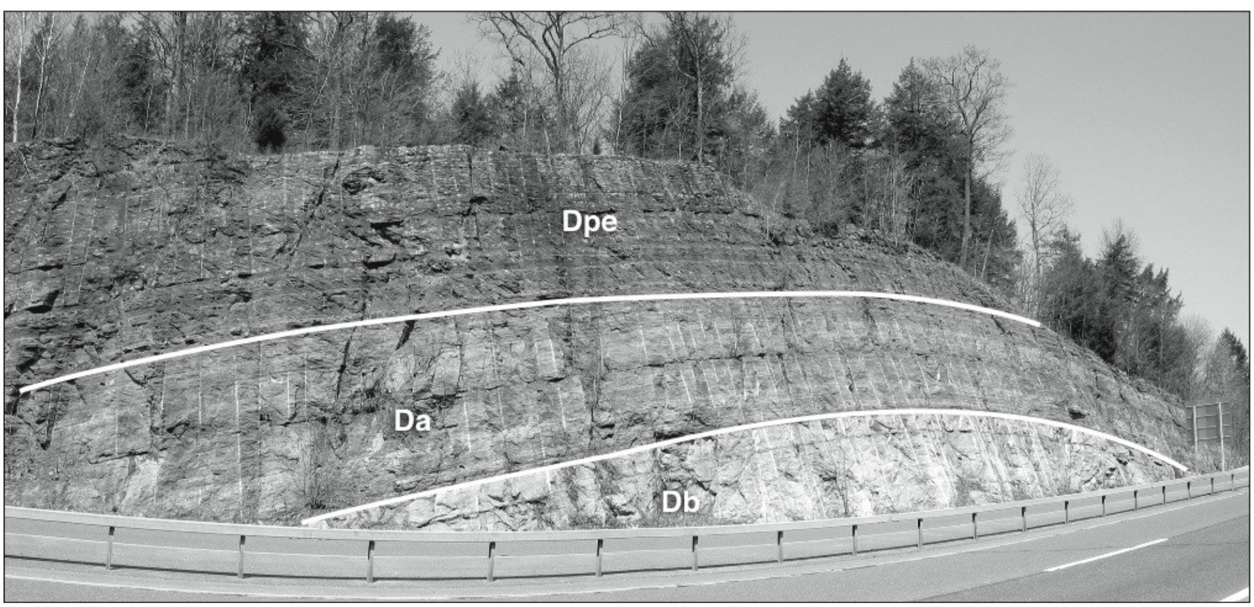

Figure 8. Photograph of roadcut exposure showing a first-order anticline involving Becraft Limestone (Db), Alsen Formation (Da), and Port Ewen Formation (Dpe) along the north side of State Route 209/199, north of Kingston.

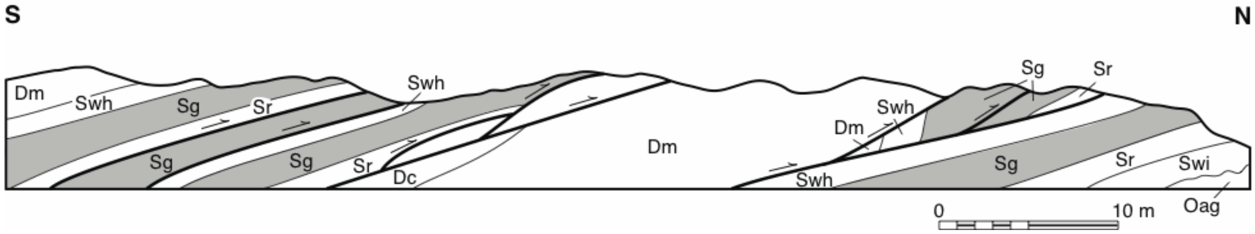

Figure 9. Schematic cross section with slight vertical exaggeration of road cut exposure along west side of State Route 32 just-south of intersection with State Route 199. Note duplication of Silurian and Devonian strata in series of imbricate thrust sheets and horses. Oag = Austin Glen Formation; Rondout Formation [Swi = Wilbur Member; Sr = Rosendale Member; Sg = Glasco Member; Swh = Whiteport Member (Swh)], Dm = Manlius Limestone; and Dc = Coeymans Formation. Figure redrawn after D.B. McEachran (1985 - UIUC M.S. thesis).

ity to examine deformation associated with the stratigraphically highest detachment of the HVB (Bosworth, 1984; Nickelsen, 1986; Ver Straeten and Brett, 1995). Nickelsen referred to the structures in this outcrop as "cleavage duplexes," implying that the planar laminations within the shear zone is slaty cleavage not bedding. An alternative view is that the laminations are bedding planes that have rotated almost 90°, due to shear. The kinematics of these zones remains unclear.

Stop 3 - Roadcuts along State Route 199/209, just north of Kingston: Exposures of large anticlines and synclines. Stop 3 exposes large, slightly asymmetric open folds with no visible thrust faulting or mesoscopic folding. Five major, map-scale fold hinges cross State Route 209 between Routes 9W and 32 (McEachran, 1985; Marshak and Tabor, 1989; Marshak, 1990). The most prominent of the folds at Stop 3 is a large anticline involving the upper Becraft Limestone, the Alsen Formation, and the Port Ewen Formation (Figure 8). Note the differential development of cleavage in these units. The Becraft Limestone contains little to no cleavage, whereas a strong, southeast-dipping cleavage is developed in the Alsen and Port Ewen Formations. These folds are characteristic of structural styles in the northern arm of the Kingston Orocline, in that they trend roughly N015°E and lack structural complexity (Marshak and Tabor, 1989).

Stop 4 - Roadcuts along Route 32 (Flatbush Ave) north of Kingston: Lateral ramping in the Rondout Formation. Stop 4 is along the west side of State Route 32 (Flatbush Ave.), 0.3 miles south of US 199 overpass (Figure 9). Stop 4 exposes four major thrust faults duplicating the Rondout and Manlius Formations in a series of imbricate thrust sheets along the west side of State Route 32 (Figure 7; Waines and Hoar, 1967; McEachran, 1985; Marshak, 1990). Thrust faults in this outcrop strike roughly N040E. Calcite slip fibers on the fault surfaces suggest a transport direction of N060E-N070E. In places, these faults have a flat-on-flat geometry (i.e., thrust faults are bedding parallel in both the hanging wall and footwall), suggesting large displacements. These thrusts occasionally appear to cut down-section due to the obliquity of the road cut face to the orientation of the structures and the transport direction (hanging walls are thrust westward into the outcrop). These faults are untraceable west of the road cut, but may ramp laterally up-section and die out to the north.

Optional Stop C - Route 9W Roadcut in Onondaga Limestone, north of Kingston: Cross-cutting cleavage. At this exposure, in the center of the Kingstone orocline, a bedding surface of Onondagaga limestone at the top of a roadcut on the east side of the Highway, appears to contain two distinct cleavage trends (Figure 10). This relationship is evidence that two distinct segments of the fold-thrust belt cross cut in the Kingston area.

Stop 5 - Hasbrouck Park, Kingston: The foreland edge of an antiformal stack along the Helderberg Escaprment. Stop 5 at Hasbrouck Park provides a cross-sectional view through the leading edge of a duplex structure involving horses from the Rondout through Kalkberg Formations (Figure 11; Marshak and Tabor, 1989; Marshak, 1990). The basal thrust fault in this duplex, the Hasbrouck thrust, cuts laterally up-section along the sloping footpath between the parking lot and Stop 5. The Hasbrouck thrust fault reappears north of Delaware Avenue, where it places the Manlius Formation over the Alsen Formation. A tear fault with a trace roughly coincident with Delaware Avenue may extend to the west of the lateral ramp. The complexity of the structural relationships at Hasbrouck Park is characteristic of the geology along the Helderberg Escarpment near Kingston.

Optional Stop D - Exit Ramp from 9W to Delaware Avenue: Fly Mountain Thrust. At this locality, we see an exposure of a thrust fault that places Esopus Shale against Onondaga Limestone. The fault surface is decorated with calcite fiber slip lineations. This fault changes trend, south of Kingston.

Optional Stop E - Callanan Quarry: Backthrusts along the Helderberg Escarpment. The northwest wall of the quarry (the high wall below the railroad line) is a spectacular exposure of complex structural relationships, including backthrusts, out-of-the-syncline faults, and duplex structures that are characteristic of the Helderberg Escarpment near Kingston (Fig 12). The Upper Becraft Limestone provides a distinctive marker horizon.

Optional Stop F - Rosendale Landfill: Exposure of Ordovician strata in the core of the Hickory Bush anticline. Outcrop at this stop exposes a complete, east-dipping sequence of Middle Ordovician through Middle Devonian strata in the northern wall of the Rosendale Landfill and Recycling Center. Here, the Martinsburg Shale is strongly deformed by complex brittle faulting. The Shawangunk Conglomerate is little more than a 5 to 10 cm thick lag deposit of characteristic milky white quartz pebbles overlying the Taconic unconformity. The Shawangunk Conglomerate, a silica cemented quartz-pebble conglomerate, thickens dramatically to the south, where it becomes a mechanically rigid strut in the pre-deformational stratigraphic section involved in fold-thrust belt deformation in the northernmost Valley and Ridge Province. Overlying the Shawangunk Conglomerate are the High Falls Shale and Binnewater Sandstone. The Rosendale and Whiteport Members of the Rondout Formation are quarried at this location, leaving the Glasco Member, which contains beautiful Halycities chain corals. The Rondout Formation is overlain by the Manlius Limestone, which is truncated by a fault.

The east-dipping strata exposed here form the eastern limb of the Hickory Bush anticline. The involvement of Martinsburg Shale in the fold core suggests this structure developed as the result of slip along a detachment at depth in the underlying Ordovician strata. The 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 of two detachment horizons. A smaller thrust fault exposed at the eastern end of the exposure 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).

Optional Stop G - Rail Trail, near Fourth Lake: Limb of Hickory Bush anticline. Walk southwest along the rail trail from the parking lot along Hickory Bush Road for roughly 350 m until you encounter a cut exposing northwest dipping strata. The exposed sequence includes High Falls, Binnewater, Rondout, and Manlius Formations (Figure 13). 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. The Rosendale and Whiteport members of the Rondout Formation were quarried at this location. 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

Figure 10. Photo of a bedding surface in the Onondoga Limestone, in north Kingston, illustrating two different cleavage orientations. The compass points due north. In the intersection orocline model, the earlier cleavage trends about N10°E, and the later cleavage dates about N30°E. The earlier cleavage is better developed, and may have continued to be an active locus of pressure solution even after the second cleavage starts to form, thus explaining ambiguous cross-cutting relationships.

once a tramway that serviced the cement quarries in this area. Watch your step and be careful to stay away from the large openings atop the cement kilns that are hidden in the underbrush.

Optional Stop H - Former Williams Lake Hotel property: Exposures of an asymmetric anticline in an abandoned room-and-pillar mine. Abandoned cement mines at Stop G provide unique exposures of a series of large, asymmetric folds in the High Falls, Binnewater, Rondout, and Manlius Formations on the property of the former Williams Lake Resort. Watch your step-abandoned cement kilns and sunken shed foundations are scattered along this tramway and are often difficult to see. The floor of the "Chop Shop" mine in the Rosendale Member of the Rondout Formation is formed by the contact with the underlying Binnewater Sandstone, whereas the contact with the overlying Glasco Member forms the ceiling. Because of a recent change in ownership, it is not clear if permission can be obtained to visit this property.

Stop 6 - Snyder Estate: Historic mine in the footwall of the laterally ramping Century thrust fault. This outcrop is an extensively mined exposure of the Rondout Formation in the footwall of the Century thrust fault. As units in the mechanically rigid Siluro-Devonian strut thin along strike to the north, the Century thrust ramps laterally up section. South of Rondout Creek, the Century thrust juxtaposes Ordovician and Late Silurian strata, but ramps up section into Middle Devonian strata north of Rondout Creek. The abandoned mine at this stop is one of the oldest in the Rosendale natural cement region and is an example of a classic, two-tiered Rosendale cement mine. Dolostone

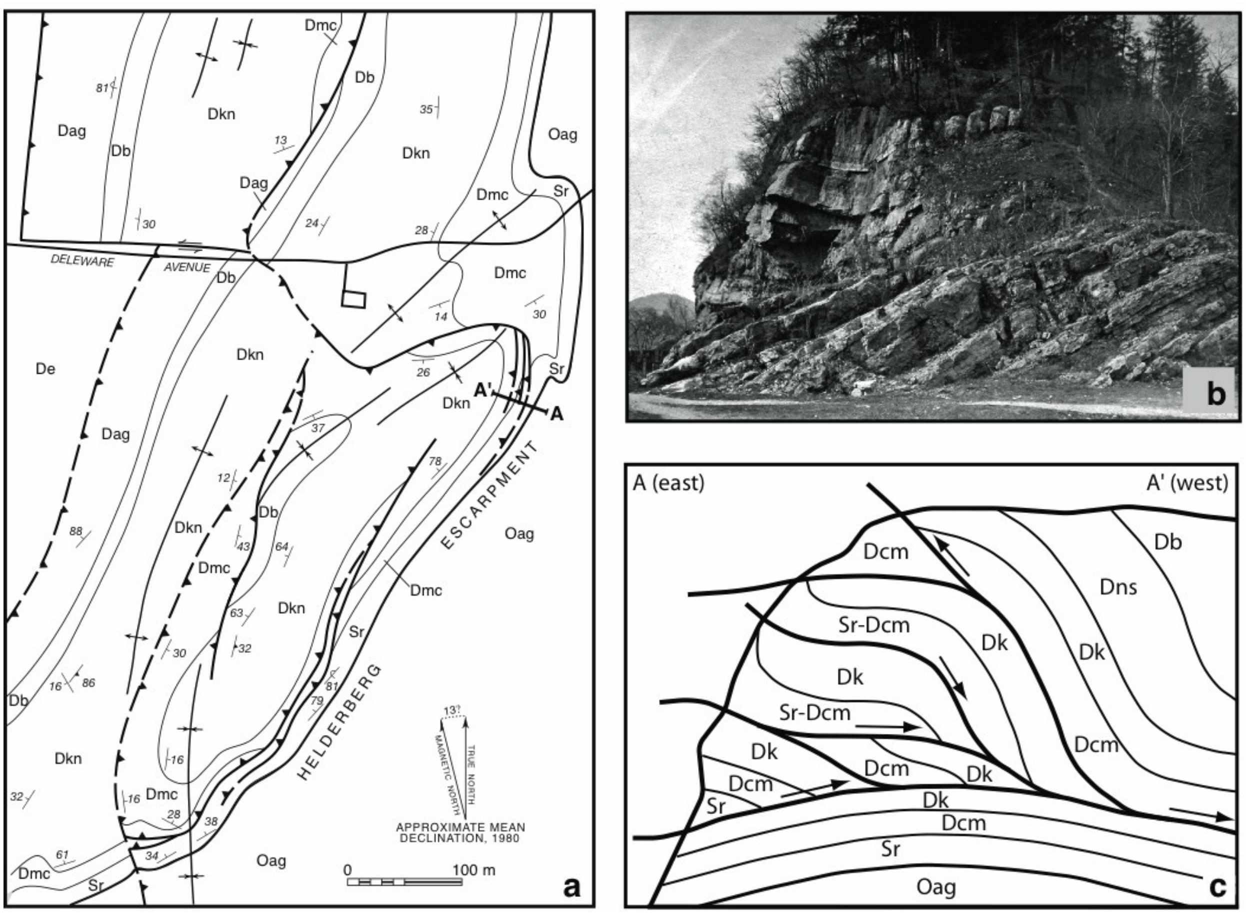

Figure 11. (a) Simplified geologic map of Hasbrouck Park (after Marshak and Tabor, 1989). Note complex structural relationships along eastern map margin. (b) Photo by G. van Ingen in Cairnes (1920) shows the NE corner of the escarpment in the park before regrowth of the forest. (c) A schematic cross-section above (not to scale), showing an imbricate thrust interpretation along Line AA'.

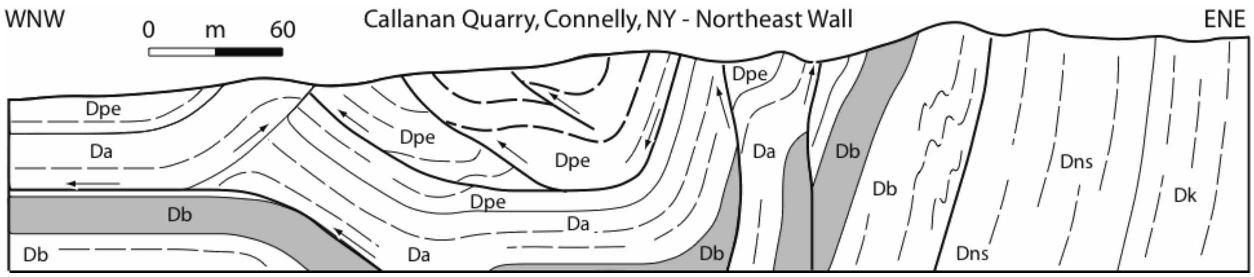

Figure 12. Sketch of the northeast highwall in the Callanan quarry in Connelly, south of Esopus Creek. Note the backthrusts and the steep dips. (From Marshak and Tabor, 1986, modified from an unpublished version by P. Kwizinski, UIUC M.S. student.)

was extracted for the production of natural cement from the Rosendale and Whiteport members of the Rondout Formation, which were historically referred to as the upper and lower cements, respectively. The Glasco Member, historically referred to as the middle ledge, is left un-quarried between the dolomitic layers. There are many remnants of the cement industry on the historic Snyder Estate property, including the ruins of cement kilns, a screening house, and many tramway roadbeds. Use caution when exploring these ruins and be careful to stay away from the large openings atop the cement kilns.

Optional Stop I - Rondout Creek, Lawerenceville. Optional Stop I can be reached by continuing west 0.7 miles on State Route 213 from the entrance to the Snyder Estate. Pull into the public parking lot along the left (south) side of the road for longer stays at this location. This stop affords a good view of the Kalkberg and New Scotland Formations in the Lawrenceville anticline. This anticline is the westernmost major, map-scale fold exposed in the Rosendale region and appears in numerous historical photographs taken of the Delaware & Hudson Canal in this region. This exposure is often obscured by vegetation during the spring and summer months.

Optional Stop J - Route 213, High Falls: Exposure of a bedding-parallel slip surface in Shawangunk Conglomerate. Optional Stop J provides an excellent exposure of the Shawangunk Conglomerate. The contact with the overlying High Falls Shale lies near the top of the road cuts. Rocks exposed at the eastern end of this road cuts lie in the footwall of a thrust fault that strikes roughly perpendicular to the trend of State Route 213. The hanging wall of this fault is exposed in the next set of road cuts east of R8 along State Route 213. A distinct, bedding-parallel slip surface exposed along the north side of State Route 213 at this stop contains a cleavage duplex composed of powdered quartz. This duplex suggests 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 sur-

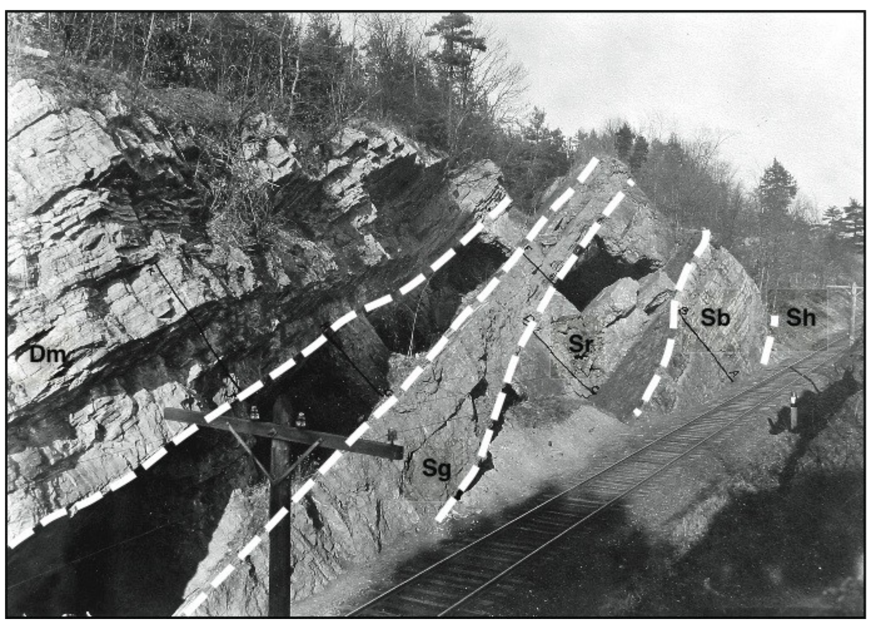

Figure 13. Annotated photograph of a cut along the rail trail, near Fourth Lake, showing the west limb of the Hickory Bush anticline, and the remnants of abandoned roof and pillar cement quarries. The photograph was taken by G. van Ingen, before reforestation, and was reprinted by Osborn (1921).

Figure 14. Panoramic photograph along the north bank of Rondout Creek and High Falls Park (Central Hudson power plant) in High Falls, NY. This is the westernmost fold at this latitude.

face. 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).

Stop 7 - Waterfall at High Falls: Exposure of an east-verging asymmetric anticline at High Falls. Stop 7 can be reached by continuing west on State Route 213 for 0.4 miles before turning right (north) into High Falls Park/Central Hudson Power Station. Follow paths north down the hill to the bank of the Rondout Creek. Stop 7 exposes an asymmetric anticline in the Binnewater Sandstone and High Falls Shale along the Rondout Creek, northwest of High Falls (Figure 14). To the southwest of High Falls, Rondout Creek flows north, roughly parallel to the strike of gently west-dipping strata. At High Falls, Rondout Creek bends sharply to the east and begins cutting perpendicular to strike, down-section towards Rosendale. The highest waterfall is over an outcrop of the Rondout Formation. Downstream, smaller waterfalls occur in the Binnewater Sandstone and High Falls Shale, and are followed by minor rapids in shallowly east-dipping Shawangunk Conglomerate. The asymmetric anticline in the Binnewater Sandstone and High Falls shale at Stop 7 is the westernmost mesoscopic structure in the fold-thrust belt near Rosendale, and is best exposed along the north bank of the creek. Note that the axial surface of the fold dips to the west, which is a vergence opposite to the regional trend. The geometry 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 detachment horizons in the Ordovician strata at depth.

ROADLOG

Optional Stop A - Abandoned quarry near Fuerra Bush (Lat 42°33'27.37"N; Long 73°51'55.04"W). This quarry is now owned by the South Bethlehem Police, and is used for firearms training. It cannot be entered without permission. The high walls are very unstable and dangerous, and should only be observed from a distance. The best exposure of the duplex is at the base of the north high wall. To reach the quarry, take the Selkirk Exit (Exit 22) off the NYS Thruway. After the tollgates, turn right onto Route 144. Proceed southwest on 144 for about 0.4 miles, then turn right and head west on Rte 396 through Selkirk, to South Bethlehem (about 2 miles). Continue on Rte 396 for another 0.5 miles west of South Bethlehem to the junction with Old Quarry Road (County Rte. 102). Turn right and head north on Old Quarry Road for about 1.5 miles. There will be a highway department shed on the left, and a parking lot. The quarry is up the hill behind the shed, and can be reached by walking about 10 minutes along a trail.

Stop 1 - Route 23 Roadcuts, northwest of Catskill (Lat 42°14'20.76"N, Long 73°53'9.41"W to Lat 42°14'54.51"N, Long 73°53'46.13"W). To reach the Roadcuts, take the Catskill Exit (Exit 21) off the NYS Thruway. At the end of the tollgate access road, turn left (southeast) onto State Route 23B heading toward Jefferson Heights and Catskill. Continue on State Route 23B for 0.2 mi (0.3 km) to the junction with State Route 23. Park here. To reach outcrops 1A and 1B, park on the west shoulder of 23B just north of the entrance ramp that leads onto State Route 23 heading northwest. Depending on logistics, it may be easiest to walk the length of the highway to Catskill Creek. Drivers can pick up participants on the shoulder of Route 23 near Catskill Creek. WARNING! These highways are very busy, and vehicles are traveling very fast. Outcrop 1A is along the exit ramp from State Route 23 northwest leading to 23B, and outcrop 1B is along the entrance ramp from 23B onto 23 northwest. To reach outcrops 1CN-1EN and 1CS-1ES, drive onto State Route 23 heading northwest toward Cairo.

Stop 2 - The Esopus Detachment, along Route 23A. (Lat 42°11'52.94"N, Long 73°55'1.45"W). These outcrops can be reached by continuing west from 1EN/1ES on State Route 23. Turn left (south) on State Route 47. Turn right (west) at the intersection with Old Kings Road and continue to the intersection with State Route 23A. Turn left (east) on State Route 23A and pull off the road to the right (south) after 0.1 miles onto the abandoned Thruway ramp. The exposure is a roadcut along the abandoned ramp.

Optional Stop B - Bakoven Shale Exposures, City View Terrace Road, Kingston (Lat 41°56'58.75"N, Long 74° 2'31.29"W). Take the Kingston Exit (Exit 19) from the NYS Thruway. Follow the roundabout to Route 28. Head west on Route 28 across the Thruway, and then across Route 209. At 0.3 miles west of the Route 28 bridge over Route 209, turn right off of Route 28 onto Forest Hills Drive. Head north on Forest Hills Drive for about 50 m, and turn right to head east on City View Terrace Road. Pull off on the shoulder. The exposures at Optional Stop B are along the north side of City View Terrace Road.

Stop 3 - Route 209/199 roadcuts, north of Kingston. (Lat 41°58'27.37"N, Long 73°59'4.88"W to Lat 41°58'34.00"N, Long 73°58'30.84"W). To reach these outcrops, take NYS Thruway Exit 19. Leave the Thruway and pass through the tollgate. At the end of the tollgate access road, bear right (west) onto State Route 28. Proceed west on Rte 28 for 0.3 miles and bear right to take the entrance ramp onto Route 209 north. Proceed north on Rte 209 (toward the Rhinebeck Bridge) for about 3.7 miles. The road curves and heads east. When it crosses Route 9W, it becomes Route 199. Park along the south shoulder of Rte. 199/209 about 0.7 miles east of the State Route 9W underpass. [*Note:* If you are heading to Stop 3 after Optional Stop B, simply backtrack from B back to the junction with Route 209 to pick up the route described above.]

Stop 4 - Roadcuts exposing lateral ramps in the Rondout (Lat 41°58'12.84"N, Long 73°58'18.10"W). To reach these outcrops from Stop 3, continue east on Rte 199 to the exit for Route 32 (the last exit before the Kingston-Rhinecliff Bridge over the Hudson River). At the end of the ramp, turn left and head south on Rte 32 (= Flatbush Avenue). Proceed about 0.5 miles south on Route 32 and pull off on the shoulder to the right. The exposures are roadcuts on the west side of the road.

Optional Stop C - Cross-Cutting Cleavage in the Onondoga Limestone, Kingston. (Lat 41°56'33.88"N, Long 73°59'19.02"W). To reach this stop from Stop 4, proceed drive south to southwest along Rte 32 (Flatbush Road) for about 2.2 miles. You will go 0.2 miles past the entrance to Route 9W south (part of a divided highway), to the junction with non-divided Route 9W north (East Chester Street). There is a convenience store at the corner. Park where convenient, then walk north along the east side of Route 9W (East Chester Street) to the first roadcut. Climb to the top of the roadcut and look for bedding planes.

Stop 5 - Hasbrouck Park, Kingston (Lat 41°55'31.44"N, Long 73°58'32.57"W, and Lat 41°55'21.91"N, Long 73°58'41.63"W). Turn south off of Route 32 and proceed south for 1.1 miles on Route 9W south (part of a divided highway). Take the Delaware Avenue Exit. At the end of the exit ramp, turn left and proceed east on Delaware Avenue, on a bridge across Route 9w. You need to take the right turn immediately after the bridge to stay on Delaware Avenue. Proceed for 0.4 miles on Delaware Avenue to Hasbrouck Park Road. (The park entrance road is small and not well marked; it occurs before Delaware Avenue goes over the Helderberg Escarpment.) For the first part of this stop, proceed south on Hasbrouck Park Road for 100 m, and turn left into the small parking lot. Follow the trail from the parking lot to the outcrop in the woods, about 100 m to the east of the lot. For the second part of this stop, drive to the viewpoint at the south end of the park. First, look at the view to the south. Then, walk back north following the trail through the woods to where there is an access trail over the escarpment. The exposures are old roof and pillar quarries. WARNING! The trails are steep and slippery, and the cliffs have loose rock.

Optional Stop D - Exit Ramp from Route 9W to Delaware Avenue (Lat 41°55'39.86"N, Long 73°59'12.78"W). Backtrack from Hasbrouck Park toward Route 9W. Park on Delaware Avenue before the bridge over 9W, and walk to a viewpoint where you can see the roadcuts along 9W and the exit ramp from 9W to Delaware Avenue.

Optional Stop E - Callanan Quarry, Connelly (south of Kingston) (Lat 41°54'29.71"N, Long 73°59'47.00"W). This stop can be reached by driving south on US 9W from Kingston, crossing Rondout Creek, and continue into Port Ewen (about 0.7 miles south of the bridge). In Port Ewen, turn right (west) onto Salem Street (County Road 25). Continue on Salem Street across railroad tracks and around a sharp bend to the right. The entrance to Callanan Quarry is approximately 2.2 miles west of the intersection of Salem Road and US 9W. The Quarry cannot be entered without permission, hardhats, etc..

Optional Stop F - Rosendale Landfill (Lat 41°52'39.33"N, Long 74°04'06.41"W). This stop can be reached by continuing south on State Route 32 from Bloomington (Figure 1). Turn right onto Kallop Road 0.8 miles south of the New York State Thruway overpass and then bear right onto Hickory Bush Road at the first three-way intersection. Continue north on Hickory Bush Road for 1.0 mile and pull onto the dirt parking lot along the left side of the road. This stop is along the north wall of the Rosendale landfill and recycling center and permission to visit must be obtained from the Town of Rosendale.

Optional Stop G - Rail Trail exposure near Fourth Lake (Lat 41°52'22.68"N, Long 74°04'25.01"W). This stop can be reached by walking 350 south along the Wallkill rail trail from the dirt parking lot on Hickory Bush Road. Warning! The exposure is an abandoned roof and pillar mine. There are steep drop offs and obscured openings.

Optional Stop H – Former Williams Lake Hotel property (Lat 41°52'52.46"N, Long 74°04'50.11"W).

Stop 6 - Snyder Estate (Lat 41°50'28.70"N, Long 74°05'51.05"W). This stop can be reached by driving south on Hickory Bush Road for roughly 0.8 miles and turn right (west) onto Breezy Hill Road. At the first stop sign, turn left (south) onto Binnewater Road/County Route 7. Turn right (west) at the intersection with State Route 213 in the Town of Rosendale. Continue east on State Route 213 for 0.2 miles before turning right (north) into the driveway of the Snyder Estate. Proceed up the driveway and across the bridge before parking in the gravel lot on the right.

Optional Stop I – Rondout Creek Exposures, Lawrenceville (Lat 41°50'23.72"N, Long 74°06'23.35"W).

Optional Stop J - Roadcuts in Schwangunk, Old Route 213 (Lat41°49'36.33"N, Long 74°07'32.19"W). Exposures at Stop 10 are along both north and south sides of State Route 213, 1.8 miles west of the Snyder Estate. Turn right onto Old Route 213 or Bruceville Road to park, because the road shoulders at the stop are low and generally muddy.

Stop 7 - Waterfall in the High Falls Shale, High Falls (Lat 41°49'45.07"N, Long 74° 7'56.90"W). To reach this outcrop, take Route 213 to High Falls. The outcrop is a stream cut in Rondout Creek, viewed from a state historic site, on the north side of Route 213, about 0.4 miles northwest of the village of High Falls, and about 1.4 miles southeast of the junction between Route 213 and Route 209.

REFERENCES

Bhagat, S., and Marshak, S., 1990, Changes in microlithons associated with development of solution cleavage in limestone: Textural, trace-elemental, and stable-isotopic observations: Journal of Structural Geology, v. 12, p. 165-175.

Bosworth, W., 1984, Foreland deformation in the Appalachian Plateau, central New York: the role of small-scale detachment structures in regional overthrusting: Journal of Structural Geology, v. 6, p. 73-81.

Boyer, S. E., and Elliott, D., 1982, Thrust systems: American Association of Petroleum Geologists Bulletin, v. 66, p. 1196-1230.

Burmeister, K. C., and Marshak, S., 2002, Affects of along-strike changes in stratigraphy on fold-thrust belt structural style and geometry; an example from the Northern Appalachian Mountains, central Hudson Valley, New York: Abstracts with Programs - Geological Society of America, v. 34, p. 371.

Burmeister, K. C., and Marshak, S., 2003, Examples of along-strike changes in fold-thrust belt architecture; structural geology of the Rosendale natural cement region, Ulster County, New York, in Johnson Eric, L., ed., Field trip guidebook, Volume 75: New York State Geological Association, p. 238-266.

Burmeister, K. C., Marshak, S., and Wilkerson, M. S., 2003, Influence of mechanical stratigraphy on the 3-D structural architecture of the Northern Appalachian fold-thrust belt; Rosendale, New York: Abstracts with Programs - Geological Society of America, v. 35, p. 642.

Burmeister, K. C., 2005, Aspects of deformation and strain in the Appalachian fold-thrust belt (New York) and the shear zones of the Sveconorwegian orogen (Norway) [Ph.D. thesis]: Urbana, IL, University of Illinois.

Cairnes, C. E., 1920, Report on the geology of the Rosendale cement region based on data collected by students of Princeton University in October 1919 [Senior thesis]: Princeton, NJ, Princeton University.
Chadwick, G. H., 1944, Geology of the Catskill and Kaaterskill Quadrangles, Part 11. Silurian and Devonian geology, with a chapter on glacial geology: New York State Museum Bulletin 336, 251 p.
Chapple, W. M., and Spang, J. H., 1974, Significance of layer-parallel slip during folding of layered sedimentary rocks: Geological Society of America Bulletin, v. 85, p. 1523-1534.
Dahlstrom, C. D. A., 1970, Structural geology in the eastern margin of the Canadian rocky mountains: Bulletin of Canadian Petroleum Geology, v. 18, p. 332-406.
Davis, W. M., 1882, The Little Mountains east of the Catskills: Appalachia, v. 3, p. 20-33.
Davis, W. M., 1883, The folded Helderberg limestones east of the Catskills: Harvard College Museum Comprehensive Zoology Bulletin, v 7, p. 311-329.
Epstein, J. B., and Lyttle, P. T., 1987, Structure and stratigraphy above, below, and within the Taconic unconformity, southeastern New York (Trip C), in Waines R. H., ed., Field trip guidebook, Volume 59: Annual Meeting of the New York State Geological Association, p. C1-C78.
Goldring, W., 1943, Geology of the Coxsackie Quadrangle, New York: New York State Museum Bulletin 332, 374 p.
Laporte, L. F., 1969, Recognition of a transgressive carbonate sequence within an epeiric sea, Helderberg Group (Lower Devonian) of New York State, in Friedmann, G. M., ed,. Depositional Environments in Carbonate Rocks: A Symposium: Society of Economic Paleontologists and Mineralogists Special Publication 14, p. 98-119.
Leftwich, J. T., 1973, Structural geology of the West Camp area, Greene and Ulster counties, New York [Masters thesis]: Amherst, MA, University of Massachusetts. 88 p.
Marshak, S., 1983, Aspects of deformation in carbonate rocks of fold-thrust belts of central Italy and eastern New York State [Ph.D. thesis]: New York, New York, Columbia University, 223 p.
Marshak, S., 1986a, Structure and tectonics of the Hudson Valley fold-thrust belt, New York: Geological Society of America Bulletin, v. 97, p. 354-368.
Marshak, S., 1986b, Guidebook to the Hudson Valley fold-thrust belt between Catskill and Kingston, New York: Field guide prepared to accompany the 1986 meeting of the Geological Society of America, Northeast section.
Marshak, S., 1989, Introduction to Appalachian geology; a geological sketch of southeastern New York State, in Engelder, T., Dunne, B., Geiser, P., Marshak, S., Nickelsen Richard, P., and Wiltschko David, V., eds., Metamorphism and tectonics of eastern and central North America; Volume 2, Structures of the Appalachian foreland fold-thrust belt.: Washington, DC, United States, Am. Geophys. Union, p. 3-6.
Marshak, S., 1990, Structural geology of Silurian and Devonian strata in the mid-Hudson Valley, New York: fold-thrust belt tectonics in miniature: Albany, New York, New York State Museum, 66 p.
Marshak, S., 2004, Arcs, Oroclines, Salients, and Syntaxes -- The origin of map-view curvature in fold-thrust belts: (in) McClay, K.R., (ed.), Thrust Tectonics and Petroleum Systems: Am. Assoc. of Petroleum Geologists Memoir 82, p. 131-156.
Marshak, S., and Bosworth, W., 1991, Noncoaxial deformation along the northeastern edge of the Appalachian Plateau, New York: Implications for faulting processes in orogenic forelands: Northeastern Geology, v. 13, p. 263-270.
Marshak, S., and Engelder, T., 1985, Development of cleavage in limestones of a fold-thrust belt in eastern New York: Journal of Structural Geology, v. 7, p. 345-359.
Marshak, S., and Geiser, P., 1980, Guidebook to pressure-solution phenomena in the Hudson Valley: Field guide prepared to accompany the Penrose Conference on Pressure Solution and Dissolution, 49 p.
Marshak, S., and Tabor, J.R., 1989, Structure of the Kingston Orocline in the Appalachian fold-thrust belt, New York: Geological Society of America Bulletin, v. 101, p. 683-701.
McEachran, D. B., 1985, Structural geometry and evolution of the basal detachment in the Hudson Valley fold-thrust belt north of Kingston, New York [M.S. thesis]: Urbana, Illinois, University of Illinois, 97 p.
Murphy, P. J., Bruno, T. L., and Lanney, N. A., 1980, Decollement in the Hudson River valley: Geological Society of America Bulletin, v. 91, p. 1394-1415.
Nickelsen, R.P., 1986, Cleavage duplexes in the Marcellus Shale of the Appalachian foreland: Journal of Structural Geology, v. 8, p. 361-371.
Osborne, R.B., 1921, Report on the geology of the Rosendale cement region from data obtained by Princeton University students in October 1920 [Senior thesis]: Princeton, NJ, Princeton University.
Ratcliffe, N. M-, Bird, J. M., and Baharami, B., 1975, Structural and stratigraphic chronology of the Taconide and Acadian polydeformational belt of the central Taconics of New York Stale and Massachusetts: New England Inter-Collegiate Geology Conference Guidebook. 67th meeting New York, p. 55-86.
Rickard, L. V., 1962, Late Cayugan (Upper Silurian) and Helderbergian (Lower Devonian) stratigraphy in New York: New York State Museum and Science Service Bulletin 386, 157 p.
Rodgers, J., 1971, The Taconic Orogeny: Geological Society of America Bulletin, v.82, p. 1141-1178.

Sanders, J. E., 1969, Bedding thrusts and other structural features in cross-section through "Little Mountains" along Catskill Creek. (Austin Glen and Leeds Gorge), west of Catskill, New York, trip 19 in Guidebook for field trips in New York, Massachusetts, and Vermont; New England Intercollegiate Geological Conference, 61st Annual Meeting, Albany, New York, p. 1-38.

Suppe, J,. 1983. Geometry and kinematics of fault-bend folding: American Journal of Science, v. 283, p. 684-721.

Tabor, J. R., 1985, Nature and sequence of deformation in the southwestern limb of the Kingston orocline [M.S. thesis]: Urbana, Illinois, University of Illinois, 87 p.

Ver Straeten, C. A., and Brett, C. E., 1995, Lower and Middle Devonian foreland basin fill in the Catskill Front; stratigraphic synthesis, sequence stratigraphy, and Acadian Orogeny, in Garver John, I., and Smith Jacqueline, A., eds., Field trip guidebook for the 67th annual meeting of the New York State Geological Association, New York, NY, p. 313-356.

Waines, R. H., and Hoar, F. G., 1967, Upper Silurian-Lower Devonian stratigraphic sequence, western mid-Hudson Valley region, Kingston to Accord, Ulster County, New York; New York State Geological Association Guide-book, 39th meeting, New Paltz, p. D1-D28.

Wanless, H. R., 1921, Final report on the geology of the Rosendale cement district [Masters Thesis thesis]: Princeton, New Jersey, Princeton.

Zadins, Z. Z, 1983, Structure of the northern Appalachian thrust belt at Cementon. New York [M.S. thesis.]: Rochester, New York, University of Rochester, 137 p.