The Shawangunk and Martinsburg Formations Revisited: Sedimentology, Stratigraphy, Mineralogy, Geochemistry, Structure and Paleontology

Howard R. Feldman[1], Jack B. Epstein[2] and John A. Smoliga[3]

[1]*Division of Paleontology (Invertebrates), Museum of Natural History, Street at Central Park West, York, NY 10024*
[2]*Geologist Emeritus, MS926A, US Geological Survey, 12201 Sunrise Valley Drive, Reston, VA 20192*
[3]*Senior Principal Scientist, Solid-State Characterization, Analytical Sciences, Boehringer Ingelheim Pharmaceuticals, Inc.*

INTRODUCTION

In southeastern New York Middle Silurian Shawangunk Formation (Figure 1), containing gray conglomerate, sandstone and shale, lies unconformably above the Ordovician Martinsburg Formation, consisting of shales and graywackes. In southwestern New York, near the Port Jervis area, The Shawangunk Formation is overlain by the Bloomsburg Red Beds, the same stratigraphic sequence that occurs in Pennsylvania and New Jersey to the southwest. The Shawangunk Formation thins gradually from Port Jervis to its pinchout near Hidden Valley and Binnewater, New York. Two tongues of the upper part of the Shawangunk are: the Ellenville Tongue that extends from the Ellenville-Accord area to its feather edge just southwest of the New York-New Jersey border and, the High View Tongue that is restricted to the Wurtsboro area (Epstein and Lyttle, 1987; Epstein, 1993).

Early in the Paleozoic carbonate banks lay along the east coast of the ancient North American continent. During the Ordovician plate convergence commenced in the closing of the Iapetus Sea and a deep basin developed into which thick muds and dirty sands were deposited. These were later lithified into the Martinsburg Formation. Eventually, with continued compression, these sediments were folded and faulted during the complex deformation of the Taconic Orogeny. The trend of these folds in southeastern New York is approximately N20E. As one proceeds westward across the Wallkill Valley these structures become less intense. Subsequent to the Taconic Orogeny mountains rose to the east and coarse sediments were transported westward and deposited as the conglomerates and sandstones of the Shawangunk Formation across the beveled folds of the Martinsburg. Deposition occurred on a plain of alluviation and in a marine basin to the northwest. Erosion of the source area was intense, and the climate, based on the mineralogy of the rocks, was warm and at least semiarid. The source was composed predominately of sedimentary and low-grade metamorphic rocks with exceptionally abundant quartz veins and small local areas of gneiss and granite. As the source highlands were eroded, the steep braided streams of the Shawangunk gave way to more gentle-gradient streams of the Bloomsburg Red Beds.

The Taconic Orogeny

During the Ordovician Period there existed an ocean, known as the Iapetus or proto-Atlantic, to the east of the Shawangunk Mountains. Bisecting this body of water was a narrow, mountainous landmass called the Taconic Island Arc, similar in shape to today's Caribbean or Aleutian islands. Landmasses that bordered the Iapetus Ocean began to move toward one another. On the east the landmass was present-day Western Europe composed largely of granitic rocks, whereas on the west it was present-day North America. The movement of these landmasses, or tectonic plates, resulted in the shrinking of the Iapetus Ocean and eventual collision of the Taconic Island Arc with eastern proto-North America, resulting in the formation of large mountains as high as the present-day Himalayas. The collision resulted in the (new) Taconic Mountains riding up over the edge of the proto-North American continent and pushing it down to form a basin. The sediments shed by these mountains were deposited in this basin that was more than 500m (1,500 ft) deep. This process, known as the Taconic Orogeny, or mountain-building episode, occurred during the Middle Ordovician Period about 450 million years ago. The Taconian event was the result of shelf, slope, and island arc accretion. It was during this time period that the Martinsburg Formation was deposited.

The Acadian Orogeny

During the Devonian Period (about 418-362 Million years ago) the Iapetus Ocean became much narrower and shallower, finally becoming a shallow basin. Landmasses representing North America and Western Europe began to move toward one another. This collision, known as the Acadian Orogeny, took some tens of millions of years to occur and resulted in the formation of large mountains, the roots of which are actually what we now call the Berkshires in Massachusetts. The Avolonian Terrane was accreted during the Acadian Orogeny. Eventually, these mountains were weathered and eroded. The sediment that they shed accumulated to the west forming the Catskill Delta during the middle of the Devonian Period. Some workers estimate that the volume of sediments that was dumped into this basin approached 70,000 cubic miles. The collision of two large landmasses known as Laurasia and Gondwana began after the Devonian and lasted through the Permian Period. This collision, locally called the Alleghany Orogeny, overprinted much of the deformation produced during the Acadian and Taconic orogenies and produced the major structures of the central and southern Appalachians. With Laurasia and Gondwana now sutured together, the supercontinent Pangaea had been formed. This was the last major orogenic event to affect the present-day east coast of North America. The relationship between the overlying Shawangunk and the underlying Martinsburg formations is an angular unconformity. That is, there is a significant gap in the rock record that resulted from a change that caused deposition of the Martinsburg to cease for a considerable amount of time during which there was uplift and erosion with loss of the previously formed record. In other words, although the Shawangunk overlies the Martinsburg, it is not in stratigraphic succession; there is a hiatus of between 10-30 million years between the formation of the Martinsburg and the deposition of the Shawangunk.

STRATIGRAPHY

The following is a list of formations that occur in the field trip area from the mid-Hudson Valley to Port Jervis, listed from youngest to oldest. The last carbonate unit is the Onondaga Limestone, above which occur the clastics of the Middle Devonian Hamilton Group.

Plattekill Formation of Fletcher (1962) (Middle Devonian): red and gray shale, siltstone and sandstone; 500+ feet thick.

Ashokan Formation (Middle Devonian): thin- to thick-bedded olive gray sandstone with minor siltstone and shale; 500-700 feet thick.

Mount Marion Formation (Middle Devonian): olive-gray to dark-gray, platy, very fine to medium grained sandstone, siltstone and shale; >1000 feet thick.

Bakoven Shale (Middle Devonian): dark gray shale; 200-300 feet thick.

Onondaga Limestone (Middle Devonian): fossiliferous limestone with the following members • Edgecliff at base (light-weathering chert), Nedrow above (dark-weathering chert; shaly) and Moorehouse at top (dark-weathering chert). The Seneca Member, missing in the Hudson Valley, can be observed at Cherry Valley; 100 feet thick.

Figure 1. Mohonk Lake lies in a faulted, glacially scoured basin bounded by the light, quartz pebble Shawangunk Conglomerate. Beyond the Shawangunk lies the Port Jervis trough underlain by glacial sediments and occasional outcrops of Onondaga Limestone (see Feldman, 1985). Note the Catskill Mountains in the distance. The valleys in the Catskills are aligned along linears that are presumably controlled by structural weakness.

Schoharie Formation (Lower Devonian): thin- to medium-bedded, calcareous mudstone and limestone, more calcareous toward top. From top to bottom - Saugerties, Aquetuck, and Carlisle Center members; 180-215 feet thick.

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

Glenerie Formation (Lower Devonian): thin- to medium-bedded siliceous limestone, chert and shale; 50-80 feet thick.

Connelly Conglomerate (Lower Devonian): dark, thin- to thick-bedded pebble conglomerate, quartz arenite, shale and chert; 0-20 feet thick.

Port Ewen Formation (Lower Devonian): dark, fine- to medium grained, sparsely fossiliferous, calcareous, partly cherty, irregularly bedded mudstone and limestone; 0-175(?) feet thick (180 feet thick near Port Jervis).

Alsen Formation (Lower Devonian): fine- to coarse-grained, irregularly bedded, thin- to medium-bedded, argillaceous to partly cherty limestone; 20 feet thick.

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

New Scotland Formation (Lower Devonian): calcareous mudstone and silty, fine- to medium grained, thin- to medium-bedded limestone; may contain some chert; 100 feet thick.

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

Ravena Limestone Member of the Coeymans Formation (Lower Devonian): wavy bedded, fine- to medium-grained and occasionally coarse grained limestone with abundant thin shaly partings; 15-20 feet thick.

Thacher Member of the Manlius Limestone (Lower Devonian): laminated to thin-bedded, fine-grained, cross-laminated, graded, microchanneled, mudcracked, locally biostromal limestone with shale partings; 40-55 feet thick.

Rondout Formation (Lower Devonian and Upper Silurian): Fossiliferous, fine- to coarse-grained, thin- to thick-bedded limestone and barren laminated, argillaceous dolomite. Limestone lentils come and go but the more persistent ones have been named (from top to bottom) - Whiteport Dolomite, Glasco Limestone and Rosendale members; 10-50 feet thick.

Binnewater Sandstone (Upper Silurian): fine-grained, thin- to thick-bedded, cross-bedded and planar cross-bedded, rippled quartz arenite, with gray shale and shaly carbonate. Probably grades southwestward into the Poxono Island Formation; 0-35 feet thick.

Poxono Island Formation (Upper Silurian): poorly exposed gray and greenish dolomite and shale, possibly with red shales in the lower part; 0-500 feet thick.

High Falls Shale (Upper Silurian): red and green, laminated to massive, calcareous shale and siltstone, occasional thin argillaceous limestone and dolostone; ripple marks, dessication cracks; 0-80 feet thick.

Bloomsburg Red Beds (Upper Silurian): grayish-red and gray shale, siltstone and sandstone; 0-700 feet thick.

Tongue of the Bloomsburg Red Beds: grayish-red siltstone and shale and slightly conglomeratic, partly cross-bedded sandstone with pebbles of milky quartz, jasper, and rock fragments, and gray sandstone; 0-300 feet thick.

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

Tongue of the Shawangunk Formation: cross-bedded, cross-laminated (distinctive very light and medium-dark-gray laminae), planar-bedded, thin- to thick-bedded, medium-grained quartzite and conglomerate with quartz pebbles as much as 2 inches long and greenish-gray silty shale and siltstone; 0-350 feet thick.

Diamictite (Lower Silurian or Upper Ordovician): diamictite (colluviums and shale-chip gravel with exotic pebbles and fault gauge of sheared clay and quartz veins; lower contact unconformable; less than 1 foot thick.

Martinsburg Formation (Upper and Middle Ordovician): greater than 10,000 feet thick.

Shale and Graywacke at Mamakating: dominantly thick sequences of thin- to medium-bedded, medium dark gray shale interbedded with very thin to thick-bedded graywacke (as much as 6 feet thick) alternating with thinner sequences of medium-bedded graywacke interbedded with less thin- to medium-bedded shale. Grades downward and laterally into the sandstone at Pine Bush.

Sandstone at Pine Bush: medium-grained, medium- to thick-bedded, medium gray, speckled light-olive-gray- and light-olive-brown-weathering quartzitic sandstone interbedded with, and containing rip-up clasts of thin- to medium-bedded, medium-dark-gray, greenish gray-weathering shale and fine-grained siltstone. Lower contact with Bushkill Member is interpreted to be conformable, but in many places it is marked by a thrust fault; grades upward and laterally in the shale and graywacke Mamakating.

Figure 2. The Shawangunk Conglomerate, a quartz pebble conglomerate that is quartzitic in places, cross-bedded and planar-bedded, with minor gray shale and siltstone.

Bushkill Member: laminated to thin-bedded shale and slate containing fine-grained graywacke siltstone; bed thickness of shales does not exceed 2 inches and bed thickness of graywackes rarely exceeds 12 inches; lower contact conformable with underlying Balmville Limestone of Holzwasser (1926), but often disrupted by thrust faulting.

ROAD LOG AND STOP DESCRIPTIONS

We will be traveling through tick-infested areas; take the proper precautions and be sure to use DEET, especially on da FEET!

Total Miles	**Miles Between Stops**	
0.0	0.0	Leave parking lot at SUNY New Paltz. This locality is on blacktop of Holocene age, conformably overlying fill of unknown age brought in by contractors. Make a left turn on Plattekill Avenue and continue to stop sign; bear right.
0.4	0.4	Turn left at stop sign onto Main Street (Starbucks on left) and proceed through town; cross bridge over Wallkill River.
0.8	0.4	Make first right turn onto Springtown Road.
1.3	0.5	Make first left onto Mountain Rest Road. Continue until stop sign at four corners.
2.5	1.2	Continue straight up steep hill. Several sharp curves will signal approach to the top of hill. Note outcrops of Martinsburg Formation on right, consisting of thin-bedded shale, minor siltstone, and very rusty weathering with fine-grained graywacke. Cleavage is poorly developed.
4.7	2.2	Turn left at Gatehouse onto Mohonk Mountain House grounds. Stop at gatehouse and check in. Proceed to guest parking about 2 miles ahead.
6.9	2.2	Park cars in last guest parking lot.

STOP 1. WE WILL BE SPENDING ABOUT 2 HOURS HERE EXAMINING VARIOUS OUTCROPS ON THE MOHONK MOUNTAIN HOUSE GROUNDS. Please, no hammers, only cameras!

The Shawangunk (pronounced *Shongum*) Formation (Figure 1) was deposited during the Silurian Period, approximately 438-418 million years ago. At that time a shallow sea covered the southeastern part of New York State into which drained rivers and streams. The bottoms of these streams were layered with pieces of abraded quartz. Constant motion of the water eroded the chunks of quartz into sub-rounded 'pebbles' that were eventually "glued" together by silica-rich cement carried by percolating ground water. The name of the sedimentary rock formed by this process is conglomerate (Figure 2). The exact source of the quartz that makes up the conglomerate is not clear. It may have formed by braided streams or alluvial fan deposition. A braided stream divides into an interlacing network of several small branching and reuniting shallow channels. An alluvial fan is a low outspread flat to gently sloping mass of rock material shaped like an open fan, deposited by a stream at the place where it issues from a narrow mountain valley upon a plain (Jackson, 1997). The Shawangunk Mountains (Figure 3) extend to the southwest into New Jersey where they are called the Kittatinny Mountains. The Shawangunk Formation ranges in thickness from 733m (2,200 ft) near Ellenville, to the southwest, to <1m (about 1 ft) near Hidden Valley, to the northeast, finally 'pinching out' and disappearing. Stratigraphically below the Shawangunk lies the Middle to Late Ordovician age (489-439 million years old) Martinsburg Formation, consisting mostly of shale, up to a thickness of almost 3333m (10,000 ft).

Figure 3. The Shawangunk Ridge that continues southwestward into New Jersey and Pennsylvania where it is overlain by the Bloomsburg Red Beds. In the foreground note the famous Trapps (Gunks) that, according to Van Diver (1985), as all mountain climbers know, constitute the best rock-climbing region of the eastern United States.

Glacial Geology

Note the beautiful glacially paved surface with striations and chattermarks. Chattermarks are small, closely spaced curved scars or cracks made by chipping a brittle bedrock surface, in this case the conglomerate, by rock fragments carried in the base of a glacier. Each chattermark is roughly transverse to the direction of ice movement and its 'horns' point in the direction the glacier moved. Compare the direction of the striations here (about

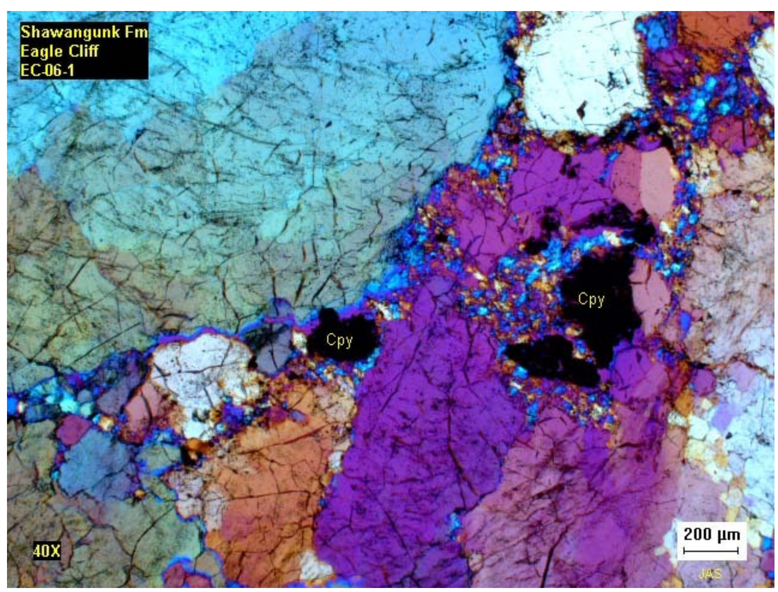

Figure 4. Chalcopyrite (copper-iron sulfide, Cpy) in the Shawangunk Conglomerate along Eagle Cliff Road, lake side.

10 degrees to the northeast) with the direction of the striations at the top of the crevice (about 20 degrees to the northwest). As the glacier moved down through the valley a small lobe moved around the ridge changing direction slightly resulting in a change in strike.

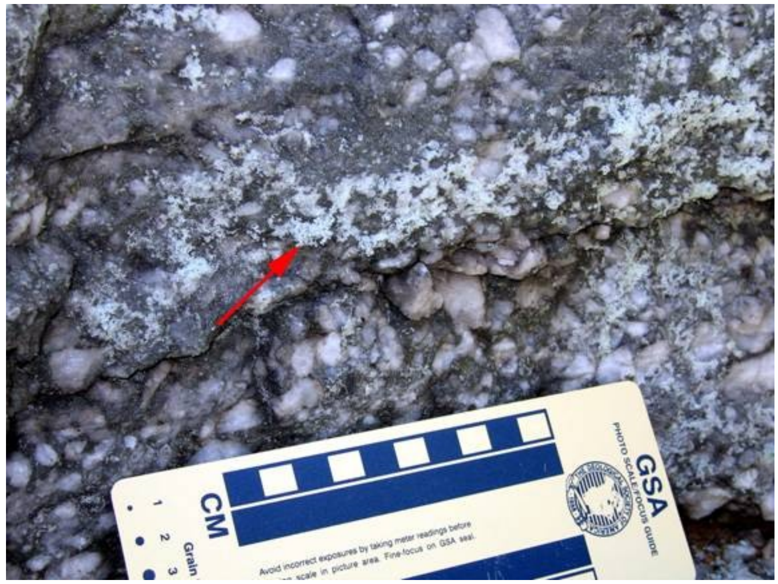

Figure 5. Melanterite, a white precipitate, can be found in the Shawangunk Conglomerate along Eagle Cliff Road, valley side.

Mineralization within the Shawangunk Formation

The sulfide mineralization observed within the Shawangunk Formation along Eagle cliff consists of predominately marcasite and pyrite with small amounts of chalcopyrite (Figure 4). The sulfides are disseminated within the conglomerate. Emplacement appears to be associated with fault structures. SEM/EDS analysis of the sulfides also shows trace amounts of lead and zinc. Gossan in the form of goethite, hematite and jarosite has formed in places as a result of sulfide weathering. In some areas the water soluble sulfate minerals melanterite $Fe(SO_4)\cdot 7H_2O$) and rozenite $Fe(SO_4)\cdot 4H_2O$) are observed as a white to yellowish encrustation on the surface of sulfide containing exposures, when weather conditions permit (Figure 5). One from Eagle Cliff (valley side) sample contained two hydrated Fe-sulfate phases: melanterite $Fe(SO_4)\cdot 7H_2O$) and rozenite $Fe(SO_4)\cdot 4H_2O$). Rozenite is a lower hydrate containing 4 moles of water, as compared to melanterite which contains 7 moles of water. Rozenite can be formed in one of two ways: 1. Dehydration of melanterite or, 2. during lower relative humidity conditions; at room temperature rozenite is the stable phase below 70-80% RH. Examination by polarized light microscopy of the sample shows euhedral (well formed) crystals of rozenite encased in melanterite. This relationship indicates that the rozenite crystallized first, followed by the melanterite. Additionally, no alteration/dehydration textures were observed in the melanterite. From this we conclude that the rozenite crystallized during lower RH conditions, followed by melanterite which crystallized during increased RH conditions (i.e., above 70-80% RH depending on ambient temperature).

Figure 6. Mohonk Lake with a pH of 7 near the surface. This is one of five sky lakes on the ridge; the others are: Minnewaska, Awosting, Mud Pond and Maratanza.

The Sky Lakes

Looking toward the southwest observe the ridge forming the "backbone" of the Shawangunks. Continuing along the ridge, located at its highest point about 30km (10 mi) away, is Sam's Point and the Ice Caves, so called because of the cold air trapped at the bottom of open vertical joints. Within the deep recesses of the caves one can find ice that lasts all summer long. Along the top of the Shawangunk Ridge are located four "Sky Lakes" in addition to Mohonk Lake (Figure 6), that are so-called because they receive their water supply solely from rainwater. These lakes are Minnewaska (closest to Mohonk), Awosting, Mud Pond and Maratanza. The lakes most likely overlie faults that weakened the bedrock, which was then scooped up by the passing glaciers. Interestingly, Mohonk Lake (Figure 6) is the only one of the five sky lakes that has greenish water; the others have clear blue water. The reason for this is that the acidic pH of the water of the four sky lakes (4.0) precludes algae and fish from living in them. However, Mohonk Lake's water is buffered by the alkaline rocks of the underlying Martinsburg Formation that floors the southeastern portion of the lake and has a pH of 7-7.5. This raises the pH level such that the conditions are more conducive to life. Between the Shawangunks and the Catskill Front is a broad valley known as the Port Jervis trough. The trough was formed by erosion and glacial scouring of the relatively weak sediments beneath the Catskill Formation. The floor of the valley is fairly flat due to the deposition of glacial debris (till) and lake sediments. Looking toward the southeast one can see the Hudson Valley (the Hudson River is about 18km [6 mi] to the east).

Continue to the Huntington Lookout summer cottage. The view here is spectacular. Toward the southwest we see the Shawangunk Ridge and the Trapps (famous among technical rock climbers). To the northwest one can see the Catskill Mountains, also known as the Catskill Front, rising in the distance to a height of 700m (2,100 ft) above the Hudson River. The highest peak in the Catskill Mountains is Slide Mountain which rises 1,282m (3,846 ft) above sea level. These mountains began to rise in New England and the Canadian Maritime Provinces during the Devonian Period (due to a collision of tectonic plates known as the Acadian Orogeny). Throughout the Middle and Late Devonian Period the mountains were eroded by streams and rivers that flowed toward the west, carrying vast quantities of mud and sand that were deposited on the floor of a great inland sea as the rivers lost velocity. Closer to the ancient shoreline the heavier particles settled out first, leaving mostly sands and some shale, whereas farther from the shoreline the deposits consisted of mainly shales with some sand and, farthest from the shoreline we find only shale. Thus, as the rivers and streams lost velocity, the heaviest particles (larger sand-size grains) settled out first and the smallest, finer particles settled out last forming the fine-grained shales.

		Make a right turn out of parking lot and proceed toward Gatehouse.
8.2	1.3	On right observe the (covered) contact between the Shawangunk and Martinsburg at Woodland Bridge. Note the relatively shallow dip of the shales typical of the proximity to the contact with the Shawangunk.
8.3	0.1	Make right turn into shale pit.

Figure 7. Shale pit in the Martinsburg Formation dominated by medium-dark gray shale with fine-grained graywacke. The graywackes are fossiliferous and contain a fair amount of pyrite. The Martinsburg here contains fault-related structures interpreted to be of two different ages. A mélange zone that is Taconic in age has been carried westward over the Silurian Shawangunk in the hanging wall of the younger Kleine Kill thrust (See Epstein and Lyttle, 1987) that is Taconic in age with a strike of N5E-N10E. Most of the small faults (see eastern wall of the pit) and slickensided surfaces that are common at this location are probably related to this younger thrust fault. The trace of the Kleine Kill thrust has a strike of N15E and is interpreted to be Alleghanian in age.

STOP 2. SHALE PIT. In this shale pit (Figure 7) the Martinsburg contains fault-related structures interpreted to be of two different ages. A mélange, or broken formation, is part of a mélange zone that is Taconic in age that has been carried westward over the Silurian Shawangunk in the hanging wall of the younger Kleine Kill thrust. Most of the small faults and slickensided surfaces that are common in this locality are probably related to this younger thrust fault. The trace of the Kleine Kill thrust nearby has a strike of N15E and is interpreted to be Alleghanian in age. The fault zones in the Martinsburg which clearly do not cut Silurian and younger rocks generally have: (1) a trend more northerly than the northeast-trending folds and faults in the Silurian rock, (2) a diagnostic scaly cleavage, (3) tightly folded "floating" knockers of graywacke whose axes plunge predominantly to the northeast with variable azimuth, and (4) very little, if any, vein quartz. The faults that definitely cut both the Ordovician Martinsburg and the Silurian Shawangunk, and which we interpret to be Alleghanian in age, generally have: (1) a slightly more easterly strike, (2) well-developed "pencils" in the shale formed by the intersection of bedding and cleavage, and (3) vein quartz parallel to bedding and/or cleavage that commonly contains shale fragments.

Figure 8. Oscillation ripples in Martinsburg Formation, shale pit.

The exposure here consists of predominantly dark gray shales and siltstones interbedded with fine grained graywacke beds, occasional prominent pyrite layers and disseminated sphalerite, chalcopyrite and galena. Oscillation ripples (Figure 8) occur on some bedding surfaces. Carbonaceous material occurs mostly as fine-grained patches throughout the matrix. The studied section is tectonically stressed with shiny quartz slickensided surfaces, parallel cross-laminated strata and ripple marks. Crinoid stems, some disarticulated, and free columnals occur on different bedding surfaces, indicating a possible change in current regime. Scattered linear to sinusoidal horizontal burrow structures ranging in diameter from .5-3 cm are found on the silty beds. Some of the burrows are infilled with coarse quartz grains. The faunal constituents include brachiopods (93%), crinoids (*Ectenocrinus*; 3%), bivalves (3%), ostracodes (<1%), corals (<1%), trilobites (*Cryptolithus*, <1%) (Figure), conulariids (<1%) and unidentified burrowers (<1%). The brachiopods are represented by a low diversity assemblage of dalmanellids and what may be a new species of *Sowerbyella*. The fauna can be classified into distinct trophic groups: (1) high-level suspensions feeders (crinoids, corals); (2) low-level suspension feeders (brachiopods, bivalves); (3) animals that collect food from the sediment surface (ostracodes, trilobites); and (4) animals

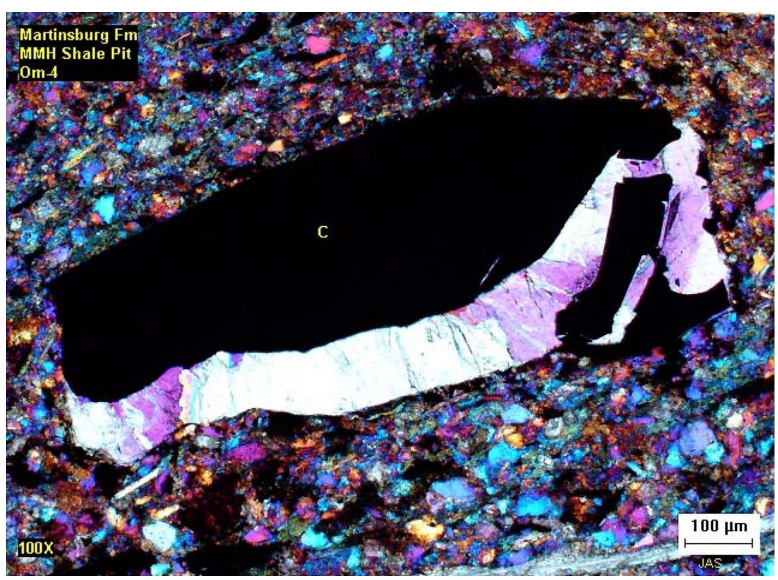

Figure 9. Carbonaceous material (thin section) in Martinsburg Formation, shale pit.

that feed within the sediment (burrowers). This partition of feeding niches leads to a reduced competitive trophic structure and therefore increased community stability.

Mineralization within the Martinsburg Formation

Within the Martinsburg Formation at the Mohonk shale pit sulfide mineralization has also been observed. The sulfides include pyrite, chalcopyrite, galena and sphalerite. The sulfides are found associated with calcite veins and as disseminations throughout the shale. Carbonaceous material has also been observed in thin section (Figure 9).

		Make right turn out of shale pit and proceed to gatehouse. At stop sign make right turn onto Mountain Rest Road. RESET ODOMETER TO ZERO!
0.0	0.0	Turn right at stop sign just past Gatehouse (Mountain Rest Road).
2.1	2.1	Make right turn at the bottom of the hill onto Butterville Road. As we progress in a southerly direction on Butterville Road observe cliffs of the extremely resistant Shawangunk Formation on the right. The lowland and hills in the foreground are underlain by the shales and graywackes of the Martinsburg Formation, striking toward the northeast. Note Sky Top (tower) from which one can see six states (New York, New Jersey, Pennsylvania, Connecticut, Vermont, and Massachusetts). Sky Top sits atop a rock scramble and steep climb through the "Crevice" and ending with an egress called the "Lemon Squeeze." This is the signature hike of Mohonk Mountain House that is adjacent to the 6,400 acre Mohonk Preserve.
3.7	1.6	At the stop sign make a right turn onto NY 299 heading west. On the right note the overturned shales and thin graywackes of the Martinsburg Formation. Here there are several narrow fault zones with vein quartz.
4.8	1.1	On the right note the steeply dipping and overturned Martinsburg shales and thin graywackes. Ahead view the "Trapps" a world famous site for rock technical climbers locates on the Mohonk Preserve. The Mohonk Preserve, founded in 1963, was established to protect the northern Shawangunk Ridge. Its mission is to protect the ecology of the area and to provide for public environmental education and recreation.
5.0	0.2	Jenkins-Lueken orchards.
5.5	0.5	Steeply dipping and overturned Martinsburg shales and thin graywackes on right. View of the Shawangunk cliffs at the Trapps straight ahead.
6.0	0.5	Note Martinsburg with graywackes on right. The bedding appears to be right-side-up however, the poorly developed cleavage in the shales dips steeply to the west suggesting that both bedding and cleavage have been rotated by faulting.
7.3	1.3	At stop sign make right turn onto US 44/55. We will be climbing to the top of the Shawangunk Mountains for the next mile or so.
7.8	0.5	Visitor's Center, Mohonk Preserve on right. Shortly we will be making a sharp left turn with the Martinsburg (on the right) and shale interbedded with thin-bedded (up to 5 in), cross-bedded to planar laminated siltstone, and minor fine-grained sandstone. Soft-sediment slump folds are common in the siltstones. Cleavage is absent or very poorly developed, except near tight folds and narrow fault zones. Most of these faults and folds do not affect the overlying Shawangunk Formation and must be Taconic in age. They trend from N5E to N20E, whereas structures in the overlying Shawangunk trend in a more easterly direction.
8.6	0.8	On the left is a scenic overview of the Wallkill Valley.
8.7	0.1	The contact between the Shawangunk and Martinsburg formations is exposed at two spots approximately 400 feet southwest of the road at the base of the cliffs. Fairly regular and linear mullions can be observed in the basal Shawangunk at the contact.
8.8	0.1	As we pass under the Trapps Bridge note the conglomerates and quartzites of the Shawangunk dipping to the northwest (31NW).

10.2 1.4 Cross Coxing Kill. As we cross Coxing Kill note that the Coxing Kill Valley coincides with the trough of a broad, open syncline that plunges gently to the northeast. This is also a favorite site for skinny dipping. For the next 0.5 mile we will begin to cross a broad open anticline that exposes a window of Martinsburg that is about 2 miles long. To the right note an outcrop of basal Shawangunk with unconformably underlying shales of the Martinsburg exposed about 40 feet away. Dips in both units are very gentle and the angle of unconformity is as little as 2°. The divergence in strike, however, is as much as 38°, with the strike in the Martinsburg being more northerly. The Martinsburg here is in the broad open-fold Taconic tectonic zone (zone 3 of Epstein and Lyttle, 1987).

Figure 10. "Pods" in Shawangunk Conglomerate are often conical with flat bottoms and associated with quartz pebbles. Note that the quartzite is recrystallized. The matrix filling the pods is dark gray and seems to follow the bedding and/or crossbedding and cleavage.

10.7 0.5 Peters Kill parking area on right.
11.8 1.1 Entrance to Minnewaska State Park on the left.
12.0 0.2 Trailhead leading to Lake Awosting on left.
12.5 0.5 Cross Sanders Kill.
13.8 1.3 Turn into small parking area with scenic overview of the Rondout Valley underlain by Upper Silurian through Middle Devonian rocks that are buried by a variety of glacial sediments. In the distance note the Middle and Upper Devonian clastics forming the Catskill Mountains. There is a thrust fault with nice slickensides across the road from the parking area. BE CAREFUL OF ONCOMING CARS!

Figure 11. Large "pod" in Shawangunk Conglomerate. Note quartz pebbles at bottom right.

STOP 3. MYSTERIOUS 'PODS'. Walk back along NY 44/55 (north side of road) and observe the mysterious 'pods' of Feldman et al., (2009) that follow the beds (N20E; 38NW) in the upper part of the Shawangunk Formation. The pods (Figures 10, 11) are often conical with flat bottoms and associated with quartz pebbles. Note that the quartzite is recrystallized. The matrix filling the pods is often dark gray and seems to follow the bedding and/or crossbedding. WHAT ARE THEY? The pods range from 0.2 to 7 cm across (at the base) and 0.2 to 6 cm in height. Internally, the 'pods' are mostly non-recrystallized quartz grains with interstitial mica and possibly clays (Figure 12). In contrast, the areas outside the 'pods' consist of pressure solution welded quartz grains consistent with the quartzitic nature of the formation. The pods are restricted to a relatively narrow stratigraphic interval and show no evidence of internal bedding. The pods may be: (1) microbial mounds/algal mats, (2) sponges, (3) mud balls or SOMETHING ELSE! They are similar in general outline to some thrombolites in that the internal texture is non-laminated but there is no indication of microbial activity such as clotting. The possibility that they are sponges or algal mats is somewhat doubtful because the braided stream depositional environment was one of relatively fast-moving fresh water draining mountains to the southeast; in addition, most sponges live in a marine environment. The conical shape does not favor a mud ball origin. Hint: note that the gray matrix follows the cleavage. PLEASE DO NOT COLLECT SAMPLES; ACTIVE RESEARCH SITE!)

END OF TRIP

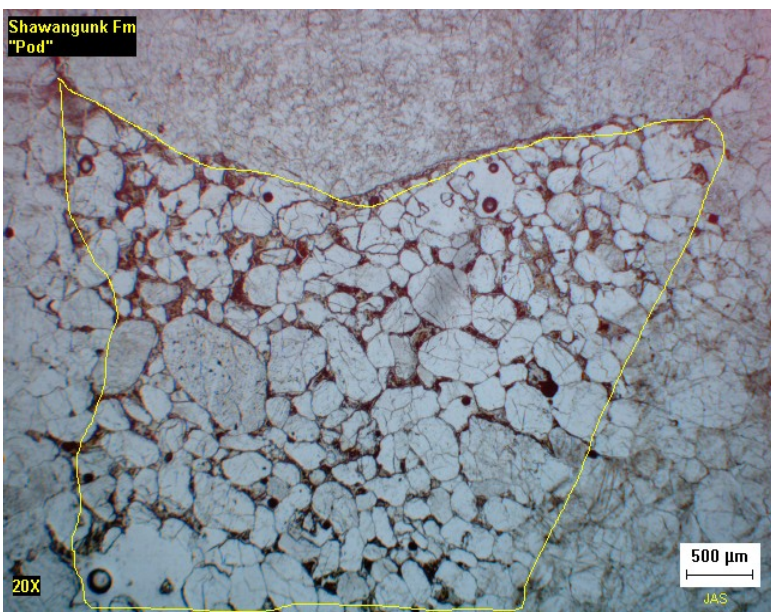

Figure 12. Thin section of "pod" containing non-recrystallized quartz grains with interstitial mica and possibly clays. In contrast, the areas outside the pod consist of pressure solution welded quartz grains.

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