Trip A-3

THE GREEN VEDDER MEMBER – A HIGHSTAND SYSTEMS TRACT IN THE "PERITIDAL" MANLIUS FORMATION

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INTRODUCTION

Since the stratigraphic synthesis of Rickard (1962) and the sedimentologic interpretations of Laporte (1967, 1969), the Manlius Formation of the Helderberg Group has attained iconic status representing peritidal environments in the overall transgression of the Helderberg Sea. Although Laporte (1969) described Manlius facies that recorded subtidal conditions (e.g., stromatoporoid biostromes), most workers think of the Manlius as dominated by facies that represent supratidal and intertidal environments. The Manlius actually displays much greater variability of facies than is commonly thought. On this field trip, we will explore the Green Vedder Member of the Manlius Formation (Ebert and Matteson 2003a, b), a distinctive and traceable stratigraphic unit that records highstand (subtidal) conditions within the Manlius Formation. This Manlius highstand occurred well before the New Scotland highstand that is regarded as the transgressive maximum in the lower Helderberg sequence. Recognition of the Green Vedder highstand has also provided important biostratigraphic information with respect to the location of the Silurian/Devonian boundary (Matteson and Ebert 2011) in the Appalachian Standard Succession of New York State (Johnson and Murphy 1969).

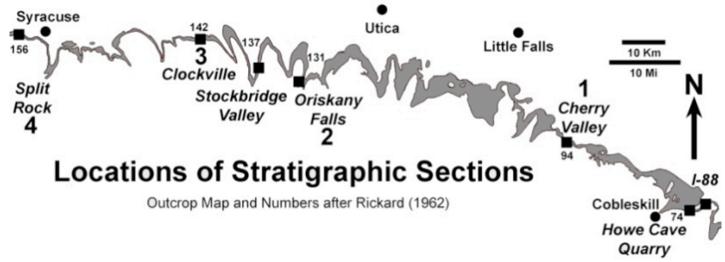

Fig. 1 Portion of the outcrop belt of the Helderberg Group in central New York. Small numbers are outcrop numbers of Rickard (1962). Large numbers 1-4 mark stops on this field trip.

STRATIGRAPHY OF THE GREEN VEDDER MEMBER OF THE MANLIUS FORMATION

The Green Vedder Member occurs in outcrops from the Syracuse area (e.g. Split Rock Quarry) eastward to Schoharie (Fig. 1), disappears in the region near Albany, and reappears as shallower facies in the Hudson Valley. This trip will focus on the member between Cherry Valley and Syracuse.

The Green Vedder Member of the Manlius Formation overlies the Thacher Member and is overlain by the Olney Member of the Manlius Formation in western outcrops and the Dayville Member of the Coeymans Formation to the east (Fig. 2).

The Clockville Unconformity at the Base of the Green Vedder Member

Throughout its extent, the Green Vedder Member is separated from the underlying Thacher Member of the Manlius Formation by the Clockville Unconformity (Ebert and Matteson 2003a, b). The Clockville Unconformity is always sharp and locally erosional. Where evidence of erosion is lacking, sedimentologic features consistent with sediment starvation are apparent. At Clockville, the unconformity is marked by several centimeters of relief (Fig 3). Topographic lows on this surface are filled with coarse, skeletal grainstones to packstones. These coarse lithologies include echinoderm debris, fragments of thick-shelled brachiopods, rare branching bryozoans, and the calcified green alga, *Garwoodia* (Laporte 1963, 1967). Erosional relief of several centimeters, lithoclasts of underlying Thacher lithology, isolated hardgrounds, encrusting stromatoporoids and pyrite impregnation highlight the Clockville Unconformity at Schoharie (I-88).

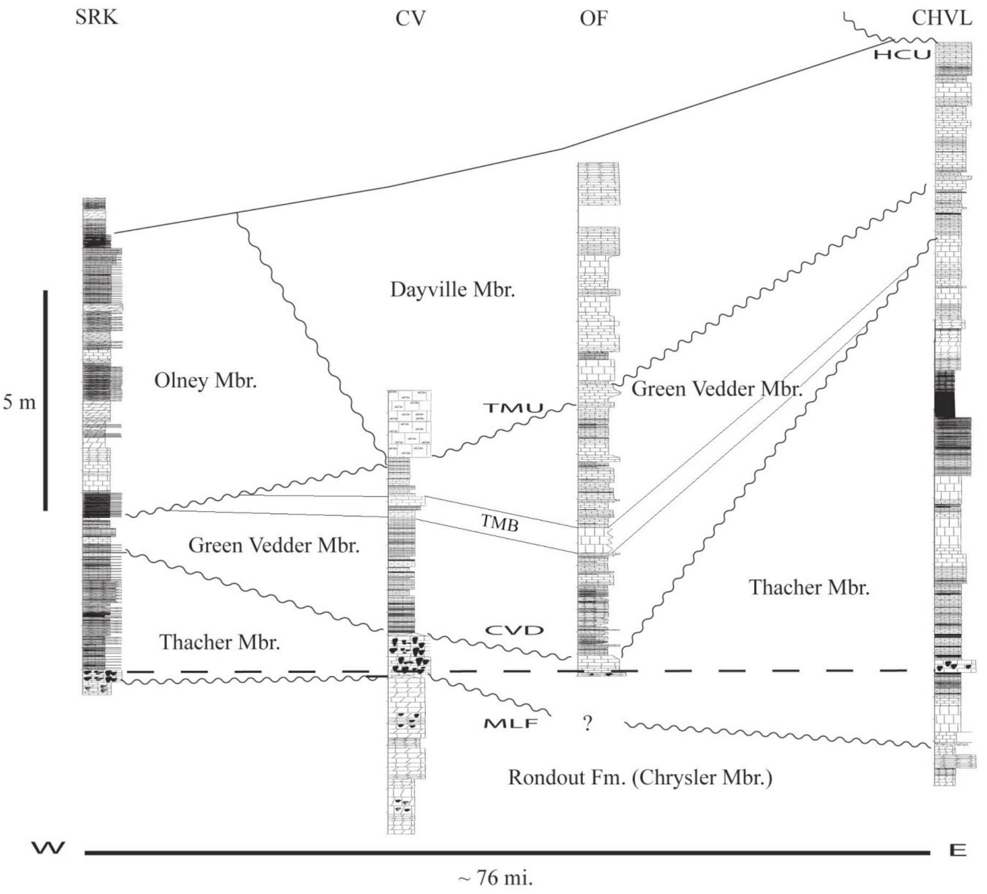

Fig. 2 Correlation and variation in thickness of the Green Vedder Member of the Manlius Formation across the study area. Datum for correlation is a distinctive zone of thrombolitic mounds in the Thacher Member of the Manlius Formation. Outcrop designations are SRK = Split Rock Quarry; CV = Clockville; OF = Oriskany Falls (Type section of the Green Vedder Member on Green Vedder Road); CHVL = Cherry Valley. MLF = Mine Lot Falls Unconformity; CVD = Clockville Discontinuity (unconformity); TMU = Terrace Mountain Unconformity; TMB = thick middle bed in Green Vedder Member.

At locations such as Cherry Valley, the Clockville Unconformity appears as an unremarkable bedding plane that separates drastically differing lithofacies. The Green Vedder Member has been recognized only recently in the Hudson Valley (Van Leuven Lake and Jefferson Heights outcrops). Here, the Green Vedder Member displays different lithologies (described below) compared to all other outcrops. However, the Clockville Unconformity remains recognizable. At Van Leuven Lake, the Green Vedder abruptly overlies mud-cracked laminites of the Thacher Member with extremely rare, bored, phosphatic nodules indicating sediment starvation.

We interpret the Clockville Unconformity as a flooding/transgressive surface because it bears evidence of sediment starvation and/or bypass and separates markedly deeper water facies (described below) of the Green Vedder Member from the underlying peritidal facies of the Thacher Member. Preliminary correlations (Ebert and Matteson 2005) suggest that the Clockville deepening event may be at least basin-wide in scale. The presence of a transgressive event recorded by the Clockville Unconformity and the overlying highstand systems tract of the Green Vedder Member indicate a more complex history of sea level change during Helderberg deposition than the simple transgression interpreted by Rickard (1962) and Laporte (1969).

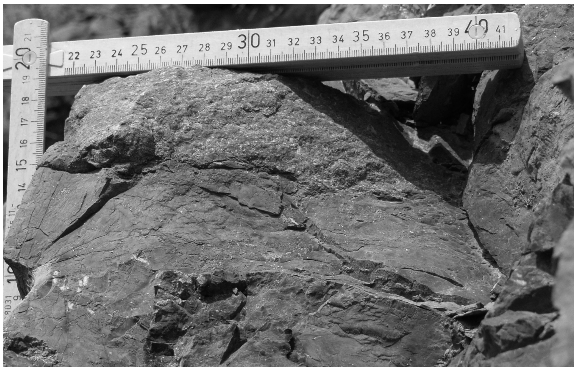

Fig. 3 Erosional relief and coarse skeletal fill of scoured pocket on the Clockville Unconformity. Clockville outcrop (**STOP 3**).

Correlation and Variations in Thickness of the Green Vedder Member

Wilson (2010) correlated the Green Vedder Member from the western limits of exposure near Syracuse through the Schoharie Valley (Fig. 2). The Green Vedder varies in thickness from of 0 to ~40 cm at Nedrow, 0 to ~30 cm at Split Rock and Clark Reservation State Park, to a maximum thickness of ~5.6 m at Oriskany Falls (type section of the Green Vedder Member). East of the type section, the Green Vedder thins to 70 cm at Cherry Valley, where only the upper beds of the member are present. It thickens to nearly 4 m in the Schoharie and Cobleskill valleys and is apparently absent east of Schoharie (Ebert and Matteson 2003a, b). However, recent fieldwork in the Hudson Valley has led to recognition of a more proximal, hardground-dominated facies of the Green Vedder Member (1.9 meters) within strata previously assigned to the Thacher Member (Matteson and Ebert 2011). Stratigraphic relationships among the Green Vedder Member, the subjacent Thacher Member and overlying strata previously referred to the Thacher Member in the Hudson Valley and Capital District are currently under investigation.

These variations in thickness and in the expression of the muddier interbeds led Rickard (1962) to assign strata above the quarry floor as Olney at Split Rock. Earlier and nearly contemporaneous interpretations conflicted with this assignment (see Sanders 1956; Chute and Brower 1964). Sanders (1956) noted a thin horizon similar with the upper Thacher (here referred to as Green Vedder) of alternating limestone and shales at Split Rock, which he interpreted as interfingering with the Olney Member. Chute and Brower (1964) reported 9 feet (~2.75 m) of Thacher Limestone above the Rondout Fm. at Split Rock Quarry and noted similar lithologic characteristics within the lowest 5 feet (~1.5 m) of the Thacher to the east. Indeed, the lowermost “ribbon limestone” from Split Rock to Jamesville shares similarities with counterparts of the Thacher from Cherry Valley eastward. The overlying Green Vedder Member is exposed at Clark Reservation State Park, Nedrow, and Split Rock, although stratigraphically thinned (~0 to 40 cm). Mudstones and wackestones are slightly more dolomitic than in eastward sections; shales display the characteristic carbonized biota of the Green Vedder.

Terrace Mountain Unconformity above the Green Vedder Member

In central New York, the Green Vedder Member is overlain unconformably by the Olney Member of the Manlius Formation from Perryville westward and by the Dayville Member (currently assigned to the Coeymans Formation, but see Ebert and Matteson 2003a, b) to the east of Perryville (Fig. 2). This surface is the Terrace Mountain Unconformity of Ebert and Matteson (2003a, b).

The Green Vedder Member holds biostratigraphic data pertinent to the location of the Silurian – Devonian boundary in the Appalachian Standard Succession (New York stratigraphy; Johnson and Murphy 1969). These data are discussed below, following the section on the sedimentology of the Green Vedder Member.

SEDIMENTOLOGY OF THE GREEN VEDDER MEMBER

The Green Vedder Member is a distinctive, heterolithic unit that bears a diagnostic fauna and unique taphonomy (Matteson, Natel and Ebert 1996; Ebert and Matteson 2003a, b). The Green Vedder Member encompasses skeletal and peloidal packstones, wackestones and mudstones (1-18 cm beds; average 5-7 cm) with interbeds of dark, carbonaceous shale (0-6cm).

(Fig. 4). An unusually thick set of burrow-amalgamated beds (up to 80 cm thick) occurs near the middle of thicker exposures of the Green Vedder. We refer to this marker informally as the thick middle bed (TMB; Fig. 4).Carbonate beds of the Green Vedder display sharp bases and planar to wavy laminated undulatory tops. Topmost laminae are dolomitic and slightly pyritized (Matteson et al. 1996). Many beds are discontinuous laterally because they comprise large-scale hummocks and swales. Individual hummocks are typically between 20 and 50 cm in wavelength with amplitudes of up to 12 cm (e.g., Stockbridge Quarry exposure). Hummocks alternate with much broader swales (~1 to 2 meters). To the East, at Schoharie, hummocks display much shorter wavelengths and beds appear nodular. These short wavelength hummocks appear to be a variant of large ripples or dune forms.

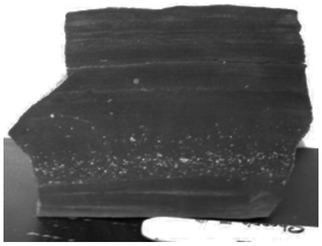

Fig. 5 Graded tempestite from the Green Vedder Member. Wall Street outcrop of Wilson (2010). Marker for scale.

Fig. 6 Gutter cast on the base of a thick tempestite bed in the lower Green Vedder Member at Clockville (STOP 3). Hammer for scale.

Though laterally discontinuous beds are common, other beds in the Green Vedder are more or less planar and persist across individual outcrops. Wavy to cross-bedded strata within the upper wave-rippled portions of the tempestites occur with winnowed skeletal debris.Both continuous and discontinuous beds in the Green Vedder exhibit the distinctive features of tempestite deposition (e.g., Aigner 1985) and many beds are clearly amalgamated from several storm events. Beds display sharp erosive bases that are overlain by graded wackestones to packstones with randomly oriented skeletal debris (Fig. 5). Gutter casts with up to 5 cm of erosional relief (Fig. 6) record initial scouring of consolidated sediment. Basal scouring is generally more pronounced at eastern outcrops of the Green Vedder (e.g., I-88 near Schoharie). Though remnants of grading are visible, extensive bioturbation obscures other internal structures. Infiltration fabrics are common in the coarser packstones. These features and the shallow-water aspect of the fauna suggest these beds were deposited as tempestites on an open shelf, below fair-weather wave base but above storm wave base.

Thin, skeletal-rich firmground/hardground grainstone horizons (sub mm to ~2 cm) and/or shell pavements are common in Green Vedder strata. Skeletal material within these condensed horizons is slightly pyritic. These grainstones commonly bifurcate into thin, discrete beds. Stacked hardgrounds comprise most of the member in the Hudson Valley.

Encrusting bryozoans adorn hardgrounds and shell pavements. Small *in situ* clusters of small rugose corals are less common. Thin, horizontal, simple, and singly branching burrows commonly mark the surfaces of these once semi-consolidated substrates. Hardgrounds also display linear to curvilinear fractures that taper downward from the lithified upper surfaces (Fig. 7). Though spar-filled, these fractures are clearly synsedimentary because thin veneers of sediment have been observed overlying the spar. We attribute these fractures to subaqueous slumping or liquefaction of sediments on a paleoslope beneath cohesive (hardground) surfaces.Black to gray, organic-rich shales are interbedded with the coarse, hummocky beds and hardgrounds. Some shales grade laterally into mudstones that are capped by thin laminae of sucrosic dolomite. Shales in the Green Vedder represent long intervals of sediment starvation during which many organisms were excluded, but a soft-tissue biota including bacterial mats and soft-bodied organisms were present (see below).

Medusaegraptus, a non-calcified, aspondyl, dasycladacean alga, preserved in these shales may have been opportunistic colonizers of an otherwise inhospitable seafloor or they were specialized for living in low oxygen environments (Brett and Baird 1986).

Fig. 7 Synsedimentary fracture in a mm-thick hardground from the Green Vedder Member at the Howe Cave Quarry, near the Schoharie. Such fractures cross-cut clasts and skeletal grains, taper downward and are filled with spar. Spar fill in fractures is draped by micritic or peloidal sediment in the upper portions of the fractures.

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The lithologic, sedimentologic, and paleontologic characteristics of the Green Vedder Member record episodic events of storm deposition that alternated with longer periods of relative sediment starvation. These features document the existence of a relatively deep, open shelf environment during early Helderberg time. This interpretation stands in stark contrast to the intertidal to supratidal environments that most workers (e.g., Laporte 1969; Goodwin and Anderson 1985; Kradyna 1987; 1991; Demicco and Smith 2009) associate with the Manlius Formation (See also Discussion of Demicco and Smith by Ebert, Matteson and Wilson 2010). The relatively deep, subtidal environment (below average wave base) recorded by the Green Vedder Member was brought about by transgression and subsequent highstand conditions following the non-depositional hiatus (flooding surface) marked by the Clockville Unconformity.

PALEONTOLOGY OF THE GREEN VEDDER MEMBER

Brachiopods dominate the macrofauna in the carbonate beds. *Mesodouvillina varistriata* and *Howellella vanuxemi* are most common. Fewer bryozoans and high-spired gastropods occur. Shell pavements comprising valves of the ostracod *Hermannina alta* are common. Echinoderm debris occurs throughout the member, much of which is attributable to the pelagic scyphocrinitid, *Camarocrinus* (see Biostratigraphy below). Rare, articulated specimens of *Lasiocrinus scoparius* and fragments of trilobites occur throughout the unit. Tentaculitids are rare in comparison to the underlying Thacher Member. Large orthocone cephalopods (~ 3 cm wide, over 20 cm long) occur in the upper beds at Schoharie. Bryozoan-encrusted spirorbid worm tubes, first recognized within the Thacher by Laporte (1967), are present within basal mudstone-wackestone beds at Clockville (Fig. 8). Skeletal fragments in the Green Vedder are typically angular and slightly abraded. Facies with *Howellella*, *Mesodouvillina*, and *Hermannina* are assignable to the BA 2 paleocommunity (Brett and Baird 1999), although hummocky cross-strata and the ichnofabrics described below suggest a deeper setting.

Carbonaceous shale interbeds hold a very distinctive carbonized biota (Fig. 9) that includes scolecodonts, poorly preserved annelid soft tissues, *Conularia* sp. and *Medusaegraptus* (Matteson, Natel and Ebert 1996).

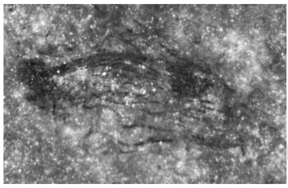


Fig. 9a *Medusaegraptus* from Green Vedder carbonized biota. Length = 1 cm.

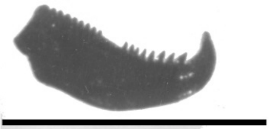


Fig. 9b Scolecodont from Green Vedder carbonized biota. Scale bar = 1mm.

ICHNOLOGY OF THE GREEN VEDDER MEMBER

Green Vedder ichnofauna belongs predominantly to the *Cruziana* ichnofacies. Observed ichnogenera include *Planolites*, *Thalassinoides*, *Chondrites, and Helminthoides* (?). *Planolites* are displayed as simple, meandering horizontal burrows (<1 cm wide, up to 10 cm long) which are prevalent within post-event horizons. These likely represent opportunistic colonization of new substrates. *Thalassinoides* burrows are larger (~1-3 cm wide, up to 10+ cm long) and are lobate branching systems that occur at the base of the TMB and in some overlying beds of the upper Green Vedder. Burrows are slightly enlarged at bifurcations between branches and filled with fine, and dolomitized skeletal debris. The presence of *Thalassinoides* demonstrates the existence of cohesive burrowing paleosubstrates (Ekdale et al. 1984) which are commonly associated with knobby, irregular hyporeliefs ~ 2-4 cm in diameter (possible resting traces?). Uniformly small, thin, bifurcating networks of *Chondrites* occur most commonly in shales and mudstones/ wackestones in western (presumably deeper) sections of the Green Vedder (e.g., Clockville, Oriskany Falls) and are less common eastward. Exposures of the base of the TMB display remarkable networks of *Thalassinoides* and *Planolites* (Fig. 10). These traces occur with disarticulated ossicles of the pelagic crinoid *Scyphocrinites*. Small vertical borings (*Trypanites*; ~1 mm in diameter) in brachiopod shells occur along the base of deeply eroded horizons. *Helminthoides* (?) are present within few beds within the upper Green Vedder strata at Cherry Valley and Wall St. (Cedarville). *Helminthoides* appear as paired structures with pyritized cores that are surrounded by diagenetically leached dolomitic halos. Singular vertical burrows occur (up to 5 cm long and 1-4 mm wide) within the Green Vedder, although they are less common than horizontal and branching burrow systems.

Fig. 10 Networks of *Thalassinoides* and *Planolites* on the base of the "thick middle bed" from the outcrop at Oriskany Falls (**STOP 2**).

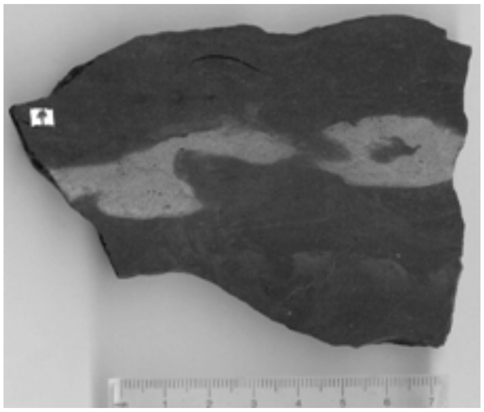


Fig. 11 "Tubular tempestites" – coarse skeletal fill of *Thalassinoides* burrows. Sample from Oriskany Falls. Scale is in centimeters.

Polished slabs from the uppermost strata of the Green Vedder Member at Oriskany Falls and Munnsville show pervasively dolomitized and chert-replaced thalassinoid burrow systems. These networks are filled passively with coarse grained and reworked dolomitic skeletal packstone (Fig. 11; i.e., "tubular tempestites" of Wanless et al., 1988). These uppermost Green Vedder beds are not present east of Oriskany Falls.

Thalassinoid burrows likely represent feeding or dwelling burrows of arthropods, similar to structures built by decapod crustaceans such as thalassinid shrimp in modern intertidal and subtidal environments (Myrow 1995). Aigner (1985) interpreted casts of *Thalassinoides* as evidence of deep exhumation (> 10cm) by storm scour. Across the study area, casts of *Thalassinoides* occur consistently on the base of the TMB (Fig. 10) and among upper beds of the Green Vedder. The producers of *Chondrites* may represent the last infaunal element in an increasingly dysaerobic environment that was inhospitable to other benthic organisms (Savrda and Bottjer 1986). The abundance of burrow systems within the Green Vedder contradicts Laporte's (1969) account of the rarity or absence of burrows within the Manlius, which he used to imply the presence of environmental stresses imposed by very shallow water and intermittent exposure. Rhoades (1967) indicated that in highly stressed environments, vertical burrows predominate over horizontal burrows and feeding traces, which is clearly not the case within the Green Vedder.Distinctive horizons of carbonaceous shale between the wavy bedded strata of the Green Vedder occur as partings between beds at many horizons. These shales vary in character across the outcrop belt, appearing as planar to wavy laminae that are black to dark grey in color west of Cherry Valley. Eastward, crinkly and less fissile shales to mudstones are found as partings at Schoharie, exhibiting a lighter grey, to a very slight reddish hue. A previously recognized distinctive biota from within the dark shales includes *Medusaegraptus,* poorly preserved annelid tissues, and scolecodonts (Matteson, Natel and Ebert 1996) (Fig. 9). Specimens of *Medusaegraptus* are common as individual ramifications (see Valet 1968) typically preserved as carbonized films and display a Y-shaped, singly branching morphology. Individual specimens of *Medusaegraptus* are typically ~2 mm wide and up to ~10 cm long. The best faunal preservation occurs within the upper and basal surfaces of the shales and among upper bedding surfaces within mudstone horizons, associated with few ostracods and small gastropods. Abundant ramifications of *Medusaegraptus* are found at Clockville as the sole faunal element in two distinctive beds of very dark, organic rich shales. At Schoharie, *Medusaegraptus* specimens are associated with vascular plant material, echinoderm debris, and rare tentaculites. Shales at Oriskany Falls have also yielded a previously undocumented microbial mat (Fig. 12). At Schoharie and Oriskany Falls (**STOP 2**), shales that are 0.5 to 1.0 m above the TMB have yielded loboliths of the pelagic crinoid *Camarocrinus* (Matteson and Ebert 2011; see below).

Tempestitic sequences in the Green Vedder are more condensed near Schoharie than in correlatives to the west. Beds at Schoharie contain lenses 2-5 cm thick consisting of winnowed strophomenid steinkerns in hydrodynamically stable positions. Farther east, in the Hudson Valley, the Green Vedder is almost exclusively comprised of hardgrounds. Crinoidal debris (individual ossicles and fragmental stems) are larger east of Cedarville as the spar/mud ratio increases eastward in the upper beds of the Green Vedder.

BIOSTRATIGRAPHY AND CARBON ISOTOPE CHEMOSTRATIGRAPHY OF THE GREEN VEDDER MEMBER AND THE SILURIAN – DEVONIAN BOUNDARY

Characteristics of the Silurian – Devonian Boundary

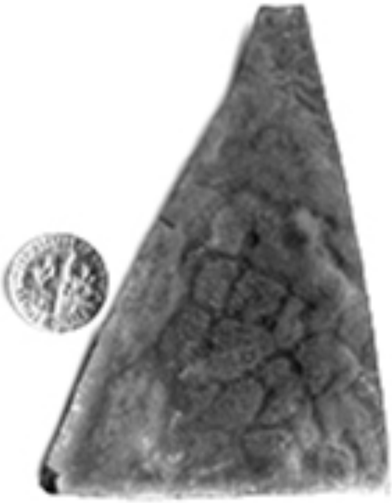


Fig. 12 Pyritized microbial mat from shaly interbed in the Green Vedder Member at Oriskany Falls (**STOP 2**).

By international agreement, the base of the Devonian is defined by the first appearance of the graptolite *Monograptus uniformis uniformis* in the International Boundary Stratotype (GSSP) at Klonk in the Czech Republic (Chlupáč, Jaeger and Zikmundová 1972). Although the index conodont *Icriodus woschmidti woschmidti* has been used as a proxy for the boundary, there are distressing problems with the conodont taxonomy and biostratigraphy in this interval (e.g., Kleffner et al. 2009; Carls, Slavic and Valenzuela-Rios 2007). Biostratigraphically significant graptolites are conspicuously absent from the Helderberg Group in New York and the central Appalachian Basin. As a result, definitively locating the S/D boundary in New York has been problematic. Some authors have placed the boundary as low as the Rondout Formation (Rickard 1962) and potentially as high as the Kalkberg Formation (Kleffner et al. 2009).

From numerous studies across the globe, other proxies have been developed to aid in locating the S/D boundary. There is growing recognition that the boundary is associated with transgressive/highstand conditions, a positive $\delta^{13}C$ excursion, and an epibole of pelagic scyphocrinitids with their distinctive floats (loboliths). In the Barrandian Basin (Czech Republic), scyphocrinitids first appear in the *ultimus* zone (Přídolí, Late Silurian), reach peak abundance at or just above the S/D boundary and disappear within the lower portion of the basal Lochkovian *uniformis* zone (Chlupáč et al. 1972). The large, ornate, pelagic scyphocrinitid crinoids *Scyphocrinites, Carolicrinus, Marhoumacrinus,* and *Camarocrinus* have been reported from strata close to the Silurian/ Devonian boundary from all over the world. These crinoids play a pivotal role in locating the S/D boundary in New York.

Scyphocrinitid Crinoids and the Silurian – Devonian Boundary One of the most distinctive features of scyphocrinitid crinoids is their float, or lobolith (Fig. 13). Loboliths consist of two main types: the plate-type, consisting of a large hollow chambered bulb with a double outer wall formed from numerous polygonal plates; and a presumably more primitive cirrus-type consisting of a bulb bearing more numerous, irregular chambers comprised of walls formed from numerous tightly packed branching rootlets (Haude 1972).

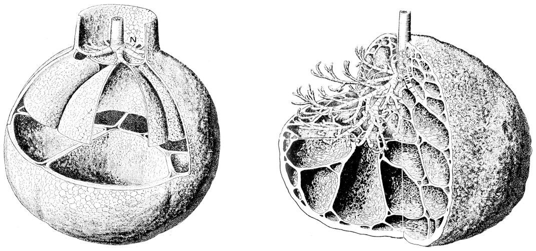


Fig. 13 Line drawings of scyphocrinitid floats (loboliths). Plate-type (left) and cirrus-type (right) are represented. Adapted from Haude (1972).

To date, not a single specimen exists of a fully articulated scyphocrinitid, with crown, stem, and lobolith. As a result, we can only infer which lobolith belonged to which crown. Curiously, plate type loboliths and cirrus type loboliths have not been found together on the same bedding plane (Haude 1972; 1989; Prokop and Petr 1994; 2001). In addition to loboliths, debris from these intriguing crinoids forms a considerable fraction the sediments surrounding the S/D boundary in the Czech Republic (Kriz et al. 1986; Chlupáč et al. 1972). Therefore, scyphocrinitid debris can also serve as a proxy for identification of the boundary interval in areas where biostratigraphic control is sparse.

Plate-type loboliths were first reported in James Hall's 1875 "Notice of Some Remarkable Crinoid Forms from the Lower Helderberg Group," in which Hall described material collected by John Gebhard Jr. at Schoharie, NY. The genus *Camarocrinus,* the first scyphocrinitid genus ever described, consists entirely of plate-type loboliths. Gebhard's original material, still archived at the New York State Museum, consists of several whole, well preserved loboliths that are filled nearly completely with dark, micritic matrix. Hall described these specimens and christened them as *Camarocrinus stellatus*. However, the question has remained – where in the Helderberg Group did Gebhard collect the first specimens of *C. stellatus* nearly two hundred years ago? Hall gives the occurrence as the "Tentaculite limestone" (an obsolete term for the Manlius Formation) but until recently the exact position and range of scyphocrinitid crinoids in the Helderberg of New York has been unknown.

At Schoharie, the Manlius Formation is represented by the Thacher Member, which is overlain by approximately four meters of the Green Vedder Member. The Terrace Mountain Unconformity (Ebert and Matteson 2003a, b) separates the Green Vedder from the Dayville Member of the Coeymans Formation. The Dayville, in turn, is truncated by the Howe Cave Unconformity (Ebert and Matteson 2003a, b) and is overlain by the Ravena Member of the Coeymans Formation. Ossicles bearing the characteristic stellate lumen (Fig. 14) as well as whole and partial plate-type loboliths (Fig. 15) have been recovered from the Green Vedder Member at Schoharie and Oriskany Falls. To date, loboliths and scyphocrinitid debris have been found only in the Green Vedder Member in central NY and the Keyser Member in the Central Appalachian Basin (Ebert and Matteson 2005; Matteson and Ebert 2010). Southeast of Schoharie, near Catskill, scyphocrinitid debris becomes increasingly abundant in the Green Vedder Member and includes partial to complete loboliths that range from 5 cm to more than 10 cm in diameter, stem ossicles, and discrete clusters of plates from the outer walls of plate-type loboliths. These occur with abundant current aligned orthocone cephalopods, bored stromatoporoids, and high-spired gastropods. This assemblage also includes the first examples cirrus-type loboliths from the Appalachian Basin and east of the Mississippi (Matteson and Ebert 2011).

Although plate-type loboliths can be quite large (in excess of 20 cm in diameter), the plates forming the interior and exterior walls are mere millimeters in thickness, and the entire double wall (including any separation between the inner and outer wall plate layers) is less than 5 mm (Haude 1992). As a result, specimens of loboliths can be difficult to find in the field, even when complete bulbs are present. Loboliths in cross section can be camouflaged, particularly when they have been completely filled by the surrounding matrix (including skeletal elements from other fauna) or the specimen consists of only a fraction of the outer wall of the float. Occurrences of whole and nearly complete loboliths (informally termed "cricket ball cemeteries," J. Hladil, written communication 2008), such as the spectacular deposits of *Camarocrinus ulrichi* from Oklahoma, bearing thousands of complete and three-dimensional loboliths (Springer 1917; Ray 1986), are likely more the exception than the typical occurrence. Plate-type loboliths in many parts of the Barrandian are represented by clusters of a few tens of plates or less, or even isolated individual plates (Hladil, J., written communication 2008). As a result, the true global geographic distribution of these crinoids may not be completely recognized.

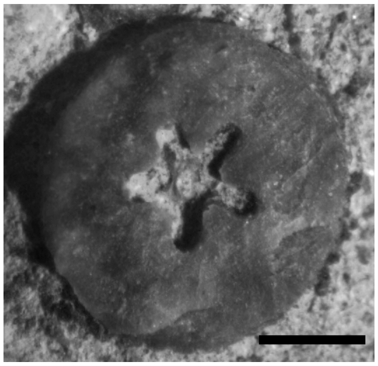


Fig. 14 Stellate lumen in scyphocrinitid columnal from outcrop at Van Leuven Lake (Hudson Valley). Scale = 1 mm.

Fig. 15 Cross section of a lobolith from the upper Green Vedder Member at Howe Cave Quarry near Schoharie. Scale is in cm.

Species of scyphocrinitid crinoids bear yet another distinctive feature – their long stems (which may have reached a meter or more in length) are constructed from numerous ossicles that bear a distinctly stellate central lumen, that is wider and more pentameral proximate to the calyx, and more narrow and cinqelobate near the junction with the lobolith (Springer 1917). *Scyphocrinites, Marhoumacrinus,* and *Carolicrinus* share this distinctive feature (Prokop and Petr 1987). Crinoid stems disarticulate very rapidly post mortem, leaving hundreds of readily available macroscopic elements that can be found in the field more easily than fragments and whole loboliths. Crinoid ossicles bearing stellate lumens conforming to scyphocrinitid crinoids are more abundant in eastern exposures of the Green Vedder Member and decrease in abundance westward from Schoharie to Clockville. Partial plate loboliths (Fig. 16) are present in outcrop at the Green Vedder type locality at Oriskany Falls (**STOP 2**).

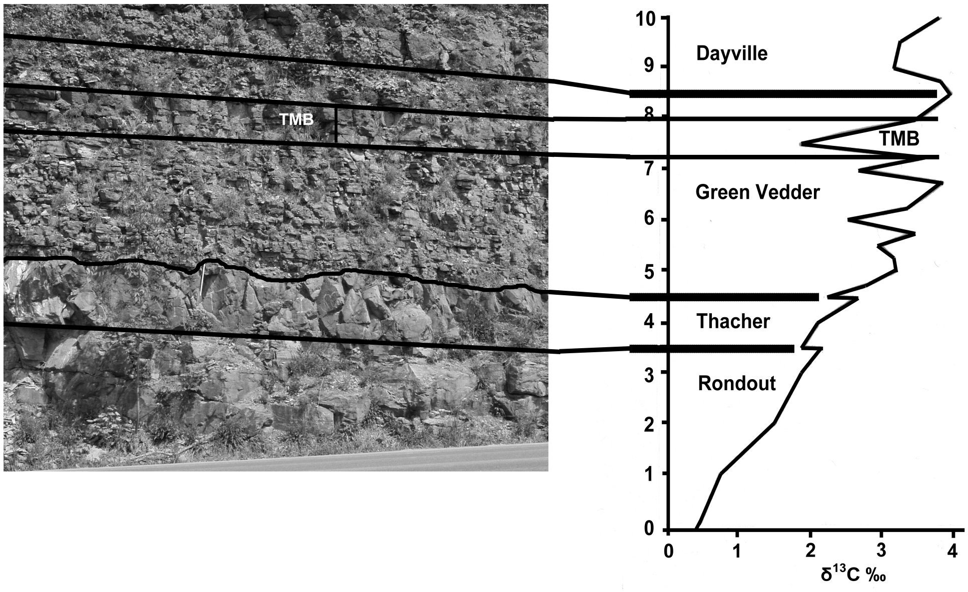
Fig. 16 Partial plate loboliths in the upper Green Vedder Member at the type section near Oriskany Falls (**STOP 2**).

Thus far, no traces of scyphocrinitid crinoids have been found in stratigraphically younger or older units in the Helderberg Group, including units that display more diverse faunal assemblages, such as the obrution deposits and coarse encrinites of the Dayville and Ravena members of the Coeymans Formation. The unique occurrence of debris of scyphocrinitid crinoids within the Green Vedder Member indicates close proximity to the S/D boundary and constitutes the best biostratigraphic control on this boundary yet determined in the Appalachian Standard Succession.

Carbon Isotope Chemostratigraphy and the Silurian – Devonian Boundary in the Green Vedder Member

Hladikova et al. (1997) reported a positive $\delta^{13}C$ excursion occurring across the Silurian/Devonian boundary at the Global Stratotype Section and Point (GSSP) at Klonk, Czech Republic, beginning in the Přídolí and ending in the early Lochkovian (*M. transgrediens*- early *M. uniformis* graptolite biozones). Subsequently, this positive carbon isotope excursion has been recognized globally (See Malkowski et al. 2009 and references therein). In the central Appalachian Basin, Saltzman (2002) reported the excursion from the uppermost Keyser Formation. The rediscovery of *Camarocrinus sp.* in the Big Mountain Shale/ upper Keyser at the Keyser type section (Ebert and Matteson 2005) supports the interpretation that this is the S/D boundary excursion.

In New York, Williams (2004) and Williams and Saltzman (2004) reported a positive $\delta^{13}C$ excursion at Cherry Valley (**STOP 1**) from strata reported as Manlius Formation. Kleffner et al. (2006, 2009) sampled a more complete section at Cherry Valley (**STOP 1**) and confirmed that the positive $\delta^{13}C$ excursion (peak at +3.65 ‰) at Cherry Valley and that it occurs within the Green Vedder Member. Based on the excursion at Cherry Valley and ambiguous conodont data (e.g., Carls et al. 2007), Kleffner et al. (2009) determined seven possible locations for the S/D boundary at Cherry Valley. However, the exact position of *Camarocrinus* in the succession was not known when Kleffner et al. (2009) was published.



Wilson (2010) included an examination of $\delta^{13}C$ chemostratigraphy from the more complete (~4 m of section) Green Vedder exposure at Clockville (**STOP 3**). Stable carbon isotopes vary through the lower Helderberg Group at Clockville by 3.53 ‰ (Wilson 2010; Fig 18). Values rise gradually through the Rondout Formation, from 0.88 ‰ to a maximum at 2.3 ‰ at the Mine Lot Falls Unconformity and then fall slightly at this horizon. Within the Thacher Member of the Manlius Formation, values increase slightly to a maximum of 2.79 ‰ at the Clockville Unconformity, followed by a slight decrease in the lower Green Vedder Member. Within the Green Vedder, $\delta^{13}C$ values fluctuate somewhat but show an overall positive trend. The most significant decrease in $\delta^{13}C$ (-1.74 ‰) occurs within the thick middle bed (TMB), a packstone-grainstone package associated with abundant pyritized pelmatozoan debris. A marked positive $\delta^{13}C$ excursion occurs within the upper Green Vedder and corresponds to the interval containing the most organic rich, black shales in the Clockville outcrop. Values of $\delta^{13}C$ between 3.58 ‰ and 4.12 ‰ occur within the upper 3.25 m of the member and peak in the uppermost Green Vedder bed. $\delta^{13}C$ values fall across the Green Vedder – Dayville contact (Terrace Mountain Unconformity), before climbing to a second peak (3.96 ‰) in the Dayville Member.

The $\delta^{13}C$ curve from Clockville (Fig. 17) compares well with the isotope curve for Cherry Valley from Kleffner et al. (2009). The carbon isotope data support the correlation of the dramatically thinned Green Vedder at Cherry Valley with the upper Green Vedder at Clockville (Wilson 2010).

The occurrence of loboliths and scyphocrinitid debris in the Green Vedder Member, along with a significant, positive $\delta^{13}C$ excursion, strongly suggest that the excursion is, in fact, the S/D boundary event. These data indicate that the S/D boundary occurs within the upper portions of the Green Vedder Member or in the erosional vacuity of the Terrace Mountain Unconformity that separates the Green Vedder from the overlying Dayville or Olney members. Chitinozoan studies (e.g., Bevington, Ebert and Dufka 2010) are currently in progress and may shed further light on the position of the boundary. Until such time, the combination of the $\delta^{13}C$ excursion and scyphocrinitids represents the most precise placement to date of the Silurian/Devonian boundary in the Appalachian Standard Succession.

SUMMARY

The Green Vedder Member records highstand deposition in an open-shelf setting in which the bottom waters or surface sediments were dysaerobic to anaerobic. As such, the member represents significantly deeper, subtidal conditions than the peritidal environments that are typically associated with the Manlius Formation. The initial pre-Green Vedder deepening is recorded by the Clockville Unconformity, which represents conditions of localized erosion and sediment starvation and/or bypass. We interpret the Clockville surface and immediately associated lithologies as a transgressive surface, perhaps closely linked with maximum flooding.

The Green Vedder open shelf was characterized by generally dysaerobic conditions recorded by interbeds of dark shale and carbonate mudstone to wackestone. This relatively quiet setting was interrupted episodically by storms that delivered skeletal and peloidal debris from shallower parts of the shelf to the zone below average wave base. Shell pavements that developed during storm winnowing and early-lithified hardgrounds hosted opportunistic, encrusting, and boring fauna that persisted as long as oxygenation was sufficient. Deposition of fine-grained, likely condensed beds resumed with the re-establishment of dysoxia.

Relatively thin accumulations of the Green Vedder Member near Syracuse represent onlap onto the western margin of the Appalachian Basin (Ebert 2008). East of Syracuse, the Green Vedder thickens owing to localized subsidence and then thins again at Cherry Valley, via onlap onto a local paleotopographic high that experienced little or no subsidence. East of Cherry Valley, subsidence facilitated a second area of thickened Green Vedder deposition that reached a maximum near Schoharie. The more proximal nature of tempestites in the Schoharie area indicates that the eastern sub-basin was shallower than the contemporaneous sub-basin in the west (Wilson and Ebert 2008).

The Green Vedder highstand established partial connection with the global ocean, which enabled loboliths of scyphocrinitids to drift into the otherwise restricted Appalachian Basin during the Silurian – Devonian transition. Loboliths and scyphocrinitid debris in the Green Vedder Member occur in the same strata as a strong, positive $\delta^{13}C$ excursion. Combined, these biostratigraphic and chemostratigraphic data strongly suggest that the Silurian – Devonian boundary in the Appalachian Standard Succession occurs in the Green Vedder Member of the Manlius Formation.

ACKNOWLEDGMENTS

We thank Jim Barrick and Mark Kleffner for the carbon isotope analyses of samples collected by RW for his thesis. We also thank Leigh Fall and Les Hasbargen for helpful suggestions on an earlier draft of this contribution.

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ROAD LOG FOR THE GREEN VEDDER MEMBER – A HIGHSTAND SYSTEMS TRACT IN THE "PERITIDAL" MANLIUS FORMATION

Road Log begins at the end of the ramp for Exit 30 (Herkimer/Mohawk) on I-90, the New York State Thruway, approximately 65 miles east of Syracuse (Fig. 18).

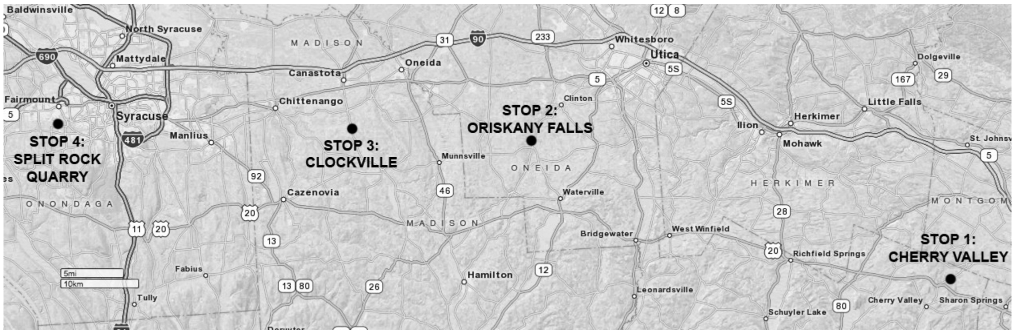

Fig. 18 Road map of field trip area with stop locations.

Note: This road log was compiled in Google Earth. Actual odometer-based mileage may differ somewhat.

CUMULATIVE MILEAGE	MILES FROM LAST POINT	ROUTE DESCRIPTION
0.0	0.0	Bottom of ramp for I-90 Exit 30, Turn left onto Rt. 28, Cross the Mohawk River
0.2	0.2	Turn right to continue on Rt. 28, concurrent with Rt. 5S
0.6	0.4	Turn left to continue on Rt. 28 south through village of Mohawk
1.3	0.9	Junction with Rt. 168, continue on Rt. 28
4.3	3.0	Denison Corners, intersection with County Rt. 46, continue on Rt. 28
11.8	7.5	Junction with U.S. Rt. 20, turn left (east) onto Rt. 20
18.6	6.8	Junction with Rt. 80, continue on Rt. 20
25.7	7.1	Exit Rt. 20 at exit for Rt. 166, Cherry Valley
25.8	0.1	End of ramp, turn left (north) onto Rt. 166
25.9	0.1	Cross under Rt. 20, road continues north as County Rt. 32, Sprout Brook Road
26.5	0.6	Continue northeast on Sprout Brook Road to **STOP 1.**

STOP 1: ROAD CUT ON SPROUT BROOK ROAD

The following stop description is modified from the description of Stop 1 of Ebert and Matteson (2003b) and Stop 1a by Ebert and Matteson in Ver Straeten et al. (2005). **STOP 1** is the stratigraphically lowest of a series of outcrops on Sprout Brook Road (Cty. Rt. 32), Rt. 166 and U.S. Rt. 20 that expose the upper Silurian (Ebert and Matteson 2003a, b) and much of the Lower Devonian section that is present in New York State (See Brett and Ver Straeten 1997). This outcrop corresponds approximately to Rickard's (1962) section 94, which was measured in nearby Judd's Falls.

The section begins at the north end of the outcrop with approximately one meter of the Rondout Formation (Přídolían). The Rondout is abruptly overlain (Mine Lot Falls Unconformity of Ebert 2008) by the Thacher Member of the Manlius Formation (11.2 m thick). A distinctive zone of thrombolitic mounds occurs two meters above the Mine Lot Falls Unconformity. Regional tracing of the thrombolitic zone shows it descending westward relative to the Mine Lot Falls Unconformity (westward onlap of the Thacher Member) and rising stratigraphically eastward (Ebert 2008). This thrombolitic marker zone is also present at **STOPS 3** and **4** on this trip and is important in recognizing the Thacher Member where it is thinned by truncation and onlap.

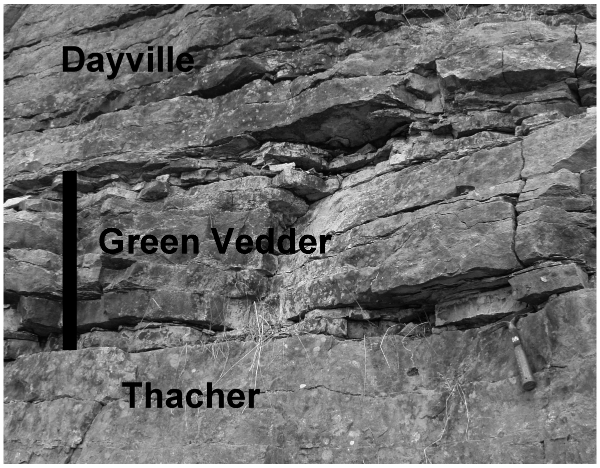

Fig. 19 Clockville Unconformity separates the Thacher Member of the Manlius Formation from the Green Vedder Member. The Green Vedder (only 0.82 m thick here) is cut by the Terrace Mountain Unconformity at the base of the Dayville Member. Hammer for scale.

Less than one meter below the top of the Manlius Formation, the Clockville Unconformity (Ebert and Matteson 2003a, b) marks an abrupt change in the style of bedding to thinner (decimeter scale) limestone beds with interbedded dark gray to black shale (Fig. 19). These beds (total thickness = 0.82 m) comprise a thinned portion of the Green Vedder Member. The dark shale interbeds of the Green Vedder Member contain a distinctive carbonized biota comprising scolecodonts, annelid bodies, and non-calcified green algae (*Medusaegraptus*) (Matteson, Natel and Ebert 1996). The faunal content and general lithology of this thin remnant of the Green Vedder Member are strikingly similar to upper portions of the member from thicker sections to the west (e.g., Oriskany Falls) and to the east (I-88, Schoharie Valley). This similarity suggests onlap of the Green Vedder Member onto a paleotopographic high in the Cherry Valley area and that the Clockville Unconformity is more pronounced here than at sections that record greater subsidence to the west and east.

The Green Vedder beds are cut by a sharp surface which is the Terrace Mountain Unconformity (13.27 m from base of section) (Ebert, Matteson and Natel 2001; Ebert and Matteson 2003a, b). The Dayville Member of the Coeymans Formation rests on this unconformity. The Dayville is comprised of coarse echinoderm grainstones and packstones, interbedded with mudstones and skeletal wackestones. Total thickness of the Dayville here is 4.03 meters (corrected from Ebert and Matteson 2003). The overlying Ravena Member of the Coeymans Formation is separated from the Dayville Member by the Howe Cave Unconformity (Ebert, Matteson and Natel 2001; Ebert and Matteson 2003a, b).

Combined, the Green Vedder beds and the Dayville Member appear to constitute a gradational transition (Grabau's [1906] "transition beds") between the Manlius and Coeymans formations, a key factor in Rickard's (1962) stratigraphic reconstruction. However, such a gradation does not exist owing to the presence of the Clockville Unconformity and the Howe Cave Unconformity, which bound the interval and the Terrace Mountain Unconformity, which occurs within it. The Green Vedder Member and Dayville Member are traceable across the northern portion of the outcrop belt of the Helderberg Group. These members are distinctive and do not comprise an ambiguous zone of transition.

CUMULATIVE MILEAGE	MILES FROM LAST POINT	ROUTE DESCRIPTION
26.7	0.2	Continue northeast on Sprout Brook Road to area with wide shoulder on the left. Turn around and return to Rt. 20
27.4	0.7	Junction with Rt. 20, get on Rt. 20 heading west
34.7	7.3	Junction with Rt. 80, continue on Rt. 20
41.6	6.9	Junction with Rt. 28, continue on Rt. 20
49.0	7.4	Junction with Rt. 51, continue on Rt. 20
51.9	2.9	Main intersection in West Winfield, continue on Rt. 20
55.0	3.1	Junction with Rt. 8 in Bridgewater, continue on Rt. 20
62.6	7.6	Junction with Rt. 12 in Sangerfield, continue on Rt. 20
68.0	5.4	Junction with Rt. 26/12B, turn right, north onto Rt. 26/12B
70.5	2.5	Intersection with Broad Street in Oriskany Falls
70.53	0.03	Turn Right onto Main Street
71.3	0.8	Pass quarry and turn left onto Green Vedder Road to **STOP 2**.

STOP 2: GREEN VEDDER ROAD – TYPE SECTION OF THE GREEN VEDDER MEMBER, MANLIUS FORMATION

STOP 2 (associated with R-131 of Rickard 1962), which is located on Green Vedder Road on the edge of the large active quarry near Oriskany Falls, comprises the type section of the Green Vedder Member of the Manlius Formation. The member reaches its greatest thickness (5.6 m) here. The lower contact (Clockville Unconformity) with the underlying Thacher Member is exposed near the base of the outcrop at the southern end of the exposure. The Terrace Mountain Unconformity marks the top of the Green Vedder Member and separates it from the overlying skeletal-rich, stromatoporoid-bearing packstones to grainstones of the Dayville Member (previously mapped here as Olney Member by Rickard [1962]).

The Green Vedder Member comprises decimeter-scale beds of skeletal/peloidal packstones and wackestones interbedded with gray, calcareous shales. The carbonate beds in the Green Vedder display broad hummocks (>1m; Fig. 20) that are much greater in wavelength than equivalent strata to the east (e.g., I-88 near Schoharie).

Fig. 20 Hummocky bedforms in the Green Vedder Member at Munnsville

We interpret the carbonate beds of the Green Vedder as tempestites that record episodic storms in the Helderberg Sea. Greater thicknesses of shaly interbeds and longer hummock wavelengths suggest that the Green Vedder at its type section represents deeper conditions than those that existed to the east.Some carbonate beds display *Thalassinoides* and *Planolites* burrows. These are particularly well developed on the base of the thick middle bed (TMB). Abundant *Garwoodia* (codiacean alga) occur approximately 20 centimeters below the top of the member. Skeletal debris of pelagic scyphocrinitid crinoids are abundant in the carbonate beds and a partial lobolith (*Camarocrinus*) is exposed on the bedding plane (Fig. 16) across the road from the main outcrop.

Shaly interbeds in the Green Vedder type section exhibit the carbonized biota that is so distinctive of this member (Matteson, Natel and Ebert 1996). *Chondrites* burrows are common in the shaly beds and a pyritized microbial mat (Fig. 12) was collected here from one of the shaly interbeds.

CUMULATIVE MILEAGE	MILES FROM LAST POINT	ROUTE DESCRIPTION
71.3	0.0	Return to Main Street/Rt. 26/12B heading south back through Oriskany Falls to Rt. 20
74.7	3.4	Junction with Rt. 20, turn right (west) onto Rt. 20
76.3	1.6	Village of Madison
77.6	1.3	Split between Rt. 20 and 12B (south). Remain on Rt. 20
78.5	0.9	Village of Bouckville
83.4	4.9	Village of Morrisville
83.7	0.3	Turn Right (north) on Cedar Street, which becomes County Rt. 101, which becomes Old County Rt. S
88.4	4.7	Bear right onto Pleasant Valley Road
89.2	0.8	Village of Peterboro
89.35	0.15	Bear left onto Oxbow Road (County Rt. 25) just north of Peterboro
94.9	5.5	Large outcrop on Oxbow Road **STOP 3.** Park in parking area on west side of road

STOP 3: CLOCKVILLE ROAD CUT Approximately four meters of the Chrysler Member of the Rondout Formation are exposed in this large road cut (Section 142 of Rickard 1962). The contact with the overlying Thacher Member of the Manlius Formation is the Mine Lot Falls Unconformity, a sharp surface upon which thrombolitic mounds have nucleated. We regard this massive, thrombolitic bed (0.9-2.0 m thick) as the total thickness of the Thacher Member at this location.

Fig. 21 Lowest Green Vedder beds lapping onto irregular topography of the Clockville Unconformity at the top of the Thacher Mbr. at Clockville (**STOP 3**).

The top of the Thacher Member displays up to 20 cm of erosional relief along the Clockville Unconformity (Fig. 3). This surface is overlain by a coarse, cross-stratified skeletal grainstone that is semi-continuous across the outcrop. Lithoclasts of Thacher lithologies are incorporated in this grainstone. The lithology and texture of this bed is atypical for both the Thacher and Green Vedder members of the Manlius Formation. Where the coarse bed is discontinuous, it is preserved locally in scoured pockets along Clockville Unconformity.

Approximately four meters of the Green Vedder Member rest on the Clockville Unconformity. The cm- to dm-scale beds of the Green Vedder contrast sharply with the massive Thacher below (Fig. 17). In several places along the outcrop, the lowest beds of the Green Vedder lap onto local high spots along the Clockville Unconformity (Fig. 21). Shaly interbeds in the Green Vedder contain the member's signature carbonized biota. The TMB is well-displayed in the Clockville road cut. Carbonate beds in the upper portions of the Green Vedder are noticeably thicker than in the lower half of the member. These beds also tend to be richer in skeletal debris than beds in the lower half. Thinner beds reappear in the uppermost 1.5 m of the member.

The Terrace Mountain Unconformity separates the Green Vedder Member from the superjacent Olney Member of the Manlius Formation. Here, the lowest Olney is a massive stromatoporoid biostrome.

CUMULATIVE MILEAGE	MILES FROM LAST POINT	ROUTE DESCRIPTION
94.9	0.0	Return to Oxbow Road and continue north
97.8	2.9	Intersection with Rt. 5, continue north on S. Peterboro Street through village of Canastota to I-90 on-ramp.
98.7	0.9	Merge onto I-90 westbound
113.6	14.9	Exit I-90 at Exit 34A for I-481 South, toward Syracuse
114.5	0.9	Merge onto I-481
117.0	2.5	Merge onto I-690 West
123.2	6.2	Exit I-690 at Exit 10, North Geddes Street
123.4	0.2	Turn left (south) onto North Geddes Street
123.6	0.2	Turn right onto West Genesee Street (Rt. 5)
125.2	1.6	Turn left onto Fay Road
127.0	1.8	Turn right onto Onondaga Boulevard
127.5	0.5	Intersection with Rt. 173, continue straight through intersection on Onondaga Boulevard

128.7	1.2	Park at gated extension of Onondaga Boulevard and walk to **STOP 4**, the inactive Split Rock Quarry.

STOP 4: SPLIT ROCK QUARRY

Rickard (R-156; 1962, p. 54 and 149) described the section exposed at Split Rock Quarry as "33 feet of fine-grained, even bedded limestones" of the Olney Member, overlain by 3 feet of Elmwood waterlimes. Rickard did not recognize any Thacher Member at this location. Rickard's "Olney" rests upon a sharp contact (Smith 1929; Logie 1933) with the underlying Rondout Formation, which is exposed in the floor of the quarry (Fig. 22). This sharp contact is the Mine Lot Falls Unconformity of Ebert (2008). In the northeastern section of the quarry, an additional 1.3 m of the Rondout, comprising dolomitic mudstones with abundant domal stromatoporoids are exposed below the Mine Lot Falls Unconformity. In this area, approximately 30 cm of the thrombolitic marker bed within the Thacher Member rests on the unconformity (Fig. 23). Above the thrombolitic horizon, an additional ~2.9 m of the Thacher Member are exposed. Here, the Thacher displays mudstones and skeletal wackestones that alternate with very fine grained dolomitic grainstones. Planar to wavy or lenticular beds, with laterally discontinuous and rippled laminae are common in this section of the Thacher.

Fig. 22 Thrombolites of the Thacher Member colonized the irregular topography of the Mine Lot Falls Unconformity at the top of the Rondout Formation. Split Rock Quarry (**STOP 4**).

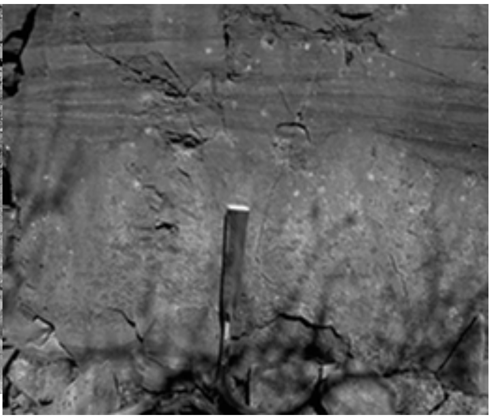

Fig. 23 Thicker development of the thrombolitic marker horizon in the Thacher Member. Split Rock Quarry (**STOP 4**).

The Clockville Unconformity separates the Thacher Member from approximately 30 cm of the Green Vedder Member, which is exposed in the western section of the quarry. The Green Vedder comprises thin to medium-bedded skeletal wackestones to packstones with dark shale interbeds containing *Medusaegraptus*, a representative of the distinctive biota that occurs in the Green Vedder throughout central New York. Fauna in the limestones includes *H. vanuxemi*, *M. varistriata*, ostracods, crinoid and trilobite debris, and rare pelecypods.

The Terrace Mountain Unconformity separates the Green Vedder from ~6.4 m of the Olney Member of the Manlius Formation. The Olney is a hard, grey, dolomitic skeletal limestone, which ranges from laminated to massively bedded. The sedimentology and ichnology of the Olney are described by Wilson (2010). Numerous sedimentologic and ichnologic features in the Olney indicate deposition under arid to semi-arid, evaporative supratidal (sabkha) to high intertidal conditions.

End of road log. After **STOP 4**, return to Syracuse University.