A2 AND B2: UPPER DEVONIAN KELLWASSER EXTINCTION EVENTS IN NEW YORK AND PENNSYLVANIA: OFFSHORE TO ONSHORE TRANSECT ACROSS THE FRASNIAN-FAMENNIAN BOUNDARY ON THE EASTERN MARGIN OF THE APPALACHIAN BASIN

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INTRODUCTION

Earth-system perturbations caused a series of mass extinction events during the Devonian Period, including the Taghanic event in the Givetian, the Lower and Upper Kellwasser events in the Frasnian, and the Hangenberg event in the Famennian (House, 2002; Bambach, 2006). These extinctions occurred against the backdrop of orbitally forced sea-level fluctuations, the Acadian Orogeny (Averbuch et al., 2005), the expansion of plants and animals on land (Algeo et al., 1995), and ecological changes in the marine biosphere (Signor and Brett, 1984; Bambach, 1999). The Frasnian-Famennian boundary in particular represents a significant global crisis, considered one of the "big five" mass extinctions (Raup and Sepkoski, 1982) that led to the demise of the widespread and diverse Devonian reef community (Copper, 2002).

The Appalachian Basin preserves a tremendous record of Devonian stratigraphy, and these rocks have been studied for about 200 years (Aldrich, 2000). They have been, in whole or in part, the inspiration for numerous advances and theories in geology and paleontology, including the concepts of facies (Chadwick, 1935), punctuated equilibrium (Eldredge, 1971), coordinated stasis (Brett and Baird, 1995), and considerable work on paleoecology (Sutton et al., 1970; Bowen et al., 1974; Thayer, 1974; McGhee, 1976; McGhee and Sutton, 1981; 1983; 1985; Sutton and McGhee, 1985; Stigall Rode and Lieberman, 2005). Critical faunas and floras document the invasion of land (Daeschler et al., 1994; Daeschler, 2000; VanAller Hernick, 2003).

In particular, foreland basin sediments provide an exceptionally thick and complete record of the Upper Devonian, and thus the opportunity to examine Late Devonian extinction events. Studies of the late-Frasnian Kellwasser events have been concentrated in the more offshore settings of western New York, where geochronology is well constrained by conodont biostratigraphy and carbon isotope chemostratigraphy (Over, 1997; Murphy et al., 2000; Over, 2002; Tuite and Macko, 2013; Lash, 2017). Specifically, the Pipe Creek Formation is temporally equivalent to the Lower Kellwasser Event (LKW), and a thin black shale bed in the upper Hanover Formation is equivalent to the Upper Kellwasser Event (UKW) (Over, 1997; 2002). Baird, Bush, and students have been investigating the Kellwasser events in shallower-water paleoenvironments further to the east, primarily in Steuben County, New York, and adjacent areas of Pennsylvania (Bush et al., 2015; Beard et al., 2017) (Fig. 1).

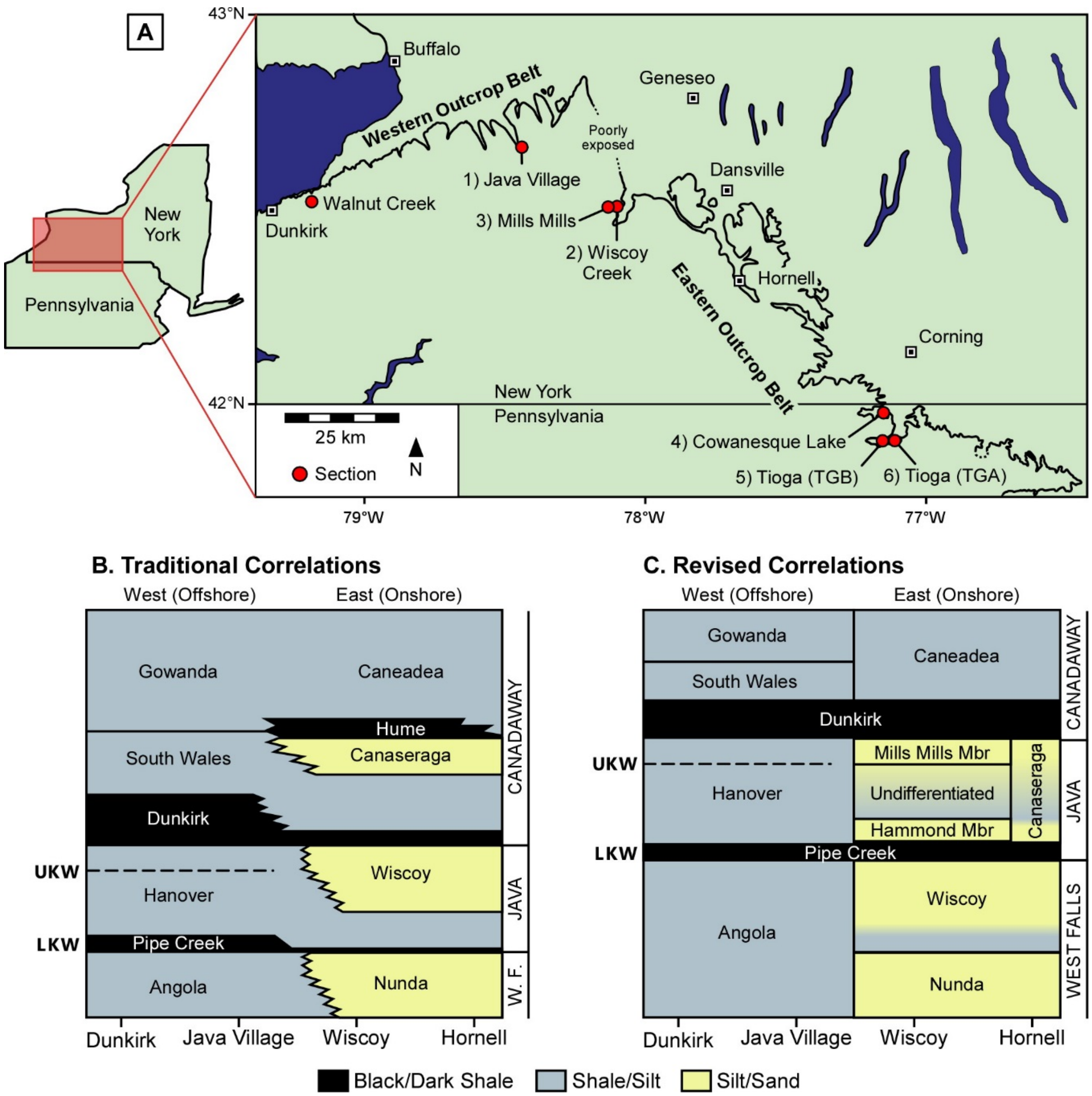


Fig. 1. A. Map of study area. The black line marks the Pipe Creek Formation, as currently correlated. **B.** Traditional stratigraphic correlations between the western and eastern portions of the outcrop belt (Pepper and de Witt, 1950; 1951; Smith and Jacobi, 2000). **C.** Revised correlations (Bush et al., 2015; Beard et al., 2017). "LKW" and "UKW" indicate the positions of the Lower and Upper Kellwasser events, and "W. F." stands for WEST FALLS. Stratigraphic groups are indicated in capital letters. B-C slightly modified from Bush et al. (2015), with permission from Elsevier.

The Java Group-through-Dunkirk Formation, in which the Lower and Upper Kellwasser events are developed, consist of interbedded organic-rich shales, gray shales, and thin nodular carbonates in the western outcrop area in Chautauqua, Erie, and Wyoming counties (Fig. 1). Eastward in Allegany, Steuben, and Tioga (PA) counties, the Java Group and equivalents become thicker and coarser, consisting of gray shales, siltstones, and sandstones with more abundant benthic faunas. The Java Group overlies the West Falls Group, where the Pipe Creek Formation rests on the Angola to the west and the Wiscoy (revised correlations, Fig. 1C) or Nunda (traditional correlations, Fig. 1B) to the east. The Hanover or the eastern equivalent Canaseraga Formation (revised correlations, Fig. 1C) overlies the Pipe Creek. The Java Group is overlain by the Canadaway Group, which is marked by the Dunkirk Formation at the base, the highest extensive organic-rich shale in the New York Upper Devonian.

Inferred paleoenvironments are variable and include (1) nearly anoxic for portions of black shale units, (2) more broadly dysoxic for the gray facies in the offshore realm characterized by depauperate benthic faunas and rare to common pelagic faunas, and (3) well-oxygenated for the interbedded sandstones, siltstones, and light-colored shales in more nearshore settings that are highly bioturbated and contain a shelly fauna (see Boyer et al., 2011; Boyer et al., 2014; Haddad et al., 2016). The closing of the Frasnian age was marked by two major episodes of ecological disruption and faunal extinction, the LKW and UKW. The second of these, marking the Frasnian-Famennian boundary and associated mass extinction, was the greater crisis globally. This extinction, in part, probably explains the lower diversity and more generalized ecological character of Famennian neritic faunas seen higher in the Devonian succession in Chautauqua and Cattaraugus counties. In Europe, North Africa, and elsewhere, the two extinction events are marked by black shale or black limestone beds within slope and basin successions (e.g., Schindler, 1993).

DAY 1 - FRASNIAN-FAMENNIAN BOUNDARY INTERVAL IN CHAUTAUQUA, ERIE, WYOMING, AND ALLEGANY COUNTIES, NEW YORK

(Over, Baird, Tuskes, Beard, Bush)

Stratigraphy and Geochronology in Western New York

Walnut Creek and Silver Creek in Chautauqua County (Fig. 1A) expose a complete section of the Java Group in the banks and stream bed (Fig. 2). The Pipe Creek Formation is a persistent black petroliferous shale that is recognized in the subsurface from eastern Kentucky to New York State by a high positive shift on gamma ray logs (de Witt and Roen, 1985). These shales represent dysoxic and anoxic benthic conditions that developed as the result of deepening in the Appalachian Basin. This deepening is the IId2 transgression of Johnson et al. (1985) and Day et al. (1996). At Walnut Creek, the Pipe Creek is a 0.6 meter-thick, very hard, black shale that abruptly overlies the softer, gray Angola Formation (Fig. 2). The laminated microfacies of the Pipe Creek contrasts dramatically with a subjacent zone of gray, pyritic Angola mudstone. The Pipe Creek can be traced regionally southwestward through Chautauqua County where it is approximately 0.6 meters thick in its westernmost section (Tesmer, 1963). To the east, it thickens to about 6 or 7 meters near Warsaw, then becomes more depositionally complicated and interbedded with turbiditic silts and sands of the underlying Nunda Formation (Baird and Jacobi, 1999, Stop 1) (which the correlations in Fig. 1C suggest might actually correlate with the Wiscoy).

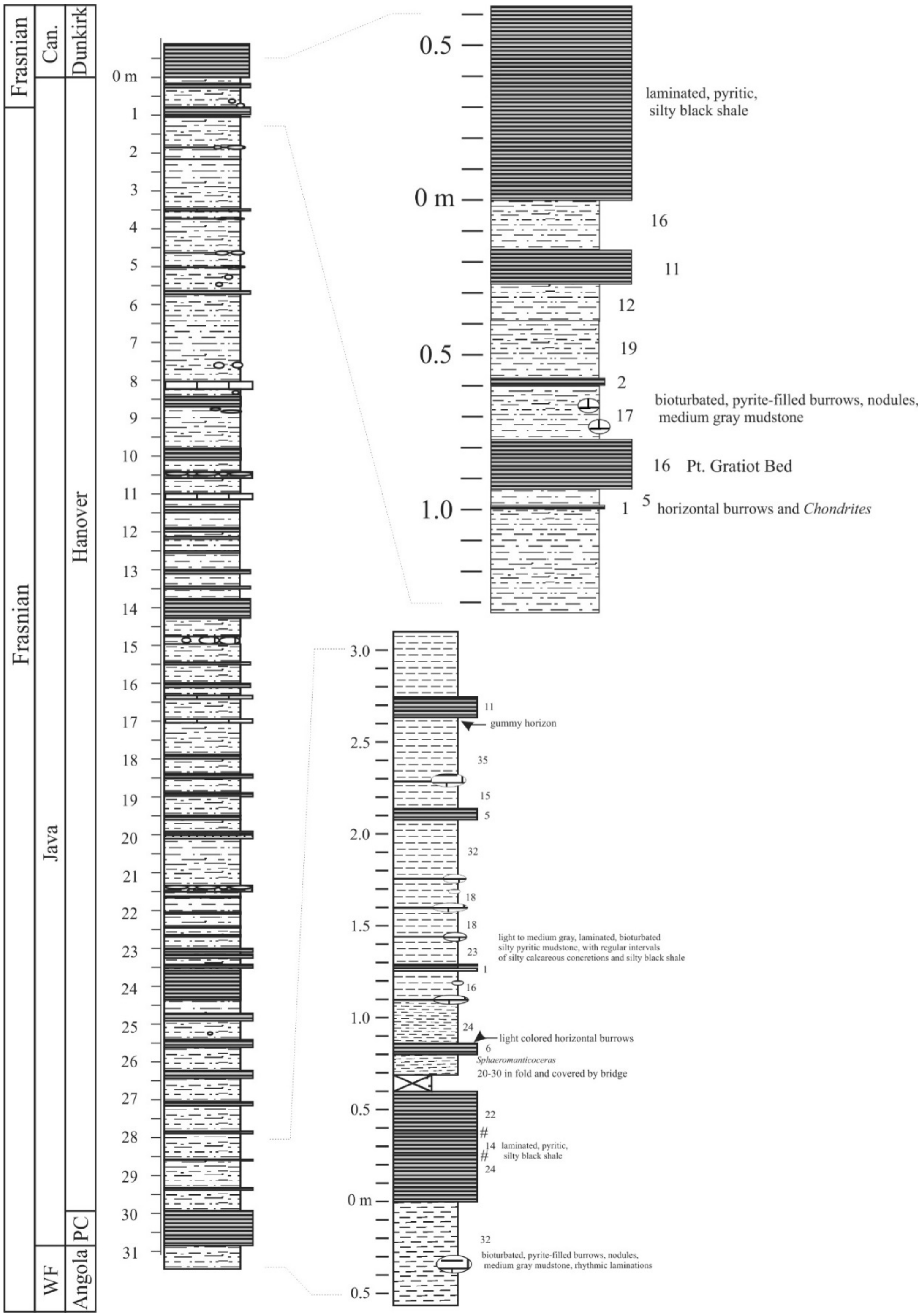


Fig. 2. Schematic stratigraphic section of Java Group exposed along bed and banks of Walnut Creek upstream and downstream from US 20 bridge in Silver Creek, NY, with details of lower and upper Java Group strata. See Fig. 4 for key to lithologic symbols. Frasnian-Famennian boundary is at the top of the Pt. Gratiot Bed. Can. = Canadaway Group; PC = Pipe Creek Formation; WF = West Falls Group.

The Hanover Formation at Walnut Creek is 30 m thick and shows a distinct near-meter-scale cyclicity of alternating thin organic-rich shales and/or nodular carbonate-rich beds with thicker gray shales which are superimposed on larger scale cycles of more organic-rich and less organic rich strata that are also evident in geochemical analysis (Lash, 2017). Dates derived from zircons in tephra horizons within the Kellwasser interval at quarry Benner in Germany yielded a calculated date of 372.55 $\pm$ 0.15 Ma for the Lower Kellwasser Bed and 371.85 $\pm$ 0.11 Ma for the Upper Kellwasser Bed. The Center Hill Tephra at Hurricane Bridge, TN ,which is in the highest Frasnian strata in the Chattanooga Shale, was dated at 371.91 $\pm$ 0.15 (Schmitz, 2014, pers. comm.). Thus the duration for deposition of the Pipe Creek and Hanover formations was approximately 800,000 years.

Bulk magnetic susceptibility data collected at 5-cm intervals through the Walnut Creek section were used to assess sea level fluctuations. The amount of magnetic minerals contained in marine sedimentary rocks varies with the amount of detrital minerals contributed from continents, which varies during eustatic, climatic, and tectonic changes (Tuskes et al., 2014). Therefore, the magnetic susceptibility curve increases during a sea level regression when base level is lowered and heightened erosion increases the detrital contribution into the marine system. A decrease in the magnetic susceptibility signature occurs during transgressions, when detrital minerals are not being weathered, eroded, and dispersed as heavily. Constant values demonstrate an aggradational phase, and increasing values demonstrate a regressive phase. The variation in magnetic susceptibility curve can then be used to document changes in sea level (Da Silva and Boulvain, 2006).

Data were analyzed using the astrochron package for the r program (Meyers, 2014) for orbital frequencies, bandpass, and the sedimentation rate, and all calculations were done through pre-programed analyses in the package. Six different cycles were identified as a frequency, and then calculated as cycles in terms of ka. The shortest two frequencies are representative of the two precession cycles that are 16.9 and 20.0 ka respectively. The middle two frequencies correlate to the two obliquity cycles of 32.25 and 40.0 ka, and the last two frequencies correlate with the eccentricity cycles of 100 and 416 ka. The MS data was then put through multiple bandpass filters in order to better understand the location of the cycles within the strata. The six cycles coalesce into three, with the small and large cycles modulating each other, and the values given by the analysis being the extreme values in the cycle. The eccentricity shows eight short eccentricity cycles and two long eccentricity cycles. In the lower 14 m of the Hanover the eccentricity curve fluctuates much more than the upper 16 m. In the lithology, this is associated with the deposition of black shales. The obliquity shows about 18 cycles, where the lower half of the Hanover experiences much more exaggeration than the upper half. The obliquity is associated with limestone or strata that are representative of a shallowing environment due to the obliquity's effect on the tides and influence in the deposition over lower latitudes.

The precession cycle shows about 34 cycles, which occur in an approximate 5:1 ratio with the eccentricity, and are associated with the occurrence of black shale beds as well. Much like the eccentricity, the precession varies much more in the lower half of the Hanover then becomes less exaggerated in the upper half. It is clear that the ~20 ka cycle corresponds to the 60 cm lithologic cycles in the lower half of the Hanover. This cycle is not as clear in the lithology of the upper portion of the section, although the signal is clear throughout the entire column based on the MS data (Fig. 3).

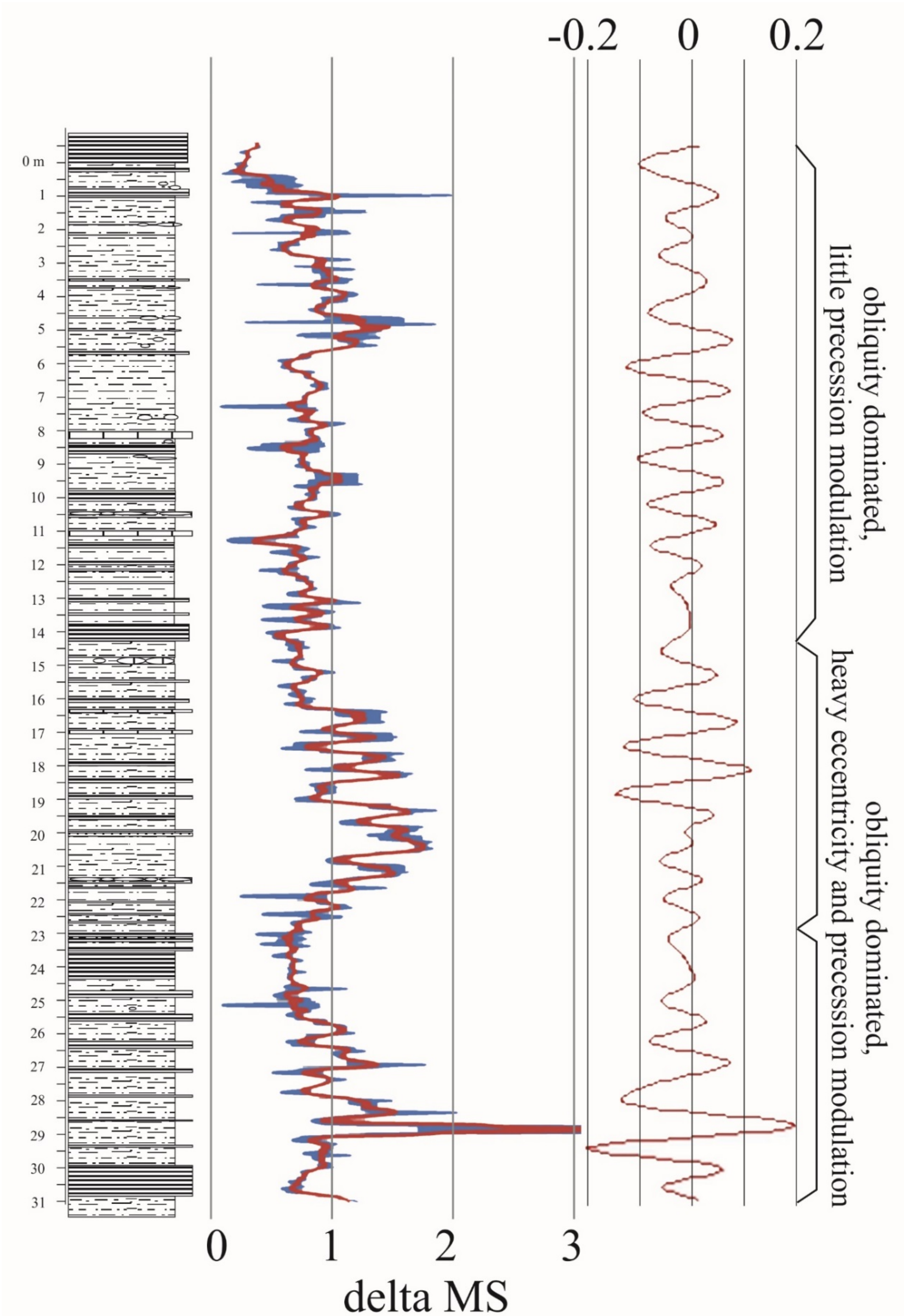


Fig. 3. Magnetic susceptibility values plotted as δMS (blue is data, red is spline of 5 values) and combined bandpassed signal of frequency analysis of three recognized cycles showing obliquity dominated cycles modulated by precession and eccentricity next to lithologic succession at Walnut Creek (see Fig. 2).

When the three cyclic frequencies are filtered together, it becomes apparent that the cycles not only modulate themselves, but also can dramatically affect each other. Again, the lower half of the Hanover is much more exaggerated compared to the upper, which implies that while the obliquity seems to be the metronome of the cycles according to the bandpass signal analysis, the depositional area was actually under significant influence from the precession and eccentricity cycles. The obliquity cycle is most apparent and unaffected in the lower Hanover, while in the upper half the obliquity may have been muted by the effects of the other two cycles. This is more apparent in the strata where there are more carbonate beds as compared to the alternating black and gray shales (Fig. 3).

The Upper Kellwasser Bed is expressed as a fissile black shale unit with some silty laminations in the upper part. This bed was designated the Point Gratiot Bed for the excellent exposure along Lake Erie at Point Gratiot at the southwest edge of Dunkirk, Chautauqua County (Over et al., 2013). This layer, which is 18 cm-thick along Walnut Creek, is traceable eastward to the vicinity of Hornell and Canisteo in Steuben County where it is approximately 2 meters-thick (Over, 1997; 2002). At Point Gratiot and at Beaver Meadow Creek at Java Village (Stop 1) the upper part of this layer has yielded articulated fish remains, including part of an arthrodire carcass (*Dunkleosteus*?) at Point Gratiot. At Beaver Meadow Creek, *Spathiocaris*, a probable cephalopod aptychus, are common. It is important to note that the Point Gratiot Bed does not mark the base of the Dunkirk Formation of the Canadaway Group as was indicated by Baird and Lash (1990) and Baird and Brett (1991); the Point Gratiot Bed marks an apparent change to finer grained, more basinal facies within the upper part of the Hanover Formation. Between Point Gratiot and Java Village the interval between the Upper Kellwasser Bed and the overlying Dunkirk thickens from 0.15 to 7 meters with addition of numerous alternating black and gray-green shale beds. At Walnut Creek the Point Gratiot Bed is 0.72 m below the base of the Dunkirk. The occurrence of reworked pyrite in the form of wire-like detrital burrow fragments at the bases of the black Dunkirk Shale and underlying upper Hanover black bands indicates that these contacts are of erosional character; some of the southwestward thinning of the upper Hanover is apparently due to collective overstep at such contacts (Baird and Lash, 1990).

The upper Frasnian Zone 13 (*linguiformis*)/*subperlobata-triangularis* chronozonal conodont boundary and inferred Frasnian-Famennian contact is crossed near or at the top of the Upper Kellwasser Bed based on work at Point Gratiot in Dunkirk, Irish Gulf, and at Beaver Meadow Creek in Java Village (see Over, 1997; 2002). Again, the major extinction event, observed globally at this level, is cryptic in the black shale facies except for the microfossil changes. A bed containing shelly taxa of earliest Famennian brachiopods and bivalves, in a thin, anomalous layer only one meter above the extinction horizon near Java Village, was described by Day and Over (2002). This “recovery layer” sheds important clues as to the nature of macrofossil changes in western New York following the mass extinction.

The Dunkirk Shale, which marks the base of the Canadaway Group, represents a significant deepening in the Appalachian Basin. The base of the Dunkirk is within the *Palmatolepis delicatula platys* (= Middle *triangularis*) conodont zone and corresponds to the base of the Huron Member of the Ohio, Gassaway Member of the Chattanooga, and Morgan Trail Member of the New Albany as well as other organic-rich shale units in North America. This extensive black shale body is the IIe transgression of Johnson et al. (1985). At Walnut Creek the lower Dunkirk black shale is on the order of 12 m thick.

Offshore-Onshore Correlations

Detailed correlation of shallow-water Upper Devonian strata in New York has been difficult due to the limited number exposed stratigraphic sections and their shortness relative to the thickness of the entire package. In addition, there is considerable variation in facies across the outcrop belt, with shales in the west and an increasing proportion of sandstones to the east. The history of correlation in this region is described in more detail by Pepper and deWitt (1950; 1951), Pepper et al. (1956), Smith and Jacobi (2000; 2001; 2006), and Bush et al. (2015).

There is a relatively continuous outcrop belt for the upper Frasnian and lower Famennian in Chautauqua, Erie, and western Wyoming counties in western New York ("western outcrop belt"; Fig. 1A), and geochronology is based on many methods, including lithostratigraphy (Pepper and de Witt, 1950; 1951; Pepper et al., 1956), conodont biostratigraphy (Over, 1997; 2002), goniatite biostratigraphy (House and Kirchgasser, 2008), carbon isotopes (Murphy et al., 2000; Tuite and Macko, 2013; Lash, 2017), and magnetic susceptibility (Tuskes et al., 2014).

After an interval of poor exposure, there is good exposure from the Genesee River Valley southeastward towards Tioga, PA ("eastern outcrop belt"; Fig. 1A). The proportion of coarse siltstone and sandstone increases greatly in the eastern outcrop belt, and several new formation names are applied to these intervals (Pepper and de Witt, 1950; 1951) (Fig. 1B,C). Unfortunately, conodonts and goniatites are less common in the shallower-water paleoenvironments of the eastern outcrop belt, where, until recently, geochronology has been based largely on lithostratigraphic correlations with the western outcrop belt. Traditionally, the Pipe Creek Formation of western New York was correlated with a dark gray shale unit directly on top of the Nunda Formation in the eastern outcrop belt (Pepper and de Witt, 1950; Rickard, 1964). Likewise, the Dunkirk Formation of western New York was often correlated with a dark gray shale above the Wiscoy Formation (Pepper and de Witt, 1950; 1951; Rickard, 1964), although Rickard (1975) and Roe (1975) presented alternate correlations (see discussion in Bush et al., 2015). Based on these correlations, the LKW should be located on top of the Nunda Formation and the UKW should be located near the top of the Wiscoy Formation (Fig. 1B).

Based on several lines of evidence, Bush et al. (2015) argued that these traditional correlations between offshore and onshore formations in New York were incorrect, and they presented revised correlations (Fig. 1C). Specifically, the Pipe Creek Formation was correlated with a dark shale above the Wiscoy Formation (not the Nunda Formation). The Dunkirk was correlated with a dark shale interval above the Canaseraga Formation, which was previously called the Hume Shale; this correlation had previously been suggested by Rickard (1975) and Roe (1975). These correlations suggest that the Kellwasser events occur higher in the section in the eastern outcrop belt than has been commonly suspected: the LKW-equivalent Pipe Creek Formation sits atop the Wiscoy Formation, and the UKW-equivalent Point Gratiot Bed (Over et al., 2013) should have an equivalent in the Canaseraga Formation (Fig. 1C).

Several lines of evidence supported the revised correlations (Bush et al., 2015):

1. The conodont *Palmatolepis winchelli* was found in the shale above the Wiscoy, indicating it was late Frasnian in age, not Famennian. Thus, it is unlikely to correlate with the Dunkirk Formation. The lower Famennian conodont *Ancyrognathus symmetricus* was found in the "Hume" Shale, which is consistent with a Dunkirk-Hume correlation.
2. The brachiopod *Spinatrypa planosulcata* commonly occurs in the lower parts of the Canaseraga Formation. Atrypid brachiopods are generally considered to have gone completely extinct in the Kellwasser extinctions, suggesting that the lower Canaseraga is Frasnian in age.
3. Correlating the Dunkirk with the shale above the Wiscoy implies that the Hume black shale exists only at the shallower end of the outcrop belt, which is odd because black shales are typically interpreted as the deepest-water facies in the basin.
4. The Dunkirk Shale is thicker than the Pipe Creek in western New York. Correlating the Dunkirk with the shale above the Wiscoy implies that it becomes much thinner in the eastern outcrop belt.
5. According to Pepper (1954), there is not actually a black shale of note above the Nunda in the Hornell area and eastward, despite depictions in summary diagrams.

The correlations shown in Fig. 1C solve these problems. All fossils considered to be markers for the Frasnian are in Frasnian strata; there is no black shale in the eastern outcrop best that lacks a correlative black shale in the deeper water to the west; and the eastward extensions of the Dunkirk and Pipe Creek are relatively similar in thickness to what is seen in the west.

Beard et al. (2017) proposed several additional changes to stratigraphic terminology. First, they suggested that the lower boundary of the Canaseraga Formation be extended downward to the top of the Pipe Creek. This solved two problems: first, Bush et al.'s (2015) correlations had left the rocks immediately above the Pipe Creek without a name, and second, the lower boundary of the Canaseraga had been placed at different horizons by different workers. The placement suggested by Beard et al. (2017) should be easier to recognize reliably across the basin. Beard et al. (2017) also began dividing the Canaseraga Formation into members (Fig. 1C).

In northern Pennsylvania, shallow-marine strata have been referred to the Lock Haven Formation (equivalent to the Chemung of New York) (Faill and Wells, 1977). In other words, all of the formations in the eastern end of the outcrop belt in New York are mapped one large formation (Berg et al., 1980), making it more difficult to identify and study Late Devonian bioevents. To make it easier to identify and discuss these events, Beard et al. (2017) proposed raising the Lock Haven to group status and dividing it into formations that match those present in New York. In the Tioga area, they recognized the Wiscoy, Pipe Creek, Canaseraga, Dunkirk, and Caneadea formations. In addition, Woodrow (1968) mapped Bradford County, Pennsylvania (to the east of Tioga) using many of the New York formation names.

FIELD GUIDE AND ROAD LOG: DAY 1

Meeting Point: Beaver Meadow Creek, Java Village, NY

Meeting Point Coordinates: N 42°40.33' W 78°26.15'

Meeting Time: 10:00 AM

Stop 1: Beaver Meadow Creek (Baird, Over)

Location Coordinates: N 42°40.33' W 78°26.15'

The strata exposed in Beaver Meadow Creek at Java Village (which are on private land) include the uppermost Angola and Nunda formations of the West Falls Group, the type locality of the Java Group (Pipe Creek Formation, including an anomalous "Nunda" facies, and Hanover Formation, including the initial coarser clastic strata that thicken to the east), and the lower portion of the Dunkirk Formation of the Canadaway Group. Approximately 50 m of strata are exposed along the bank, bed, and in several waterfalls. (Note that Fig. 1C suggests that these Nunda beds may actually correlate with the Wiscoy; until this question is examined in more detail, however, we continue to refer to them as Nunda.)

Two thick-bedded sandstone units are visible in Angel Falls in Java Village (Fig. 4). This is the uppermost part of the greater Nunda Sandstone succession characterized by light gray thin to thick bedded cross-laminated and bioturbated (*Planolites* and *Skolithos*) coarse silt–very-fine quartz sand. The gray sandstones and silty mudstones at the base of the falls are separated from the upper sandstone that forms the top of the falls by a thin (10 cm-thick) black shale that marks the base of the Pipe Creek Shale, the basal unit of the Java Group. The lower and medial part of the Nunda Formation interfingers and grades westward into the Angola Shale. The upper sand is stratigraphically distinct, designated "Nunda," as it interfingers and toes out westward within the Pipe Creek Shale (Baird and Jacobi, 1999) (Fig. 5). The base of the "Nunda" sharply overlies the thin basal black shale bed; the top is interbedded and mixed with black shale.

The brownish lumpy sandstone of the topmost "Nunda" and superajacent Pipe Creek Shale show chaotic bedding, irregular sandstone masses, and complex swirly interlayering of micaceous sandstone and sandy black shale. Diffuse breccia clasts of black shale within brown sandstone matrix suggests emplacement of fluidized sand into variable water-rich, surficial black mud deposits. The thick "Nunda" sandstone seems to be a major fan lobe sand unit (Jacobi et al., 1994; Baird and Jacobi, 1999). The "Nunda" flow event scoured the lowest Pipe Creek Shale as indicated by olistoliths of Pipe Creek Shale within the massive unit at several localities. The uppermost chaotic and diffuse "Nunda" Sandstone may represent later, smaller flow events. These sands were also reworked by storm waves as indicated by hummocky cross-stratification.

At Beaver Meadow Creek the Pipe Creek Formation is 6.2 m of organic-rich shale and the underlying 3 m of fine quartz sand of the "Nunda." A deep recessive bed at ~1.1 m is a possible tephra bed; a tephra was also described from the upper Pipe Creek at Eighteenmile Creek, as well as the upper Pipe Creek along PA 287 (Ver Straeten et al., in revision). The Pipe Creek has a limited benthic fauna consisting mainly of inarticulate brachiopods. Nektic fauna/flora consists of dacryoconarids, cephalopods, and algal spores; conodonts are uncommon, consisting of *Ancyrodella, Palmatolepis*, and *Polygnathus* indicative of FZ 12 (Over, 1997).

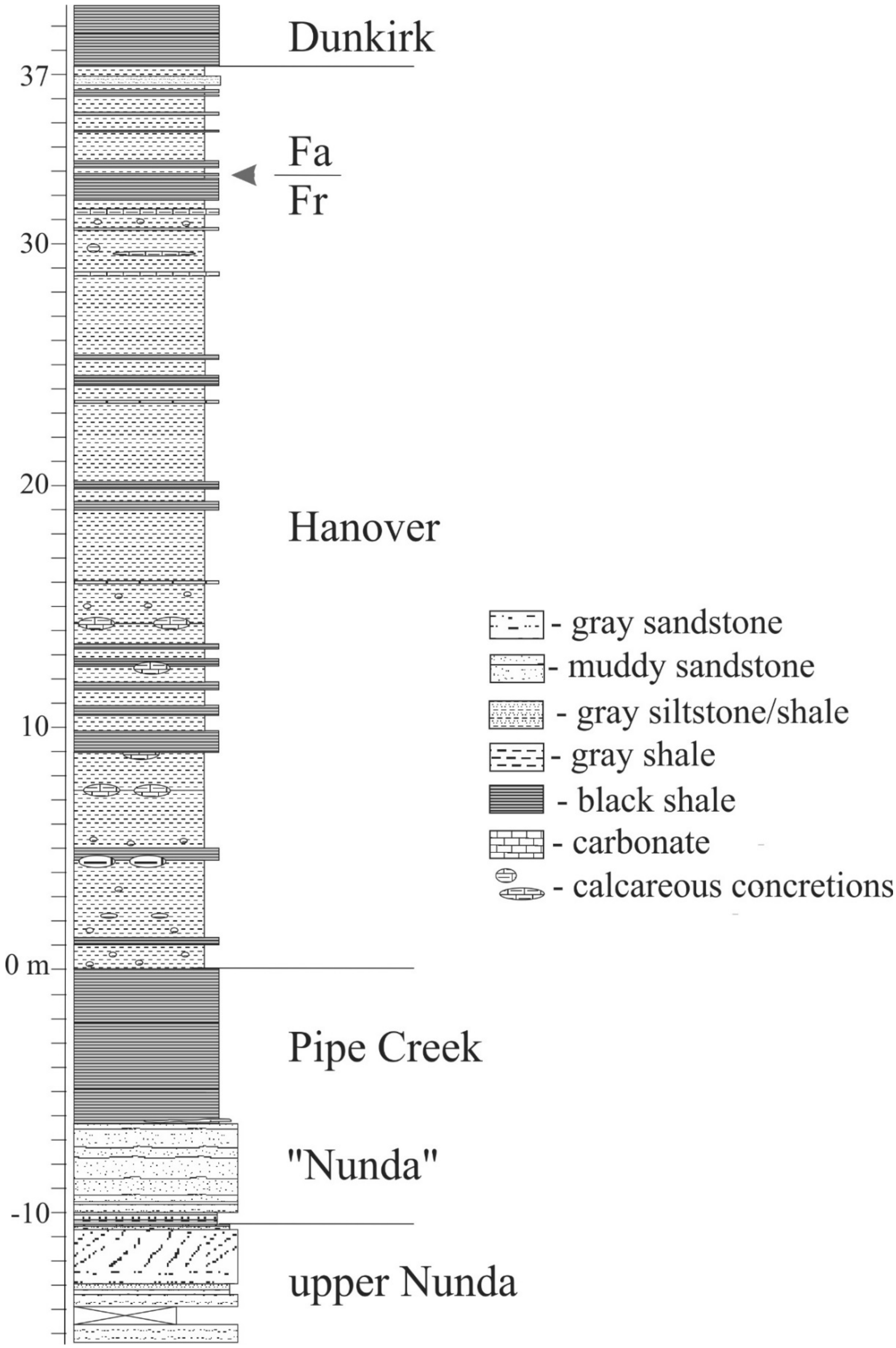


Fig. 4. Schematic diagram of the Java Group and adjacent strata exposed in the bed and banks of Beaver Meadow Creek at and upstream from NY 78 in Java Village. Fa = Famennian; Fr = Frasnian.

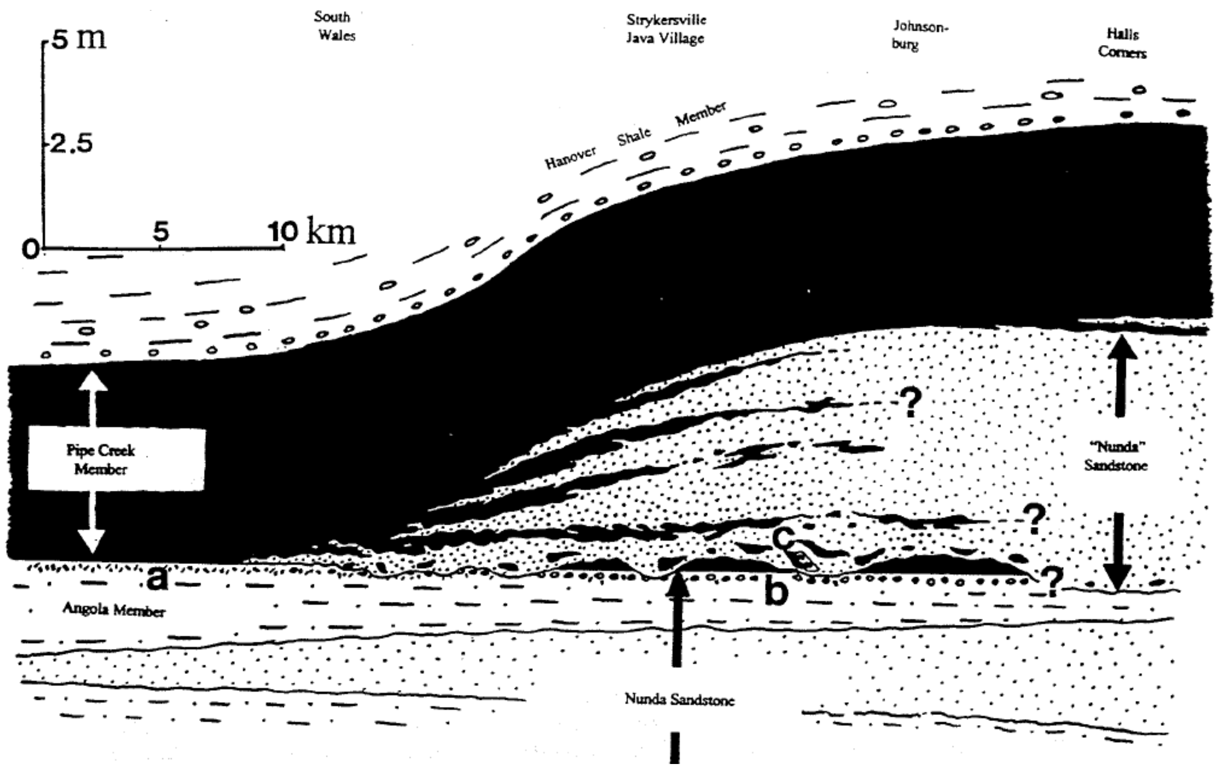


Fig. 5. Generalized east-west cross-section of the Pipe Creek Formation and associated stratigraphic units in the "western" outcrop region in Erie and Wyoming counties. Lettered features include: a, pyrite-rich zone of the Angola Shale below Pipe Creek Formation in eastern Erie County; b, carbonate nodule-rich zone below lower contact of Pipe Creek shale in non-eroded inlier below "Nunda" sandstone; c, olistolith showing exhumed Angola-Pipe Creek contact. Question marks denote uncertainty as to the position southwest of Warsaw, NY, and as to whether discrete "Nunda" beds within Pipe Creek in the Strykersville area amalgamate eastward to give the impression of a single massive flow event or whether the massive bed in the Johnsonburg-Halls Corners area is truly a single event (from Baird and Jacobi, 1999).

The Hanover Formation along Beaver Meadow Creek is 37.5 m thick consisting of intensely bioturbated gray shale interbedded with argillaceous nodular carbonate beds, calcareous nodules, and organic-rich laminated shales (Fig. 4). Concretion horizons, some with concretions ranging up to 0.7 m in diameter, are common in the lower half of the section. Similar to Walnut Creek strata, gray shale and thinner black shales and carbonates occur in near-meter scale cycles. These correspond to ~20 ka precession cycles as seen at Walnut Creek; the longer scale cycles are also evident in the organic- and less-organic-rich strata packages.

Calcareous concretions in the lowermost Hanover contain a diverse nektic and low-diversity benthic fauna of acrotretid brachiopods, ostracodes, tentaculitids, the goniatites *Delphinites cataphractus* and *Sphaeromanticoceras*, and notably the conodont *Palmatolepis bogartensis* which indicates the base of FZ 13, the highest Frasnian conodont zone. The overlying gray shales contain a pyritized molluscan fauna dominated by gastropods. The middle Hanover is notably siltier, both in the gray shales and organic-rich shales, indicative of a more proximal source area compared to Walnut Creek. A thin carbonate bed at 24.5 m in the section yielded abundant conodonts, including *Pa. hassi* s.s. and *Pa. juntianenesis*. Other carbonate horizons contain crinoid debris and the small solitary rugose coral

Metriophyllum. The Point Gratiot Bed rests on a long platform above the last waterfall. The base of the Dunkirk Formation is 4.5 m higher.

The Frasnian-Famennian boundary horizon is at or just below the top of a 10-cm organic-rich black shale bed that has distinct 1-2 cm wide light colored horizontal *Thalassinoides* burrows (cf. Boyer et al., 2014). This bed rests on a 0.7 m thick organic-rich black shale—the Pt. Gratiot Bed—that has a recessive weathering lamination at the base that is possibly equivalent to the Center Hill Tephra in Tennessee (Fig. 6). The top of the Pt. Gratiot Bed is a disconformable surface that yields abundant coalified wood and fish material, including an articulated skeleton of the placoderm *Coccosetus*? (similarly, part of an arthrodire carcass, possibly *Dunkleosteus*, was excavated from the Pt. Gratiot Bed at Point Gratiot in the 1980s). The nowakiid *Homoctenus* is relatively common to abundant on bedding planes, and has been recovered above the boundary in several places. These are some of the last dacryoconarids documented.

The Hanover Formation above the Pt. Gratiot Bed consists of bioturbated gray shales with thin interbeds of black shale, siltstones, and fine sandstones. Approximately 1.5 m above the Frasnian-Famennian boundary is a thin shell-rich bed that contains abundant articulate brachiopods, notably *Retichonetes, Tylothyris*, and *Praewaagenoconchia,* as well as the lingulid *Barroisella* (Day and Over, 2002). A thin sand just below the Dunkirk represents a bed of Canaseraga facies before the IIe deepening.

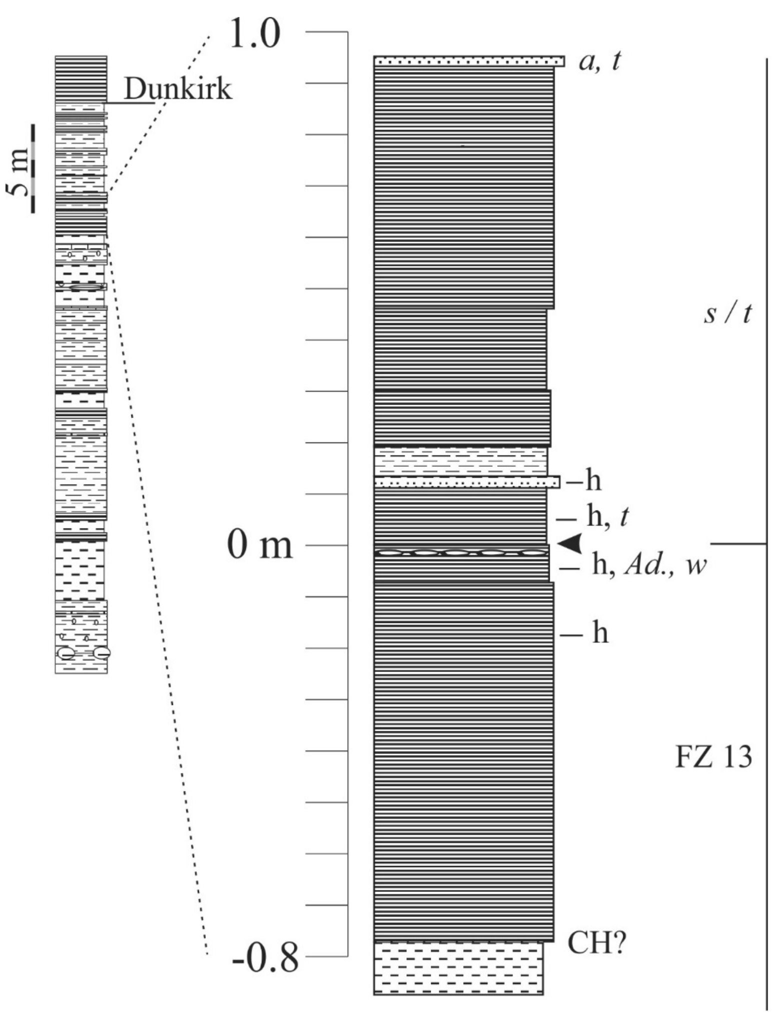


Fig. 6. Schematic diagram of Pt. Gratiot Bed and adjacent strata in the upper Hanover Formation along Beaver Meadow Creek. Frasnian-Famennian boundary is marked by arrow. a = *Icriodus alternatus*; Ad. = *Ancyrodella curvata*; CH = Center Hill Tephra; FZ = Frasnian conodont Zone; h = dacryoconarids (mostly *Homoctenus*); s = *Palmatolepis subperlobata*; t = *Pa. triangularis*; w = *Pa. winchelli*.

STOP 2: Wiscoy Creek

Location Coordinates: N 42°30.280' W 78°5.014'

Wiscoy Creek is the type location of the Wiscoy Formation, and the section has been illustrated and discussed by many authors (e.g., Pepper and de Witt, 1950; Pepper and de Witt, 1951; Smith and Jacobi, 2000; 2001; 2006; Bush et al., 2015). Overlying the Wiscoy Formation is a black shale unit that has often been correlated with the Dunkirk Formation (Pepper and de Witt, 1950; 1951; Smith and Jacobi, 2000; 2001; 2006), but that Bush et al. (2015) correlated with the Pipe Creek Formation (Fig. 7).

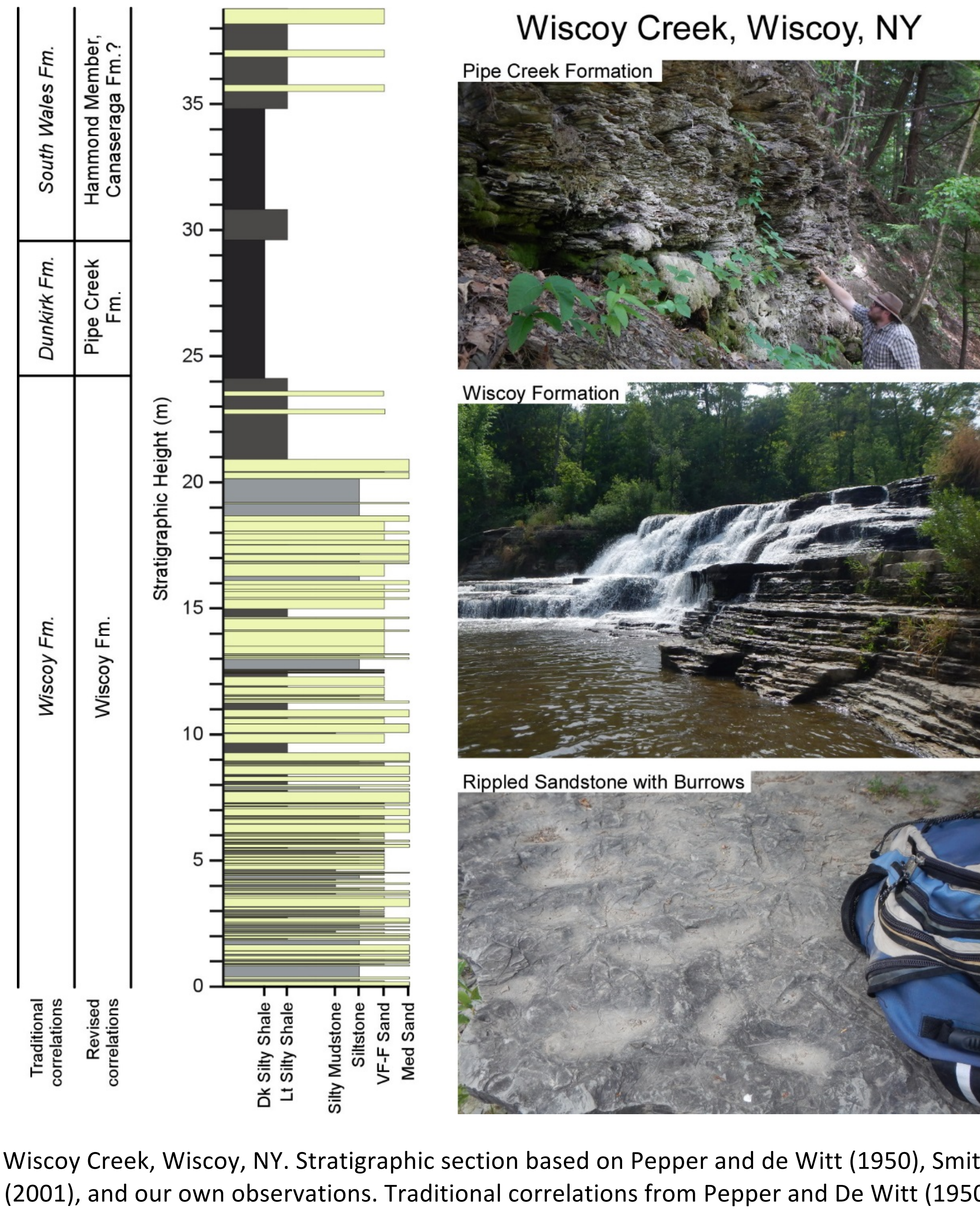


Fig. 7. Wiscoy Creek, Wiscoy, NY. Stratigraphic section based on Pepper and de Witt (1950), Smith and Jacobi (2001), and our own observations. Traditional correlations from Pepper and De Witt (1950, 1951), and revised correlations from Bush et al. (2015) and Beard et al. (2017) (see Fig. 1B, C).

Smith and Jacobi (2001) interpreted the depositional environment of the Wiscoy as lower shoreface, transitioning to more offshore environments in the upper part of the formation. (They also suggested a lagoon or bay as a possibility, but given our observations of the Wiscoy in more proximal settings, that is less likely.) Body fossils are scarce, but trace fossils are abundant in the Wiscoy; Smith and Jacobi (2001) noted the presence of *Skolithos*, *Arenicolites*, *Teichichnus*, *Planolites*, *Rhizocorallium*, and *Zoophycos*.

The dark shale that we correlate with the Pipe Creek Formation, and that previous authors have correlated with the Dunkirk Formation, is visible on the north bank by the dam. It consists of dark, silty shale interpreted as an offshore environment, possibly with low oxygen levels (Smith and Jacobi, 2001). It is overlain by sandstones or siltstones, visible above the dam, that could be correlative with the Hammond Member of the Canaseraga Formation, as defined by Beard et al. (2017).

STOP 3: Mills Mills, Wiscoy Creek

Location Coordinates: N 42°30.12' W 78°07.18'

The Mills Mills locality (Fig. 8) is also located along Wiscoy Creek, upstream from Location 2. The upper part of the Canaseraga Formation is exposed along the creek on private land, downstream from the parking area, and the Dunkirk Formation ("Hume Shale") is exposed along Pond Road and adjacent roads. Smith and Jacobi (2001) indicated that there is approximately 30 m of section between the Pipe Creek and the base of the exposure at Mills Mills.

A meter or two of sandstone and siltstone are exposed at the base of the Mills Mills outcrop, followed by a dark silty shale with interbedded siltstones (Fig. 8). This is overlain abruptly by a thick amalgamated sandstone. Smith and Jacobi (2001, 2006) defined this sandstone as the base of the Mills-Mills Formation, and Beard et al. (2017) treated it as the base of the Mills Mills Member of the Canaseraga Formation. Smith and Jacobi (2001) interpreted these sandstone beds as "TA/B starting turbidites (proximal) that represent channel deposits" in "a channel-levee complex in a prograding deep sea fan. The interbedded shales and siltstones may represent interchannel deposits." An additional sandstone bed at the top of the Mills Mills was interpreted similarly. Much of the remainder of the Mills Mills consists of gray and black shales, interpreted as representing the beginnings of the deepening that culminated in the Dunkirk ("Hume") Shale.

Given the correlations proposed by Bush et al. (2015) (Fig. 1C), the UKW plausibly is exposed at the Mills Mills section, somewhere within the upper Canaseraga Formation. There are numerous intervals of black or dark gray shale that could be correlative with the Point Gratiot Bed. Carbon isotope analysis (in progress) may resolve this question.

Below the top of the Beaver Meadow Creek section is a thick, falls-capping bundle of turbiditic beds, followed by a major transgressive kick to black shale approximately 25 - 30 m above the top of the UKW. If the turbiditic bundle and highest black shale interval on Beaver Meadow Creek are respectively correlative to the Mills Mills and Hume divisions, then this should provide a clue as to the best interval along Wiscoy Creek for searching for the UKW on Wiscoy Creek, knowing the aggregate thickness of the Canaseraga interval at that locality. Moreover, the conspicuous lithologic change from intensely bioturbated, nodular, gray mudrock (lower–middle Hanover interval) below the F-F transition into variably turbiditic, dark shale facies above it at Beaver Meadow Creek, should still be quite findable on Wiscoy Creek, given the modest 25 km distance between the two sections. The shell-rich "recovery bed" above the UKW, noted by Jeff Over at Glade and Beaver Meadow creeks, might also be similarly present above the UKW on Wiscoy Creek and better developed in this upslope setting.

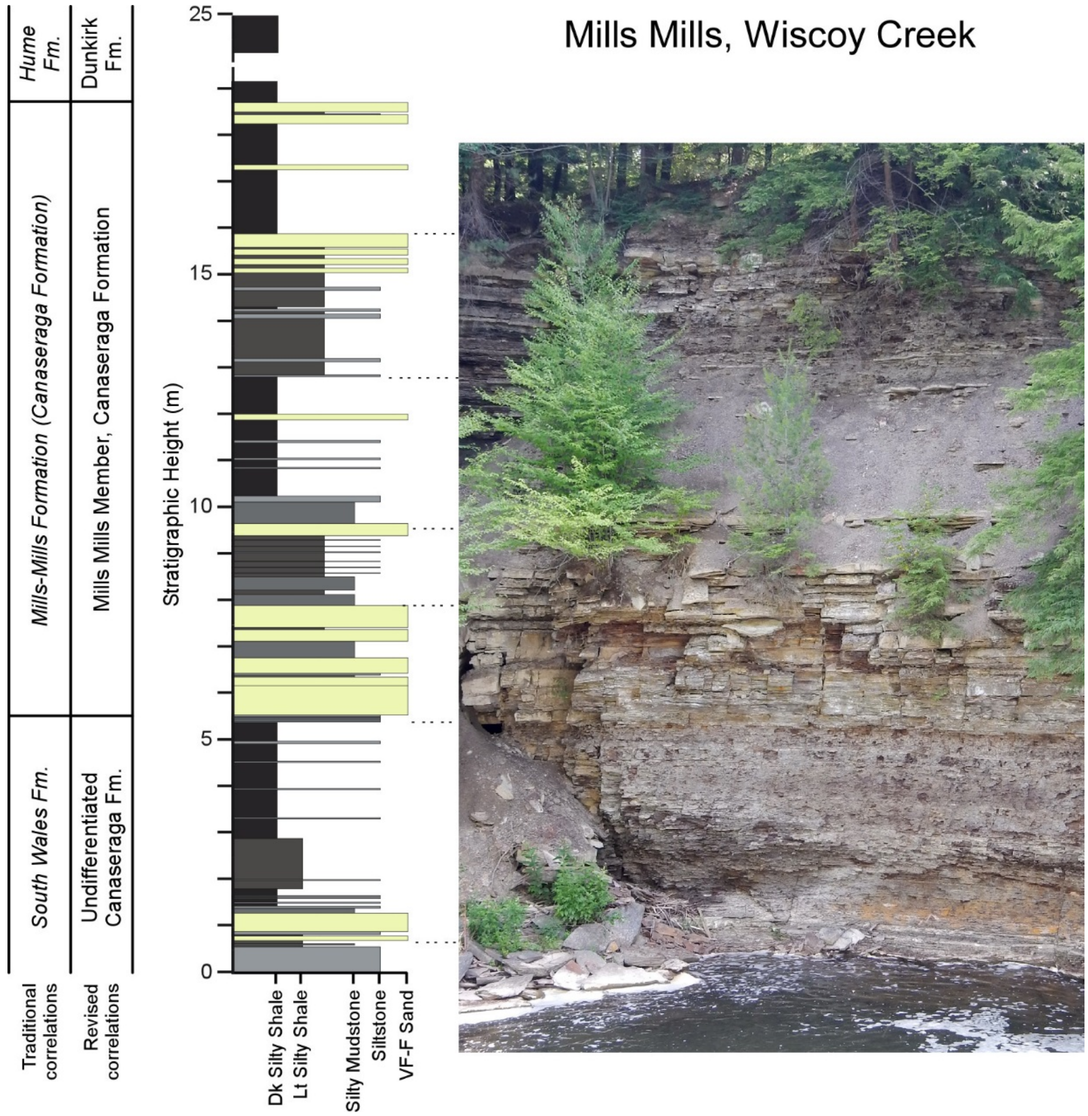


Fig. 8. Mills Mills, Wiscoy Creek, NY. Stratigraphic section based on our own observations. Traditional correlations from Smith and Jacobi (2001); revised correlations from Bush et al. (2015) and Beard et al. (2017) (see Fig. 1B, C).

DAY 2 - FRASNIAN-FAMENNIAN BOUNDARY INTERVAL IN TIOGA COUNTY, PENNSYLVANIA

(Bush, Beard, Brisson, Pier, Over, Baird)

Brachiopod Biostratigraphy

Macrofossil biostatigraphy has long been essential in establishing correlations in the Upper Devonian of the Appalachian Basin (e.g., Chadwick, 1935; Dutro, 1981; Warne and McGhee, 1991; Rossbach, 1992; Brame, 2001), and we present a revised stratigraphic range chart for biostratigraphically important brachiopod species (Table 1) along with photographs of species from the Wiscoy-Candeadea formations (Figs. 9-49). The range chart expands on the one presented by Bush et al. (2015). We expect to add more species to the range chart, but for now we include only those that we are reasonably certain can serve as stratigraphic markers—other species either ranged from the Wiscoy through Caneadea formations, or their range is uncertain. Some ranges may be extended as collecting continues.

The greatest turnover of species occurs from the Wiscoy to the Canaseraga—that is, across the Pipe Creek Formation/Lower Kellwasser equivalent according to revised correlations (Bush et al., 2015). The turnover across the Upper Kellwasser is much less pronounced, although additional work may pinpoint additional species that go extinct in the Upper Kellwasser event or first occur shortly thereafter.

Table 1. Stratigraphic ranges of biostratigraphically useful brachiopod species. The two species marked by asterisks only occur in the lowermost Canaseraga (Hammond Member).

	Wiscoy	Lower Canaseraga	Upper Canaseraga-Caneadea
	pre-LKW	LKW-UKW	post-UKW
Douvillina arcuata	X		
Douvillina cayuta	X		
Strophonelloides coelata	X		
Nervostrophia nervosa	X		
Orthid sp. A	X		
Stainbrookia infera	X		
Pseudoatrypa devoniana	X		
"Spirifer" williamsi	X		
Cyrtina cf. *hamiltonensis*	X		
Schizophoria amanaensis	X	*	
Spinatrypa cf. *hystrix*	X	*	
Cyrtospirifer chemungensis	X	X	
Spinatrypa planosulcata		X	
"Productella" rectispina		X	?
Semiproductus onustus		X	X
"Productella" stigmata		X	X
"Thiemella" leonensis		X	X
Jacoburbirostrum duplicatus		X	X
"Athyris" angelica		X	X

Many of the species documented here are in need of taxonomic revision; some have not been examined in detail since the various work of James Hall (e.g., Hall, 1867; Hall and Clarke, 1892; 1894). Here, we merely seek to provide photographs of the fossils, since standard guidebooks (Linsley, 1994; Wilson, 2014) only contain reprints of Hall's lithographs, and some species are not included. We make no attempt at taxonomic revision—for continuity with existing literature, we use previously applied genus names, often from Linsley (1994). Our identifications are based on comparisons with published works and, in many cases, type specimens. Locality information is provided in Table 2, after the figures. In a few cases, we have photographed fossils from other Upper Devonian formations in order to show better specimens. This work is still in progress, so additional species may be recognized in the future.

Lingulates

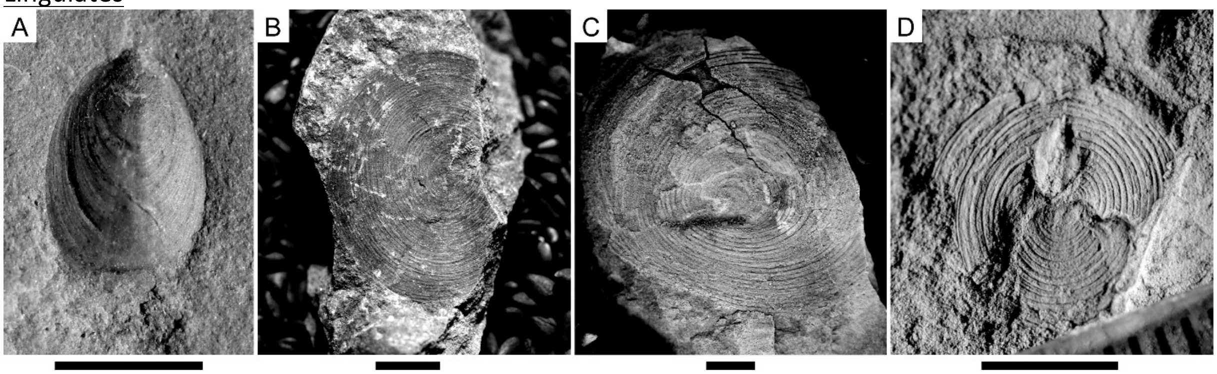


Fig. 9. **Lingulate brachiopods**. We have not attempted to identify these in detail, but both linduloids (**A**) and discinoids (**B-D**) are present. A. Sample ERC-1. B. Sample TGA 20. C. Location ERC. D. Sample CAM 160. Canaseraga Formation. Scale bars = 5 mm.

Strophomenids

Fig. 10. ***Douvillina arcuata***. **A**. Ventral internal mold, sample BCP 106. **B**. Dorsal internal mold, sample CAM 43. **C**. Dorsal external mold, CAM 43. Wiscoy Formation. A-B reprinted from Bush et al. (2015), with permission from Elsevier.

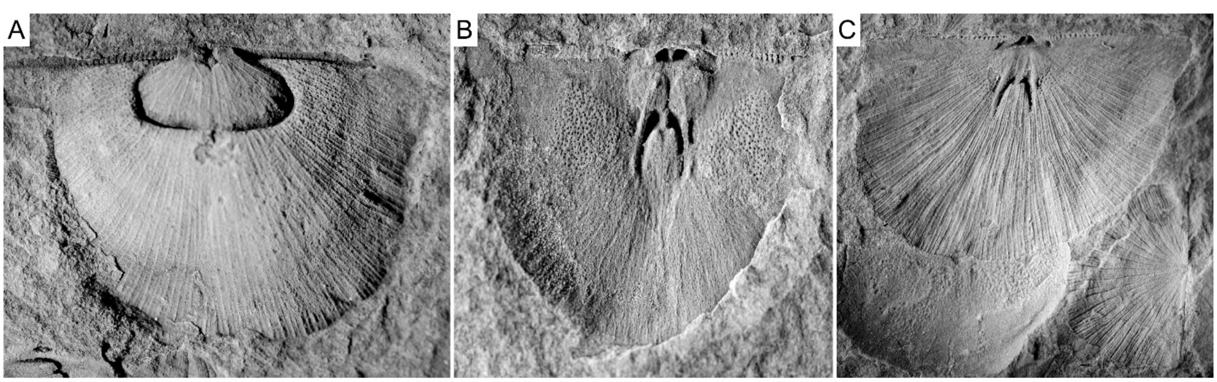
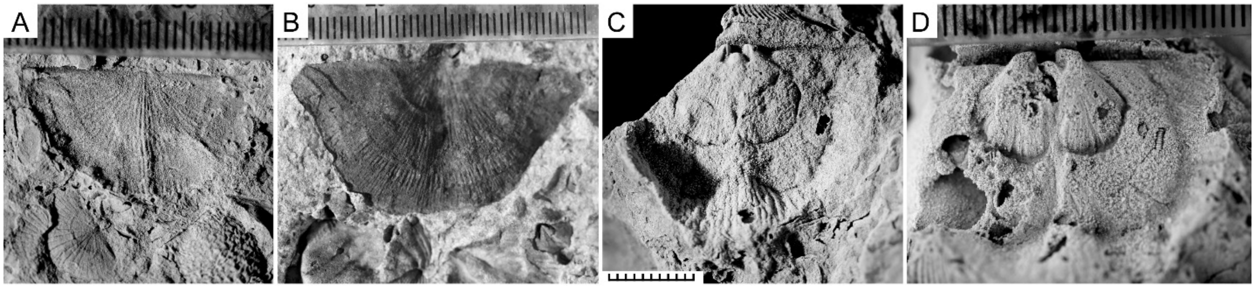


Fig. 11. ***Douvillina cayuta***. **A**. Ventral internal mold. **B**. Dorsal internal mold. **C**. Dorsal internal mold (upper) and exterior mold (bottom right). Location WEL, Gardeau Formation. Scale bars = 5 mm.



E

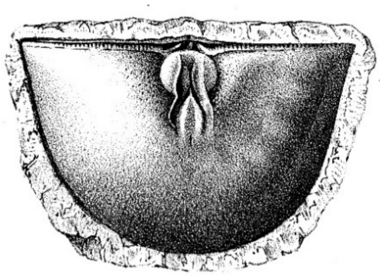


Fig. 12. ***Strophonelloides coelata***. **A**. Ventral external mold, location CRR. **B**. Dorsal external mold, location ADR. **C**. Ventral internal mold, sample TGB 5. **D**. Ventral internal mold, sample CAM 12. **E**. Dorsal internal mold, from Hall (1867, plate 19, fig. 7). Panel A from the Nunda Formation, B-D from the Wiscoy Formation. Scale bars in mm. C reprinted from Bush et al. (2015), with permission from Elsevier.

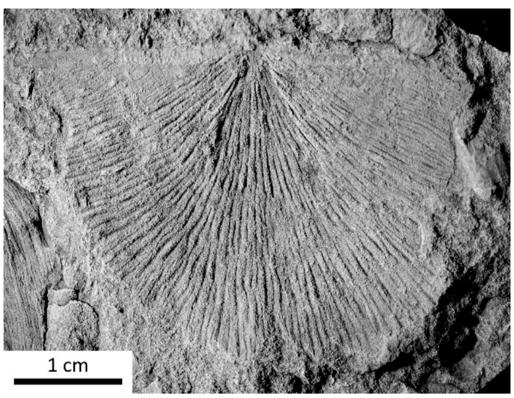


Fig. 13. ***Nervostrophia nervosa***. Mold, location BPH. Wiscoy Formation. Reprinted from Bush et al. (2015), with permission from Elsevier.

Chonetids

Fig. 14. **Chonetid brachiopods**. The small forms are not always well preserved, and we have not tried to identify them in detail. **A**. Ventral external mold, location CRR, Nunda Formation. **B**. Sample CAM 108, Canaseraga Formation. **C**. Sample CAM 106, Canaseraga Formation.

Productids

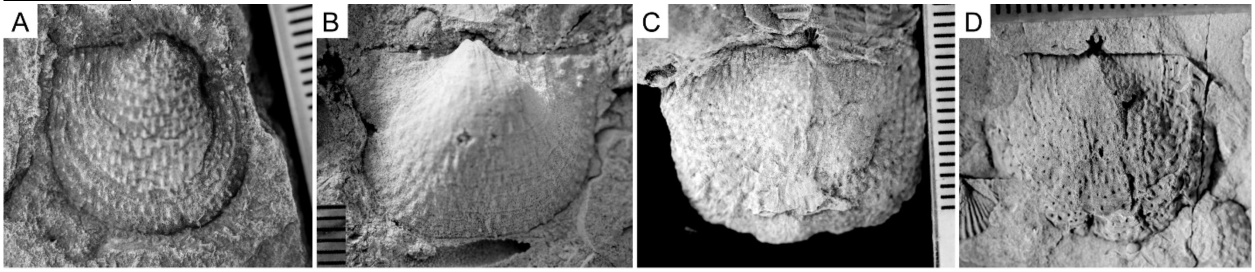


Fig. 15. ***Praewaagenoconcha speciosa***. **A-B**. Ventral molds, CAM 152 and TGA 35, Canaseraga Formation. **C**. Dorsal valve, mold, CAM 148, Canaseraga Formation. **D**. Dorsal valve, mold, Rt. 119 north of Cameron, NY, Wiscoy Formation.

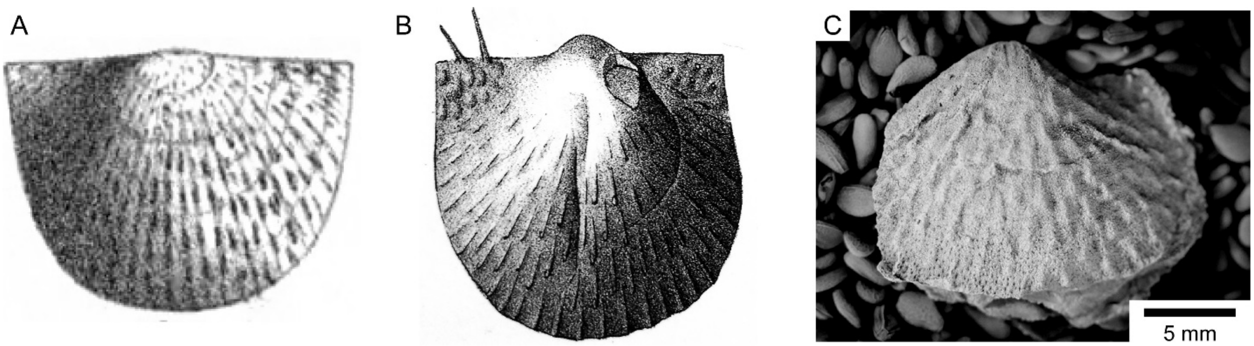


Fig. 16. ***Praewaagenoconcha lachrymosa***. **A-B**. Ventral valves from Conrad (1842) and Hall (1867). Chemung Narrows, Gardeau Formation, the type locality. **C**. Possible *P. lachrymosa*, CAM 132, Canaseraga Formation. Hall (1867) also illustrated fossils from well into the Famennian as *P. lachrymosa*, some of which do not greatly resemble the Chemung Narrows forms. We suspect that some of these belong to a different species. Leighton (2000) felt that *P. lachrymosa* and *P. speciosa* from the late Frasnian were conspecific, representing a morphological gradient.

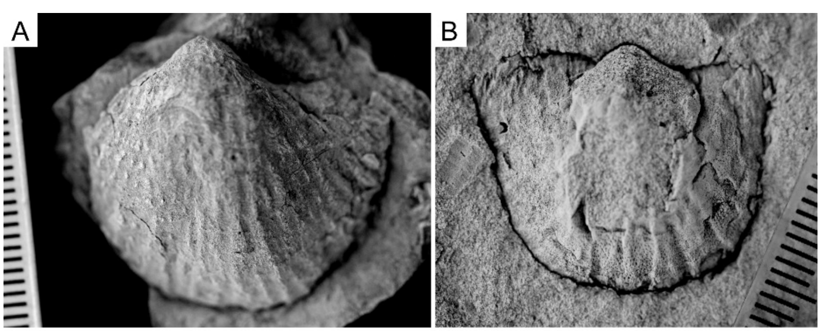


Fig. 17. Productid with ridges. Possibly *Spinulicosta arctirostrata*, or poorly preserved *P*. *lachrymosa*? **A**. Ventral valve, location TGA, base of section. **B**. Ventral valve, location SWA. Canaseraga Formation. Scale in mm.

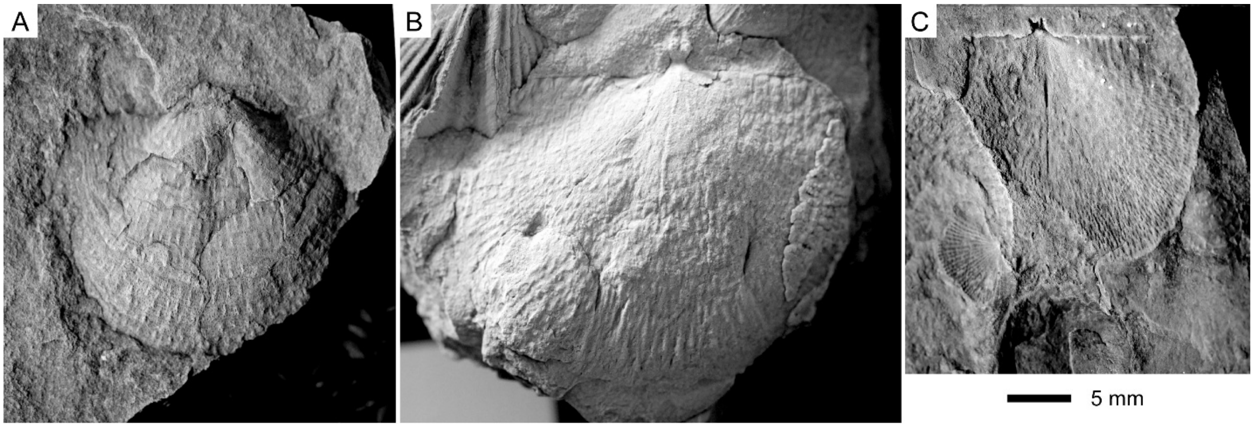
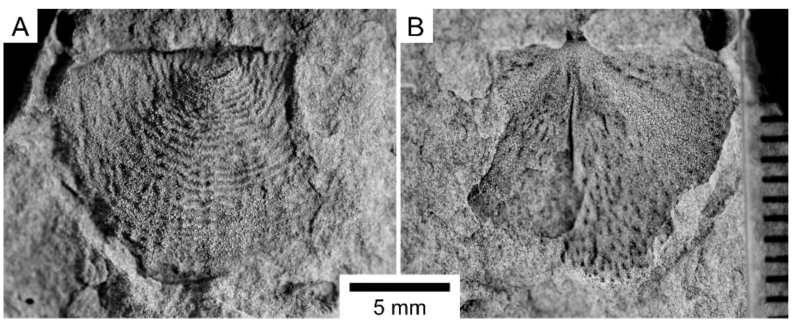


Fig. 18. ***Semiproductus onustus***. **A**. Ventral exterior, location TGA, float, Canaseraga or Caneadea formation. **B**. Dorsal interior, sample TGA 45, Canaseraga Formation. **C**. Dorsal interior mold, sample CAM 108, Canaseraga Formation.



F **Fig. 19**. ***Devonoproductus* cf. *walcotti***. **A-B**. Dorsal external and internal mold, sample BCP 106. Wiscoy Formation.

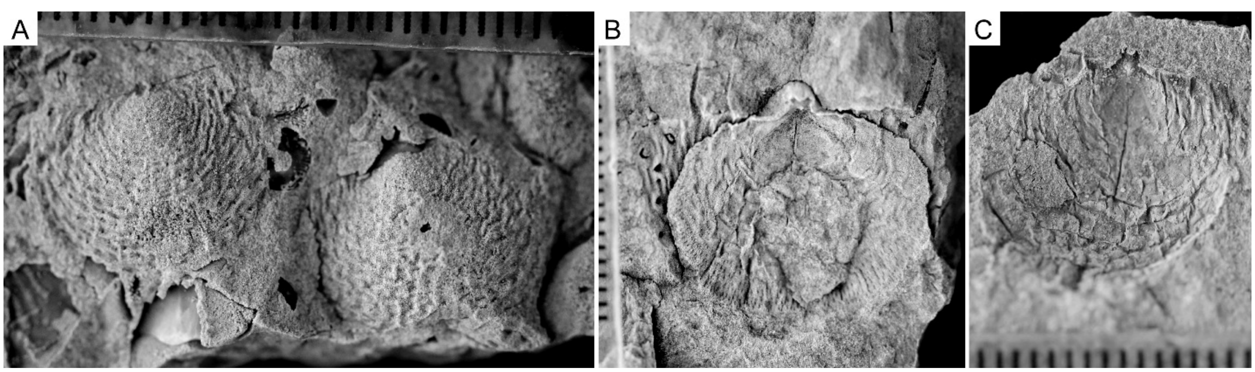


Fig. 20. ***Whidbornella hirsuta***. **A**. Sample CAM 20, Wiscoy Formation. **B**. Dorsal interior mold overlying ventral exterior mold, sample BCP 22, Wiscoy Formation. **C**. Dorsal internal mold, location EHR, base of section, Canaseraga Formation. Scale in mm.

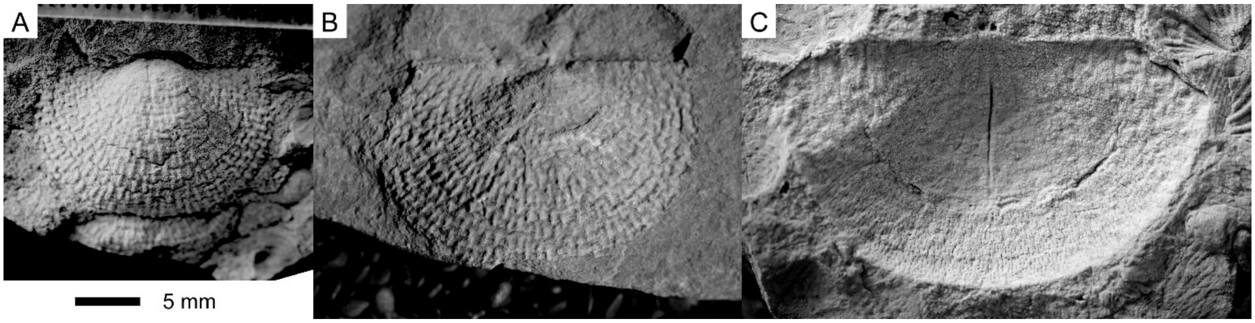


Fig. 21. ***"Productella" rectispina***. **A**. Ventral, location CSA. **B**. Dorsal, sample CAM 79F. **C**. Dorsal internal mold, sample CAM 110. Canaseraga Formation.

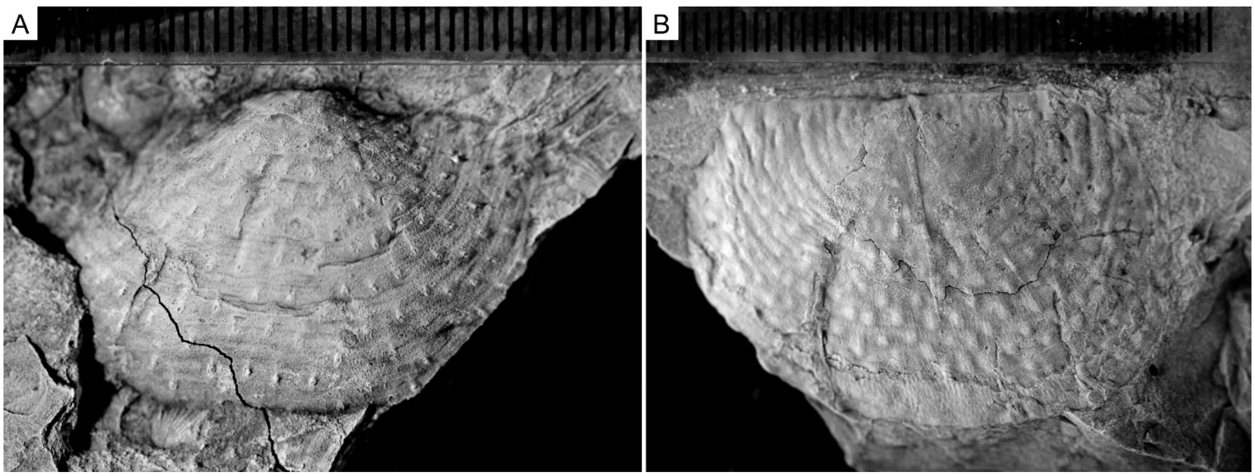


Fig. 22. "*Productella*" *stigmata*. **A-B**, Ventral and dorsal, location PD. Mapped as the Towanda Formation (Woodrow, 1968) or Lock Haven Formation (Berg et al., 1980); these fossils are from strata that are probably equivalent to the Caneadea Formation. This species resembles *Productella lachrymosa* var. *stigmata* Hall (1867), although some fossils that he described as *P. lachrymosa* may belong to this species as well. Scale bars in mm.

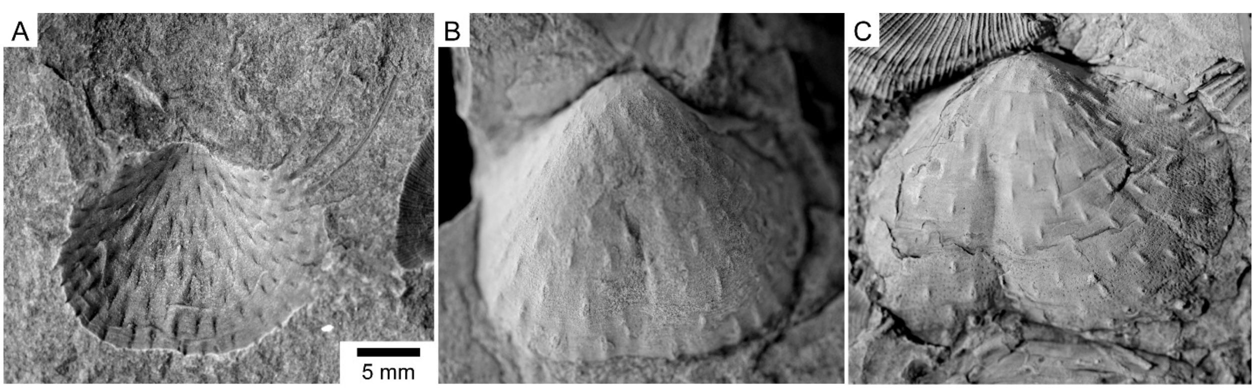


Fig. 23. **"*Productella*" *boydii***. **A**. Ventral external mold, location USA. **B**. Ventral, sample TGA 16R. C. Ventral, location TGB. Canaseraga Formation.

Orthotetids

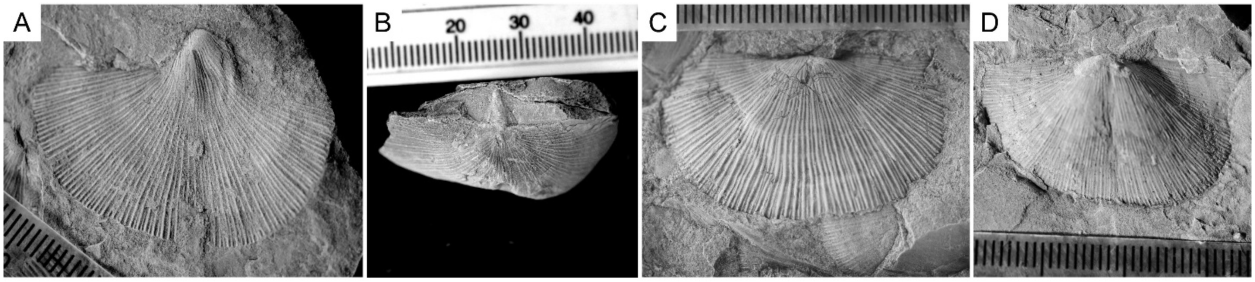


Fig. 24. ***Floweria chemungensis***. **A**. Location TGA, float, Canaseraga or Caneadea. **B**. Ventral exterior, oblique view showing delthyrium, location TGA, base of section, Canaseraga Formation. **C**. Location TGA, float, Canaseraga or Caneadea. **D**. Ventral exterior, location CAM, float, Wiscoy or Canaseraga. All scale bars in mm. See Stigall Rode (2005) for more information on the genus.

Orthids

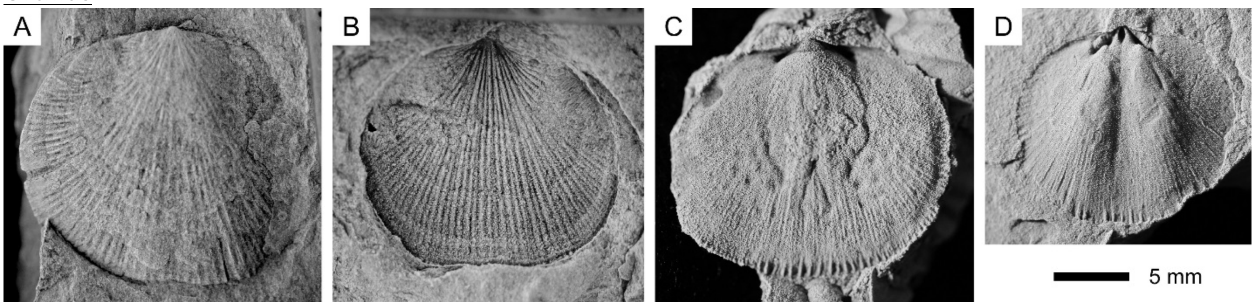


Fig. 25. "*Thiemella*" *leonensis*. A. Exterior, sample SLD-2013. **B**. Exterior mold, location unknown. **C**. Ventral internal mold, sample CAM 132. **D**. Dorsal internal mold, float from above the Pipe Creek Formation, location BCP. Canaseraga Formation. C-D reprinted from Bush et al. (2015), with permission from Elsevier.

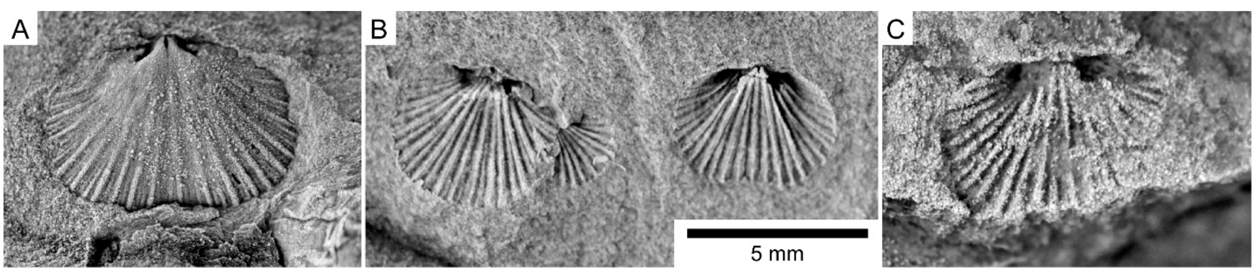


Fig. 26. **"*Dalmanella*" *allegania* (?)** of Williams (1908). **A**. Dorsal internal mold, location BCP, float, above the Pipe Creek Formation, thus presumably Canaseraga Formation. **B**. Same location. **C**. Location PCR, Canaseraga Formation.

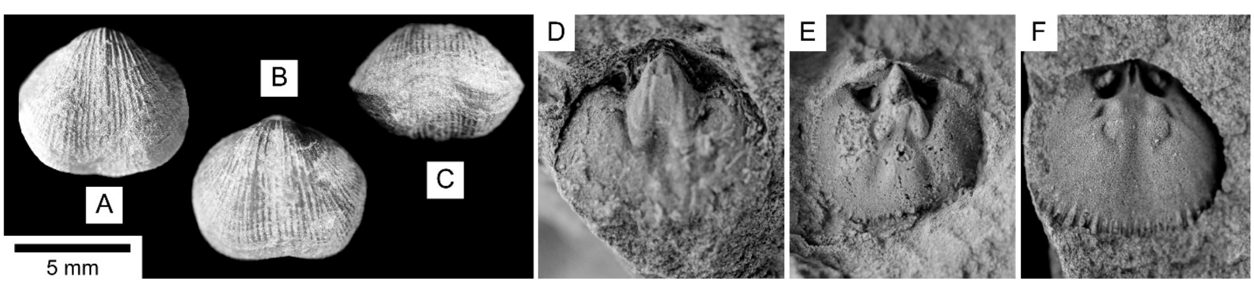


Fig. 27. ***Stainbrookia infera*. A-C**. Ventral, dorsal, and anterior views, location HNS. **D**. Ventral internal mold, sample BCP 125. **E**. Ventral internal mold, location DAN. **F**. Dorsal internal mold, location BRC. Wiscoy Formation. A-C reprinted from Bush et al. (2015), with permission from Elsevier.

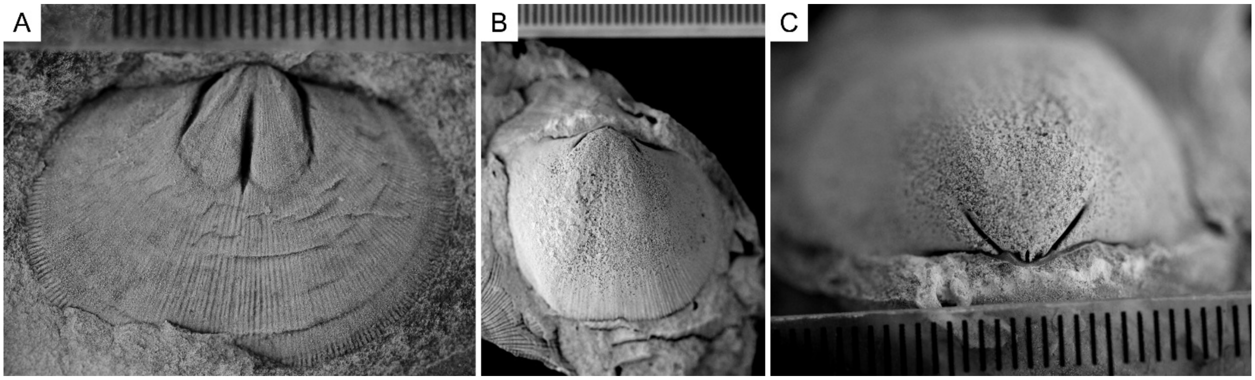


Fig. 28. ***Schizophoria impressa*****, "small" morphotype. A**. Ventral internal mold, sample PCE-1. **B-C**. Dorsal internal mold, sample TGA 1. Scale bars in mm. Canaseraga Formation. See Stigall Rode (2005) for more information on the genus. As defined by Hall (1867), *Schizophora impressa* appears to encompass two forms, referred to here as "small" and "large".

Fig. 29. ***Schizophoria impressa*****, "large" morphotype**, ventral internal mold, location SGU. Scale in mm. Canaseraga Formation.

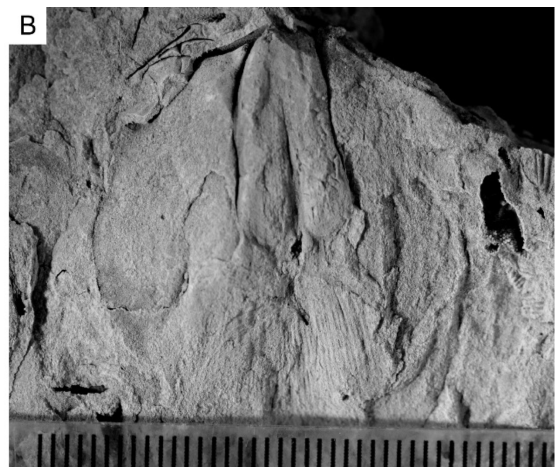


Fig. 30. ***Schizophoria*** **sp.?** Ventral internal mold, sample TGA 27. Scale in mm. Canaseraga Formation.

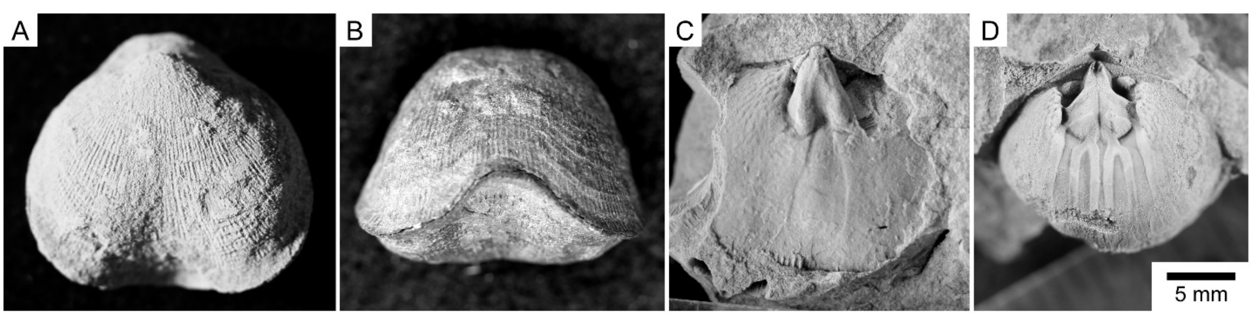


Fig. 31. ***Schizophoria amanaensis***. **A-B**. Ventral and anterior views, location HNS. **C**. Ventral internal mold, sample DAN 30. **D**. Dorsal internal mold, sample BCP 134. Wiscoy Formation. A, B, and D reprinted from Bush et al. (2015), with permission from Elsevier.

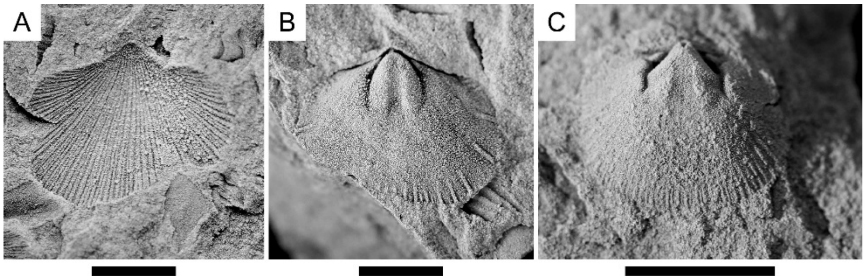


Fig. 32. **Orthid sp. A** (Bush et al. 2015). **A-B**. Ventral external and internal molds, sample CAM 23. **C**. Dorsal internal mold, sample BCP 53. Scale bars = 5 mm. Wiscoy Formation. Reprinted from Bush et al. (2015), with permission from Elsevier.

Rhynchonellids

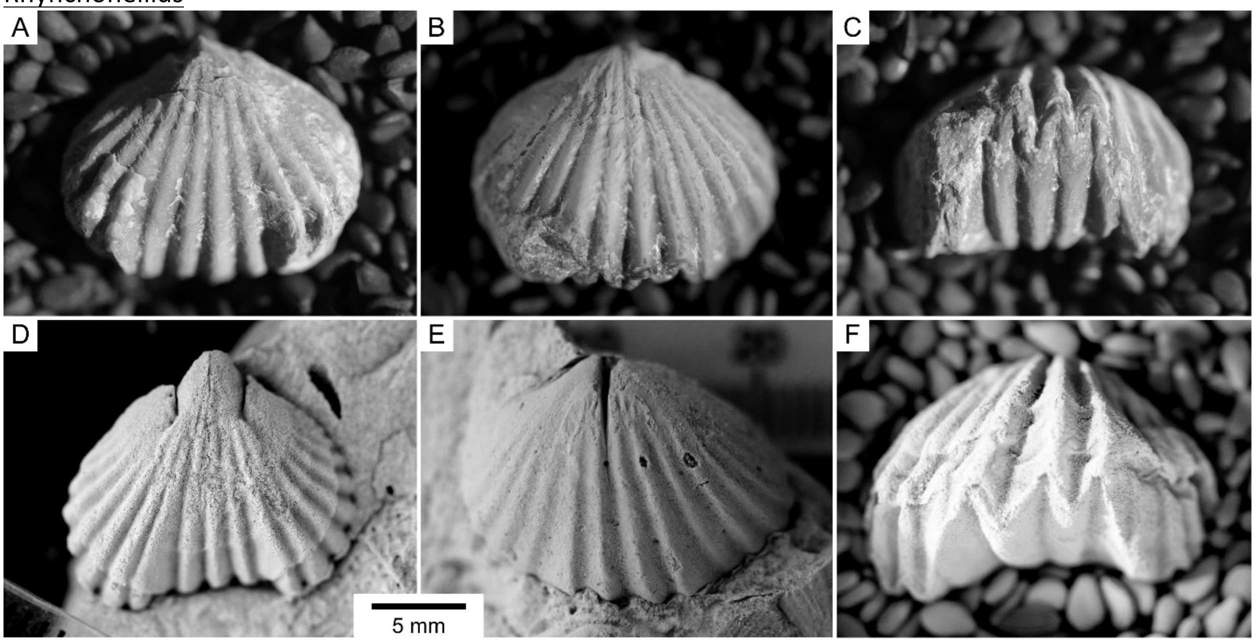


Fig. 33. **"*Cupularostrum" contractum.*** **A-C**. Ventral, dorsal, and anterior views, sample TGA 22, Canaseraga Formation. **D**. Ventral internal mold, Rt. 119 north of Cameron, NY, Wiscoy Formation. **E**. Dorsal internal mold, sample TGB 49, Canaseraga Formation. **F**. Anterior view, location unknown.

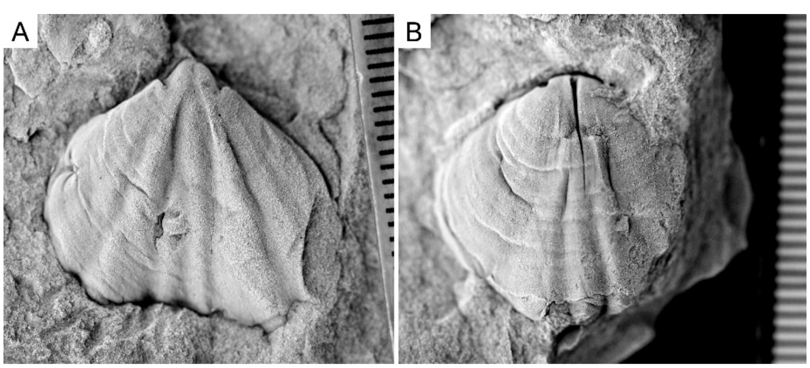


Fig. 34. ***Jacoburbirostrum duplicatus***. **A-B**. Ventral and dorsal internal molds, location PCR. Canaseraga Formation. Scale in mm. See Sartenaer (2014) for redescription.

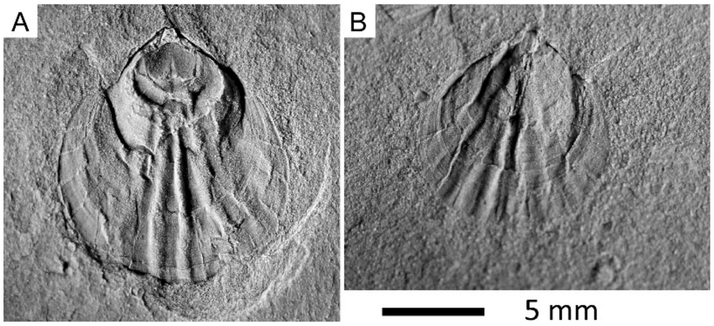


Fig. 35. ***Camarotoechia mesacostalis***. **A-B**. Compressed specimens. Sample BCP 149. Pipe Creek or Canaseraga Formation, pending exact placement of the boundary.

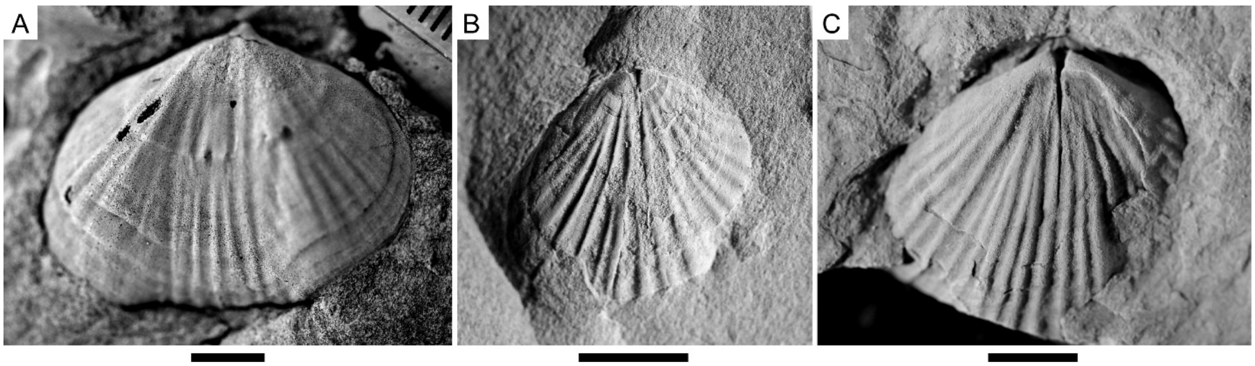


Fig. 36. ***Eumetabolatoechia multicostata***. **A**. Ventral internal mold, location SWA. **B**. Dorsal mold, sample BCP 150. **C**. Dorsal internal mold, location PCR. Canaseraga Formation. Scale = 5 mm.

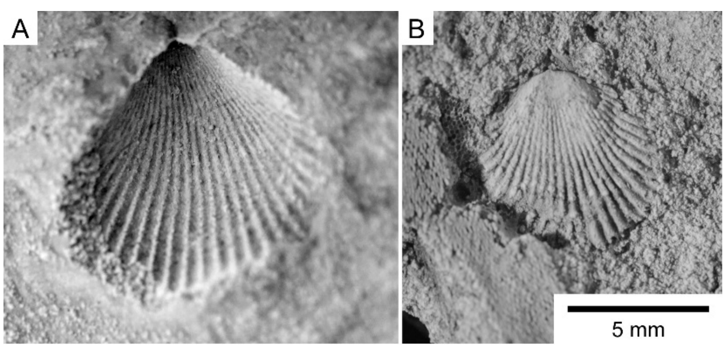


Fig. 37. **Small rynchonellids?** Location TF. Mapped as the Wiscoy Formation (Woodrow, 1968) or Lock Haven Formation (Berg et al., 1980).

<u>Atrypids</u>

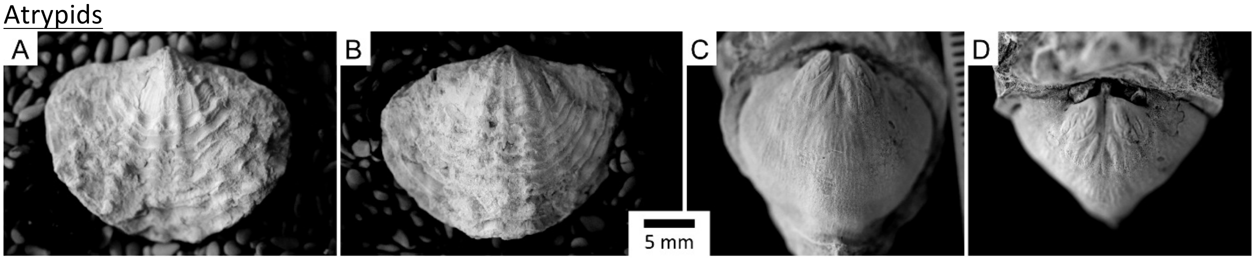


Fig. 38. ***Spinatrypa* cf. *hystrix*, "small" morphotype**. **A-B**. Ventral and dorsal views. **C-D**. Dorsal internal mold. Location HNS, Wiscoy Formation. Coarse-ribbed *Spinatrypa* in the Wiscoy Fm. have often been identified as *S. hystrix*. We suspect that there may be two species in the Wiscoy ("small" and "large" morphotypes). Further work is needed.

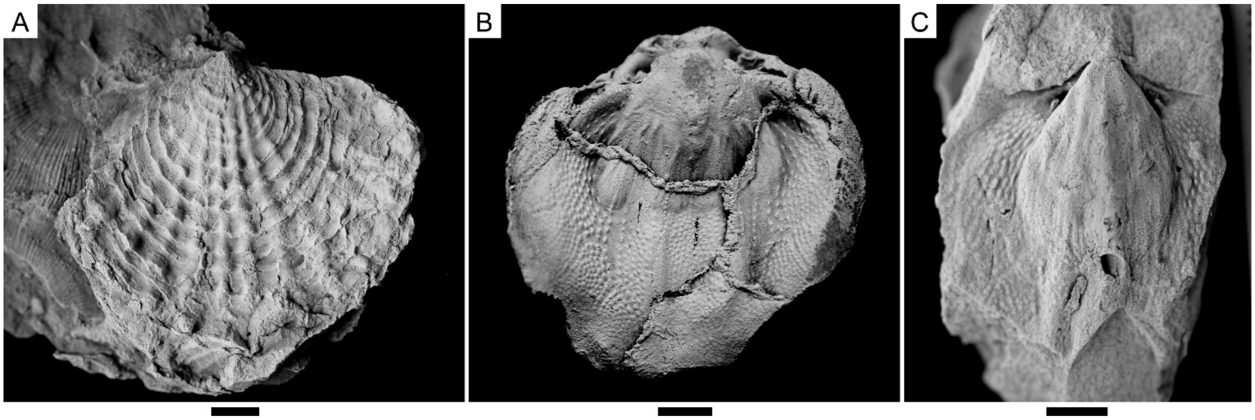


Fig. 39. ***Spinatrypa*** **cf.** ***hystrix*****, "large" morphotype**. **A**. Ventral views, location TGB, Hammond Member. **B**. Ventral internal mold, Wiscoy Formation. **C**. Ventral internal mold, sample BCP 7, Wiscoy Formation. Scale bars = 5 mm.

Fig. 40. ***Spinatrypa planosulcata*****.** External molds. Location CAM, float, Canaseraga Formation. Scale in mm. See Day and Copper (1998) for illustration of material from Iowa.

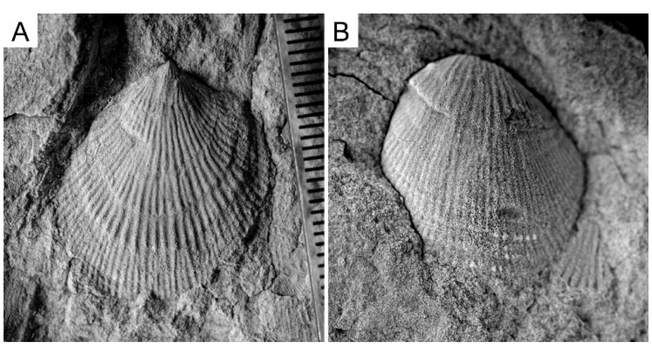


Fig. 41. ***Pseudoatrypa devoniana***. **A**. Ventral valve. **B**. Dorsal valve. Sample BPH 2, Wiscoy Formation. See Day and Copper (1998) for illustration of material from Iowa.

Athyrids

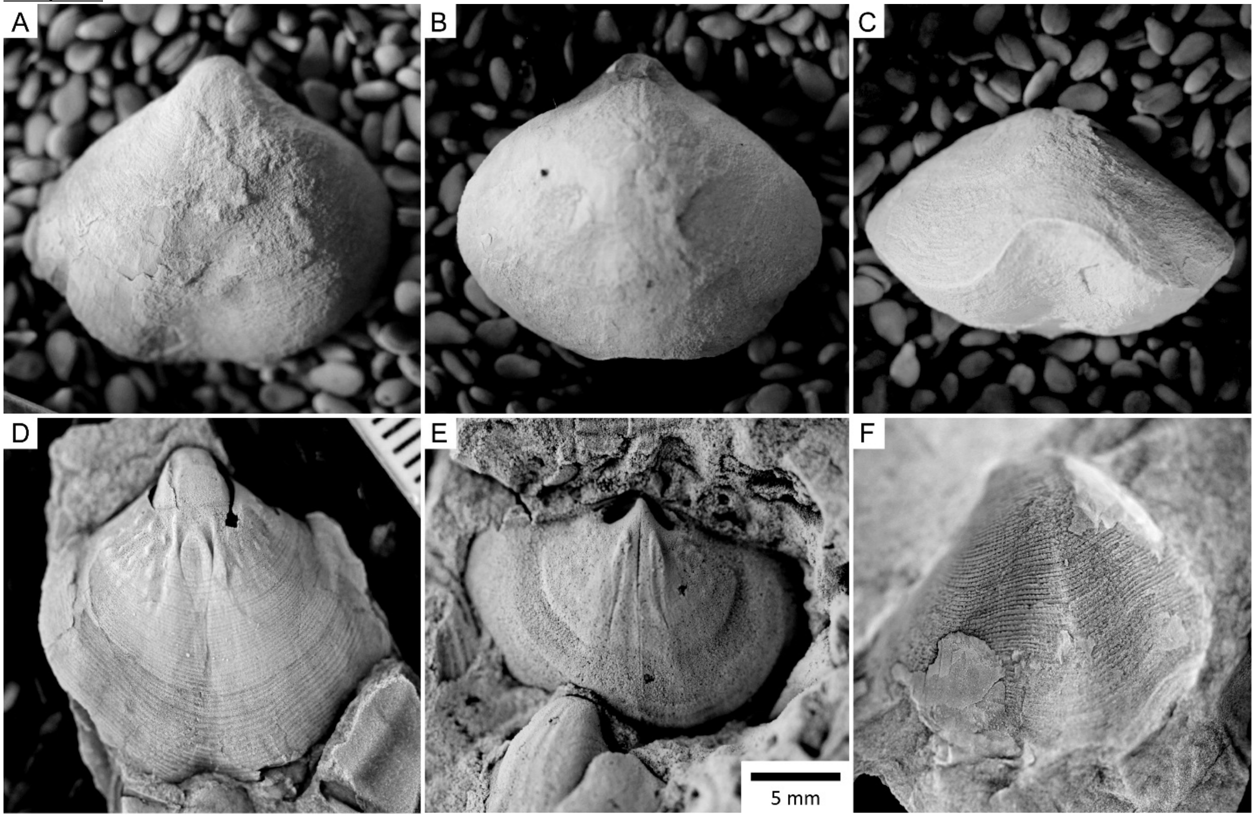


Fig. 42. "*Athyris*" *angelica*. A-C. Ventral, dorsal, and anterior views, sample TGA 13R. **D**. Ventral internal mold, sample showing growth lines, CAM 120. **E**. Dorsal internal mold, sample CAM 145. **F**. Ventral external mold showing growth lines and surface texture, location TGB. All from the Canaseraga Formation.

Spiriferids

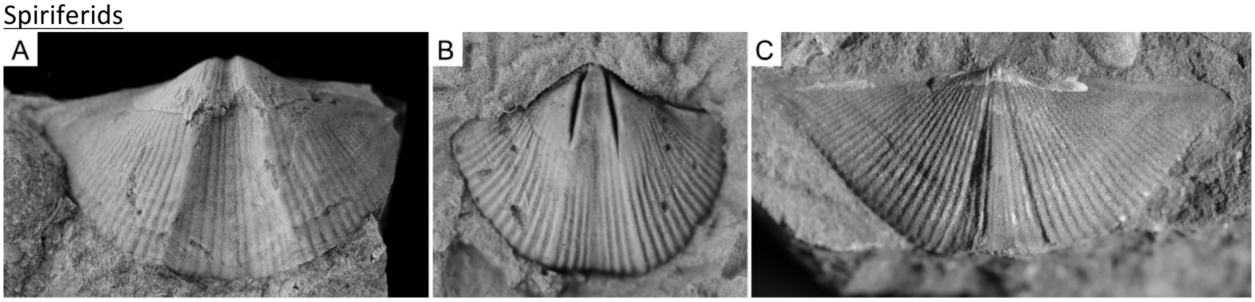


Fig. 43. ***Cyrtospirifer inermis***. **A**. Ventral valve, sample CAM 155. **B**. Ventral internal mold, sample SKI 4. **C**. Dorsal internal mold, sample CAM 155. Scale = 5 mm. Canaseraga Formation. Fossils resembling Greiner's (1957) *C. hornellensis* seem to grade into *C. inermis*; the former is typically smaller but could just represent earlier growth stages.

Fig. 44. ***Cyrtospirifer* cf. *angusticardinalis*** or ***preshoensis***. Sample CAM 159, Canaseraga Formation. Scale in mm.

Fig. 45. ***Cyrtospirifer chemungensis***. Poorly preserved specimen from sample CAM 135, Canaseraga Formation. Scale in mm.

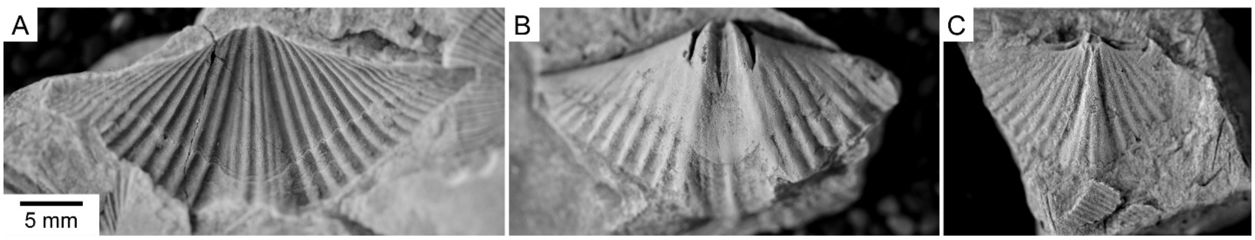


Fig. 46. **"*Spirifer" williamsi***. **A**. Ventral external mold. **B**. Ventral internal mold. **C**. Dorsal internal mold. Sample BCP 16, Wiscoy Formation.

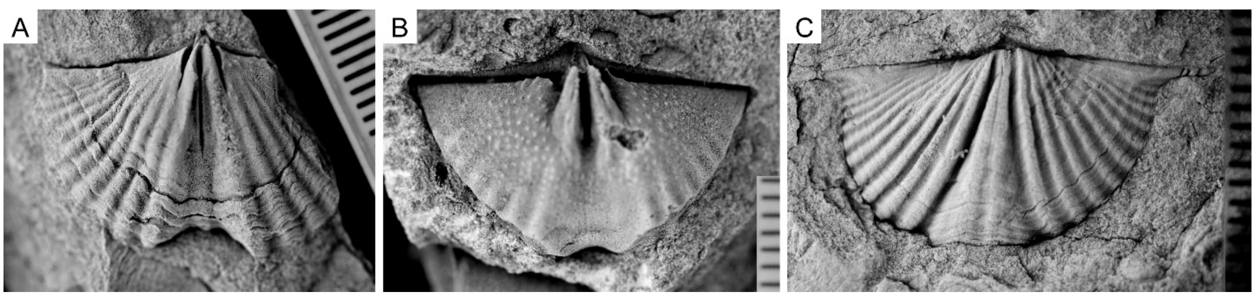


Fig. 47. ***Tylothyris mesacostalis***. **A**. Ventral internal mold showing growth lines, location PCR. **B**. Ventral internal mold, CAM 150. **C**. Dorsal internal mold, location PCR. Canaseraga Formation. Scale in mm.

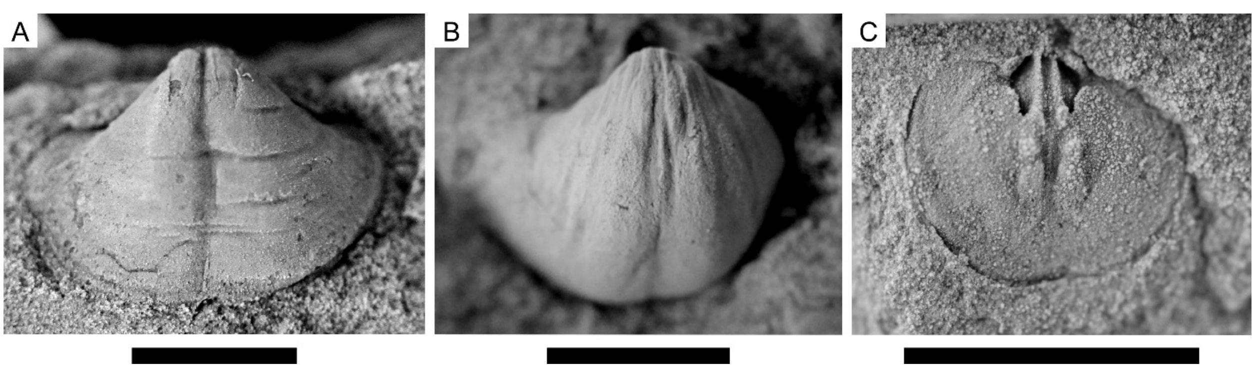


Fig. 48. ***Ambocoelia gregaria***. **A**. Ventral exterior, BCP 141. **B**. Ventral internal mold, BCP 35. **C**. Dorsal internal mold, sample BCP 106. A from Pipe Creek or Canaseraga, depending on placement of boundary. B-C from Wiscoy Formation. Scale = 5 mm. See Zambito and Schemm-Gregory (2013) for redescription.

Spiriferinids

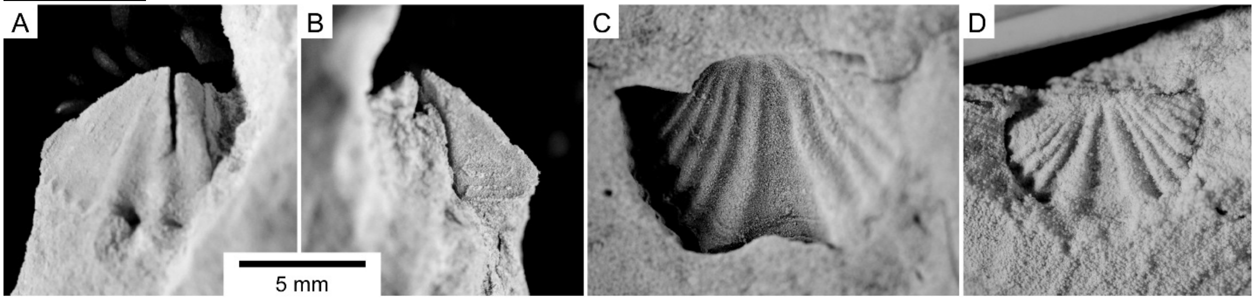


Fig. 49. ***Cyrtina* cf. *hamiltonensis***. **A-B**. Ventral internal mold, broken near the umbo, BCP 106. In B, one side of the delthyrium is visible. **C**. Dorsal external mold, sample BCP 49A. **D**. Dorsal external mold, sample BCP 8. Wiscoy Formation.

Table 2. Locality information for illustrated fossils.

	State	Latitude N	Longitude W		State	Latitude N	Longitude W
ADR	NY	42° 15.430'	77° 32.156'	PCR	NY	42° 15.584'	77° 38.852'
BCP	NY	42° 21.810′	77° 38.675′	PD	PA	41° 42.055'	76° 32.211'
BPH	NY	42° 04.394'	77° 17.953'	SGU	NY	42° 18.135'	77° 32.559'
BRC	NY	42° 23.325'	77° 43.643'	SKI	NY	42° 28.609'	77° 51.441'
CAM	NY	42° 12.008′	77° 26.219′	SLD	NY	42° 25.871'	77° 46.985'
CRR	NY	42° 09.076'	77° 18.792'	SWA	NY	42° 28.731'	77° 50.919'
CSA	NY	42° 16.123'	77° 32.201'	TF	PA	41° 48.734'	76° 30.134'
DAN	NY	42° 29.615'	77° 39.920'	TGA	PA	41° 54.690'	77° 07.446'
HER	NY	42° 28.545′	77° 50.612′	TGB	PA	41° 54.233'	77° 09.949'
ERC	NY	42° 15.303′	77° 40.773′	USA	PA	41° 49.752'	77° 05.289'
HNS	NY	42° 17.649'	77° 38.678'	WEL	NY	42° 00.998'	76° 43.492'
PCE	NY	42° 15.398'	77° 38.011'				

FIELD GUIDE AND ROAD LOG: DAY 2

Meeting Point: Cowanesque Lake Outcrop, Route 49, west of Lawrenceville, PA

Meeting Point Coordinates: N 41° 58.896' W 77° 08.951'

Meeting Time: 10:00 AM

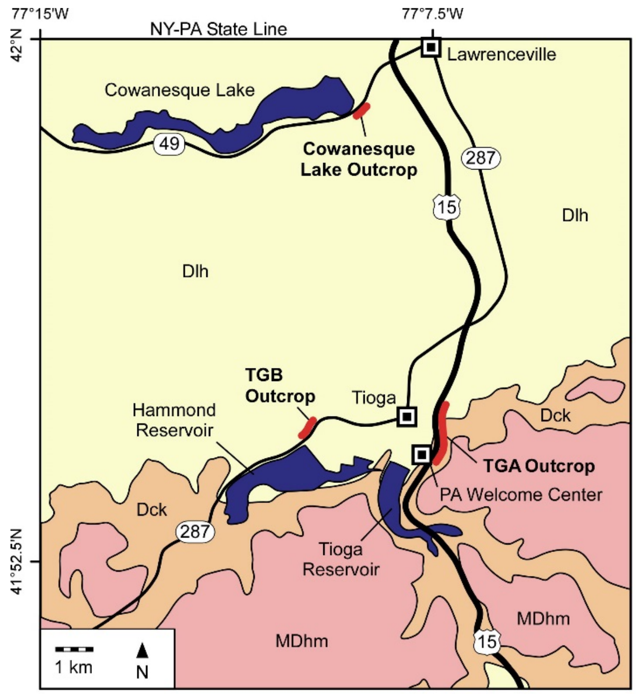


Fig. 50. Geologic map of Tioga, PA area showing the locations of field trip stops. Modified from Beard et al. (2017). Based on Berg et al. (1980). Dlh: Lock Haven Group. Dck: Catskill Formation. MDhm: Huntley Mountain Formation.

STOP 4: Route 49, Cowanesque Lake, PA

Location Coordinates: N 41° 58.896' W 77° 08.951'

This outcrop of the Wiscoy Formation (Figs. 50-51) is similar to the numerous outcrops along I-99/Rt. 15 on either side of the New York-Pennsylvania border, but it is easier to access. The strata display hummocky and swaley cross-stratification, and appear similar to facies S2-S3 of Beard et al. (2017) (see Table 3). Facies S2 indicates medium- to thick-bedded, fine-grained sandstone with < 20% interbedded mudstones with abundant swales, and was interpreted as middle shoreface, and S3 is similar but with thin to medium beds and 20-50% interbedded mud, and was interpreted as lower shoreface.

Fossils are abundant and are easy to find in the float, particularly brachiopods, bivalves, and trace fossils. Brachiopods include *Strophonelloides coelata*, *Whidbornella hirsuta*, *Spinatrypa* cf. *hystrix*, "*Cupularostrum*" *contractum*, and chonetids.

Fig. 51. Outcrop along Rt. 49, Cowanesque Lake, PA.

Table 3. Descriptions and interpretations of sedimentary facies from Tioga, PA, summarized from Beard et al. (2017).

Sand-dominated facies			
	Lithology	**Features**	**Interpretation**
S1	Medium-bedded sandstone with discontinuous coarser laminations	Mud rip-up clasts, swales, dune/ripple cross-stratification	Middle Shoreface
S2	Medium- to thick-bedded, fine-grained sandstone, < 20% mudstone	Swales, hummocks, oscillatory or combined flow ripples	Middle Shoreface
S3	Thin- to medium-bedded, fine-grained sandstone with 20–50% mudstone	Swales, hummocks, oscillatory or combined flow ripples	Lower Shoreface
S4	Very fine-grained, muddy sandstone, medium- to thick-bedded	Structureless, dewatering structures, concretions, increasing mud upwards	Shoreface, rapid deposition
S5	Scour-based, medium- to thick-bedded fine-grained sandstone	Plane-laminated or cross-stratified assoc. with 3D dunes, plant debris with iron staining, wave-ripples	Shelf Channel
Mud-dominated facies			
M1	Gray–brown mudstones with thin beds of siltstone to fine-grained sandstone	Plane-laminations, oscillatory or combined flow ripples (sandstones)	Inner Shelf
M2	Gray, fissile, silty mudstone	May have regularly spaced bedding-parallel red banding	Outer Shelf
M3	Dark gray, fissile silty mudstone	May have regularly spaced bedding-parallel red banding	Outer Shelf, dysoxic–anoxic

STOP 5: Route 287, Tioga, PA

Location Coordinates: N41° 54.423′ W 77° 09.715′

Outcrop of Wiscoy, Pipe Creek, and Canaseraga formations (Fig. 52). Location TGB of Bush et al. (2015) and Beard et al. (2017), and type section of the Hammond Member of the Canaseraga Formation.

Beard et al. (2017) provided a facies description of the Tioga sections, which is summarized below by stratigraphic interval (see Fig. 52 for section and Table 3 for facies descriptions). For other descriptions and interpretations of these sections, see Berg et al. (1981, pp. 153-158), Castle (2000), and Bush et al. (2015).

Wiscoy Formation: The lowermost portion of the TGB section consists of swaley, fine-grained sandstones with various amounts of interbedded mudstone, interpreted as lower to middle shoreface (facies S2-S3). The upper several meters of the Wiscoy are finer grained, consisting of interbedded mudstone and thin siltstone/sandstone beds, interpreted as inner shelf. Fossils include *Strophonelloides coelata*, *Schizophoria amanaensis*, *Spinatrypa* cf. *hystrix*, *Douvillina arcuata*, *Cyrtospirifer inermis*, rugose corals, other invertebrates, and trace fossils.

Pipe Creek Formation: Dark gray, silty shale, interpreted as a low-oxygen, offshore setting. However, depositional conditions could not have been permanently anoxic, because Beard et al. (2017) noted the presence of occasional trace fossils, small bivalves, and lingulid brachiopods.

Hammond Member, Canaseraga Formation: Beard et al. (2017) defined the Hammond Member at the TGB section as the basal portion of the Canaseraga Formation that directly overlies the Pipe Creek. It is considerably coarser-grained than the Pipe Creek and the overlying part of the Canaseraga, and Beard et al. (2017) interpreted it as represented a middle shoreface environment. At Tioga, the base is covered by large burrows, possibly *Teichichnus* isp. and *Thalassinoides* isp., which appear to have been mining the organic-rich sediments of the Pipe Creek once fully oxygenated conditions returned. Other beds of the Hammond at Tioga also contain abundant trace fossils. The coarsest sandstone beds at the base of the Hammond are capped by granule-rich, rippled bedform (Beard et al., 2017, fig. 6A,B) similar to those interpreted in the Appalachian Basin and elsewhere as transgressive ravinement surfaces (Castle, 2000; Plint, 2010; McClung et al., 2013).

The brachiopod *Floweria chemungensis* is extremely common in the Hammond Member, forming pavements at some horizons. The Hammond also contains the last representatives of a couple species that elsewhere have not been found above the Wiscoy, including *Spinatrypa* cf. *hystrix* and *Schizophoria amanaensis*. Trace fossils are also abundant, as well as the large bivalve *Grammysia*, as noted by Berg et al. (1981).

Undifferentiated Canaseraga Formation: The transition from the Hammond to the overlying undifferentiated portion of the Canaseraga represents a deepening. The remainder of this interval generally coarsens upward from primarily facies S3 (lower shoreface; approximately 20 to 30 m) to largely S2 (middle shoreface). The lower, slightly deeper portion of the undifferentiated Canaseraga has a diverse fauna, including several brachiopod species that first appear in this formation ("*Thiemella*" *leonensis*, "*Athyris*" *angelica*, and *Spinatrypa planosulcata*), but the upper reaches of the outcrop are dominated by *Cyrtospirifer inermis*. Glass sponges have also been found in the lower portion of the undifferentiated Canaseraga (Fig. 53).

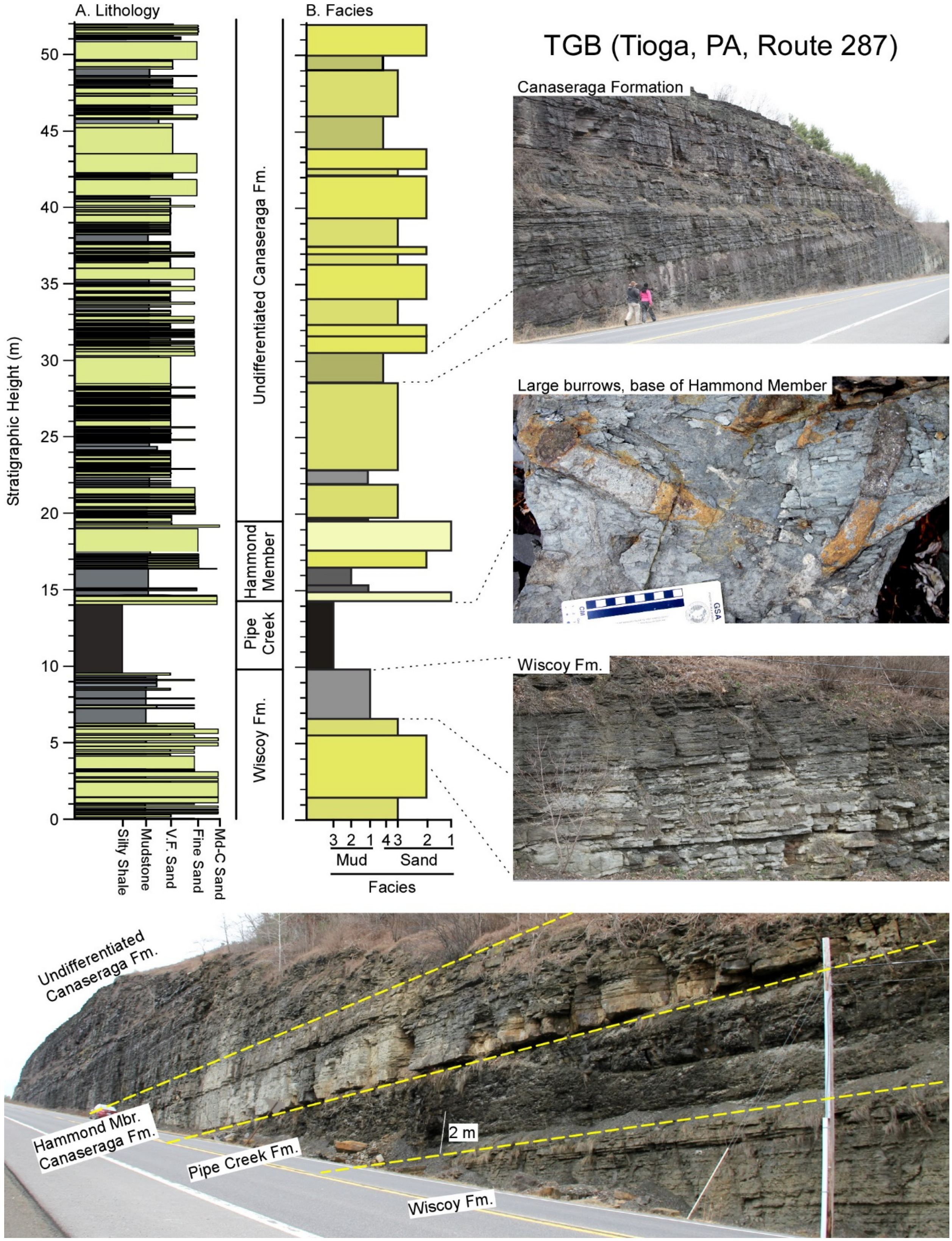


Fig. 52. TGB section, Route 287, Tioga, PA. **A.** Lithology. **B.** Facies analysis (see Table 3). Portions modified from Beard et al. (2017).

Several noteworthy beds are marked in Fig. 52 as facies S4, which consists of muddy, fine grained sand characterized by dewatering structures and convoluted bedding. Beard et al. (2017) interpreted these beds as representing the rapid deposition of mud and sand that were loaded prior to dewatering. Brachiopods are often present in these layers.

The lower 10 m of the TGB section represent an increase in water depth from the swaley sediments of the Wiscoy Formation to the offshore paleonvironments of the Pipe Creek. The transition from the Pipe Creek to the middle shoreface sediments of the base of the Hammond is abrupt, suggesting a forced regression. Additional large changes in water depth are suggested by the rippled bedform atop this basal sandstone, similar to transgressive ravinement surfaces (Castle, 2000; Plint, 2010; McClung et al., 2013), followed by mudstone, then the middle shoreface sediments of the upper Hammond Member. Facies changes are more subdued in the rest of the section, which generally coarsens upward. These patterns appear similar to those seen in the magnetic susceptibility data from further offshore shown in Fig. 3: large facies changes above the Pipe Creek, followed by smaller fluctuations.

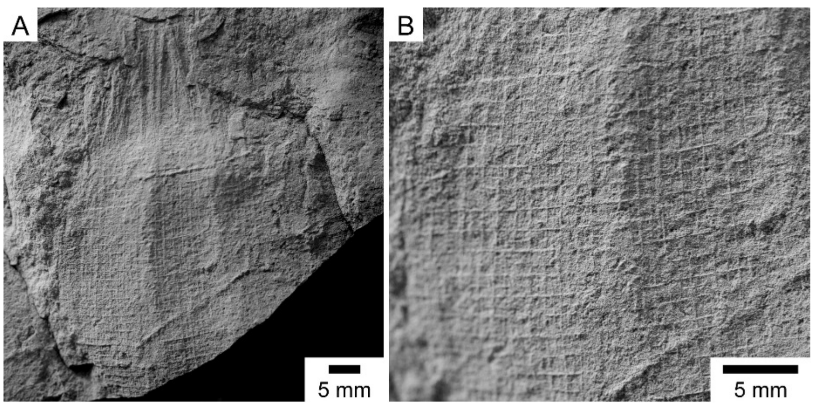


Fig. 53. A. Glass sponge, sample TGB 44, Canaseraga Formation. **B.** Close-up of specimen in panel A.

STOP 6: Route 15, Tioga, PA

Location Coordinates: N 41° 54.690' W 77° 07.446'

Location TGA of Bush et al. (2015) and Beard et al. (2017). Upper Canaseraga (Mills Mills Member), Dunkirk, Candeadea, and Catskill formations. Stratigraphic units are described below in ascending order (Fig. 54; see Table 3 for facies descriptions). Also see Berg et al. (1981, pp. 148-152), Woodrow et al. (1989), Castle (2000), Oest et al. (2013), Bush et al. (2015).

Mills Mills Member, Canaseraga Formation: 10 m of the Mills Mills is exposed at the base of the section. It fines from facies S2 and S3 (middle to lower shoreface) to M1 (inner shelf). Fossils are abundant and include "*Athyris*" *angelica*, *Tylothyris mesacostalis*, *Praewaagenoconcha* sp., *Floweria chemungensis*, *Schizophoria impressa*, and "*Cupularostrum*". Bivalves are also abundant. No Frasnian taxa have been found (e.g., *Spinatrypa* sp., *Cyrtospirifer chemungensis*), consistent with placement above the UKW event.

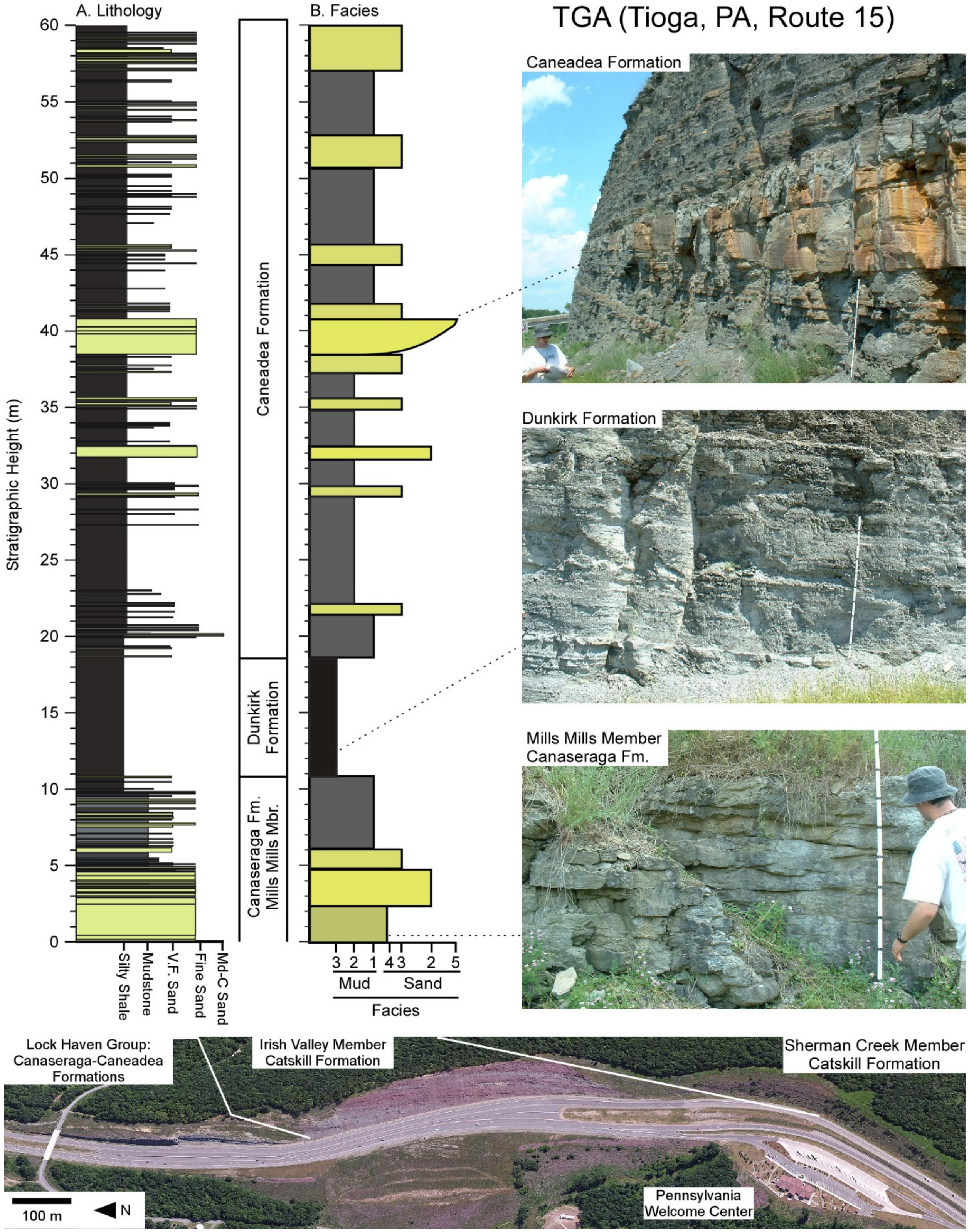


Fig. 54. TGA section, Rt. 15 (future I-99), Tioga, PA. **A.** Lithology. **B.** Facies analysis (see Table 3). Portions modified from Beard et al. (2017). Bottom panel: Imagery ©2017 Google, Map data ©2017 Google. Staff = 2 m with 20 cm divisions.

Dunkirk Formation: The Dunkirk Formation is the uppermost thick black shale unit in the Devonian of New York. At Tioga, it consists of a dark gray, silty shale, and we place the top of the unit at a package of silty-sandy interbeds. Fossils similar to those in the Mills Mills Member are found in the lowermost Dunkirk, although it becomes less fossiliferous above that. Beard et al. (2017) interpreted it as an offshore paleoenvironment, perhaps dysoxic, although the fossils near the base may indicate a gradual decrease in oxygen.

Caneadea Formation: The Caneadea is a thick interval of gray shale overlying the Dunkirk. At Tioga, there are frequent silty-sandy interbeds. It generally coarsens upward from the top of the Dunkirk to the base of the Catskill Formation. Beard et al. (2017) interpreted it mostly as facies M2 and M1 (outer and inner shelf), with increasing S3 (lower shoreface) toward the top. At 40 m, there is a thick sandstone interval with a scoured base, plane laminations, cross beds, ripples, and abundant plant material that Beard et al. (2017) interpreted as a shallow shelf channel. Fossils are generally similar to those in the Mills Mills Member, although above ~40 m, *Cyrtospirifer*, "*Cupularostrum*", and *Floweria* become the dominant brachiopods.

Catskill Formation: We have not examined the Catskill Formation in detail. The lowermost Catskill consists of alternating red and gray strata that are similar to the Irish Valley Member described elsewhere in Pennsylvania, and the overlying strata are similar to the Sherman Creek Member (McLaurin, 2010) (Fig. 54, lower panel). Cotter and Driese (1998) discussed the depositional environments of these units at an outcrop further to the south in Selinsgrove, PA. Lingulids and *Cyrtospirifer* are occasionally present in the lower portion of the Catskill, and trace fossils are abundant in the float. Fish remains are also present, and tetrapods have been found in the Fammenian of the region (Daeschler et al., 1994; Daeschler, 2000).

The lower 10 m of the TGA outcrop represent an increase in water depth from the uppermost Canaseraga Formation into the offshore environments of the Dunkirk. Overall, the section coarsens upward from the Dunkirk into the Candeadea, although it remains mostly mudrock dominated. The transition to the lower Catskill Formation represents further decrease in water depth, culminating in the transition to terrestrial sedimentation.

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