FOSSIL BEDS, FACIES GRADIENTS AND SEAFLOOR DYNAMICS IN THE MIDDLE DEVONIAN MOSCOW FORMATION, WESTERN NEW YORK

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INTRODUCTION

The Middle Devonian strata of western New York State have long provided a natural laboratory for studying paleontology and microstratigraphy along and across depositional strike. Excellent exposures along the cliffs of Lake Erie, in the vicinity of Eighteen Mile Creek south of Hamburg, NY, were made famous by A. W. Grabau, who described these sections and their fossils in detail in a classic two part series published though the Buffalo Museum of Science (Grabau, 1898, 1899). This work recognized a series of distinctive shell-coral rich beds (e.g., *Pleurodictyum* bed, Trilobite beds, "*Spirifer" consobrinus* bed) characterized by atypically abundant species at specific horizons (Grabau, 1898,1899). These fossil beds, a form of epibole (see Brett and Baird, 1997), typically can also be distinguished lithologically because of densely packed shell-rich beds and associated concretions or concretionary limestones. Subsequent detailed studies of Hamilton stratigraphy documented that all of Grabau's horizons and many others were traceable laterally for distances of more than 200 km and across rather major facies changes (Cooper, 1930, 1933, 1934; Brett (ed.) 1983, Landing and Brett (eds.) 1991, and papers therein; Brett and Baird, 1994, 1996, Brett et al. 1986, 1990, 2011). Moreover, studies by Batt (1995, 1996) revealed that even centimeter-scale shell beds were correlatable for distances of tens of kilometers.

The ability to correlate these fossil beds over great distances oblique to depositional strike and dip indicates extrinsic, regional effects that affected large portions of the foreland basin. A second key observation is that shell rich horizons within mudstones in western New York trace eastward into shell beds that overlie 1-5 m scale coarsening upward mudstone to siltstone cycles. This led Brett and Baird (1985, 1986, 1996) to postulate that the shell-rich beds record intervals of widespread decrease in sedimentation probably associated with flooding surfaces at the tops of major and superimposed minor cycles, probably of eustatic origin.

A third critical observation is that the shell beds are facies cross-cutting, that is they show lateral gradients in terms of facies, taphonomy and faunal content. Not only does this provide a strong case against the diachroneity of such shell rich horizons, but also that these beds are essentially isochronous, though condensed, intervals and provide excellent samples of "gradient transects" from shelf to basinal areas, reflecting changes in sedimentation, grain size, substrate type. To date, relatively few studies have capitalized upon this aspect of the Hamilton shell rich beds (but see Lafferty et al., 1994; Bonelli et al., 2008). Such gradient transects have value in both paleobiological and sedimentological studies as well as elucidating subtle changes in seafloor topography, shifting depocenters and synsedimentary tectonics (cf. Miller et al., 2001).

Shell beds of similar biofacies from different levels in the Hamilton Group show many similarities of composition and relative abundance that have been emphasized in discussions of relative stability and coordinated stasis in Hamilton faunas (Brett and Baird, 1995, Brett et al., 1996, 2007; Ivany et al., 2009). Perhaps most importantly, they suggest niche conservatism: taxa

tended to remain in similar positions along onshore-offshore and other gradients. However, as emphasized by Bonelli et al. (2006) no two samples of the same biofacies are identical, especially in terms of relative abundance. While this is in part an artifact of the portions of gradients sampled in the available outcrop belt, there are clearly real differences that are not so readily explained. This returns to the issue raised by Grabau: particular shell-rich horizons are identifiable based on abundances of unique taxa. The Murder Creek and Smoke Creek trilobite beds are similar in many ways both in terms of lithology, stratigraphic patterns, and faunas. However, each has distinctive, unique features that set them apart from one another and other such beds. For example, the Murder Creek bed of the Wanakah Shale is particularly rich in the pink nacreous brachiopod *Pholidostrophia nacrea*, which is not known to occur in the seemingly very similar Smoke Creek bed of the Windom Member, while the latter is rich in the brachiopod *Mucrospirifer consobrinus*, a form rare throughout most of the rest of the Hamilton Group. Such epiboles are poorly understood. They do show that a simple tracking model (e.g. Brett et al., 2007) is inadequate to explain all of the variation seen in the Hamilton Group. Presumably some factor other than typical depth or sedimentologically related parameters controlled the abundance of these taxa. This is evident from the facies cross-cutting nature of epibole taxa: *Mucrospirifer consobrinus*, is common in calcareous mudstone and concretionary limestones in Erie County, but also occurs in rather dark shale near the basin center and in siltstones and even fine grained

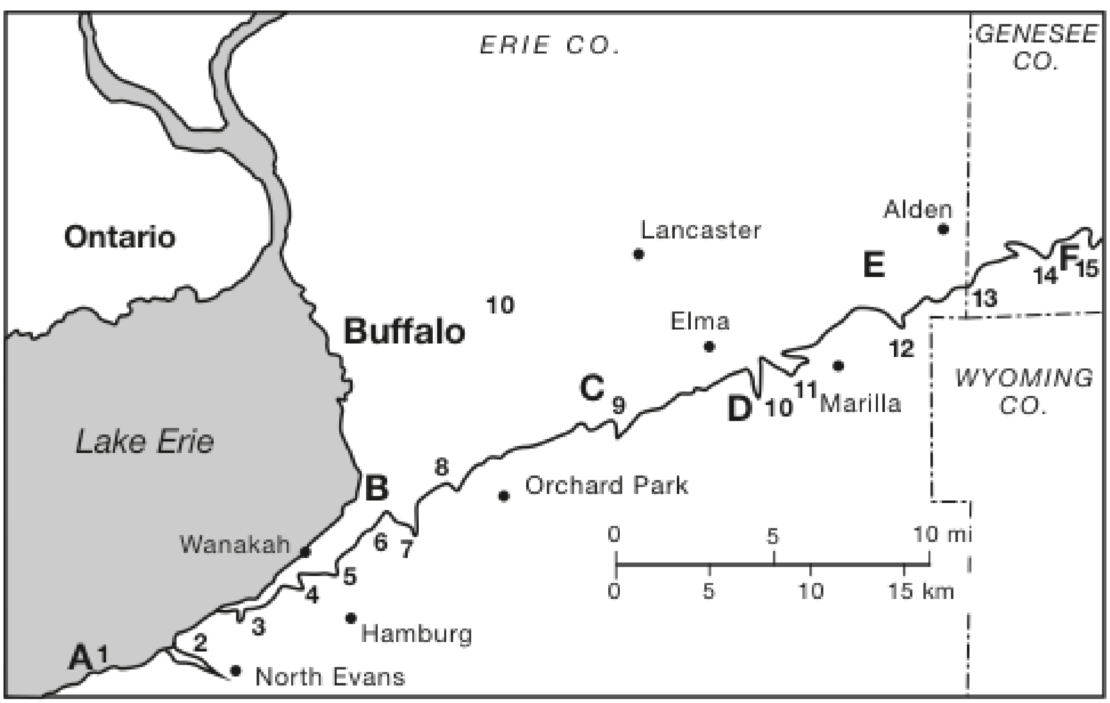

Figure 1. Location map for sections in Erie County, NY. Key localities, identified by numbered sections include: 1) Pike Creek; 2) Eighteen Mile Creek; 3) unnamed creek near Weyer; 4) unnamed creek next to

Amsdell Road; 5) Cloverbank shale pit; 6) unnamed creek south of Big Tree Road; 7) Penn Dixie Fossil site (shale pit); 8) South Branch Smoke Creek; 9) Cazenovia Creek near Northrup Road; 10) Buffalo Creek at Bullis Road; 11) Little Buffalo Creek at Marilla; 12) Cayuga Creek at Clinton Road; 13) Durkee Creek, Darien; 14) Eleven Mile Creek; 15) Murder Creek. Sites used for this field trip are designated by letters and include: A) Pike Creek; B) Penn Dixie site near bay View, NY; C) Cazenovia Creek; D) Buffalo Creek; E) Cayuga Creek; F) Murder Creek.

sandstones in outcrops of central New York. Such epiboles are extremely helpful in correlation, especially in the context of a framework of other such beds.

In the present paper we discuss a gradient within a single interval, the Bay View and Smoke Creek beds of the lower Windom Shale Member in western New York (Erie and western Genesee counties; Fig. 1) and how it compares with the idealized Hamilton gradient. Using ecological techniques of gradient analysis, specifically detrended correspondence analysis (DCA), we have quantified a gradient within the Bay View-Smoke Creek interval in western New York. Finally, we show how such beds can be used to constrain paleogeography and to provide datums for interpreting unconformities.

GEOLOGIC SETTING

The Middle Devonian (mid Givetian, ~386-383 Ma) upper Hamilton Group strata of western New York (Erie-Genesee-Livingston counties) comprises about 80 to 100 meters of medium to dark gray shaly, mudstones with thin, persistent horizons of skeletal limestone, shell beds, and concretionary mudstone, including the Bay View and Smoke Creek beds, discussed herein. The major distinctive beds identified by Grabau at Lake Erie were subsequently found to have expression much farther to the east in New York State and G.A. Cooper (1930, 1933, 1934) used some of these beds as important stratigraphic markers and subdivision boundaries within the Hamilton Group. The most prominent shell-rich limestones were used as the bases of formations. The boundary of Skaneateles Formation was placed at the base of the Stafford Limestone, the Ludlowville at the base of the Centerfield, and the Moscow at the "Portland Point"; the latter was subsequently modified to the base of the Tichenor Limestone based on studies of the Portland Point by Baird (1979). Lesser shell beds were also used as stratigraphic boundaries. For example, Grabau's concretionary *Mucrospirifer consobrinus* bed was found to extend eastward into the Finger Lakes region of New York being everywhere identified by an abundance of the normally very rare brachiopod *M. consobrinus*. This was identified as the Smoke Creek bed and formed a very useful marker in the lower Windom Member (Baird and Brett, 1983).

The Hamilton strata accumulated in an actively evolving northern end of the Acadian foreland basin, a retroarc basin developed due to thrust loading in New England and other eastern seaboard regions during the oblique transpressional collision of Avalonia and southeastern Laurentia during the second major tectophase of the Acadian Orogeny (Ettensohn, 1987, 2004). This tectophase was associated with the collision of Avalonia and the New York promontory, a salient on the old Iapetan margin of Laurentia, which focused tectonic loading and sediment supply slightly southwest of present day upstate New York. During much of Hamilton deposition the foreland basin axis extended obliquely into central-western New York with a gentle ramp oriented east-northeast to west-southwest such that the present day east west outcrop belt (itself a result of flexure during the subsequent Carboniferous-Permian Alleghenian Orogeny) is subparallel to depositional strike in western New York. Sediments derived from the eroding orogen to the southeast accumulated in a generally westwardly-thinning wedge through New York and Pennsylvania areas (Fig. 2). In western New York the primary sediments were clays to slightly silty muds. Farther east in the eastern Finger Lakes region mudstones are interbedded with siltstone and fine-grained sandstones; in turn these coarsening upward mudstone-siltstone successions pass eastward into coarser sandstones and eventually redbeds of the Manorkill and Plattekill Formations (Rickard, 1975). On the western margin of the foreland basin these siliciclastic sediments interfaced with locally derived skeletal debris including brachiopod shells,

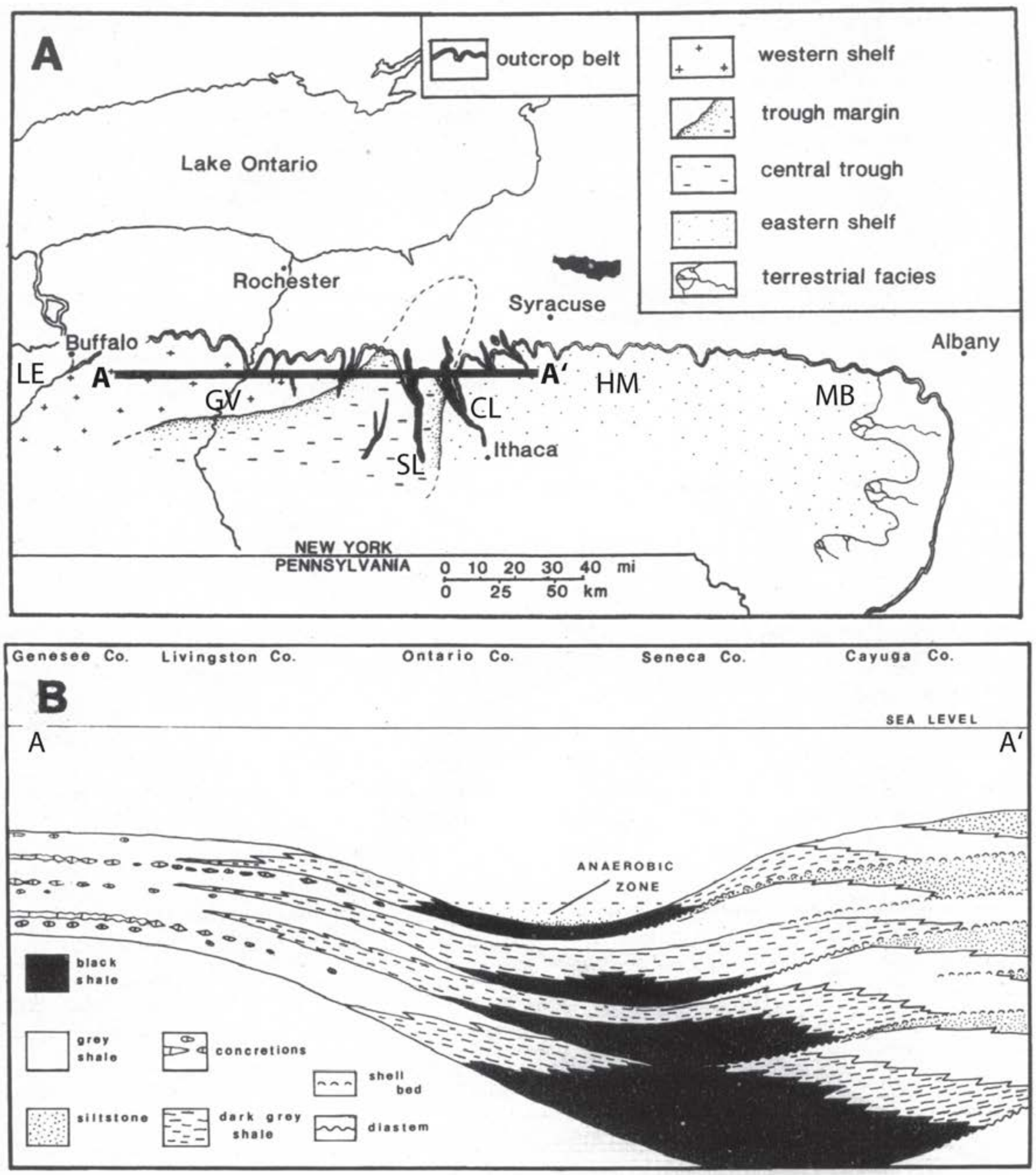

Figure 2. Paleogeography of the western New York area during Middle Devonian time showing foreland basin axis extended obliquely into central New York State. Abbreviations: LE: Lake Erie; GV: Genesee Valley; SL: Seneca Lake; CL: Cayuga Lake; HM: Hamilton type area; MB: Middleburg, the approximate eastward extent of

marine facies in Moscow Formation. Modified from Brett and Baird (1996).

bryozoans, crinoid debris, and, at some levels, abundant rugose or tabulate corals from the lower euphotic zone (based on microendoliths, Vogel et al, 1988), but well below wave base. Shelly beds, which are a focus of this study, apparently were concentrated during strong reductions of siliciclastic influx following the termination of shallowing episodes, which brought the seafloor into shallower, well-oxygenated realms. They are thus associated with flooding surfaces. The shelly beds, discussed in more detail here reflect deepening upward successions, transitional back to slightly darker, more sparsely fossiliferous, pyritic shales. In addition, concretionary carbonates are present at certain levels either in the form of discrete concretions up to 30 cm across or thinner but more tabular beds of light gray weathering, sparsely fossiliferous, concretionary argillaceous limestones.

MOSCOW FORMATION: WINDOM SHALE STRATIGRAPHY

The uppermost Hamilton Group unit in western New York is the Windom Member of the Moscow Formation (middle Givetian, *ansatus* Zone). Windom is a soft medium gray, shaly mudstone with distinct shell and concretionary horizons. A number of distinctive shelly and/or concretionary beds have been identified in the Windom and traced in considerable detail across western to east central New York; Brett and Baird (1994) provide a detailed discussion of all beds of the Moscow formation in western New York and the reader is referred to that much more comprehensive article for details.

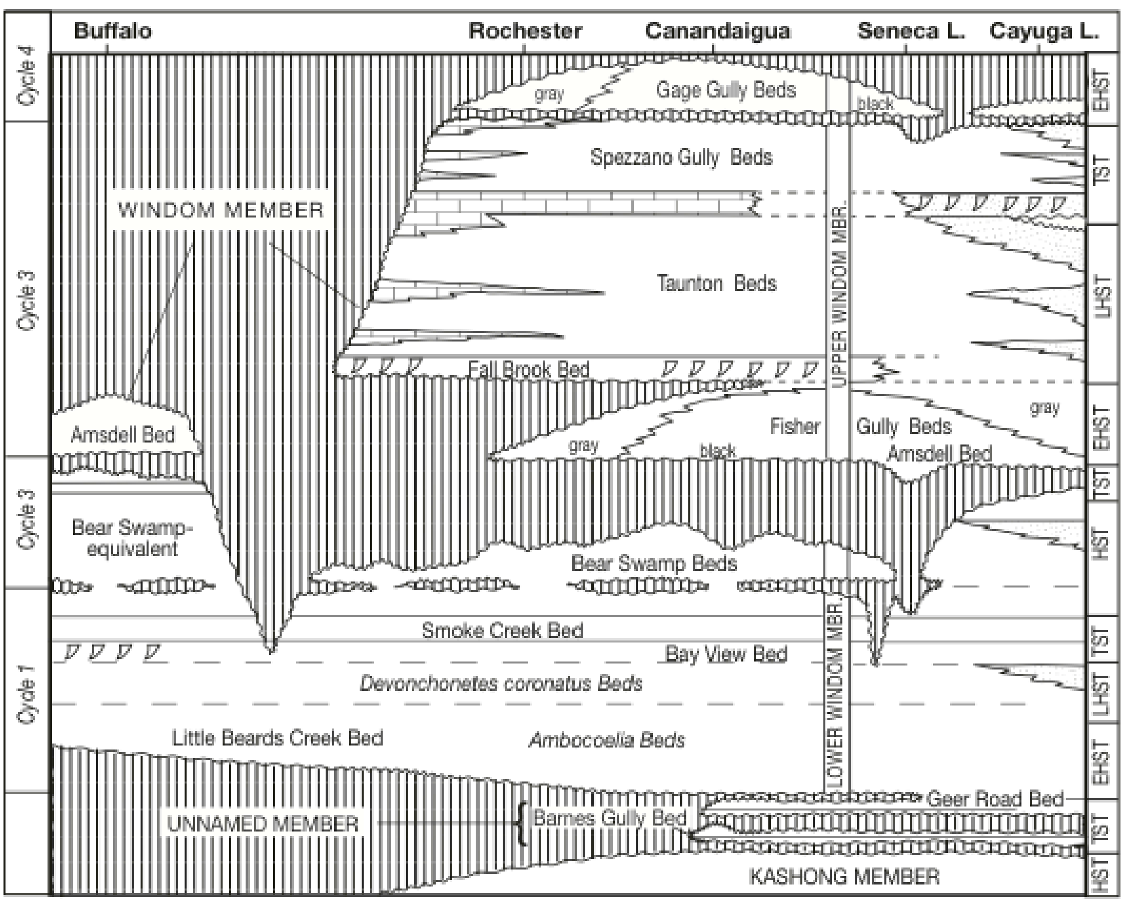

Figure 3. Time-rock diagram of Middle Devonian Windom Member of Moscow Formation showing sequence stratigraphic interpretation; abbreviations: EHST: early highstand; HST highstand systems tract; LHST: late highstand (regression); TST: transgressive systems tract. Modified from Brett and Baird (1994).

The Windom is considered to represent some four medium-scale (4th or 5th order) cycles, each of which commences with shell- and coral-rich, calcareous mudstones and/or packstones, interpreted as small-scale transgressive deposits, such as the Bay View and Smoke Creek beds discussed herein, and passes upward into thicker, dark to medium gray mudstones and to the east, siltstones interpreted as highstand deposits (Brett et al., 1994; Figure 3 herein). The base of the Windom is a third-order flooding surface of the Moscow Formation, marked by a phosphatic pebble lag. The top of the unit is an irregular major unconformity beneath the late Givetian-early Frasnian Genesee Group.

A relatively complete succession of Windom beds is exposed in the Hamburg Fossil Park (formerly Penn Dixie shale pit) near Bay View, NY (see Figure 4). Many of these beds were first named and discussed in detail in Brett and Baird (1982). Of particular interest in the present paper is the lower portion of the Windom, that is, the lower submember or *Ambocoelia* beds, the Bay View shell-coral bed and the overlying Smoke Creek calcareous beds (Figs. 3, 4). These are discussed in more detail in the following sections.

Ambocoelia Beds: The *Ambocoelia* beds are a very thin (10 cm) to several meter-thick soft shale marked at its base by scattered phosphatic pebbles of the "Geer Road" phosphate bed (Brett and Baird, 1994) and with a few concretionary limestones mainly near the top in some sections; the shale is highly fossiliferous but contains primarily small brachiopods, *Ambocoelia umbonata*, and the chonetids *Longispina mucronatus* and *Arcuaminetes scitulus*, together with less common *Athyris*, *Mucrospirifer,* other brachiopods, small bivalves, and trilobites (*Eldredgeops*, *Greenops*). The *Ambocoelia* beds are marked at the top by mudstones that are very strongly swirled with the trace fossil *Zoophycos*, pyritic nodules, and small concretions. The *Ambocoelia* beds are thickest in central Genesee County where they are in excess of 6 m.

Bay View Bed: The Bay View bed is a relatively thin interval of diverse fossils that is a primary focus of this study; this bed was discussed in detail by Brett and Baird (1982) and Baird and Brett (1983). At sections in western Erie County and along Lake Erie cliffs the Bay View bed is a compact 10-20 cm shell bed rich in large rugose corals (*Cystiphylloides*, *Heliophyllum*, *Heterophrentis*), the brachiopods *Spinatrypa spinosa*, *Pseudoatrypa* cf. *devoniana*, and *Mediospirifer audaculus*, crinoid debris, and disarticulated trilobites (see Figures 6, 7 for illustrations of some of these common fossils).

To the east, starting near Cazenovia Creek, the Bay View bed interval rapidly expands to its maximum thickness about 130 cm and shows a series of concretionary bands (Fig. 5). Fossils remain diverse but large rugose corals virtually drop out and are replaced by abundant *Amplexiphyllum*, *Stereolasma*, and smaller specimens of the domical tabulate *Pleurodictyum* frequently attached to gastropod shells (Brett and Cottrell, at of Cazenovia Creek, but certain forms, such as *Athyris spiriferoides* are more common, *Pseudoatrypa* is less common and the large chonetid *Devonochonetes coronatus* and morphologically similar orthid *Tropidoleptus carinatus*, occur rarely. These brachiopods are typical of more sparsely fossiliferous, silty mudstones such as the Kashong Member. In addition, bivalves such as *Modiomorpha concentrica* and *Cypricardella bellistriata* are relatively common and also occur as articulated specimens in approximate burrow position.

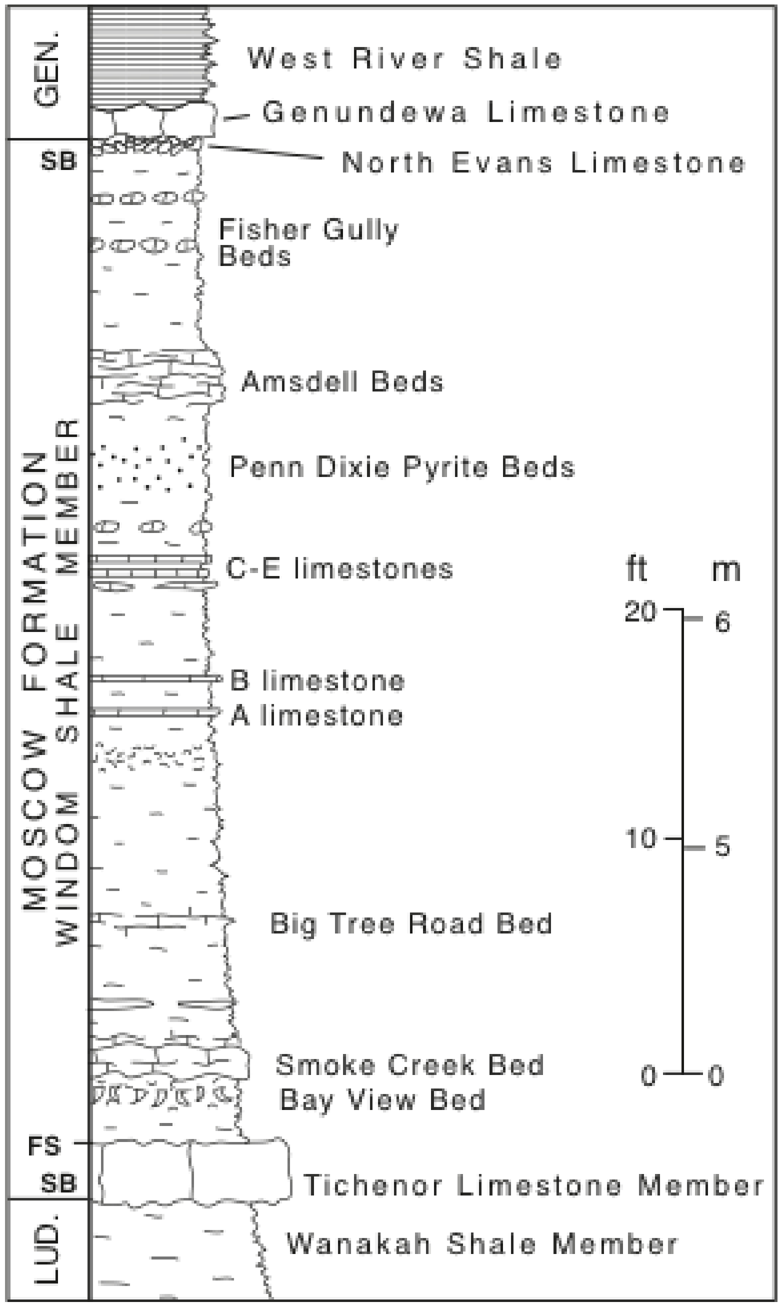

Figure 4. Generalized stratigraphic column for Penn Dixie shale pit, Blasdell, NY showing major beds of the Windom Shale. Modified from Brett and Baird (1982). Abbreviations related to sequence stratigraphi c surfaces. FS: flooding surface; SB:sequence boundary. GEN = Genesee Group; LUD = Ludlowville Formation. Modified from Brett and Baird (1982).

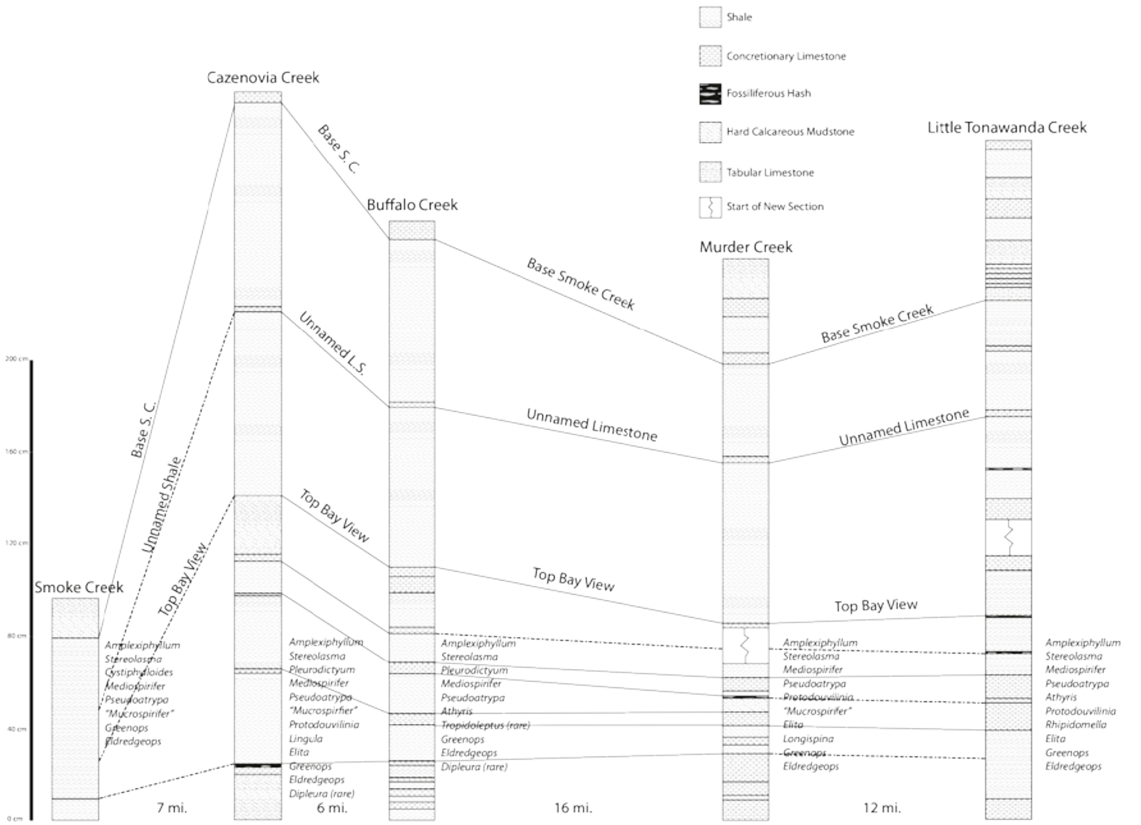

Figure 5. Detailed correlation of the Bay View to Smoke Creek bed interval in Erie and western Genesee counties. Approximate mileage between sections is given between columns; also see Figure 1 for locations.

This pattern continues into eastern Erie and Genesee County; however, in the latter localities at Eleven Mile, Alexander, Murder, and Little Tonawanda creeks the interval thins and fossils become more concentrated in a series of thin hash beds, typically rich in crinoid columnals commonly associated with concretion beds. *Pseudoatrypa* again becomes dominant and diversity increases slightly.

Unnamed shale: In all of the more easterly regions of Erie County the Bay View bed is overlain by a relatively thick (0.5 to 1.5m) interval of soft, fissile shale with scattered *Amplexiphyllum*, and small colonies of *Pleurodictyum,* abundant chonetids, and *Mucrospirife*r *consobrinus*. This unit appears transitional up into the overlying Smoke Creek bed. A single thin concretionary limestone band was found between the Bay View and Smoke Creek bed eastward from Cazenovia Creek (Fig. 5). This interval was previously treated simply as part of the Bay View bed. However, it has a sparse and somewhat distinctive fauna and is recognized as a distinct interval in this study (see Fig. 5). This shale is seen to attain its maximum thickness of 155 cm near Cazenovia Creek.

Smoke Creek bed: Brett and Baird (1982) named a distinctive trilobite-rich calcareous interval the Smoke Creek bed for exposures along the south (and north) branch of Smoke Creek in the village of Windom. The Smoke Creek bed is a relatively consistent interval of indurated concretionary, light gray calcareous mudstone or very muddy concretionary limestone (Figs. 3, 4). The unit commonly forms a low falls or rapids in creek beds. It is notable for preservation of numerous articulated trilobites, primarily *Eldredgeops rana* and *Greenops* cf. *boothi* but rarely with the proetid

Basidechenella rowi. The trilobites occur both as enrolled and prone individuals, and the interval was made famous by the occurrence of clusters of outstretched whole trilobites as well as clusters of molts (Speyer and Brett, 1985, 1986; Fig. 7). In western Erie County outcrops, the trilobites are associated with abundant small rugose corals (*Amplexiphyllum*, *Stereolasma*) and the brachiopods *Ambocoelia umbonata*, *Mucrospirifer consobrinus*, chonetids, rare atrypids, and others. In eastern Erie County the beds contain little other than trilobite remains, frequently dominated by articulated *Greenops*. These calcareous facies rather closely resemble "rhythmic trilobite" beds in other Devonian occurrences (Brett et al., 2012a,b).

Higher Windom Succession: Brett and Baird (1982) described a series of additional beds in the Windom of Erie County (Figs. 3, 4). These include a sparse pyritic fauna with small pyritized sponges and rare blastoids (*Hyperoblastus*) a meter or so above the Smoke Creek bed, which is well developed at Buffalo Creek (Fig. 3). This succession is overlain by sparsely fossiliferous shales with chonetid brachiopods, especially *Longispina*. The middle of the member is marked by a pair of thin tabular concretionary micritic limestones followed by a minor pyritic shale and then a triplet of similar tabular limestones (C-E beds). Overlying shale contains the Penn Dixie pyritic beds, noted for the occurrence of bedding planes of diminutive *Tropidoleptus* and a pyritic (commonly pseudomorphed to limonite) assemblage of burrows fills, small nuculid bivalves, nautiloids, gastropods, rare goniatites, enrolled trilobites, and wood. These beds are missing by erosion from central Erie County eastward. The uppermost Windom exposed in western Erie County is concretionary limestones and shales, carrying an unusual assemblage of *Emanuella praeumbona*, chonetids, *Athyris*, *Eumetabolotoechia*, and *Eldredgeops* trilobites. This assemblage was termed the Amsdell bed by Brett and Baird (1982). The highest shales along Eighteen Mile Creek recognized by Grabau (1898) carry assemblages of the phosphatic orbiculoid *Schizobolu*s and the small spiriferid *Allanella tullius*, suggesting higher beds of a division referred to as Fisher Gully beds in the Finger Lakes area (Brett and Baird, 1994). Most all of the middle and upper Windom in Erie County can be referred to as restricted biofacies. The presence of pyrite, lack of larger burrows, and rather sparse fossils with discrete bedding planes covered with diminutive brachiopods suggest fluctuating oxygenation of the seafloor ranging from lower oxic to dysoxic conditions (see Boyer and Droser 2009). This contrasts with middle-upper Windom to the east of Genesee County, which is mostly rather fossiliferous. Grabau's observation further suggests that the Genesee-Erie County area was occupied by a somewhat deeper and oxygen restricted basin through most of higher Windom deposition. The generally light to medium gray colors of these shales suggest relatively low organic productivity and limited organic carbon burial despite low oxygen conditions.

PALEOENVIRONMENTAL INTERPRETATION OF THE LOWER WINDOM SHALE

The *Ambocoelia* beds to Bay View stratigraphic succession of the lower Windom Shale appears to reflect an overall mid-scale (4th order) shallowing trend from slightly dysoxic facies, dominated by small brachiopods to shallower shelf, locally dominated by coral thickets. Bay View through Smoke Creek beds display a corresponding deepening upward pattern that may be interrupted by a minor shallowing. The shallowing transition is relatively abrupt, being marked by silty mudstone beds that are heavily churned with *Zoophycos* and marked by increased faunal diversity. Further east this thin interval appears to expand into several meters of silty, *Zoophycos* churned mudrock. We interpret the base Bay View beds as representing the shallowest point in this cycle, but careful inspection of the thickest successions near Buffalo Creek suggests that the Bay View interval actually shows a retrograde pattern and deepens upward into more sparsely fossiliferous shales with a chonetid-*Mucrospirifer* fauna. The Smoke Creek bed may represent a minor (5th order) cycle superimposed upon the overall upward deepening, as in some areas, it shows a return to more abundant small corals and brachiopods; however, it is also clearly retrogradational and passes abruptly upward in most sections into very sparsely fossiliferous,

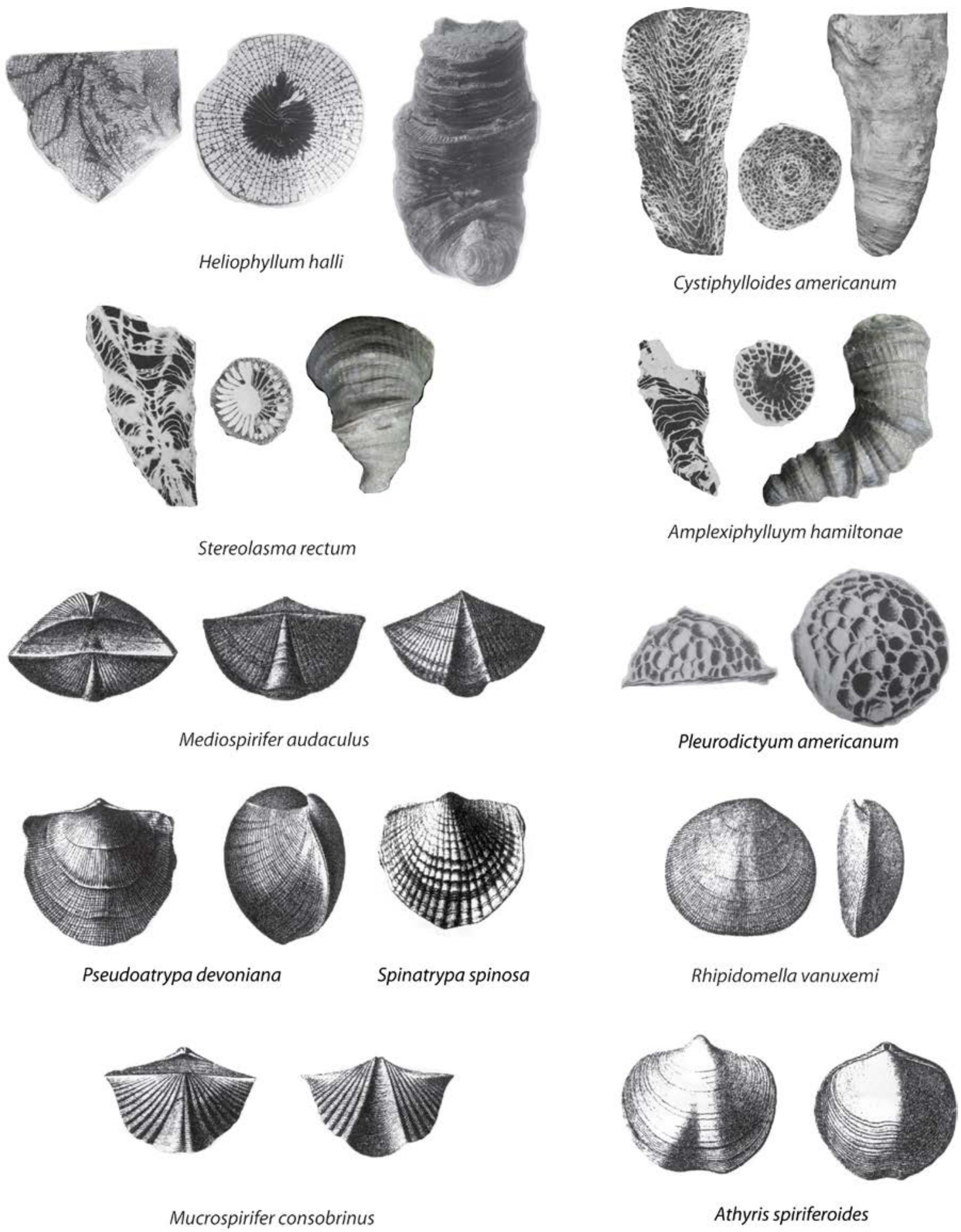

Figure 6. Illustrations of common Hamilton fossil taxa found in the lower Windom Member, Bay View bed. Most illustrations are approximately at typical size. Sources for these figures include Linsley et al. (1994) for brachiopods and Stumm and Watkins (1961), Ehlers and Kesling (1970), and Oliver and Sorauf (2002), for corals.

pyritic shale of the middle Windom. Both the Bay View and Smoke Creek intervals show superimposed very minor cyclicity in the form of concretionary/nodular beds. These may record 6th order 1-15 millennial scale oscillations in sediment supply, perhaps associated with climatic variations in the source area of the muddy sediments.

TAPHOFACIES AND TAPHONOMIC GRADIENTS

The Bay View bed shows a rather striking change in overall taphonomic aspect from west to east, which parallels its eastward thickening and faunal change. Typical western exposures such as those at Lake Erie exhibit a common shell bed pattern. Corals and brachiopod shells are abundant to closely packed and typically show evidence for some degree of reworking although not in extreme high-energy settings. Much of the fossil material occurs as debris of disarticulated crinoid and bryozoan material; brachiopods are commonly disarticulated although whole valves are common and atrypids tended to remain articulated; this is evidently a function of their resistant interlocking hinge teeth. Most shells are mud filled with exogenous skeletal material inside the shells, sometimes including articulated trilobites (Brett, 1977). Many shells and corals show encrustation, including crinoid holdfasts, encrusting trepostome bryozoans, and basal attachments of larger rugose corals. Corals themselves may show some degree of corrosion of the epitheca, mainly on one side. Most trilobites occur as disarticulated cephala (often further split into the glabella or individual eyes), pygidia, and thoracic segments. Finally, skeletal material is distributed rather uniformly through the bed although corals show some degree of patchiness in their development.

In contrast, the thicker Bay View interval in more easterly localities shows a very distinctive taphonomic signature; with the exception of limited patches of skeletal debris, most fossils occur as isolated individuals or, in some cases, tightly clustered aggregations of three or more individuals. Brachiopod shells are mostly completely unworn, un-encrusted, and most significantly, a majority of brachiopods are articulated and a large number appear to be preserved in life position. Breakage of specimens typically yields spar-filled shell interiors, rather than mud fillings. Small corals (mainly *Amplexiphyllum*) are completely unworn and show delicately geniculate corallites.

This spacing out and preservation of original patchiness point to more rapid background rates of sediment accumulation. This is also reflected in the generally articulated condition of brachiopods, including spiriferids with more readily disarticulated shells. Spar fillings of many shells suggests that brachiopods were buried rapidly before internal tissues decayed and that they remained closed owing to confining sediment pressures.

One of the major differences between the western and eastern occurrences involves the development of diagenetic carbonates. In thinner, western occurrences of the Bay View bed the matrix surrounding fossils is soft clay. In contrast, commencing at Cazenovia Creek, the eastern Erie county occurrences show a series of thin concretionary limestone beds. These occur at specific horizons, the thicker of which may be traceable among outcrops. Fossils occur both in and surrounding the concretions and some concretionary horizons appear to have no associated fossils. The diagenetic carbonates range from discrete, ovoidal concretions up to 30 cm in diameter, to more distinctly traceable sub-tabular bands of pale weathering calcareous mudstone/argillaceous limestone. Even these bands in some cases incorporate small concretions suggesting two phases of cementation in which carbonate initially nucleated around some object - commonly a pyritic burrow, followed by more pervasive cementation. Concretionary carbonate developed within the zone of sulfate reduction, as evidenced by direct association with pyrite, in muddy sediment and may, in part, represent redistribution of carbonate derived from dissolved aragonitic shell material; associated mollusks are primarily preserved as compacted decalcified molds.

Carbonate cements evidently developed in unconsolidated muds within a near surface zone during the very initial phases of compaction of these sediments. We suggest that these concretionary, cemented areas in the sediment reflect pauses in sedimentation, during which carbonate supersaturation took place eventually leading to precipitation of calcite cements at particular levels in the sediment (see Wilson and Brett, 2013, and references therein). In several cases, but by no means all, concretions are immediately overlain by shelly, crinoid hashes, which may also signify pauses in sedimentation that permitted buildup of thin layers of debris.

The occurrence of concretionary layers in the more sparsely fossiliferous thicker mudstone sections of the Bay View bed, rather than at the thinner, shell-rich western localities seems counterintuitive. However, this may simply reflect the position of appropriate geochemical conditions in dysoxic sediments near the basin center. A similar relationship has been discerned in the Upper Ordovician Kope Formation of the Cincinnati arch, in which concretions, again

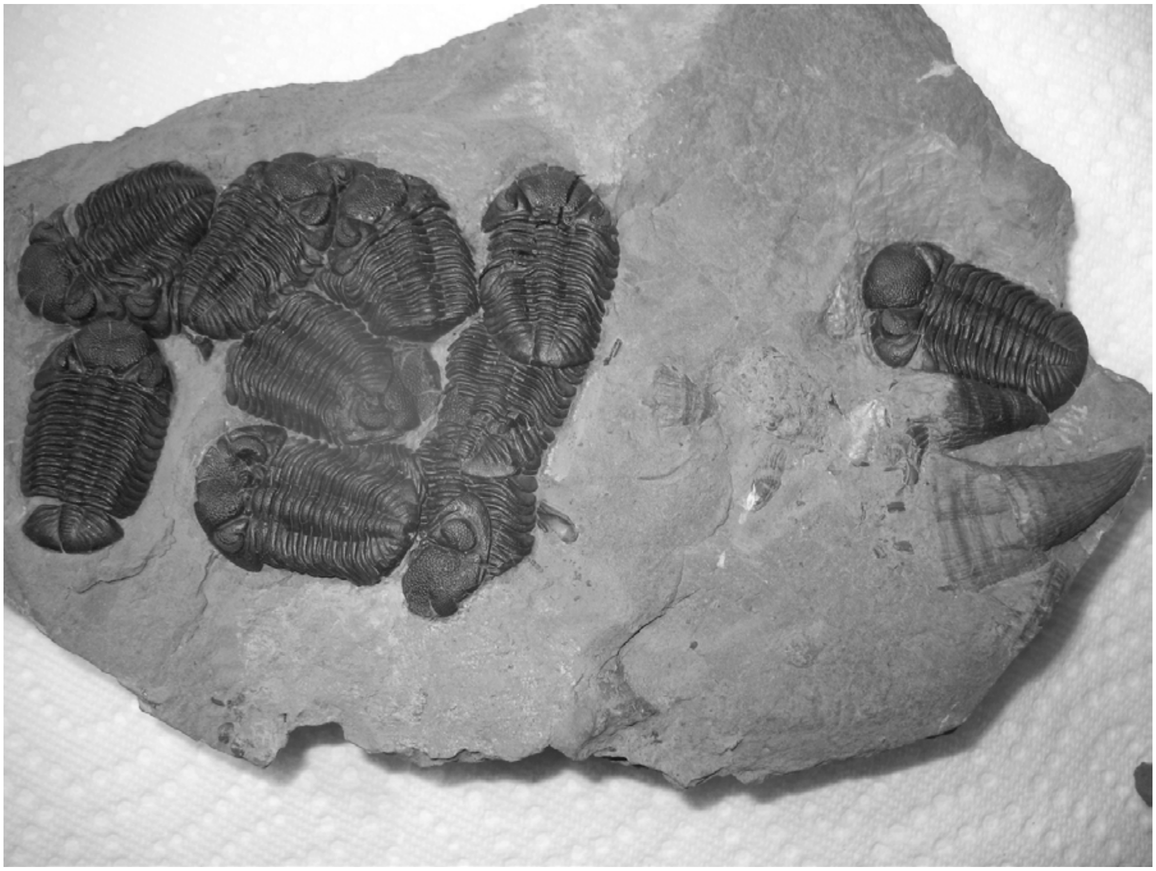

Figure 7. Cluster of articulated specimens of the trilobite *Eldredgeops rana* (Green) and the rugose coral *Stereolasma rectum* from Smoke Creek bed, lower Windom Shale at the Penn Dixie shale pit. Specimens are approximately 1.5 cm in length. Note slight disarticulation suggesting minor decay prior to burial. Photo courtesy of Matt Phillips.

associated with shell hash beds and recording pauses in sedimentation, are not developed in up-ramp areas where the shell hash beds are typically thickest; rather they tend to occur beneath thinner shell hash layers in down-ramp positions where mudstones are thicker and display more evidence of dysoxia (Brett et al., 2008).

In contrast to the Bay View bed, which is only locally concretionary, the Smoke Creek bed is everywhere developed in calcareous mudstone facies that also show evidence of greater cementation. However, the subdivisions are more discrete and the presence of nucleated centers are more obvious in distal down ramp successions. The occurrence of pervasive cementation in the Smoke Creek bed may reflect its overall more sediment-starved condition (developed at or near to maximum flooding during a transgression).

As noted, the Smoke Creek bed shows many characteristics in common with other Devonian trilobite beds, such as the Birdsong Shale of Tennessee, Harragan Formation of Oklahoma and the *Hollardops* beds of southwestern Morocco (Brett et al. 2012a). Trilobites occur both as disarticulated material, including molt clusters, and as completely articulated enrolled or outstretched individuals (Fig. 7). The occurrence of associated molt ensembles indicates that burial in the Smoke Creek bed did not involve bottom mudflows; most individuals are parallel to bedding and only rarely are trilobites seen in unusual orientations. This suggests that these beds reflect type-1 trilobite beds of Brett et al., (2012b); that is, mass mortalities associated with distal storm events and pulses of burial from suspended sediments shortly after mortality of trilobites but before major decay, rather than distal turbidites (Fig. 7).

Brett et al. (2012b) concluded that best-preserved trilobites, such as those in the Smoke Creek bed, occur in a taphonomic "window" in which distal, storm-derived muds frequently entomb remains and even live trilobites. Superimposition of early diagenetic cements on the obrution sediments aided in three-dimensional preservation of trilobites. The association of small brachiopods (chonetids, ambocoeliids) and small solitary rugose corals further indicates that this taphonomic window also occurred in a distinctive environmental zone, transitional between basinal dysoxic muds and more diverse upramp, brachiopod-coral facies.

PALEOECOLOGICAL GRADIENTS

To quantify the ecological gradient observed qualitatively in the Bay View interval (Brett and Baird, 1984) we performed detrended correspondence analysis (DCA) ordinations on a subset of a large Hamilton Group dataset, which includes data collected by Ivany et al. (2009), Boyer and Droser (2009), Bonelli et al. (2006), Baird and Brett (1983), Bezusko (2001), and our own newly collected samples. DCA arrays samples or taxa along two or more axes that best explain variations in abundance, diversity, and faunal composition among samples. These axes most commonly reflect water depth, substrate, or salinity in marine macrobenthic fossil communities (Scarponi and Kowalewski, 2004), but they may also respond to other environmental factors (see Patzkowsky and Holland, 2012).

Here, we perform both ordinations of samples and ordinations of taxa in the Bay View-Smoke Creek interval. Our objective in the former case is to emphasize the gradient of samples from locality to locality, based on degree of taxonomic similarities, and particularly to highlight how these correspond to geographic and lithological patterns along the outcrop belt. In the latter case we use an ordination of the entire Ludlowville Formation as a proxy for the “generic” Hamilton ecological gradient originally qualitatively described as biofacies (Brett and Baird, 1984), and compare it with the higher resolution Bay View-Smoke Creek interval.

Figure 8 is a plot of samples from six localities in Erie County and eastern Genesee County. From west to east these are: Lake Erie shore, 18 Mile Creek, Smoke Creek, Cazenovia Creek, Buffalo Creek and Murder Creek. Note that with a few exceptions, samples from given localities plot in east west geographic order along DCA axis 1, with Lake Erie samples to the right, reflecting high DCA1 scores and Cazenovia and Buffalo Creeks close together but in the correct geographic order to the left with low DCA1 scores. As in many studies DCA axis 1 is interpreted as correlating with factors related to relative water depth (Scarponi and Kowalewski 2004). It should be noted that although Cazenovia Creek appears to have the thickest upper Bay View shale and Smoke Creek, the fauna is more diverse and contains rare elements, such as *Spinatrypa* that suggest it was somewhat shallower than the latter site during Bay View deposition.

Moreover, the major exception to the west-to-east high to low DCA1 order is the single sample from Murder Creek, furthest to the east, which plots close to the western Eighteen Mile Creek samples. However, this reversal actually underscores the acuity of the method as qualitative observations strong suggest that the depth gradient reversed east of Buffalo Creek and that the

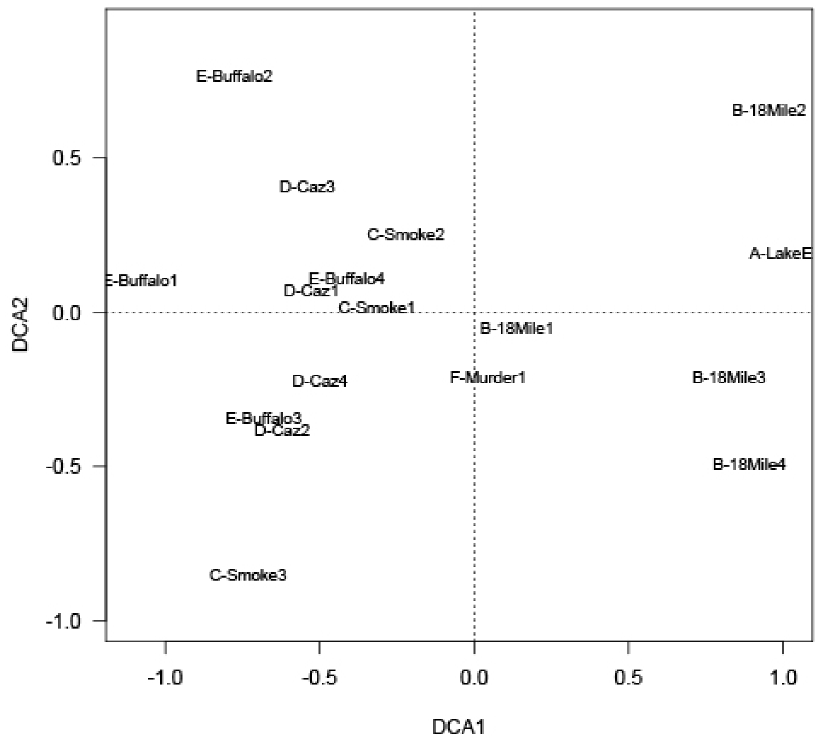

Figure 8. Plot of detrended correspondence analysis (DCA) axis 1 vs. axis 2 scores for samples of Bay View bed at six locations in western New York. Letters on locations indicate geographic position, from west to east these are A) Lake Erie shore Highland on the Lake, B) bank of Eighteen Mile Creek, C) south branch of Smoke Creek, Windom, NY; D) Cazenovia Creek at Northrup Road, Spring Brook, NY, E) Buffalo Creek at Bullis Road, Elma, NY, and F) Murder Creek south of Darien, Genesee County, NY. Note the general west to east progression of locations from right to left with lowest scores (left) for Buffalo Creek indicating lower diversity and density and probably deeper water settings and high scores on the right indicating more large coral-rich, shallower samples.

more diverse samples from Murder Creek do, indeed, reflect shallower water facies, similar to those in the far west of Erie County. Thus, this plot corroborates stratigraphic thickness, sedimentologic, and taphonomic evidence for a locally subsiding basin and depocenter in central Erie County during lower Windom deposition.

The precise interpretation of variation along DCA2, however, is not as obvious. It may record very local substrate variations associated with slightly different portions of the Bay View interval including patchiness in distribution of skeletal material. Local shelly patches may have promoted increased diversity of attached suspension feeding animals via taphonomic feedback associated with higher DCA2 scores, whereas muddy patches favored lower diversities but including other taxa such as bivalves (cf., Miller et al. 2001). Alternatively, DCA2 may also reflect water depth changes, but at a higher-resolution than DCA1. For example, samples taken from the bottom of the Bay View will be slightly different from samples taken near the top of the Smoke Creek, even if both samples are collected at the same locality. It is also possible that, given the smaller number of samples, DCA2 has no meaningful interpretation in this plot.

To better understand patterns of biofacies distribution we also ran DCA analyses on fossil species, as opposed to samples, to characterize the biofacies distribution of various common taxa (Figs. 9, 10). Hamilton faunas have long been qualitatively divided into a series of named biofacies defined by their most abundant species (Brett et al. 1990, 2007; Fig. 9). Vertical successions in western New York typically show a depth-related spectrum of change from low diversity leiorhynchid brachiopod-dominated dark shales through gray mudstones with small ambocoeliid-chonetid assemblages, and increasingly diverse coral, brachiopod, bryozoan assmblages. Lateral transitions within these depth-related biofacies mirror lithological changes along the west-east outcrop belt from Buffalo to Syracuse. The western side of the basin is dominated by soft, gray mudstones punctuated by thin concretionary or tabular limestones, while the eastern side is dominated by upward-coarsening cycles of dark shale into siltstones and sandstones. Intermediate between these two extremes are darker, thicker mudstones representing deep water, dysaerobic settings near the basin's depocenter. As a result, Hamilton ordinations produce four recognizable, lithologically correlated clusters, which in turn closely match the biofacies divisions first recognized qualitatively by Brett et al. (1990) (comparative Figures 9, 10A). First, there is a shallow carbonate cluster consisting of genera from the *Favosites*, *Pentamerella-Heliophyllum*, and "diverse brachiopod" biofacies, in this case plotting as very low scores on DCA axis 1. Second, a shallow clastic fauna representing the *Tropidoleptus*, *Spinocyrtia*, and *Allanella* biofaces with low to mid range DCA1 scores and high DCA2 values. Third, a generalist, mid-depth fauna dominated by chonetid brachiopods, *Ambocoelia*, *Mucrospirifer*, and nuculid bivalves with mid-range DCA1 scores and relatively low DCA2 values. Fourth, deep water, dysaerobic taxa dominated by the brachiopod *Eumetabolotoechia* and various cephalopods, with high DCA1 scores and low DCA2 scores. Importantly, these clusters do not run strictly parallel to either DCA1 or DCA2, and it is impossible to describe either axis as primarily reflecting water depth or the ratio of carbonate to clastic sediment. Both environmental gradients are instead oblique to the ordination axes, which is likely a reflection of the depth gradient's reversal back towards shallower settings on the eastern side of the depocenter.

The Bay View plot (Fig. 10B) is somewhat distinct from the Hamilton ideal because it does not contain all Hamilton lithofacies. For example, there are no black, pyritic shales in the Bay View, even at its deepest locality, Buffalo Creek. The *Eumetabolotoechia* biofacies is consequently not developed because the Bay View bed, as exposed in outcrop, never reached fully dysaerobic settings typical for this association – although deeper water taxa (inarticulate brachiopods, orthocone nautiloids) continue to plot in the lower right corner. Similarly, there are no very shallow subtidal rocks (i.e., near normal wave base) preserved in the Bay View bed of Erie County, and members of the *Favosites* biofacies (e.g., *Favosites*, *Blothrophyllum, Eridophyllum*) are not observed in the Bay View, despite being present in other Windom coral beds (e.g., South Lansing and Fall Brook coral beds).

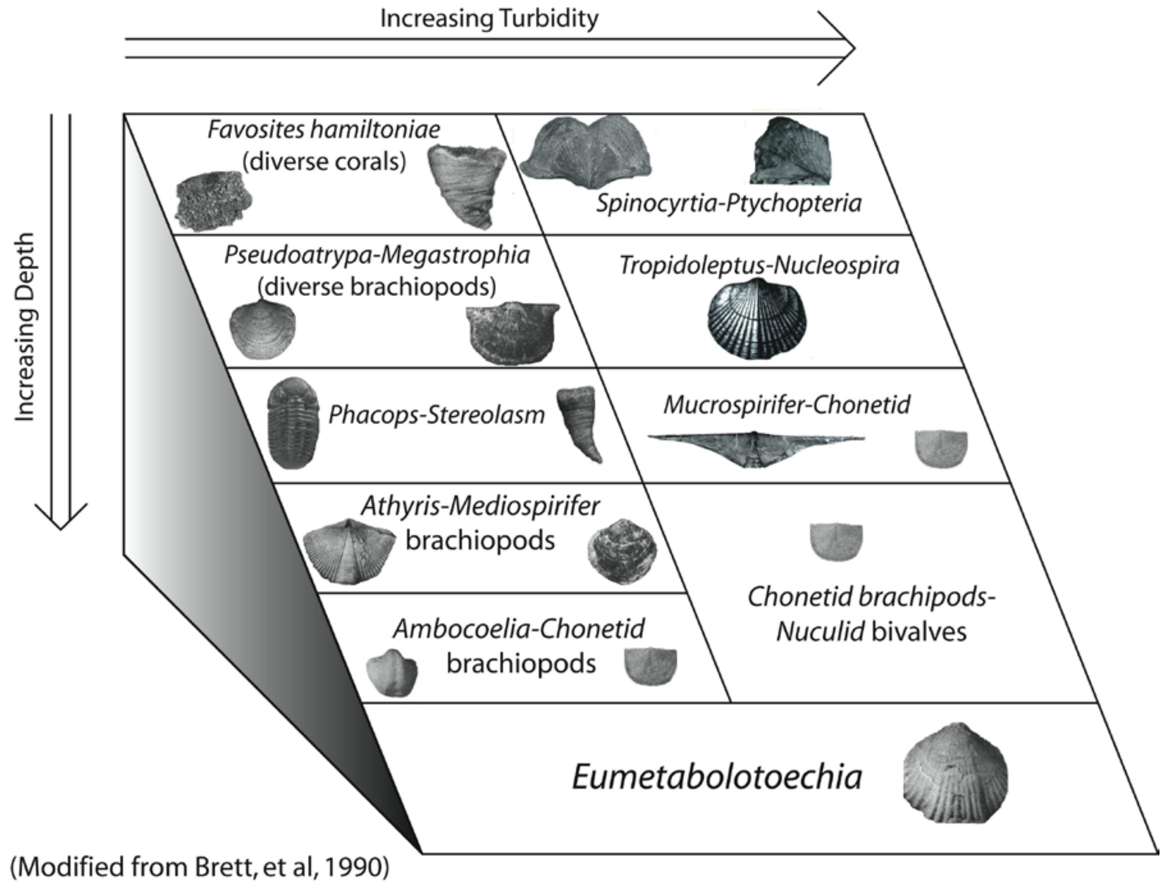

Figure 9. Model of Hamilton biofacies showing distribution of fossil association along gradients of depth-related parameters along a gently sloping ramp and also along a gradient of increasing sedimentation/turbidity (roughly east to west in the case of the Hamilton Group).

The Bay View Bed is also unique because many genera previously associated with the "diverse brachiopod" biofacies (Brett et al., 2007; e.g., *Pseudoatrypa, Mediospirifer, Protodouvilinia, Amplexiphyllum*) appear more widespread than usual for the Hamilton. This is reflected in the Bay View DCA by a more central position for these taxa in ordination space (Fig. 10B). One explanation for this is an effect analogous to zooming in or out of a digital map. When viewing a map at minimum magnification two points may appear close together, but when zoomed in further the two points appear farther apart, even though the actual distance between the two points has not changed. Similarly, because the shallowest and deepest Hamilton lithofacies are absent from the Bay View in the exposed outcrop belt, a smaller array of environments is sampled than usual, making taxa appear more spread out in ordination space.

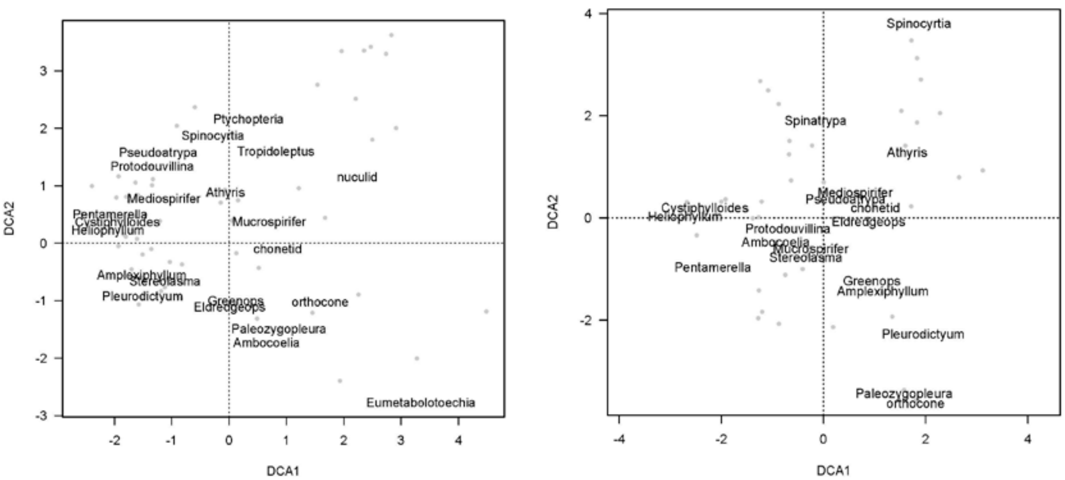

Figure 10. Plots of detrended correspondence analysis (DCA) axis 1 vs. axis 2 scores for genera of fossils from various samples. (Left) Plot of the entire Ludlowville Formation as a proxy for the "generic" Hamilton. The progression of taxa closely follows the qualitatively defined biofacies of Brett and Baird (1984), and the type-genera of these biofacies are represented in boldface text (compare Figure 9). Neither axis clearly represents either water depth or the ratio of carbonate to clastic sediment. The depth axis instead runs from the upper left corner (*Pentamerella-Heliophyllum* biofacies) to the lower right corner (*Eumetabolotoechia* biofacies); whereas the carbonate-clastic gradient runs from the middle left (*Pentamerella-Heliophyllum*) to the upper right corner (*Allanella* biofacies; the actual genus *Allanella* is not present in this dataset, but other common members of the biofacies (e.g., the bivalves *Tellinopsis*, *Cimitaria*, *Orthonota*) plot in the upper right corner). Such oblique gradients are not uncommon in DCA plots, but the degree of tilt is likely exacerbated by the reversal of the depth gradient on both sides of the depocenter.

(Right) DCA plot of taxa from Bay View – Smoke Creek samples. Genera of interest are represented in boldface text. The overall gradient structure is similar to that of the generic Hamilton plot, but see text for an explanation of the deviations. Dots indicate additional taxa.

On the other hand, the ubiquity of the "diverse brachiopod" biofacies may represent a true change in the lithologic preferences of some taxa. The rugose coral *Amplexiphyllum*, in particular, is extremely widespread throughout the Bay View Bed. It has been reported from every Bay View Bed locality sampled for this study, though it varies in abundance and body size along the outcrop belt This not only includes the more siliciclastic rocks of the Finger Lakes region, which are normally lacking in corals; it also includes a relatively high abundance in the deepest portions of the Bay View around Buffalo, Murder, and Cazenovia creeks. Although these strata do not represent the deepest, fully dysaerobic settings possible in the Hamilton, and it is because of these deeper water occurrences that *Amplexiphyllum* plots lower on DCA 2 close to members of the *Eumetabolotoechia* biofacies (Fig. 10). It is therefore possible that conditions during Bay View times were uniquely ideal for *Amplexiphyllum* and certain other members of the "diverse-brachiopod" biofacies, such as *Mucrospirifer consobrinus*. This then returns us to the notion of epiboles: unique conditions, not readily recognizable from sedimentology or other paleoenvironmental indicators must in some way favor particular taxa at specific times (Brett and Baird, 1997).

IMPLICATIONS FOR BASIN TOPOGRAPHY AND SYNSEDIMENTARY TECTONICS

The axis of the foreland basin shows a progressive westward shift throughout most of the Hamilton Group interval, presumably as a result of active thrust loading (Fig. 11). As such, the basin axis for the Marcellus subgroup lay in eastern New York, while the Skaneateles depocenter is in the central part of the state. During most of Ludlowville and Moscow deposition there was a progressive westward shift of depocenters from about the Cayuga Lake meridian to Erie County, as recorded by the thickest and most mudstone rich portions of successive members.

Detailed mapping of the beds within the Windom not only demonstrates facies changes and substantial thickening and thinning in some levels but also proves that depocenters shifted during deposition of the unit and that its submembers. During the deposition of the high Hamilton Windom Member the basin had shifted to the vicinity of Genesee to central Erie Counties. This shift is documented by an east to west precession of thickest portions of individual submember scale packages: the dramatic changes in thickness and facies of successive packages in the Windom shale, bracketed by through-going condensed shell beds such as the Bay View and Smoke Creek provides a series of snapshots of a dynamic inner margin of a foreland basin. As noted above, the lower Windom *Ambocoelia* beds are thickest in central Genesee County and thin both east and west of this area, The Bay View-Smoke Creek interval is probably thickest near Darien, whereas the mid Windom ("Bear Swamp" interval) is thickest in central Erie County (see Fig. 12). This change in geometry is also apparent in the biofacies gradient of the Bay View bed, which shows an increasingly sparse and lower diversity fauna with deeper water elements eastward in Erie County plus the beginnings of shallowing in central Genesee County eastward to the Genesee Valley though never returning to the large coral thicket condition seen in western Erie County localities (Baird and Brett, 1983).

It is possible that the Upper Windom was once thickest still further to the west past the modern day Lake Erie shoreline, but subsequent erosion during the late Givetian has removed these

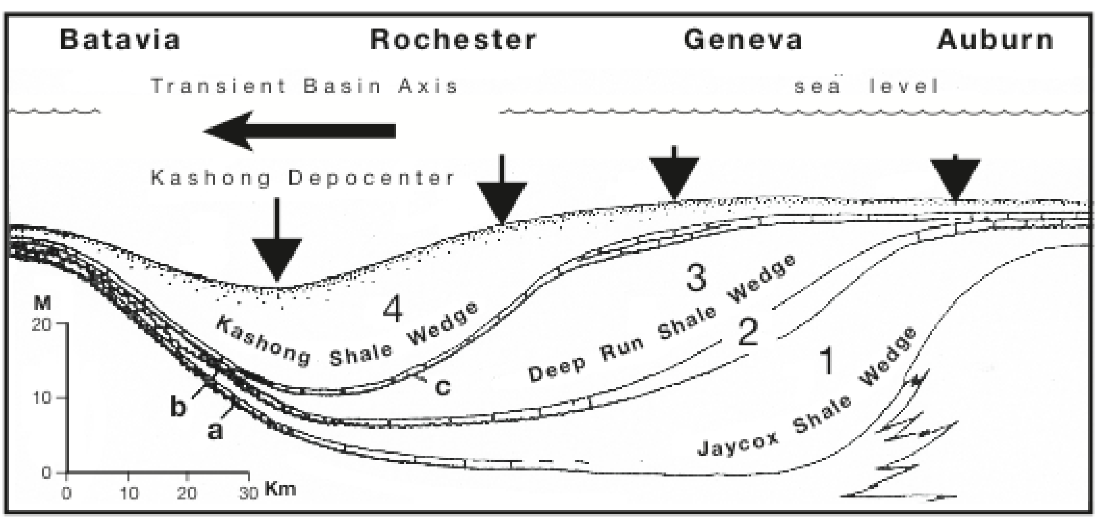

Figure 11. Generalized diagram showing westward migration of basin axis and depocenters through the lower Moscow Formation.

higher beds (Figs. 12, 13). It is clear, however, that the highest Moscow units, together with the overlying Tully Limestone, well developed east of Syracuse, are absent in western New York, where the late Givetian Taghanic unconformity and an associated marine erosion surface produced regional truncation to the northwest (Baird and Brett, 1986, 2003, 2008). This erosion surface is prominently displayed in the outcrops discussed herein by examining the succession between the Smoke Creek bed, and Middle/Upper Devonian Genesee Formation contact (Fig. 12).

At Lake Erie, where the entire Windom is reduced to a few meters in thickness, there is a relatively complete representation of the component strata, although uppermost deposits, constituting the diverse Fall Brook coral bed and overlying dark upper Windom beds, are missing. However, thin concretionary limestones, termed Amsdell beds and about a meter of overlying Fisher Gully equivalent shale are still present beneath the sharp contact with the remarkable North Evans, condensed conodont bed. Proceeding northeastward toward Cazenovia Creek, and despite overall four-fold thickening of the Windom the uppermost beds are missing and the Leicester Pyrite, a distinctive pyrite, bone, and conodont lag associated with the Genesee black sale rests almost directly upon the Amsdell bed (Fig. 12). The middle Windom has ballooned in thickness to occupy most of the section. In the vicinity of Cayuga Creek in west Alden-Cowlesville, the Amsdell interval is removed and the Leicester Pyrite (formerly termed Cowlesville Marcasite) rests on mid Windom concretionary beds about 8 meters above the Smoke Creek bed. Finally, in the vicinity of Darien on Elevenmile, Murder, and Little Tonawanda creeks the contact with the Geneseo Formation and its local pods of Leicester Pyrite is just 1-3 m above the Smoke Creek bed with the entire middle and upper Windom removed (Fig. 12).

Proof that the truncation is in a northward or northwestward direction is seen at Little Tonawanda Creek where in the main outcrop at Darien Center the Leicester Pyrite is just 1.5 m above the Smoke Creek bed. Conversely, where the section is repeated further south at Linden about 2.5 km to the south, owing to up-throw on the Clarendon-Linden fault, the Fall Brook bed, a unit above the Amsdell-Fisher Gully interval, appears directly below the Leicester; this means that the entire mid Windom succession, including the Amsdell beds and overlying Fisher Gully and Taunton beds have been preserved. The northward truncation of Windom strata shows that in late Givetian time the basin geometry had returned to a previous condition in which the western New York shelf was oriented ENE to WSW and sub-parallel to the outcrop belt.

It is also probable that the basin center/depocenter for the uppermost Hamilton and Tully formations abruptly reversed its trajectory and migrated in an eastward direction into central New York (Baird and Brett, 2003; Fig. 13). This reversal may signal thrust load relaxation during a period of relative quiescence or alternatively the tipping point between the end of tectophases 2 and 3 (Ettensohn 1985, 1987, 2004) in the foreland basin. Regardless, there is strong evidence in the overlying Genesee Group for develop of a new and deeper foreland basin that again shifted westward from the central Finger Lakes to the vicinity of present day Cleveland, Ohio through the remainder of the Devonian.

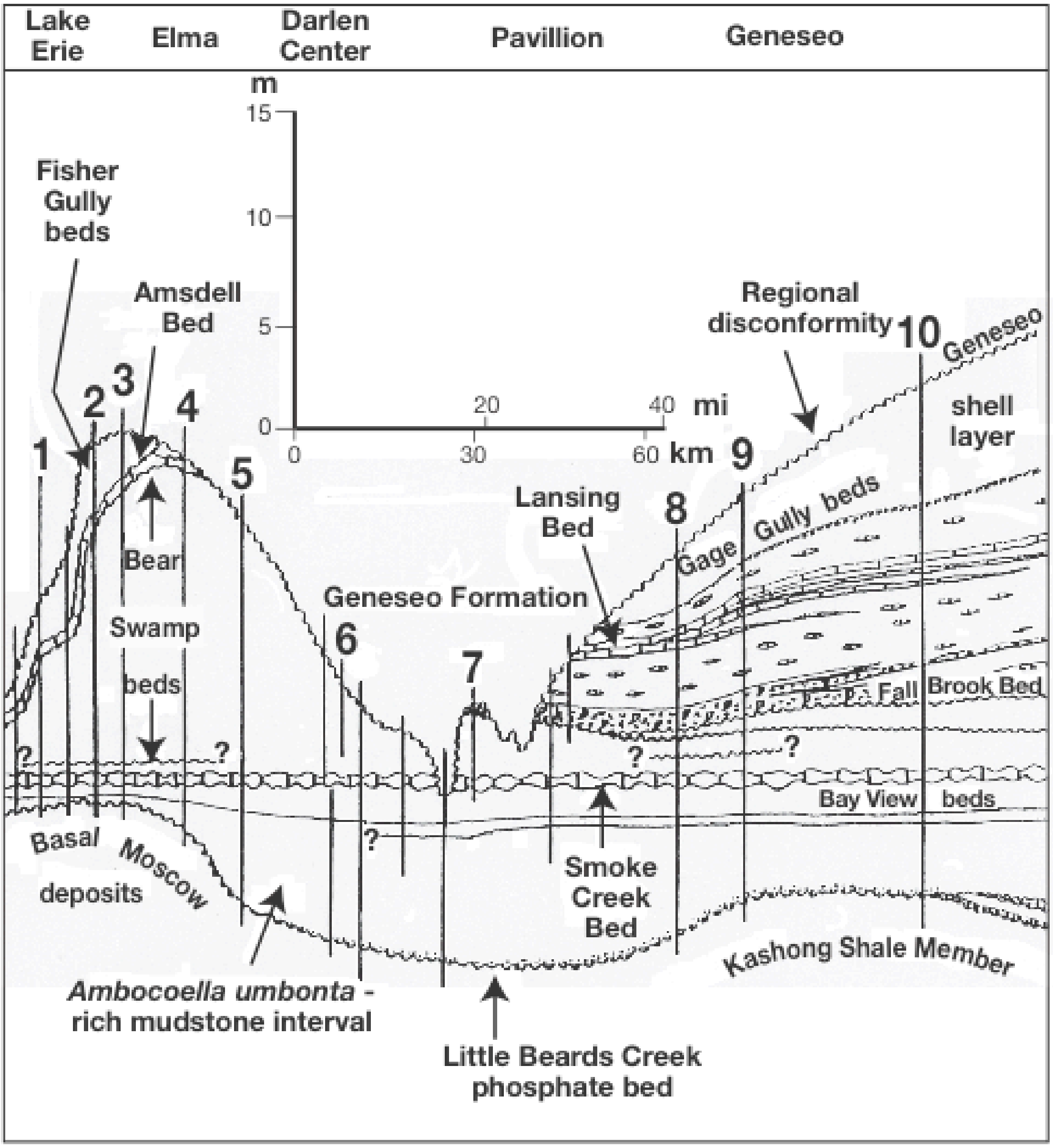

Figure 12. Stratigraphic columns of Windom Shale at various locations in western New York showing differential thickening of the lower Windom to the east and regional northeastward truncation of the upper Windom beds in central Erie to eastern Genesee Counties. Columnar sections are as follows: 1) Eighteen Mile Creek; 2) Penn Dixie Fossil site (shale pit); 3) South Branch, Smoke Creek, Windom, NY; 4) Cazenovia Creek at Northrup Road, Spring Brook; 5) Buffalo Creek at Bullis Road; 6) Eleven Mile Creek, Darien; 7) Little Tonawanda Creek, Linden; 8) Little Beards Creek, Leicester; 9) Fall Brook, Geneseo; 10) Frost Hollow north of Honeoye. Modified from Brett and Baird (1994).

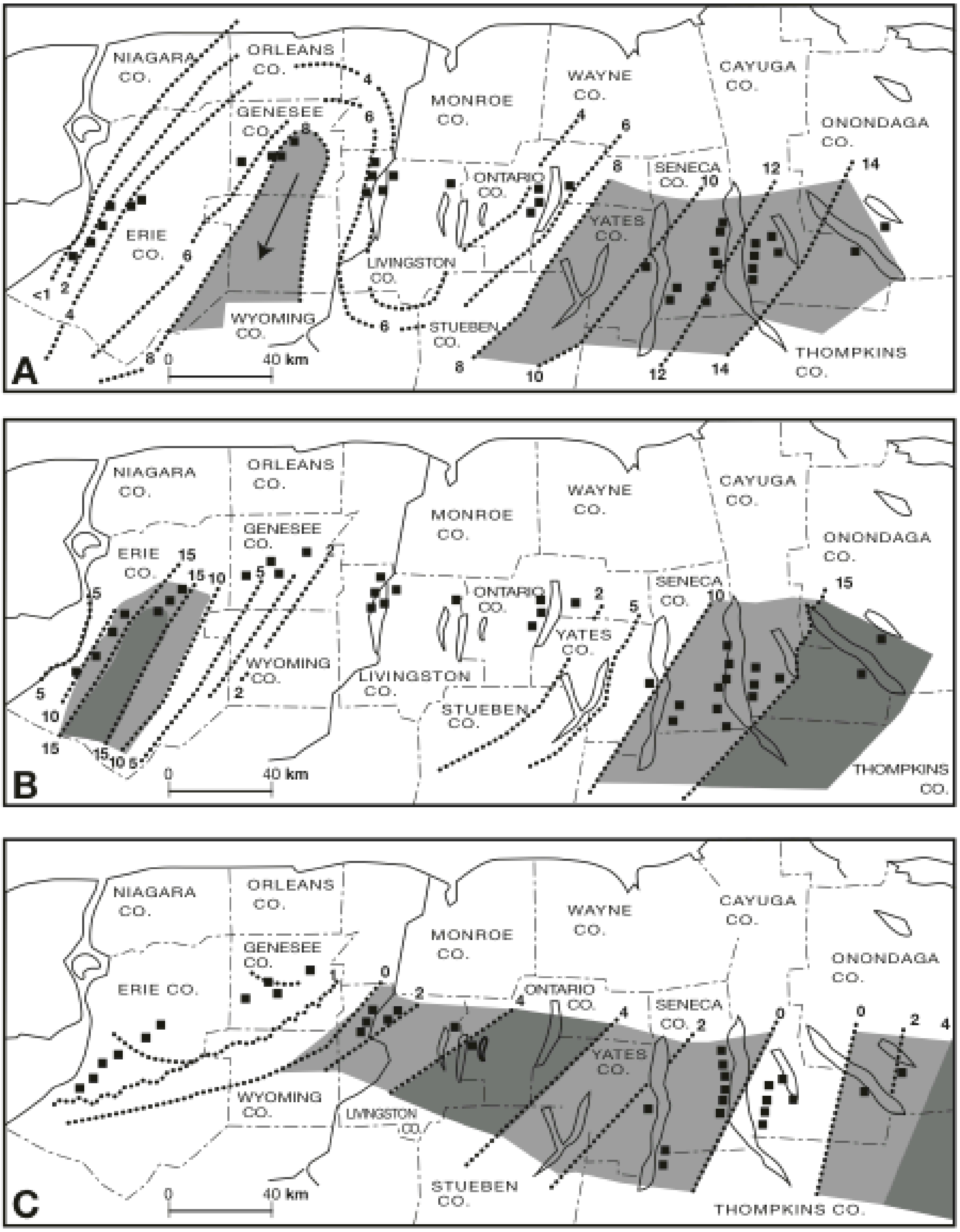

Figure 13. Isopach maps showing approximate position of basin axis during deposition of the Windom Shale; contour intervals in meters; darker areas show basins. A) lower Windom up to Smoke Creek bed; note presence of two depocenters, including western sub-basin; note migration to a position in Genesee County during deposition of the *Ambocoelia* beds; B) mid Windom (Bear Swamp-Fisher Gully interval) note westward shift of sub-basin into central Erie County. During deposition of the middle Windom. C) upper Windom, Gage gully beds; note rapid reversal of depocenter to the east in Ontario County. This time series suggests a dynamic movement of subsidence during this time interval, which may represent less than a million years.

CONCLUSIONS

The Middle Devonian Windom Shale possesses several widespread calcareous and typically highly fossiliferous beds that reflect pauses in siliciclastic deposition during minor rises in base level associated with transgressions. The Bay View and Smoke Creek beds together form a back-stepping, transgressive succession. The presence of concretionary carbonates in this interval reflects oscillations in sediment supply and buildup of alkalinity within sediments during minor episodes of increased sediment starvation. Extraordinary trilobite beds in the Smoke Creek interval indicate pulses of mass mortality in some case associated with intraspecific clustering and followed by rapid, though not instantaneous burial. Concretionary cementation has aided in robust preservation. These beds also record an epibole with certain taxa particularly abundant, in this case the brachiopods *Mucrospirifer consobrinus*, *Amplexiphyllum*, and *Spinatrypa*. These beds laterally crosscut facies and thus provide transects that reveal subtle changes in seafloor topography. Gradient analysis using detrended correspondence analysis (DCA) of samples from several locations indicates a lateral gradient from western to central Erie County, NY and again eastward from an apparent microbasin center. DCA of fossil taxa show patterns within the Bay View bed that to some degree mirror those seen in the Hamilton Group biofacies as a whole though with certain taxa, such as *Amplexiphyllum*, atypically abundant and widespread.

High-resolution study of stratigraphy, taphonomy and fossil content illustrate the fine scale architecture of the Windom Shale. Details of facies change-including quantified biofacies change and differential thickness of different stratal intervals (submembers) in the Windom indicate that a micro-basin, related to the Acadian foreland basin, migrated into and across the present day Erie County during late Givetian time. This example shows progressive westward shifting of the basin center up to the middle part of the Windom, nearly 80 km, during approximately half a million years. Following deposition of the Windom the western New York ramp apparently steepened and shallowed to the northwest (Fig.13). During a late Givetian lowstand (sub-Tully unconformity) erosion apparently beveled upper and middle Windom beds to the north.

This case study of a relatively thin interval in the Devonian illustrates the efficacy of integrating data on fossil taxonomic composition and relative abundance, sedimentology, taphonomy and microstratigraphy. Such research provides insights into paleoecology, sedimentary process and even basin dynamics and synsedimentary tectonics.

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ROAD LOG AND STOP DESCRIPTIONS

0.0 0.0 Depart from parking area at SUNY Fredonia, 280 Central Avenue

0.1 0.1 Turn left onto Central Avenue

0.5 0.6 Turn right onto Millard Fillmore Drive

0.5 1.1 Vineyard Drive

0.6 1.7 Take ramp onto I-90E (NY State Thruway); note toll

0.3 2.0 Keep right and merge onto I-90

12.0 14.0 Note outcrop of Upper Devonian (Frasnian-Famennian) Hanover and Dunkirk Black shale

0.1 14.1 Take exit 58 for Silver Creek, toward US 20

1.1 15.2 Keep right at fork toward NY5/US20

0.1 15.3 Keep right at fork to merge onto NY5/US20

0.9 16.2 Slight left onto NY5

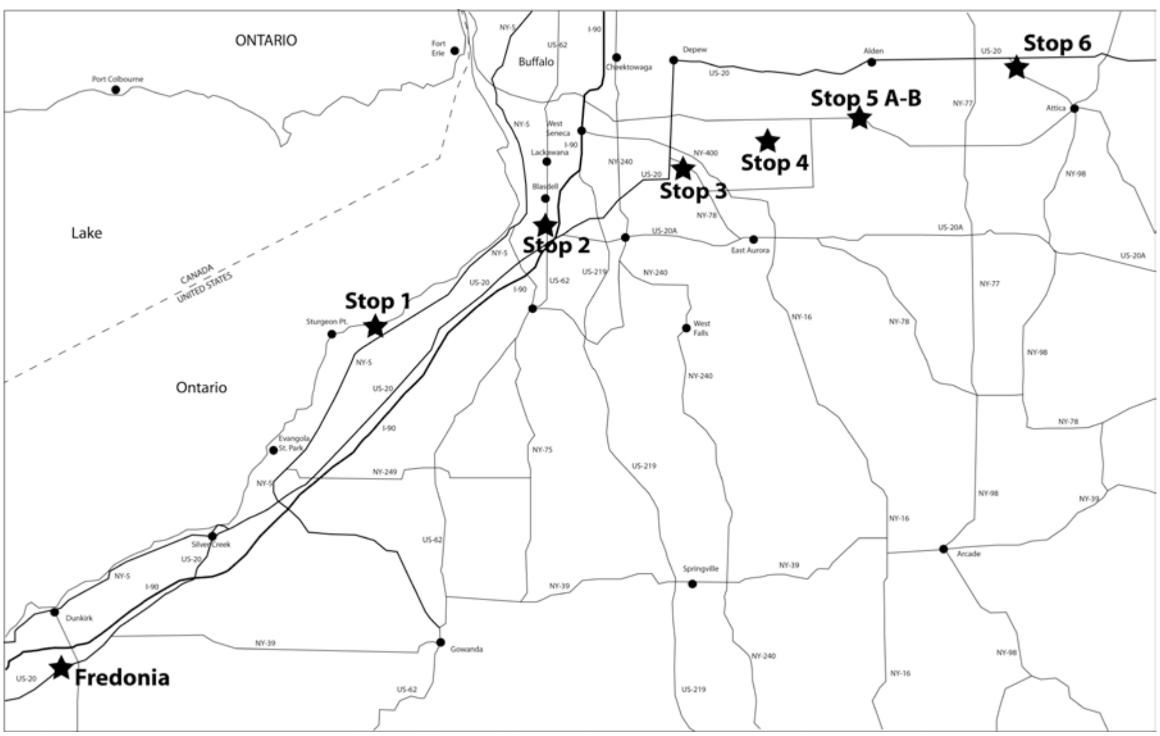

Figure 13. Location of stops for field trip relative to major highways in western New York.

10.4 26.6 Turn left onto Delamater Road

0.6 27.2 Junction Lake Shore road, jog left onto driveway opposite Delamater Road

0.2 27.4 Pull to end of driveway and walk to mouth of Pike Creek

Stop 1. Lake Erie shore north of the mouth of Pike Creek.

This locality provides an overview of the Windom Shale at its thinnest and westernmost exposures. The top of the Tichenor Limestone is exposed just above the lake level and the entire thickness of the Windom Shale, here about 3.5m thick is exposed to good advantage. Lower beds of the Windom member in unconformable contact with a hardground at the top of the Tichenor Member show a very thin succession of *Ambocoelia* beds overlain by a condensed Bay View bed, about 10 cm thick with abundant large rugose corals, primarily *Cystiphylloides*, *Heliophyllum* and *Heterophrentis*, the atrypid brachiopods, *Pseudoatrypa* cf. *devoniana* and *Spinatrypa spinosa*, and the spiriferid *Mediospirifer audaculus*. This bed is overlain in turn by a light gray calcareous band of the Smoke Creek trilobite bed with abundant small rugose coral (*Amplexiphyllum*, *Stereolasma*) and the trilobites *Eldredgeops rana* and *Greenops boothi*. This thin argillaceous limestone persists eastward with relatively little change in thickness or lithology to the western Finger Lakes area despite major changes in thickness of adjacent portions of the Windom Shale.

The remainder of the Windom consists of sparsely fossiliferous medium gray shale with calcareous beds. Near the top, concretionary limestones bear the brachiopod *Emanuella praeumbona* marking the position of the Amsdell bed of the mid Windom Fisher Gully submember. Thus, the upper portion of the unit is absent here.

Windom Member Shale is sharply overlain by a thin (1-2 cm) slightly pyritic, bone and conodont rich crinoidal packstone- the North Evans Limestone, or conodont bed. This bed is a classic exemplar of a condensed interval. Recent studies indicate that this thin band contains relict conodonts spanning at least five zones ranging from mid Givetian *Pol. anasatus* to lower Frasnian *Ancyrodella rotundiloba*) At the basal unconformity, a manifestation of the global Taghanic unconformity, surface not only the upper half of the Windom Member, but also the Tully Limestone and most of the Genesee Group are missing. The North Evans is overlain by a thin dark, laminated shale and ledge forming brownish, concretionary styliolinid packstone, the Genundewa Limestone.

This section demonstrates a number of features. First, the lower beds of the Windom shale record relatively shallow water diverse large coral assemblage in the Bay View bed suggesting a position upramp of those seen further to the northeast. The Windom also shows strong condensation without loss of marker beds. Yet, despite this thinness, the facies of the upper Windom record mainly dysoxic gray mudstones that probably accumulated in relatively sediment starved basinal settings to the west of a late Givetian depocenter.

0.1 27.5 Return to Old Lake Shore Road and turn left (N)

5.1 32.6 Bear left onto NY5 and Lake Shore Road

3.8 36.4 Turn right onto Big Tree Road

1.3 37.7 Slight right to stay on Big Tree Road

0.1. 37.8 Junction of Bay View Road; continue east of Big Tree

0.4 38.2 Turn left onto Bristol Road

0.1 38.3 Drive to parking area at end of Bristol Road and continue on foot into site of former Penn Dixie shale pit, presently Hamburg Natural History Society Fossil Park

Stop 2. Penn Dixie Shale Pit Site

This disused shale pit has served as an important reference section for the upper Hamilton Group for more than 40 years. Originally a quarry for clay for the Penn Dixie Cement company, this shale pit has been conserved as the site of the Penn Dixie Paleontological and Outdoor Education Center operated by the Hamburg Natural History Society for the past two decades. This is a highly active educational and fossil collecting site recently rated as the number one fossil park in the US (see http://www.penndixie.org). The complete exposure of the Windom Member along the gently sloping quarry floor provides a reference section for this unit, which is here exposed to better advantage than those along Smoke Creek in the nearby village of Windom; it still affords the most accessible section for the entire Windom Member and adjacent units; fossil collecting is permitted here for a small fee.

The Penn Dixie succession was originally described by Brett and Baird (1982), who provided a stratigraphic column, herein reproduced with minor revisions. The contact of the Tichenor Limestone and lower Windom beds, a focus of this trip, are exposed in the northeast corner of this quarry. As at Pike Creek the lower Windom *Ambocoelia* beds are highly condensed and overlain by the richly fossiliferous Bay View bed that here yields thousands of specimens of *Cystiphylloides, Heliophyllum*, and other rugosans as well as *Spinatrypa*, *Pseudoatrypa*, *Mediospirifer*, *Rhipidomella Protodouvillina*, *Megastrophia* and others. Of particular note here are the excavations by amateur fossil collectors in the Smoke Creek bed. This bed yields very abundant *Amplexiphyllum*, and *Stereolasma* corals and the brachiopods *Ambocoelia umbonata*, "*Mucrospirifer*" *consobrinus* and several others, but it is most noted for its abundant and frequently articulated trilobites. Since its discovery and description by Brett and Baird (1982, 1983) and Speyer and Brett (1986) this thin calcareous mudstone has yielded many hundreds of complete prone and enrolled specimens of the trilobites *Eldredgeops rana* and *Greenops boothi*.

The remainder of the Windom Shale, substantially thicker here than at Pike Creek is sparsely fossiliferous shale. However, there are several other interesting levels including the A, B and C, D, E beds, comprising thin concretionary limestones in the mid Windom Shale and the overlying "Penn Dixie" pyritic beds, which have yielded abundant pyritic and limonitic molds of nuculid bivalves, nautiloids and less common goniatites and enrolled *Greenops* trilobites (see Brett et al, 1991). The Amsdell bed forms a low platform in the quarry floor and yields prolific specimens of the large ambocoeliid, *Emanuella praeumbona*. This is a key marker bed, traceable at least to Schenevus in eastern New York State.

The southern rim of the quarry shows the upper contact of the Windom with the North Evans Limestone which here has yielded abundant placoderm plates, cladodid shark teeth and ptyctodont crushing teeth. This unit also contains reworked clasts and *Emanuella* brachiopods, derived from the Windom Shale.

	38.3	From parking area take first right onto Bristol Road
0.3	38.6	Turn right onto Big Tree Road
0.2	38.8	at traffic circle take third exit onto US 62, South Park Avenue, north
1.2	40.0	Turn right onto NY 179E, Mile Strip Road
1.9	41.9	Abbott Road junction on Right
0.1	42.0	Cross south branch of Smoke Creek; possible stop to see lower Windom; this is the type locality of the Windom Member
0.6	42.6	Junction US 219Southern Expressway; continue straight on Mile Strip Road
0.7	43.3	Junction US 20, Southwestern Boulevard; turn left
3.8	47.1	Curve left following US20
0.3	47.4	Cross Cazenovia Creek on high bridge; bed of creek is in lower Wanakah Shale
0.7	48.1	Junction NY 16S/NY78S, S. Seneca Street; turn right
0.8	48.9	Junction Northrup Road; turn right
0.2	49.1	Pull off to left along road shoulder then walk to bridge over Cazenovia Creek and from there down to creek at waterfalls visible from bridge

Stop 3. (Optional) Cazenovia Creek at Northrup Road.

This classic locality provides an excellent view of the upper Hamilton Group. Depending upon creek conditions it may be possible to examine the succession of upper Ludlowville Wanakah Shale with a prolific diverse brachiopod fauna and overlying limestones, comprising a remnant of the uppermost Ludlowville Formation Jaycox Member, represented by the basal Hills Gulch bed with abundant large favositid corals and the overlying Tichenor Limestone which caps a low waterfall in the creek near Northrup Road. If creek conditions are extremely low it may be possible to proceed upstream about 300 meters from the waterfall to a prominent cliff exposing most of the Windom Shale Member overlain at a sharp contact with the Genesee black shale with local lenses of Leicester Pyrite, a reworked lag of pyrite and bones (Baird and Brett, 1986). The still thin *Ambocoelia* beds of the lower Windom are poorly exposed in the creek bed above the falls. The base of the cliff section, which at this writing has been relatively clear of talus, exposes the Bay View and Smoke Creek bed, Here the Bay View beds are somewhat expanded in thickness from just a few centimeters at western sections to nearly a meter at this locality, and shows a series of three or four concretionary limestones. Although this expanded mudstone is more sparsely fossiliferous than at Lake Erie, atrypid brachiopods and *Mediospirifer* remain abundant. The "flagship" Bay View taxon *Spinatrypa spinosa* is exceedingly rare at this location, although *Pseudoatrypa* remains common, and larger rugosans such as *Cystiphylloides* and *Heliophyllum* are absent, but large *Amplexiphyllum* and small specimens of the "gumdrop"-shaped tabulate *Pleurodictyum* are relatively common here. A meter-thick, shaly succession separates the main Bay View beds and the Smoke Creek beds; this yields scattered

Amplexiphyllum and "*Mucrospirifer*" *consobrinus*. The Smoke Creek beds here form a low riffle in the creek and as elsewhere yield relatively common articulated trilobites; however, corals and brachiopods are notably less common here than in the west. The majority of the thick cliff face is composed of the mid Windom Shale; the "A-B" and "C-D-E beds" (Brett and Baird, 1982; Figure 3 herein) appear well up in the cliff as clusters of thin tabular concretionary limestones, and again, the *Emanuella*-rich concretionary limestone of the Amsdell bed occurs just below the Leicester Pyrite at the Taghanic unconformity which has here cut into the Windom removing several beds present to the west.

	49.1	Reverse route and continue back on Northrup Road
0.2	49.3	Junction Rte. 16; Seneca Street; turn right
0.6	49.9	Junction Rice Road, NY 360; turn left
3.6	53.5	Junction Girdle Road; turn left
1.2	54.7	Third junction onto Bullis Road (east)
0.4	55.1	Junction of old Bullis Road at bridge over Buffalo Creek; park and walk down road to old bridge; take path on east side down to creek bank near falls

Stop 4 (Optional). Buffalo Creek at old Bullis Road bridge.

The bed and banks of Buffalo Creek provide another classic section of the lower Moscow Formation featured in a number of previous field guides. North (downstream) from the old Bullis road bridge nearly to the newer high bridge, the same series of ledge-forming limestones at the Ludlowville-Moscow Formation boundary seen at Cazenovia (i.e., Hills Gulch bed of Jaycox Member, Tichenor Member at base of Moscow, Menteth Limestone and a thin remnant of the lower Kashong Member) are well exposed and form a low waterfall and series of riffles in the creek bed. To the south of the old bridge the lower Windom Shale the medium gray shales of the lower Windom Member are readily visible. If water level is relatively low it may be possible to walk about 150 meters upstream (east) from the bridge to examine the Bay View and Smoke Creek beds, here at one of their most basinal and thickest sections. A slightly enhanced dip brings these beds rapidly down to the level of the creek bed. A series of six thin rhythmic concretionary limestones marks the position of the Bay View beds. These beds and the intervening shales are rather sparsely fossiliferous but close examination shows the presence of very scattered but often very well preserved fossils. These include the coral *Amplexiphyllum*, rare *Pleurodictyum*, and the brachiopods *Pseudoatrypa*, *Athyris*, and *Mediospirifer* commonly articulated and in life position. This is a taphonomic expression of probably more rapid overall burial rates at this section. These beds are overlain by a rather thick sparsely fossiliferous shale with rare small corals and "*Mucrospirifer*" *consobrinus*, The overlying Smoke Creek bed as at most all locations is a 0.6 meter interval of stacked light gray weathering concretionary argillaceous limestones. Corals are rare, but articulated prone and enrolled trilobites are still commonly found at this location.

Buffalo Creek provides a glimpse of some of the most distal, expanded facies of the lower Windom Bay View and Smoke Creek beds. The presence of local clusters of in situ brachiopods is symptomatic of relatively high rates of burial, which prevented local shifting of skeletons. For the same reason larger corals and *Spinatrypa* brachiopods are absent perhaps because waters were too deep and/or turbid here in contrast to sites in western Erie County.

	55.1	Turn right on Bullis Road and continue east
2.2	57.3	Junction Two Rod Road in village of Marilla, NY; turn left (north)
1.1	58.4	Junction NY 354, Clinton Road; turn right (east)
2.6	61.0	Cayuga Creek; turn into driveway to left on W side of bridge and park; walk down to creek bank and proceed upstream

Stop 5A. Cayuga Creek at Clinton Road, Cowlesville, NY.

This is yet another classic locality for the upper Hamilton Group and Genesee Formation. A low water fall just South of the Clinton Road bridge shows the upper exposed beds of the Windom Shale in sharp and locally angular unconformity with the overlying Genesee. Locally, lenses of the Leicester Pyrite up to 0.5m across occur along this contact. These are interbedded with black Geneseo Shale which locally contains the Genesee succession including a possible westernmost vestige of the Middle-Upper Devonian boundary Lodi Bed, concretionary beds of the Penn Yan Shale, a hin remnant of the north Evans bone bed and the overlying Genundewa limestone has been discussed in detail by Baird et al. (2006).

Of interest here is the upper Windom, which shows distinctive pyritic concretionary shales and a thin shell hash bed that occur immediately below the contact with the Leicester Pyrite. These beds lies within the mid Windom, well below the Amsdell bed. Hence, the higher Windom succession seen at sections such as Penn Dixie Quarry and Cazenovia Creek to the west have been removed here. The other intriguing aspect of this section is a perceptible angularity on the Windom-Genesee contact notable by the removal of a brachiopod rich hash and convergence of an uppermost concretionary bed with the sharp contact of the Genesee black shale northward along the creek bank.

	61.0	Return to Clinton Road and turn left to continue East
0.2	61.2	Junction Cayuga Creek Road; turn left and proceed N
0.4	61.6	Driveway into house on right crosses small tributary of Cayuga Creek; pull in and proceed into the small tributary

Stop 5B (optional): Cayuga Tributary, West Alden

The Bay View and Smoke Creek beds are not seen on Cayuga Creek, but are exposed poorly on a nearby tributary of Cayuga Creek about 1 mile to the N. Here, the Smoke Creek beds are very sparsely fossiliferous though still containing occasional articulated trilobites. Seemingly, this is the least fossiliferous, thickest and most mud rich facies of this succession suggesting a position deepest in the basin. The Bay View beds have nearly faded at this point.

0.4	62.0	Return to Clinton Road; turn right and continue east
0.1	62.1	Junction Co, Rte. 578, Exchange Street; turn left (North)
3.0	65.1	Junction US 20 Broadway; turn right (east)
7.4	72.5	Enter Darien Center; junction Attica Road, NY238; turn right
0.4	72.9	Junction Griswold Road ; turn left
0.2	73.1	Pull into driveway on right opposite Murder Creek; walk across road and down to creek bank

Stop 6. Murder Creek ~1 mile S of US 20 Darien Center, NY

This small outcrop provides an exceptional and accessible view of the Windom Member in sharp unconformable contact with the Genesee black shales again with pods of Leicester Pyrite marking the contact. At this meridian the Taghanic unconformity has cut out most of the upper and middle Windom Shale such that the contact lies just two meters above the Smoke Creek bed. The latter is well exposed in the creek bank opposite the farmhouse. The Bay View beds and underlying *Ambocoelia* succession are exposed at a low falls just downstream and comprise a series of concretionary beds with a capping layer of crinoidal and brachiopod rich debris. The corals *Amplexiphyllum* and *Pleurodictyum* are present in shales above the falls in beds rich in the large chonetid *Longispina* as well as atrypids and *Mediospirifer*.

End of trip; return to junction of US 20 and drive west for about 2 miles to junction NY 77; turn right (north) and proceed past Darien Theme park to entrance for NY State Thruway (I-90) and take thruway westbound to return to Fredonia.