NEW YORK STATE GEOLOGICAL ASSOCIATION

85th Annual Meeting

20 – 22 September 2013

FIELD TRIP GUIDEBOOK

Lake Erie Heritage Grape Belt

Department of Geosciences | State University of New York – Fredonia

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Department of Geosciences | SUNY Fredonia
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END-DEVONIAN GEOLOGY IN THE NORTHWEST PENNSYLVANIA REGION AND HIGHLIGHTS OF NEW YORK AND PENNSYLVANIA GAS-OIL HISTORY

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Introduction

Although early conceptual advances in our understanding of the subsurface geology of northwest Pennsylvania have long figured in the development of the oil and gas industry, our knowledge of outcrop-based geology of this region has generally remained sketchy. A general paucity of long, clean outcrop sections, particularly, in the area east of the Meadville meridian, has hampered attempts to eliminate uncertainties in unit correlations. Why is a better understanding of these strata of interest to the geologist and the informed public?

Herein, we focus on strata that accumulated during the last part of the Devonian time period up to the base of the Mississippian time division (362-359 million years before present). These beds are highly fossiliferous and have yielded new and exotic, undescribed fossils to the diligent collector. Moreover, the end-Devonian time-slice record in Pennsylvania was deposited during a time of mass extinction, drastic changes in climate, and regional tectonism that are only now beginning to be recognized. It is of prime interest to the present authors to establish chronostratigraphic (time-based) connections between the local/regional stratigraphic sections and key paleoclimate-, and extinction-related, signatures recognized globally by others within this interval. Herein, we focus on recent advances in correlation within the end-Devonian – into – earliest Mississippian succession, particularly, since the publication of the *74th Annual Field Conference of Pennsylvania Geologists* Guidebook (see Harper 2009) and initiation of westward-directed correlation efforts by Baird and colleagues across northern Ohio.

In addition to the above geological story, we review events that spawned the modern oil and gas industry for which northwest Pennsylvania is globally remembered. Starting at Fredonia in the Empire State (STOP 1), we will examine very early, successful efforts to exploit shallow gas through spring pole drilling and even bedrock fracking techniques that predated the Drake Well event. At STOP 4, we will see the role of various contingent, and highly fortuitous, events that led up to the flow of oil from Colonel Drake's well. We will also ride the wave of rising expectations, speculation, exploitation, and civic decline that is the legacy of the great city of Pithole if time permits (STOP 5).

End-Devonian world

During the latest Devonian (Upper Famennian Stage) into the earliest Mississippian, the region that is now northwest Pennsylvania was situated near the southeastern margin of the “old red continent” (Euramerica) between 30° and 45° south of the paleoequator, based on more recent paleomagnetic estimates (Miller and Kent, 1988; Van der Voo, 1988). The southeast edge of Euramerica (Laurentia plate margin) experienced a series of tectonic collision events, beginning in the latest Silurian and continuing throughout the Devonian which are collectively referred to as the Acadian Orogeny. Disturbances, involving transpressive collision of the Avalon and Carolina terranes, came as a series of overthrust pulses (tectophases), starting in the maritime region of eastern Canada and continuing southward into the central-southern Appalachian region. Collisions taking place during the very Late Devonian and Early Mississippian (Neo-Acadian Orogeny *sensu* Ettensohn, 1998; Ettensohn et al., 2009) were particularly centered in what is now the southern Appalachian region.

These collisional tectophases, in turn, produced characteristic sedimentary depophases recording initial thrust-loading of the craton margin followed by foreland basin filling as sediments, derived from the erosion of collisional mountain belts, filled in the structural basins (Ettensohn, 1998; Ettensohn et al., 2009). This series of depophase events generated a thick, detrital wedge long known as the Catskill Delta complex (Figure 1). Sediment, eroded from the rising Acadian mountain complexes was transported by river systems to an inland epicontinental sea; this coastline shifted ever westward through the Devonian as the delta grew and the basin gradually filled. It was particularly sensitive to changes in sea level, which caused to coastline to shift westward during pulses of delta growth and sea level-fall, and to shift eastward during episodes of sea level-rise. These shifts were unusually pronounced during the latest Devonian when the strata examined herein accumulated (Figure 1).

This was a time predominantly characterized by warm, tropical to sub-tropical climatic conditions (Frakes, et al., 1992). As noted by numerous authors, the Middle and Late Devonian was characterized by a series of biotic crises which resulted in widespread extinctions events and contributed to the breakdown of global biotic provinciality. The latest Famennian Hangenberg extinction and succeeding “icehouse Earth” event are increasingly seen as major setbacks to the biosphere (Figure 2). The temporal “window” or time-slice of key end-Devonian crises, defined by conodont biostratigraphy, extends from the base of the expansa zone (approximate position of the base of the Cleveland Shale in Ohio (and its equivalents in Crawford County, Pennsylvania), into the earliest Mississippian sulcata zone represented by the Bartholomew Bed and lower Orangeville Shale in northwest Pennsylvania and Ohio (Figures 3 A, B).

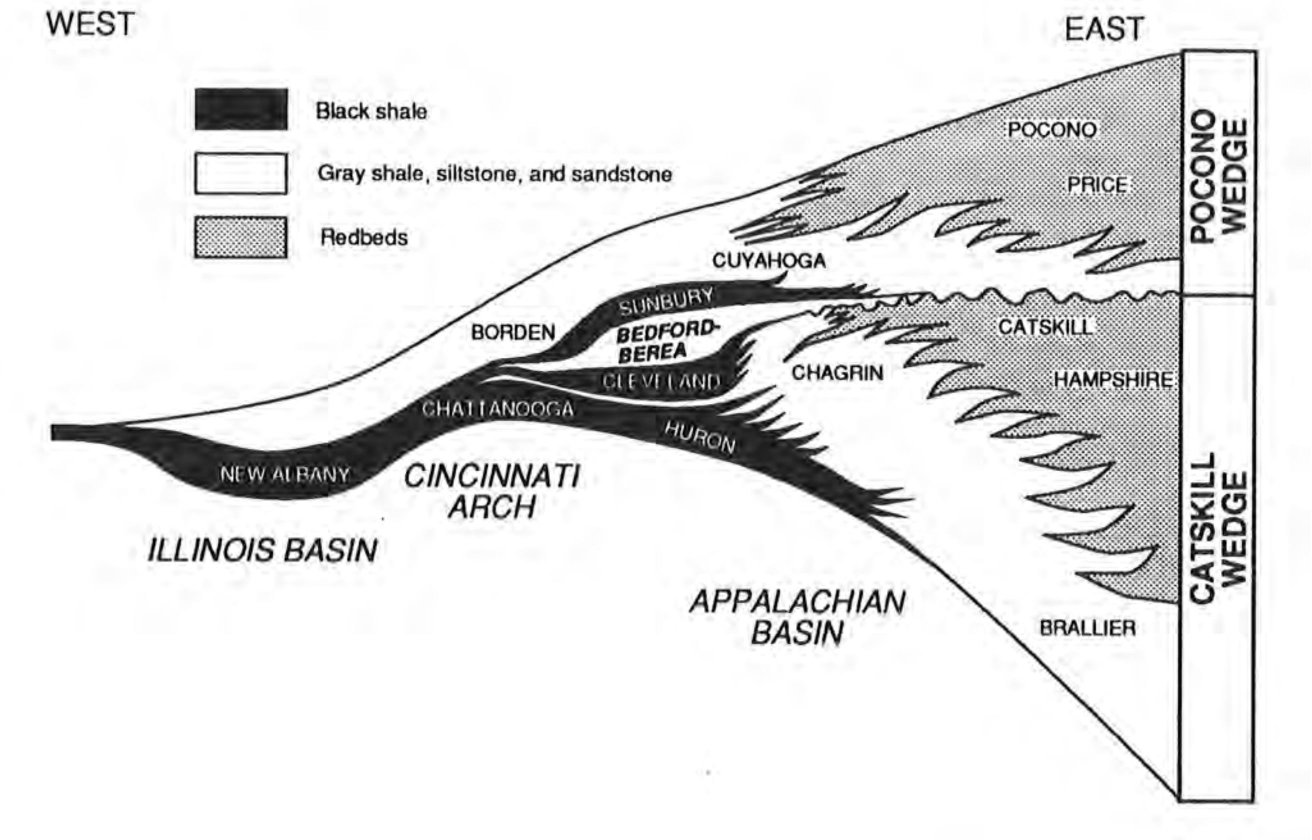

Figure 1: Regional schematic cross-section showing the generalized relationship of the end-Devonian succession in Pennsylvania and Ohio to the Catskill and Pocono clastic wedges in the northern Appalachian Basin (from Pashin and Ettensohn, 1992, 1995).

A global episode of anoxia is recorded by the “Dasberg Event” (Figure 2), which falls within the upper-medial expansa conodont zone of the Late Famennian stage (Becker and Hartenfels, 2008; Kaiser, 2008). This was a time of widespread warmth, eutrefication of marine shelf waters, burial of organic carbon, and sea level-rise (Kaiser, 2008). Part of the black Cleveland Shale of the Ohio section and its apparent temporal equivalent, the West Mead Bed in sections near Meadville, are believed to be the approximate regional expression of this “greenhouse” event, based on conodont biostratigraphy (Zagger, 1995; Baird, et al., 2009a, b; Figures 3 A, B).

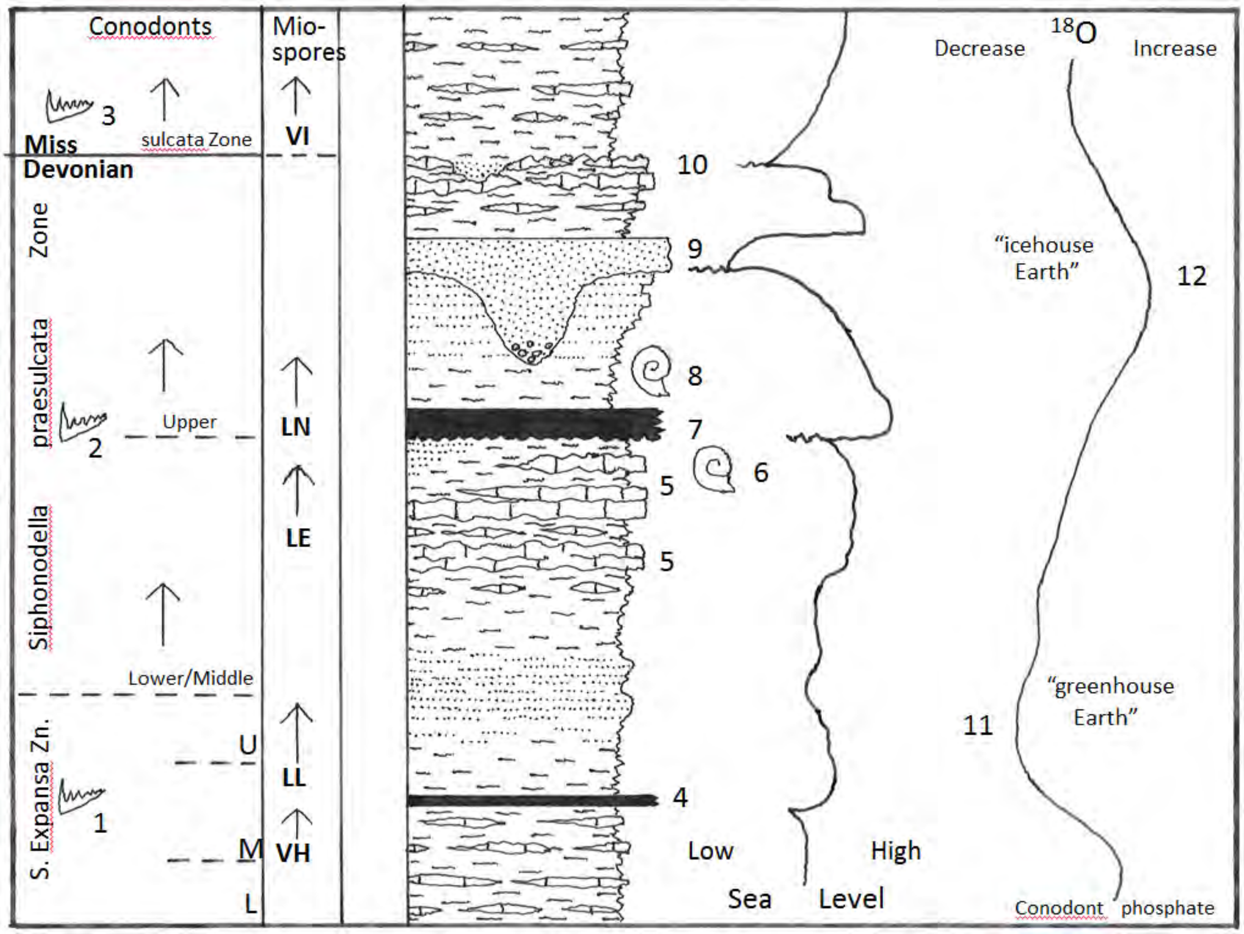

Figure 2: Generalized end-Devonian chronology in inferred eustatic and global bioevent context, based on conodont and palynomorph chronostratigraphy as well as carbon and oxygen isotopic studies (compiled from Cramer et al., 2008; Kaiser, 2008, 2011 and others). Note sea level oscillations calibrated to biozones, key facies and unconformity levels, and isotopic excursions. First appearances of key miospore assemblage are indicated by zone groupings (VH, LL, LE, etc). Numbered features are: 1, conodont element *Bispathodus aculeatus aculeatus*, 2, *Siphonodella praesulcata*; 3, *Siphonodella sulcata*; 4, Dasberg Black Shale event; 5, Wocklum Limestone; 6, ammonoid *Wocklumeria* biozone; 7, Hangenberg Black Shale event; 8, ammonoid *Acutimitoceras* (*Stockumites*) biozone, 9, Hangenberg Sandstone event with subjacent lowstand disconformity; 10, unconformity at Devonian-Carboniferous contact; 11, shift to lighter oxygen isotope during Dasberg greenhouse episode; 12, major shift to heavier oxygen, timed with excursion to heavier carbon, sea level-fall, and tillite development on Gondwana.

The later, and more intense, end-Devonian Hangenberg event is understood to be a two-part, paleoclimatic crisis. It is believed to record an initial episode of widespread, marine shelf anoxia, sea-level-rise, and "greenhouse Earth" conditions as recorded by the thin, Hangenberg Black Shale (Kaiser et al., 2008, 2011; Figure 2). Following deposition of this black shale unit was a change to non-black and increasingly sandy sediments recording an inferred major drop in global sea-level, eventually leading to erosional downcutting in coastal areas (Cramer et al., 2008; Kaiser et al., 2008, 2011). Partly coincident with this inferred sea level-drop is a shift to the heavier isotope of oxygen (^{18}O) as recorded in conodont phosphate (Kaiser, 2008; Figure 2); excursions such as this have long been understood to record the differential sequestration of the lighter oxygen isotope (^{16}O) in expanding continental ice sheets. This is consistant with major evidence of glaciation at this time (see below). Moreover, a global shift to the heavier isotope of Carbon (^{13}C) relative to ^{12}C is recorded in strata above the Hangenberg Shale (Figure 2). This suggests that more and more organic carbon (^{12}C) was being trapped in sediment (Algeo et al., 1995, 1998), implying that atmospheric CO^{2} – levels had dropped, leading to short-term, intense, "icehouse Earth" conditions; this global "cold event", marked by extensive diamictite development on Gondwana, is known as the "Hangenberg glaciation event" (Caputo, 1985; Frakes, et al., 1992; Crowell, 1999).

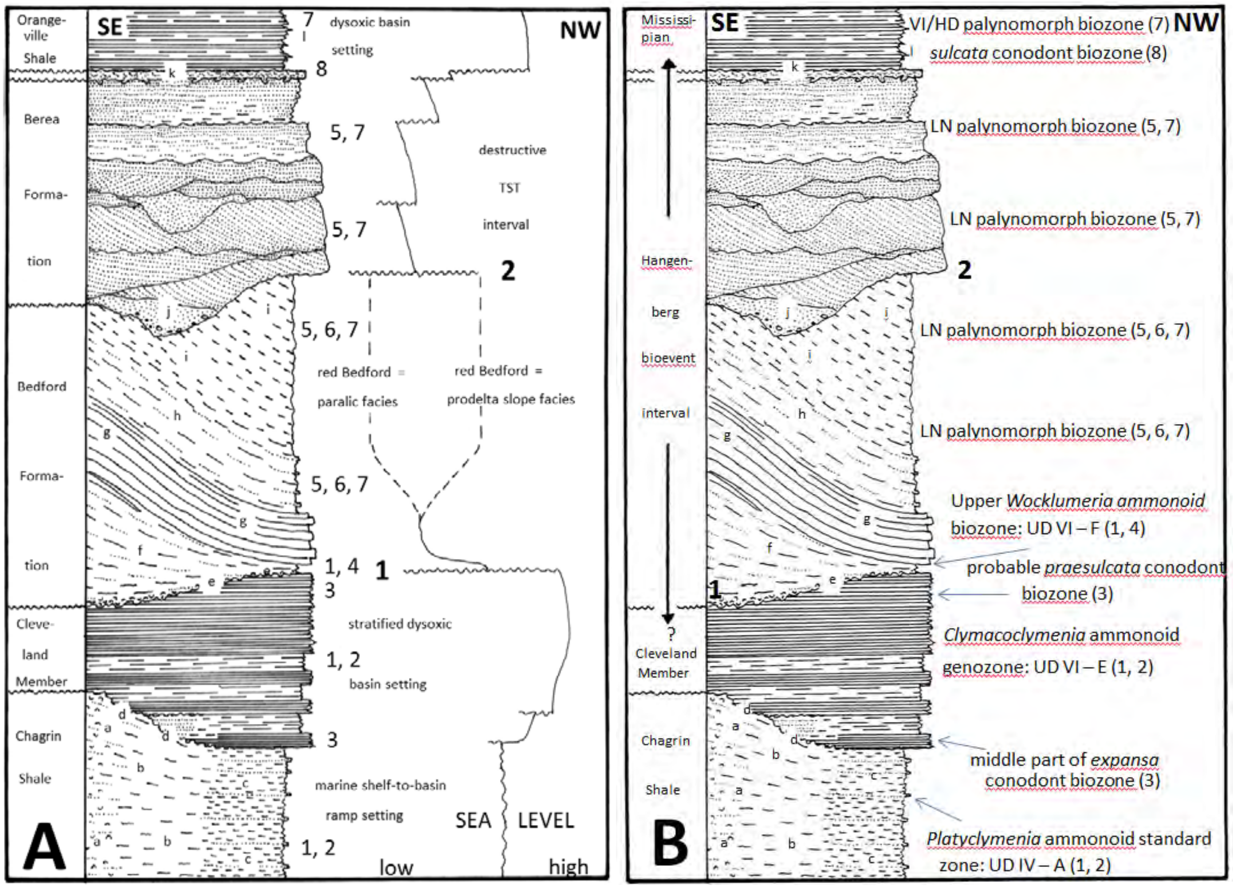

Figure 3: Temporal stratigraphic synthesis of the greater Cleveland area end-Devonian-basal Mississippian stratigraphic succession: A, Generalized stratigraphy showing inferred sea level changes. This schematic emphasizes the inferred Bedford constructional (progradational) phase preceding the base-Berea lowstand event envisioned by Pashin and Ettensohn (1995). The Berea Sandstone is interpreted as recording the destructional phase of the Cussewago Delta in Ohio during a time of modest transgression (Pashin and Ettensohn, 1995; see text). Lettered

units include: a, Skinner's Run Bed recording detrital pyrite-bone lag debris concentration during marine transgression; b, base-Bedford discontinuity horizon and overlying thin shell-rich bed recording oxygenated open marine shelf conditions; c, channelized, base-Berea contact with locally developed lags of pebbles and cobbles; d, *Lingula* – rich and pyrite-suffused, thin lag zone at the base of the Orangeville Shale interval; RB = red Bedford lithofacies. Figure 3 B, Biostratigraphy of the Cleveland area end-Devonian succession as presently understood. Note zonal uncertainty at many levels, particularly in northwest Pennsylvania. Horizon of Platyclymenia ammonoids (corresponding to trachytera/postera conodont biozones) reported by House, et al. (1986) in the "lower Cleveland Shale" at Vermilion River is not in accord with Zagger's (1993, 1995) placement of the basal Cleveland Skinner's Run Bed in the expansa conodont biozone. Recent examination of the Vermilion River section at Birmingham, Ohio by Baird suggests the possibility that the ammonoid-bearing bed may be within the uppermost Chagrin succession and, thus, may be older than the Cleveland Shale. Numbered sources: 1, House, et al. (1986); 2, Becker and House (2000); 3, Zagger (1993, 1995); 4, House and Kirchgasser (2008); 5, Eames (1974); 6, Molyneaux, et al. (1984); 7, Coleman and Claypool (1987); 8, Hass (1947).

The two Hangenberg events, recorded in Europe, North Africa, and elsewhere, are timed with the upper part of the *Siphonodella praesulcata* conodont zone and with rapid floral changes associated with the LE-LN miospore biozones (Streel, 2008). During the very brief, latest division of the Devonian (upper praesulcata zone), the "icehouse" event ended, eustatic transgression ensued, and the global climate stabilized (Figure 2). Although the full extent of this extinction event is yet to be fully realized, its effect on marine vertebrates was evidently catastrophic; a 70% drop in taxonomic diversity of lobed finned fish and total extinction of placoderms has been recently documented across the Hangenberg bioevent interval (Sallen, 2009, 2011).

Apparent glacial tillite and associated rhythmite deposits with dropstones, interpreted as glacier-generated facies, are also reported from the end-Devonian Spechty Kopf diamictites in Pennsylvania and Maryland (see: Cecil, et al., 2004; Brezinski, et al., 2008, 2010). This succession, associated with the characteristic Lepidophyta nitida (LN) miospore assemblage, is broadly time correlative to the upper part of the Cleveland Shale – through – Bedford Formation succession in the Cleveland area (Figures 3 A, B), as suggested by the work of Eames (1974). Timing of uppermost-Cleveland Member black mud accumulation with inferred "icehouse Earth" conditions is further indicated by recent discovery of a granite boulder in the topmost part of the Cleveland Shale in eastern Kentucky (Lierman, et al. 2011, 2012; Ettensohn, et al., 2008); this lonestone, weighing approximately three tons, strongly suggests the presence of icebergs in the Cleveland sea that drifted from piedmont glaciers sourcing in high collisional mountains that were rising at this time (Lierman, et al. 2011).

Similarly, a significant sea level drop at this time is inferred for the Appalachian Basin region (Pashin and Ettensohn, 1995; Sandberg, et al., 2002; Brezinski, et al., 2008, 2010; Ettensohn, et al., 2009). Pashin and Ettensohn (1995) originally speculated that this inferred glacioeustatic lowstand event was recorded in the major regional disconformity below the Cussewago Sandstone in Pennsylvania and northeasternmost Ohio (Figures 3 A, B, 4). The Kentucky boulder occurrence, coupled with biostratigraphy (Molyneaux, et al. 1984; Coleman and Clayton, 1987), now suggest that the sub-Berea contact is stratigraphically higher then where icehouse events may have first commenced (Figures 2, 3 A, B).

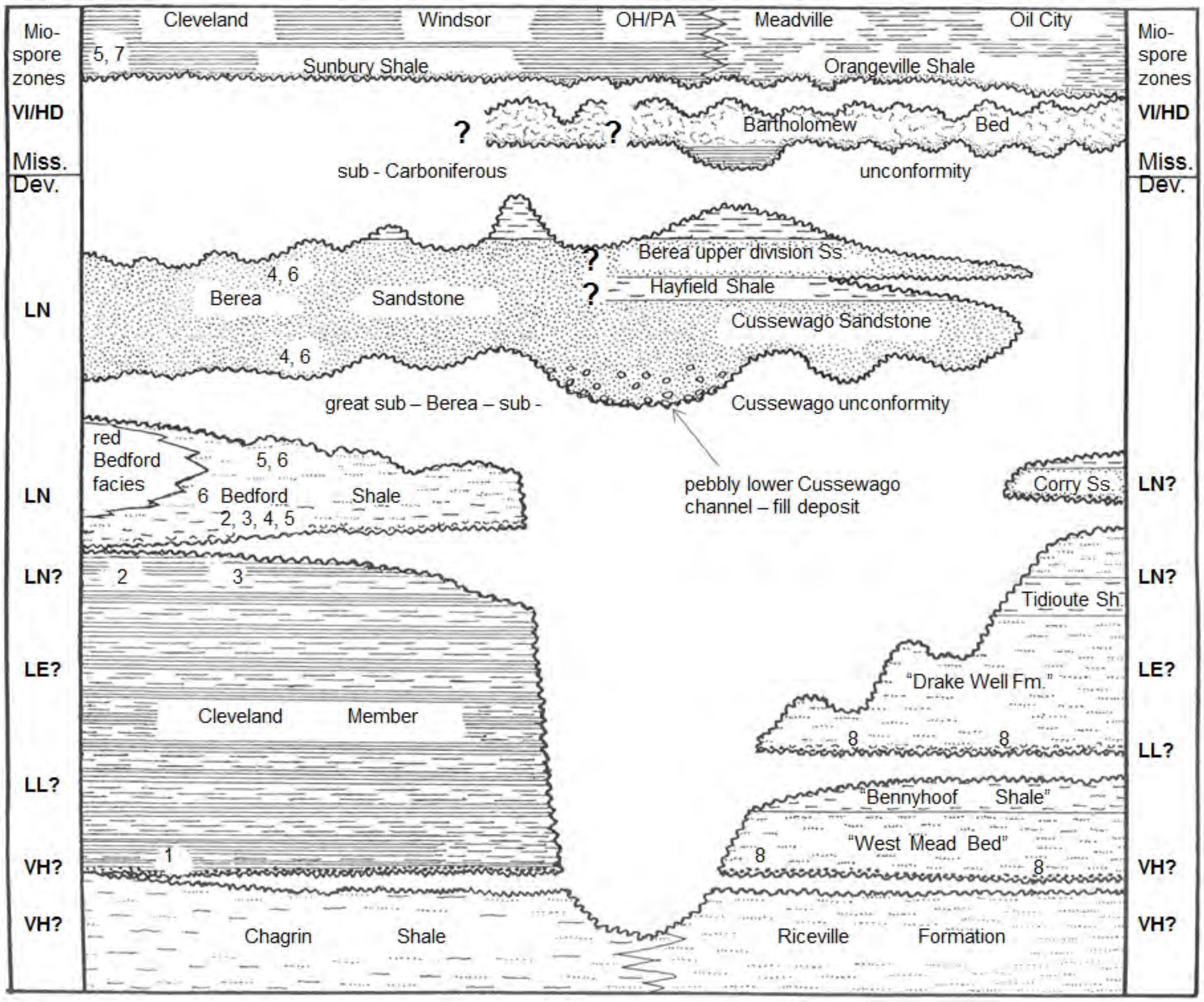

Figure 4: Proposed chronostratigraphic (time-rock) relationships of end-Devonian units across northwest Pennsylvania and northeast Ohio, based on existing reports and new, partly published work. Matches between the Ohio succession and that in northwest Pennsylvania are tentative owing to a need for biostratigraphic tie lines, particularly in Pennsylvania. Given that the base of the Cleveland Shale appears to be in the expansa conodont biozone (Zagger, 1993, 1995), and its uppermost part is in the Cymaclymenia ammonoid genozone (House, et al., 1986; Becker and House, 2000), this would suggest that Cleveland Shale deposition was long-duration (expansa biozone – into – praesulcata conodont biozone). Accordingly, we project this unit as including several key palynomorph biozones as shown as shown along the figure margins. Note

that units equivalent to the Cleveland Shale-Bedford Shale succession reappear east of the belt of major sub-Cussewago overstep in northeast Ohio. Numbers denote key biostratigraphic references, including: 1, Zagger (1993, 1995); 2, House, et al. (1986); 3, Becker and House (2000); 4, Eames (1974); 5, Coleman and Claypool (1987); 6, Molyneaux, et al. (1984); 7, Hass (1947); 8, Baird, et al. (2009 A, B, 2013).

Ohio stratigraphic synthesis

Examination of numerous Ohio sections since 2009 has led to a new stratigraphic synthesis for the north Ohio end-Devonian succession (Hannibal et al., 2012; Baird et al., 2013; Figures 3 - 5). These units are summarized below.

Chagrin Shale. The Late Famennian interval in northeast Ohio is predominantly represented by the Chagrin Shale of the Ohio Shale succession. It includes a very thick deposit of green-grey to dark grey shale with a few intervals of flaggy siltstone beds and lentils particularly in sections in the Grand River Valley in northeast Ohio. Although trace fossils are abundant in the Chagrin, body fossils such as brachiopods and bivalves occur only sparsely, both at-, and west of-, the meridian of Cleveland, Ohio. However, this succession is noteworthy for the occurrence of phyllocarids and other non-trilobite arthropods. Chagrin exposures are typified by the monotonous creek bank exposures visible along I-90 between the PA/NY line and Cleveland. The topmost part of the Chagrin grades eastward (upslope) into silty, tempestitic shelf facies of the Venango group and overlying Riceville Formation in Erie and Crawford Counties in Pennsylvania (Figure 3 A, B).

Cleveland Shale. The Cleveland Shale Member of the Ohio Shale is largely a fissile black shale unit in northern Ohio, which is best known for its fish fauna of chondrichthyians and placoderms (Newberry, 1889; Carr and Jackson, 2008). The Cleveland Shale is highly variable in thickness across the Cleveland metropolitan area, ranging in thickness from as little as 0.45 meter- (17 inches) south of Peninsula, Ohio, to well over 35 meters along the Rocky River in west Cleveland (Hannibal et al., 2012; Baird et al., 2013). Where it is thick, as at Rocky River and Big Creek in Cleveland, it displays a distinctive, rhythmic, “ribbed” appearance in stream bank sections. This unit has been formally traced eastward to the west side of the Grand River Valley in Ashtabula and Trumbull counties but it is understood to be overstepped by erosion beneath the Cussewago Sandstone in northeasternmost Ohio (Caster, 1934; Pepper, et al., 1954; Pashin and Ettensohn, 1995). Work by Baird and others now shows that deposits equivalent to the Cleveland Member apparently reappear eastward below the sub-Cussewago disconformity at the Meadville, PA meridian (see below; Figures 4, 5). Standing literature tentatively places the Cleveland Member in the middle part of the expansa conodont zone (Zagger, 1993). As such, a part of this unit is probably the regional signature of the global Dasberg event (Figure 3 B).

The base of the Cleveland Shale is understood to be marked by a regional erosion surface from Cleveland southward up the Cuyahoga Valley and eastward to the Grand River Valley. A distinctive lag deposit of detrital pyrite, permineralized wood debris, and fish bones, known as the Skinner's Run Bed (Hlavin, 1976; Hannibal and Feldmann, 1983; Baird and Brett, 1991) occurs along the Chagrin-Cleveland contact wherever this discontinuity is developed. Unusual conditions of low oxygenation, erosive bottom current activity, and transgression-related, sediment-starvation, are believed to explain the concentration of detrital pyrite on the open sea floor at such times (Baird et al., 2013).

*Bedford Shale***.** This green, gray, and red-colored unit rests disconformably on the black Cleveland Member in northern Ohio sections. The thin, basal part of the Bedford Shale-succession is the only part of the formation to yield a significant marine fauna (Pashin and Ettensohn, 1992); this interval of brachiopods and small molluscs is followed by strata yielding only trace fossils or no evident biota. Four succeeding divisions (see Figure 3 A), in upward-succession include: 1) a lower silty gray shale unit that thickens dramatically southward and eastward from the south Cleveland metropolitan region; 2) a discrete bundle of closely-spaced, thick, siltstone beds (Euclid Member) that regionally overlies the lower gray shale wedge. This unit converges toward (downlaps) nearly to the top of the Cleveland Shale to the northwest as a progradational clinoform (Figure 3 A). It rises southeastward to the unconformable base of the Berea Sandstone in the Cuyahoga Valley (Figure 3 A). The upper Bedford succession consists of another silty gray shale unit above the Euclid, followed by the thicker, highly enigmatic "red Bedford" division that is the youngest Bedford unit below the Berea in northern Ohio (Figure 3 A). From the south Cleveland (Brooklyn-Parma area) westward, this facies comprises all but the lower fraction of the overall Bedford Formation succession. However, the red interval thins rapidly southeastward by erosional overstep beneath the Berea as the lower Bedford interval expands (Baird et al., 2013).

The red Bedford facies is characterized by a blocky, reddish brown mudtone phase that generally lacks discrete siltstone layers characteristic of the underlying gray Bedford shales. Moreover, it is typically intensely microfactured with numerous intersecting slickenglided surfaces and zones of soft-sediment deformation. No fauna is recorded from this facies, though patchily distributed plant debris does occur rarely (Pashin and Ettensohn, 1995). This peculiar facies gave rise to the concept of the "Red Bedford delta" of Pepper, et al. (1954; see also Kohout and Malcuit, 1969). It has since been reinterpreted as an offshore, not terrestrial, deposit (Lewis, 1988; Pashin and Ettensohn, 1995). Extensive soft-sediment deformation, red shale development, and the localized massive siltstone deposits suggest that this unit is not well understood and that it may record several different regional events. As presently understood, the Bedford can be seen in outcrop as far east as the west side of the Grand River

Valley (Figure 4). East of the Grand River Valley it is overstepped by the younger Cussewago Sandstone (Pepper, et al., 1954; Pashin and Ettensohn, 1995).

Berea Sandstone. This unit, known as Ohio's "State Rock", is a widespread division which extends from eastern Kentucky, across most of Ohio, into Crawford County, Pennsylvania (Pepper, et al., 1954; Pashin and Ettensohn, 1995). Although the Berea generally displays an approximate thickness range from 10 meters (33 feet) to 75 meters (80 feet) across northeast Ohio, it can locally reach thicknesses of 80 + meters (260 + feet) to the west of Cleveland. The Berea is texturally a siltstone or fine sandstone, which is distinctly quartzose. Beyond these generalities, the Berea is extremely complex internally; large channels, cross-bed foresets, large-scale ball-and-pillow structures, and localized diaper-like structures are present at many localities (Figure 3 A, 4). West of Cleveland, huge soft-sediment displacements are inferred around several of the deep dimension stone quarries (see Pashin and Ettensohn, 1995).

The Bedford-Berea succession is interpreted to be a deltaic basin-fill fed from fluvial feeder channels connecting eastward into Pennsylvania and West Virginia (Pashin and Ettenson, 1995). The northern of these two channels (Murrysville-Cussewago Sandstone) is mostly developed in the subsurface of western Pennsylvania. However, pebbly sand deposits of this channelized phase are exposed in a few creek beds near the Ohio/Pennsylvania state line (Figure 4). The basal, gravelly portion of this channel deposit has been recently examined in several new sections by Baird and colleagues. These gravels are distinctive for diffuse, sand-supported pebbles, distinct angularlity of pebble/granule clasts, and high proportion of dark metamorphic and igneous pebbles, suggestive of a lack of textural maturity. Substantial erosion beneath the Cussewago-Berea paleovalley succession, east of the Grand River Valley, has removed the Cleveland-Bedford shale succession in this region (Pepper, et al., 1954; Pashin and Ettensohn, 1995; Figure 4).

Orangeville Shale. Above the Berea in south-central Ohio and northeastern Kentucky is a thin, hard, fissile, 3-6.5 meter (10-20 foot)-thick, black shale unit known as the Sunbury Shale. Its base marks the Devonian-Mississippian boundary as presently understood. As understood presently, the hard, black Sunbury Shale is believed to grade northward into the much thicker, and distinctly less organic-rich, Orangeville Shale in northern Ohio and northwestern Pennsylvania (Slucher et al., 2006). The Orangeville, characterized by a thick sequence of fissile, dark gray shale and thin black shale layers near its base in Ohio, is known to extend eastward past the Oil Creek meridian in Crawford and Venango counties where it changes by gradation into gray shale with flaggy siltstone beds (White, 1881; Caster, 1934; Pepper, et al., 1954; Pashin and Ettensohn, 1995; see STOP 3).

A thin, regionally widespread, dark gray siltstone layer (Bartholomew Bed), at the base of the Orangeville Shale in Crawford County, Pennsylvania is understood to mark the base of the

Mississippian succession in that area (Pepper et al., 1954; Pashin and Ettensohn, 1995; Baird et al., 2009a). Recent work by Baird and others suggests that this bed is traceable westward into the Cleveland metropolitan area (Baird et al., 2013; Figure 4). The base of this bed is regionally sharp, and it appears to record a significant erosion event at the Devonian-Mississippian boundary; the entire Berea is locally cut out under this layer in the Cuyahoga Valley (Baird et al., 2013).

Northwest Pennsylvania stratigraphic synthesis: Overview (see figures 4 – 8)

In the region between the Grand River Valley in northeasternmost Ohio, and the Cussewago River Valley, northwest of Meadville , the Cleveland Shale and the Bedford Formation are absent due to major downcutting below the Cussewago Sandstone (White, 1881; Caster, 1934; Pepper et al., 1954; Pashin and Ettensohn, 1995; see Figure 4). In this area, fossiliferous shale-siltstone deposits (Riceville Member), equivalent to the upper part of the Chagrin Shale farther west in Ohio, are directly overlain by soft, variably pebbly, often greenish, sandstone deposits of the Cussewago Sandstone, which is understood to be a basal paleovalley-fill phase of the greater Berea Sandstone succession (Pashin and Ettensohn, 1995; Figure 4). Where the Cleveland Shale and Bedford Formation are absent, the Cussewago deposit locally exceeds 80 feet in thickness with development of greenish, clay-bearing, gravelly, sandstone facies in its basal part (Pashin and Ettensohn, 1995; Baird et al. 2013). Granule- and pebble-size clasts in this facies include numerous dark lithologies, including granitic and metamorphic clasts, in addition to quartz (Figure 8 A), suggestive of anomalously rapid introduction of immature, extrabasinal sediment during the lowstand event.

East of the meridian of Linesville Creek in westernmost Crawford County, the Cussewago Sandstone thins dramatically and generally assumes a sandy, not pebbly, aspect. Still farther east, units higher than Riceville, appear below the base-Cussewago disconformity (Figures 4, 5). Progressively higher beds emerge eastward to the Oil Creek Valley in the Riceville-Titusville-Oil City area (Baird et al., 2009a; Figures 4, 5). We believe that some of these units are temporal equivalents of the Ohio Cleveland Shale-Bedford Formation-succession, pending further biozonal analyses of component conodont-miospore assemblages (Baird et al., 2009b).

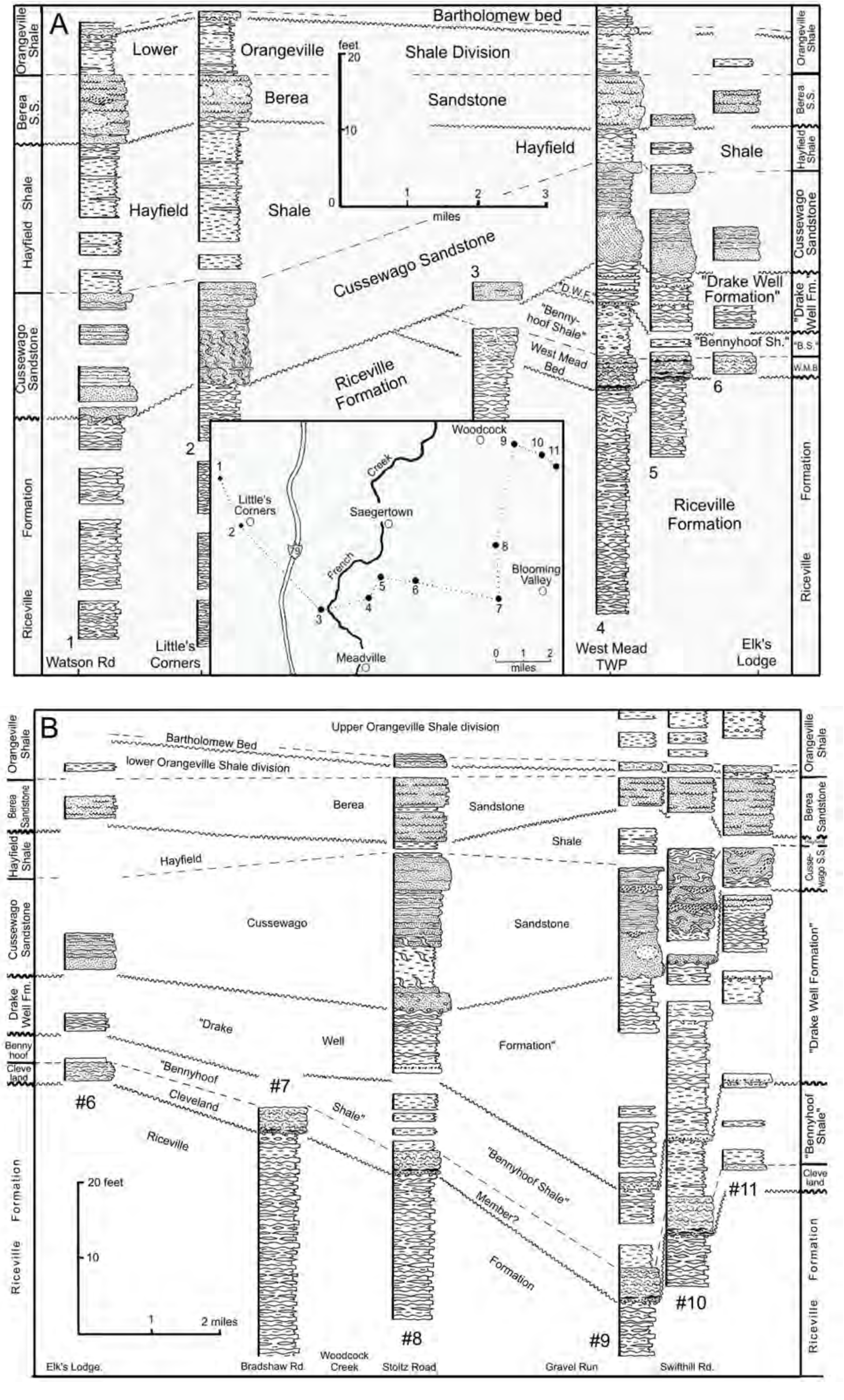

Figure 5: Stratigraphic transect of the end-Devonian-basal Mississippian succession across the French Creek Valley (Meadville area) and the Blooming Valley Quadrangle, to the northeast of Meadville (Baird et al., 2009 A). A, French Creek Valley transect. Note the progressive eastward

appearance of key divisions (West Mead Bed, Bennyhoof Shale, Drake Well Formation) along this transect; B, Blooming Valley area transect. Note continuing pattern of eastward-northeastward appearance of beds as the Drake Well Formation succession thickens.

Crawford County end-Devonian unit succession

Riceville Formation. The Riceville Formation is a flaggy to slabby succession of thin, gray-green shale partings and lenticular to tabular siltstone beds with occasional coquinitic shell concentrations. Many siltstone layers display sharp bases with current scour features and casted trace fossil markings. Thicker, lenticular siltstone beds display internal bedforms resembling hummocky cross-stratification, and fossils in coquinite lenses are typically clast-supported and disarticulated. This facies is understood to contain the record numerous, closely-stacked storm events (tempestites) in a storm-influenced, marine, mid-shelf setting. Common body fossils include: brachiopods such as *Cyrtospirifer* and associated rhynchonellides, molluscs, dominated by bivalves, crinoid debris, as well as rarer arthropods and sponges. The Riceville grades westward into shale-dominated outer shelf-to-basin deposits of the Chagrin Shale in Ohio (Figures 3, 4). Southeastward from the field trip area, the Riceville interval passes into inner shelf, marginal marine, facies (Oswayo Formation) characterized pink-weathering and locally reddish, micaceous, shale deposits interstratified with brownish sandstone beds that are frequently deformed into ball-and-pillow beds (Caster, 1934; Dodge, 1992). This facies, in turn, grades laterally into the traditional nonmarine “red bed” deposits of the Catskill Delta complex (Figures 1, 4).

“West Mead Bed”. This informal division is the lowest of several post-Riceville units to emerge below the Cussewago Sandstone in Crawford County (Baird et al., 2009a). It is a compact, erosionally-resistant, bundle of brown-weathering, bioturbated siltstone layers with associated dark grey to black shale partings. The type section for this unit is on Bennyhoof Creek north of Meadville in West Mead Township (Figure 6). This 1.0-1.5 meter-thick unit is characterized by microbioturbated siltstone beds and black shale partings which weather to a rusty red-brown in many sections. As such, layers in this unit contrast with the lighter, grey, tempestitic siltstone beds and green-grey shale partings in the underlying Riceville Formation and with overlying grey shale beds in the “Bennyhoof Shale” division (see below). Brachiopods, in this interval, include the spirifers *Sphenospira randalli* and *Cyrtospirifer* as well as numerous productids and rhynchonellids. The problematic taxa *Coleolus* and *Sphenothallus* are often abundant on bedding plane surfaces. Unidentified inadunate crinoids as well as tests of the echinoid *Hyattechinus rarispinus* occur more sparingly. Trace fossils include *Thallassinoides*, *Chondrites*, and variants of *Helminthopsis* or *Nereites*. This fauna, the intense bioturbated nature of component beds, and the black color of some shale partings are suggestive of slow deposition under conditions of fluctuating substrate oxygenation.

At localities where the base of this unit can be accessed, a lag bed of detrital pyrite with associated fish debris, conodonts, and Sphenothallus is observed (Figures 6, 7 A). Current-aligned *Coleolus* (Figure 7 B) and gastropod steinkerns are often abundant in these lag zones. Sometimes two, closely-spaced lag beds are associated with the base of this unit; the first roofed by fissile grey shale and the second by black shale or dark, microbioturbated siltstone. We interpret these contacts to record transgressive backstepping associated with marine transgression. It is notable that complete or partial sections of the West Mead Bed has been identified at a total of 27 localities in the Geneva, Meadville, Edinboro South, Blooming Valley, and Cambridge Springs quadrangles to date. The West Mead Bed will be seen by participants at Cora Clark Park in Meadville (Stop 3).

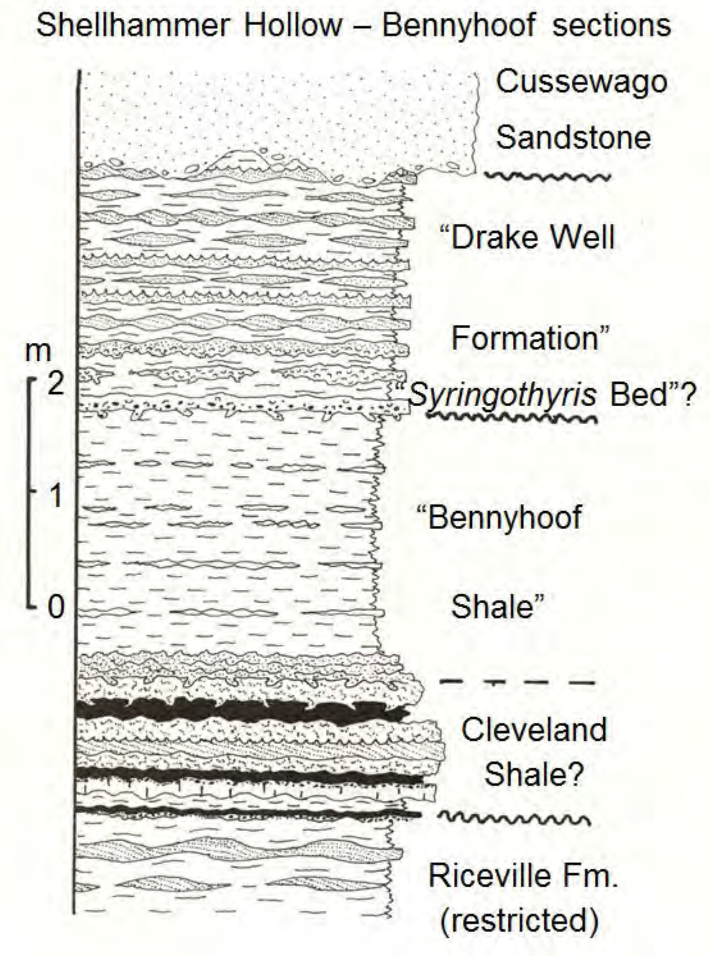

Figure 6: Top-Riceville-Formation-into-Cussewago Sandstone succession generalized from composite profiles of Bennyhoof Creek and nearby Shellhammer Hollow at the north edge of Meadville, Pennsylvania. Note presence of black shale partings and microbioturbated dark siltstone beds in the West Mead Bed (Cleveland Shale-equivalent? interval) as well as prominent discontinuities flooring both the Drake Well Formation and Cussewago Sandstone.

We provisionally interpret the West Mead Bed to be an eastern correlative of the Cleveland Member of the Ohio succession (Figure 4). Moreover, the basal lag zone at and above the base of this unit is interpreted to be the lateral equivalent of the Skinner's Run pyrite/bone bed and to have formed similarly. Jeff Over at S.U.N.Y. Geneseo isolated conodonts from the base-West Mead lags; preliminary yields have turned up the elements *Bispathodus aculeatus aculeatus* and *Polygnathus symmetricus*? (M-U expansa zones), permissive of West Mead-Cleveland Member correlational linkage (see Baird et al., 2009a, b). We believe that the West Mead accumulated in a sediment-starved transgressive regime under the influence of deep-storm turbulence, and/or bottom current-impingement. Episodes of dysoxia would have alternated with oxic, storm-influenced intervals, accounting for the complex stacking of dark shales and siltstone beds.

"Bennyhoof Shale". Above the West Mead Bed is a 1.2-2.7 meter-thick interval of soft, green-grey shale and lenticular-to-tabular siltstone layers, herein provisionally designated the "Bennyhoof Shale". The type section for this division is also on Bennyhoof Creek north of Meadville in West Mead TWP (Figure 6). The Bennyhoof is characterized by a conformable (gradational) lower contact with the West Mead Bed, but displays a sharper, unconformable, contact with the overlying "Drake Well Formation" (Figures 6, 7 C). Usually the Bennyhoof is siltier and intensely bioturbated in the basal 0.3-0.5 meter portion of the unit. The top 0.5-1.0 meter of this unit is also siltier: channelized siltstone lentils occur within the top of this shale unit at a number of localities. Owing to the soft nature of the shale, the Bennyhoof fauna has yet to be fully characterized. We will see the Bennyhoof Shale at Stop 3.

"Drake Well Formation". Above the Bennyhoof Shale is an abrupt upward change to a substantially thicker, siltstone-dominated, succession characterized by bundles of slabby, tabular-to-lenticular, tempestitic siltstone beds, frequently displaying ripple marked surfaces, basal scour features, and coquinitic fossil debris concentrations (Figures 5-7). Intervening shales occur both as thin partings and, locally, as more substantial (1.0-2.0 meter (3-6.5 foot)-thick divisions. We, herein, refer to this unit as the "Drake Well Formation" (see Harper, 1998; Baird et al., 2009a). This provisional unit largely, but not precisely, corresponds to the older "Kushequa Member" concept (*sensu* Caster, 1934) and to the "unnamed member" of the lower-medial Knapp Formation interval (Berg et al., 1980; Dodge (1992).

The base of this succession is marked by channelized lag debris, consisting of detrital pyrite, fish bone fragments, conodonts, and phosphatic mollusk steinkerns is association with disarticulated brachiopod valves (Figures 6, 7 C). Where concentrated, this lag is often associated with calcareous concretionary siltstone lentils and pods which weather to a distinctive knobbly, "popcorn"-like texture. Fossils associated with the basal lag zone and above it include: the spirifers *Cyrtopspirifer* and *Sphenospira* as well as numerous rhynchonellids in association with bivalves and occasional glass sponges. Most significant is the discovery of fully articulated echinoids in this interval at a number of Meadville-area localities (Figure 7 D), Both *Hyattechinus pentagonus* and *Hyattechinus rarispinus* have been found in the lowest 1.5 meter interval of this unit (Baird, et al., 2009a). *Hyattechinus pentagonus* usually occurs in clusters on bedding surfaces; many of the great *Hyattechinus* clusters in university and museum displays are probably from this interval. We may see *Hyattechinus* at this level at Cora Clark Park (STOP 3). Conodonts secured from the base of this interval to date include: *Bispathodus aculeatus aculeatus* and *Polygnathus communis communis* which are indicative of the Middle and Upper expansa zones, and conodonts obtained from the upper part of the

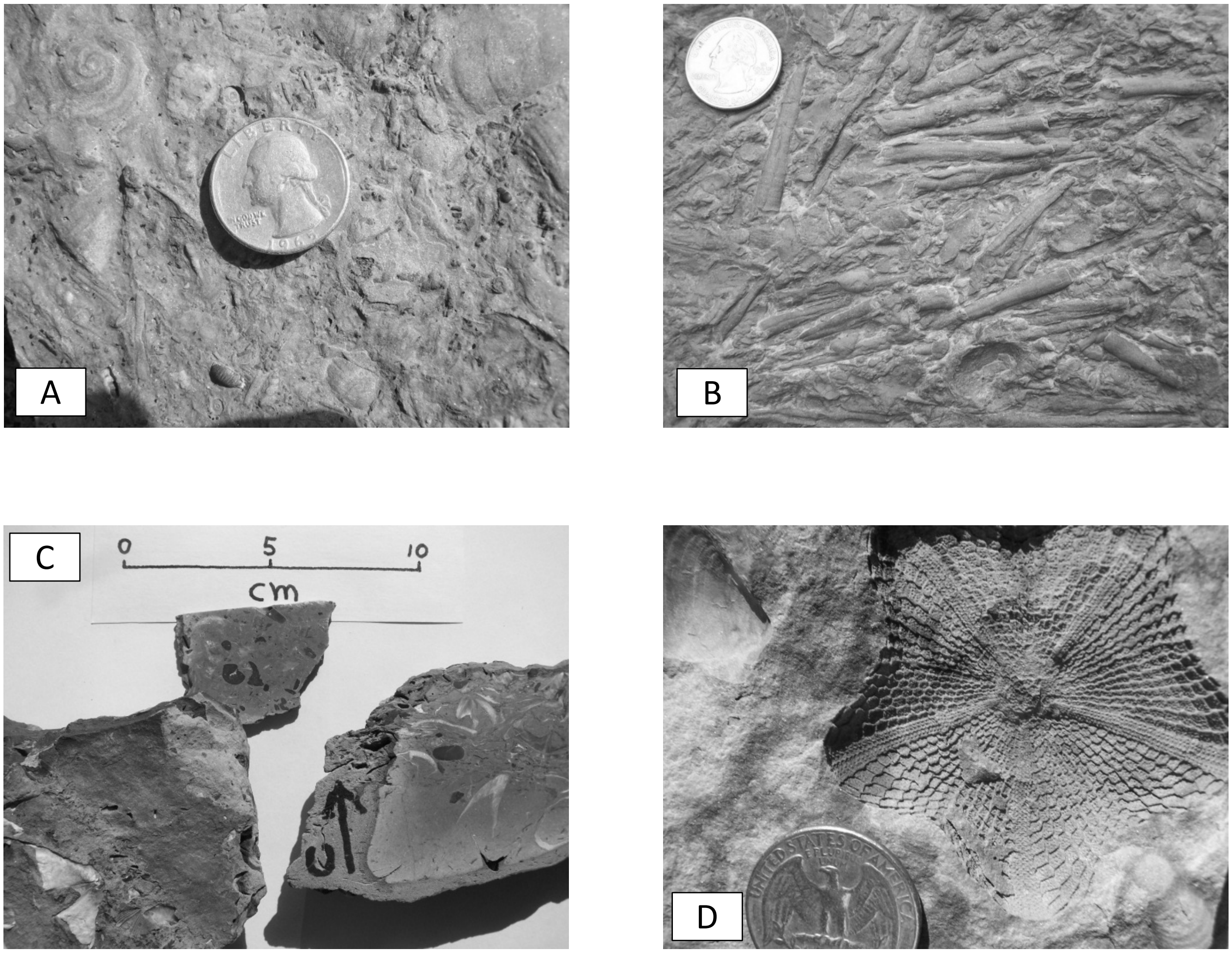

Figure 7: Distinctive features in the West Mead Bed and Drake Well Formation. A, Concentration of detrital (reworked) pyritic grains, gastropods, and fish bone debris which marks the base-West Mead Bed discontinuity. This lag deposit is believed to be correlative with the Skinner's Run Bed of the Ohio section (see text). Note ovoidal chondrichthyan crusher tooth (black object) in the lower left. This specimen is from a west-flowing tributary of French Creek above the Liberty Street overpass, two miles south of Meadville.; B, Current-aligned shells of the problematic molluscan organism Coleolus from the lower part of the West Mead Bed at

Dick Run below the East College Street overpass at the east edge of the Allegheny College campus in Meadville; C, Concentration of phosphatic pebbles, fish bone debris, conodonts, and spiriferid brachiopods which corresponds to the "Syringothyris Bed" of Caster (1934). This lag unit marks the position of the regional, base-Drake Well Formation discontinuity (see text). Note the large syringothyrid brachiopod in the lower left. This material is from a creek southwest of Riceville which corresponds to the original Riceville type section of I.C. White (1881); D, Articulated echinoid Hyattechinus pentagonus from the Drake Well Formation. This specimen, preserved as a three-dimensional open mold, was found in the bed of a northeast-flowing tributary of French Creek, 3.6 kilometers (2.2 miles) southeast of Cambridge Springs.

Drake Well Formation near Centerville have yielded *Bispathodus aculeatus anteposicornis*, *Bispathodus stabilis*, *Bispathodus aculeatus aculeatus*, and *"Icriodus" raymondi* Sandberg and Ziegler, 1979 , which are indicative of the Middle and Upper parts of the expansa zones and parts of the overlying praesulcata zone (see Baird, et al., 2009a, b).
The Drake Well Formation first comes into view below the base-Cussewago disconformity mainly east of the meridian of Interstate 79. Its base descends eastward across the county with the appearance of successively higher beds (Figure 5 A, B). Examination of sections in the Riceville-Centerville area in central Crawford County, suggest that the base-Drake Well Formation discontinuity connects eastward to Caster's (1934) base-Kushequa "*Syringothyris* Bed" at White's (1881) original Riceville type section. However, since the name "Kushequa" is no longer used, the designation "Drake Well Formation", *sensu* Harper (1998) is utilized provisionally for strata between the top of the Bennyhoof Shale and the Cussewago Sandstone east nearly to the Union City meridian, and for strata between the Bennyhoof Shale and the overlying Tidioute Shale in the Oil Creek Valley (Figures 5, 6). Given that the term Drake Well Formation was defined largely from subsurface log information (Harper, 1998), it ultimately might not ultimately fit surface sections, but that is an issue for future work. The Drake Well Formation type section will be seen at the west-facing railroad cut exposure across from the Drake Well museum and park complex (STOP 4) and the base of this division will be seen at Cora Clark Park (STOP 3).

Post-Drake Well Formation – pre-Cussewago unit succession. Three divisional units, Tidioute Shale, "unnamed sandstone", and Corry Formation overly, the "Drake Well Formation" interval and underlie the sub-Cussewago disconformity (Figure 4). Their eastward appearance, beginning in the Oil Creek Valley, and the various issues surrounding these units, are discussed at considerable length in Baird et al. (2009a).

Cussewago Sandstone. The Cussewago Sandstone is spatially the most variable and complex division that we have mapped. It is unique among the units examined here in that it is typically very poorly consolidated or unconsolidated, displays steep internal cross-stratification, and is frequently deformed. As noted above, the Cussewago thins rapidly eastward from the Linesville area to little more than 7 feet of non-pebbly, yellowish sandstone in a section north of Harmonsburg, but this unit varies widely in thickness in the Meadville area, thickening to as much as 6.5 meters (20 feet) near Little's Corners northwest of Meadville, and to as little as 0.5 meter- (1.6 feet-) thick at the I-79 Meadville interchange (Baird et al., 2009a). At Cora Clark Park (STOP 3), it is 5 meters- (16.5 feet-) thick. The base-Cussewago contact is usually sharp with underlying units, as it rests disconformably on underlying units regionally.

At Cora Clark Park (STOP 3) and at several other outcrops, the base of the Cussewago is deformed; sandstone ball-and-pillow masses are sometimes observed to occur in a green-grey shale matrix at the bottom of the unit. In addition to soft-sediment deformation, the base of the Cussewago, and units beneath it, are permeated by networks of small, usually vertical, dikes of coarse sandstone which frequently blur the basal boundary, as seen at Little's Corners, Cemetery Run in Meadville, and at the I-79 Meadville interchange. On a northeast-flowing stream, 0.8 kilometer (0.5 mile) southwest of Little's Corners, the basal 2.2 meters (7 feet) of the Cussewago is thoroughly crazed with networks of dikes which form polygon-, ring-, and boxwork patterns on bedding surfaces (Figure 8 B). This pervasive internal deformation and evidence of internal fluid release links the Cussewago to the Berea in Ohio, which displays similar features (Pashin and Ettensohn, 1995). Brezinski et al. (2010) describe similar dike networks in beds associated with the Speckty Kopf diamictites in Maryland.

Bartholomew Bed. One of the most easily recognized marker units is the Bartholomew Bed, which is widely understood to mark the base of the Mississippian System in northwest Pennsylvania (Pepper et al., 1954; Schiner and Kimmel, 1972; Figures 4, 5, 8 C). It is typically expressed as a thin, discrete ledge of rusty-weathering, dark grey, intensely bioturbated siltstone which floors overlying dark grey to gray-green, fissile shale deposits of the Orangeville Shale (Figure 8 C). The Bartholomew Bed is characterized by dense arcuate, vermiform traces of the deposit-feeding ichnotaxon *Helminthopsis*. Hence, this bed was referred to as the "cuniform sandstone" by early workers.

The base of the Bartholomew Bed is sharp, and it is marked by a basal sculpture of protruding burrows and an associated lag of fragmental *Lingula* valves. We believe that this contact is regionally disconformable; in Summerhill Township in western Crawford County, a thin, laminated, back shale unit can be seen below the Bartholomew Bed which, in turn, displays a sharp basal contact (Figure 8 D). We believe that it is possible that this black shale may represent a localized feather-edge remnant of the true Sunbury Shale of south-central Ohio sections, but this remains to be investigated.

Remaining problems

The establishment of a detailed end-Devonian event-stratigraphy, microstratigraphy, and chemostratigraphy requires knowledge of biostratigraphy (conodonts, ammonoids, palynomorphs) coupled with above-mentioned isotopic sampling. A promising start was made by Jeff Over with conodont calls from the "West Mead Bed" and the "Drake Well Formation", noted above (see Baird et al., 2009a, b), but ammonoid and palynomorph data from these strata are largely unknown. Such work, backed up by carbon and oxygen isotope investigations will be key to positioning these units relative to inferred greenhouse, icehouse, and extinction events recognized globally. Globally recognized units, such as the Dasberg and Hangenberg black shale markers, are yet to be identified in Ohio and Pennsylvania. Given that many area end-Devonian divisions are very fossiliferous relative to the better-studied North African and European sections, an improved chronostratigraphy for our units should shed new light on the extent and nature of the end-Devonian crises. Such work will provide ongoing opportunities for the intrepid graduate student.

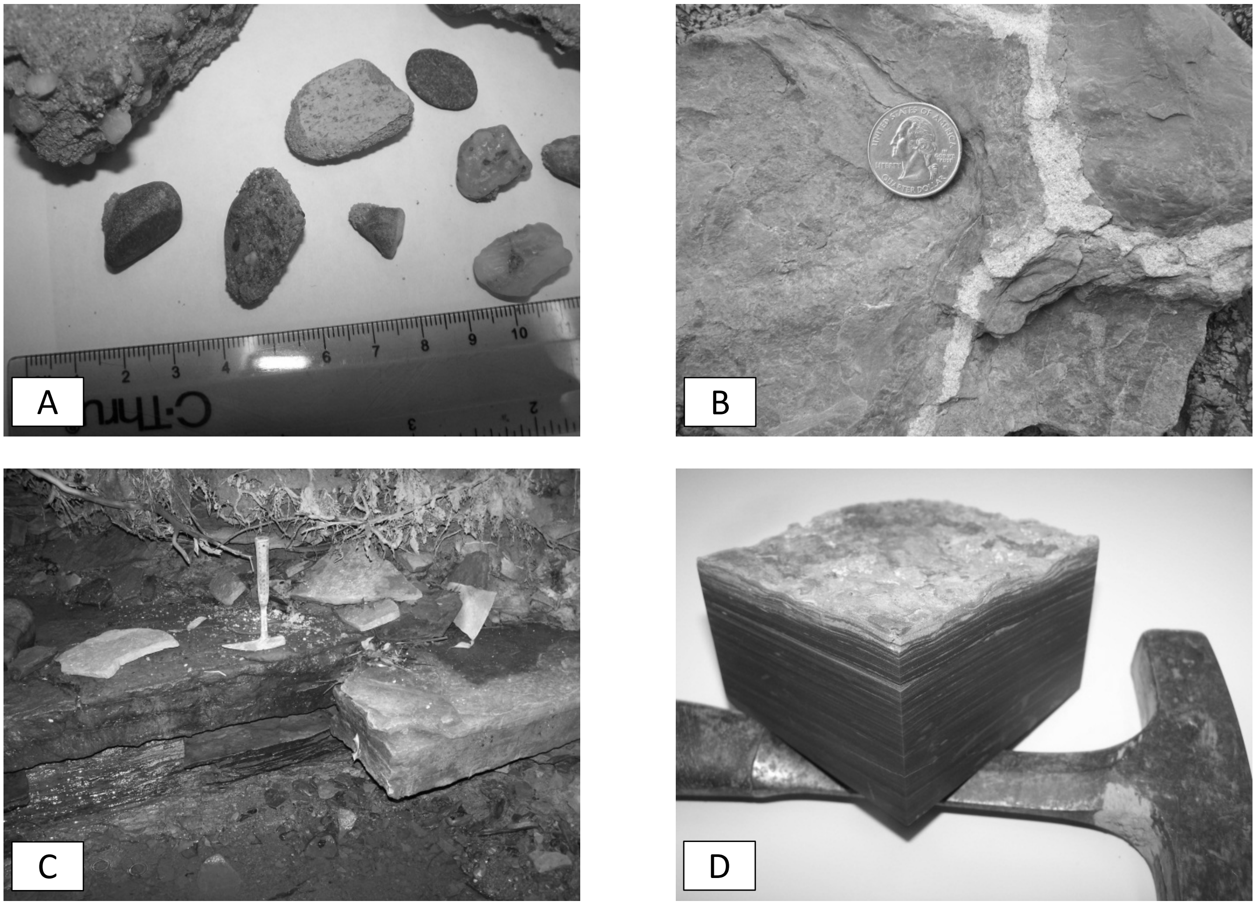

Figure 8: Key features of the end-Devonian-basal Mississippian succession. A, Dark colored, heterolithic pebbles from pebbly sandstone facies in thick, Cussewago paleovalley-fill deposits, collected along northwest-flowing Baughman Creek at North Bristol, Ohio. Note granitic and

foliated clasts in sample mix; B, Clastic dikes penetrating a shale bed in the Cussewago Sandstone. These dikes of coarse sandstone form networks, superficially resembling mudcracks as seen in bedding plane view. Specimen from northeast-flowing tributary of Cussewago Creek, 0.8 kilometer (0.5 mile) southwest of the intersection at Little's Corners in Hayfield Township; C, Bartholomew Bed at Cora Clark Park (STOP 3). Note compact character of this unit and its sharp basal contact; D, Laminated black shale deposit observed below the Bartholomew Bed in western Crawford County. This 10 cm (4 inch)-thick unit is here shown inverted with its basal contact surface shown uppermost. This bed may be a local, feather-edge expression of the Sunbury Shale (see text). Specimen from west-flowing tributary of Conneaut Creek, southeast of Conneautville, PA.

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Roadlog and stops

Miles		
Int.	**cum.**	
0.0	0.0	Exit S.U.N.Y. Fredonia campus. Turn right (south) onto Central Avenue
0.8	0.8	Intersection of Central Avenue with Temple Street. Turn left onto Temple Street.
0.2	1.0	Intersection of Temple Street with U.S. Route 20 in center of Fredonia. Turn right (west) onto Route 20.
0.2	1.2	Park along right side of Route 20 by bridge over Canadaway Creek. Exit vehicles and proceed to small granite monument by private parking area just to the east of the bridge. STOP 1: Memorial to earliest drilled gas well:

STOP ONE: Monument celebrating the drilling of the first gas well drilled in America; spudded annum 1825 in Fredonia, New York.

The small size and plainness of the monument belies the importance of the event it celebrates. We are very close to the site of a commercial gas well that was drilled here in Fredonia in 1825, quite possibly the first gas well drilled in North America or anywhere. According to accounts in the 1825 Fredonia Censor, an entrepreneur by the name of William Hart, came up with the idea of drilling for commercial gas in the local shale (Upper Devonian Gowanda Shale Member of present-day usage) that reeked of gas, which bubbled up through fracture networks (joints) in the floor of Canadaway Creek (Lash and Lash, 2011). Not only did he successfully find gas at a drilled depth of 27 feet, but he was able to transport it by pipe to a containment structure where it could be metered for use by village establishments and individuals. To economically control gas distribution, he developed the Gasometer, a sheet iron container filled with gas that was buoyant within a water-filled, rock-enclosed space; when completely gas-filled, the gasometer would rise to nearly the top of the water-filled space. When gas was drawn off by customers, it would sink, proportionally to discharge and appropriate fees. According to the Censor, two stores, two shops, and a mill had working gas outlets and 36 metered lights were in operation by late 1825 (Lash and Lash, 2011).

By the 1850s, gas use in Fredonia had increased. At this time, another Fredonian by the name of Preston Barmore, with two other associates, set up the Fredonia Natural gas Company Inc. in 1858. Prior to this event Preston had drilled two wells in the shale with only limited success. By noting the escape of the bubbling gas through fracture networks (joints), he came up with the idea of stimulating wells with explosives. In the summer of 1857, using gunpowder, he successfully fracked one of his wells at a depth of 122 feet and greatly increased his yield, two years before Colonel Drake's experiment (Lash and Lash, 2011). Finally, he set up a well pumping system to remove water from the borehole, thus, securing a considerable increase of gas. By the end of 1858, gas was available in sufficient quantity to meet a vastly greater demand in town (1,200 lights or burners). Fredonia had become a city of light (Lash and Lash, 2012). For his efforts, Preston Barmore could be referred to as "the first petroleum engineer".

Return to vehicles and proceed westward on Route 20.

0.6	1.8	Leave Village of Fredonia. Continue southwest on Route 20.
6.1	7.9	Pass through Green Arch intersection in Brocton. Continue straight (southwest) on Route 20.
7.0	14.9	Enter Village of Westfield.
1.5	16.4	Intersection of Route 20 with Route 394 (North Portage Road). Turn right (northwest) onto Route 394.
1.3	17.7	I-90 entrance on right. Proceed through toll onto southbound entrance feeder and proceed toward Pennsylvania.
11.7	29.4	Pennsylvania state line. Continue southwest on I-90.
5.4	34.8	Exit I-90 at off-ramp for PA Route 89 on the right.
0.3	35.1	Turn left from feeder ramp onto southbound Route 89.
10.9	46	Major complex of gravel pits on the right. Quaternary glacial outwash deposits present in this area.
0.7	46.7	Intersection of Route 89 with Route 8 at Lowville, PA. Continue straight (south) on combined routes 89/8.
1.5	48.2	Enter Village of Wattsburg. Continue straight (south).
0.6	48.8	Route 89 splits off to the left to Corry, PA. Continue southward to Union City on PA Route 8.

6.9	55.7	Enter Union City, PA.
0.8	56.5	Intersection of Route 8 with PA Route 97. Turn right onto Route 97.
0.5	57.0	Leave Union City. Continue west on Route 97.
2.1	59.1	Turn right (north) onto Middleton Road.
0.8	59.9	Turn left onto road for Union City Dam.
0.3	60.2	Road splits. Bear left to cross Union City Dam.
0.3	60.5	Parking lot at west end of Union City Dam. Depart from vehicles.

STOP TWO: Stratigraphy and paleontology of the classic Union City Dam spillway succession:

Stratigraphy. Depart from vehicles and proceed first to spillway overlook. Following discussion of the units, we will proceed down the access road and examine the section from a safe vantage point. We thank the Army Corps of Engineers (ACE) for permission to visit the site and to surface collect fossils over the years. For safety reasons the ACE requires advance notice of visits, plus the wearing of hard hats and secure footwear. Because of overhanging sandstone blocks please keep to the center of the spillway.

Top-Chadakoin Formation-base-Venango Group succession. Two key stratigraphic divisions are visible in the 30 meter (95 foot)-thick spillway succession. The main, 25 meter (78 foot)-thick part of the section is the shale-dominated uppermost interval of the Chadakoin Formation. This is abruptly succeeded by an approximately 5 meter (15-17 foot)-thick interval of Panama Sandstone, a massive, quartzose unit which is also known by the driller term “first Venango sand”; prior to recent modifications of this section, the Panama could be seen as a bluff-forming bench along the top of this outcrop. The Panama is the lowest of a long succession of siltstone and sandstone divisions comprising the Venango Group in northwest Pennsylvania.

Top-Chadakoin succession. The top-Chadakoin succession here is exceptionally shaley when compared to the siltstone-dominated, top-Chadakoin succession below the LeBoeuf Sandstone in the Erie, PA area. Moreover, this shale interval is notable for soft-sediment deformation and what appears to be disjunctive cleavage at several levels. However, in the Sherman-Stedman area in western Chautauqua County, essentially identical facies occurs below the Panama Sandstone at sections flowing into French Creek (Baird and Lash, 1990). Because this shale was so very different from typical underlying tempestite-dominated deposits of the Ellicott Member, it was informally termed the “chip cleaved shale” division of the Ellicott succession (Baird and Lash, 1990). The course of French Creek appears to be aligned to end-Chadakoin paleoenvironmental depositional strike as suggested by the distribution of this shale belt.

Panama Sandstone. Although *in-situ* Panama Sandstone is not accessible here, fall-down debris from it can be sampled. The base of the Panama appears to mark a discontinuity in this area; the contact is knife-sharp and the lithologic discordance with the underlying shale succession is very conspicuous. At the top of the massive sandstone interval is a bed containing quartz pebbles in association with disarticulated valves of the brachiopod *Cyrtospirifer*. This may mark the base of the succeeding Venango division, known as the Amity Shale; as such this bed may represent a transgressive lag deposit which caps the Panama Sandstone.

Important dam spillway succession fossils. The Chadakoin Formation siltstones and shales exhibit rhythmic sandstone layers that thicken upwards, culminating with the resistant Panama Sandstone that caps the section. The Chadakoin succession is very fossiliferus with many brachiopods, pelecypods, trace fossils and occasional orthocone cephalopods, crinoids and starfish. One fossil frequently seen here is *Armstrongia oryx* (Figure 9 A), which was originally named *Titusvillia drakei* (see Caster, 1939). This fossil, once thought to represent a branching glass sponge, is herein reinterpreted as a trace fossil (McKenzie, 2009a). A more complete faunal and floral list is available in the 63rd Pennsylvania guidebook (Harper, 2009).

The horseshoe crab trace fossil *Protolimulus eriensis* (Figure 9 B) is also found in the Dam spillway. The trace is a deep resting impression faithfully preserving the shape of the horseshoe crabs' underside raised from the lower side of slabs. *Protolimulus* seems to be a trace made by horseshoe crabs burrowing in the sediment to escape an influx of fresh water, bright sunlight or uncomfortable temperatures in their near shore marginal marine habitat. Because both large and small *Protolimulus* are found in close association, we suspect that these traces were not solely associated with egg-laying activity. *Protolimulus* is also found in south western New York, north east Ohio (Chagrin Shale) and in several north western and central Pennsylvania counties.

The body fossil of a horseshoe crab has been found locally and was referred to *Kasibelinurus randalii*, (Babcock, et al 1995). This fossil has been compared by James Lamsdell to the original Australian find and is seen to exhibit different morphology which will necessitate a redescription and new name. The body fossils do show sexual dimorphism with the females being slightly larger than the males. Body fossils include enrolled examples that may or may not show free segments on the opithosoma. This body fossil is almost certainly the maker of the *Protolimulus* traces.

Rarer fossils include ammonoids, *Dunkleosteus* plates and chondrophore hydrozoans. A very few tabulate corals have been found in the area: *Pleurodictyum*, an auloporid and a single small *Favosites*- like coral colony. Corals are extremely rare in the high Devonian (McKenzie 2009b), perhaps reflecting global patterns of diversity reduction observed during the end-Devonian Famennian stage.

In the shaly, lower Venango succession above the Panama Sandstone, we return to an assemblage dominated by numerous brachiopods but lacking horseshoe crabs, hydrozoans and the other unusual fossils. This Lower Venango contact represents a major change in the regional sedimentary environment.

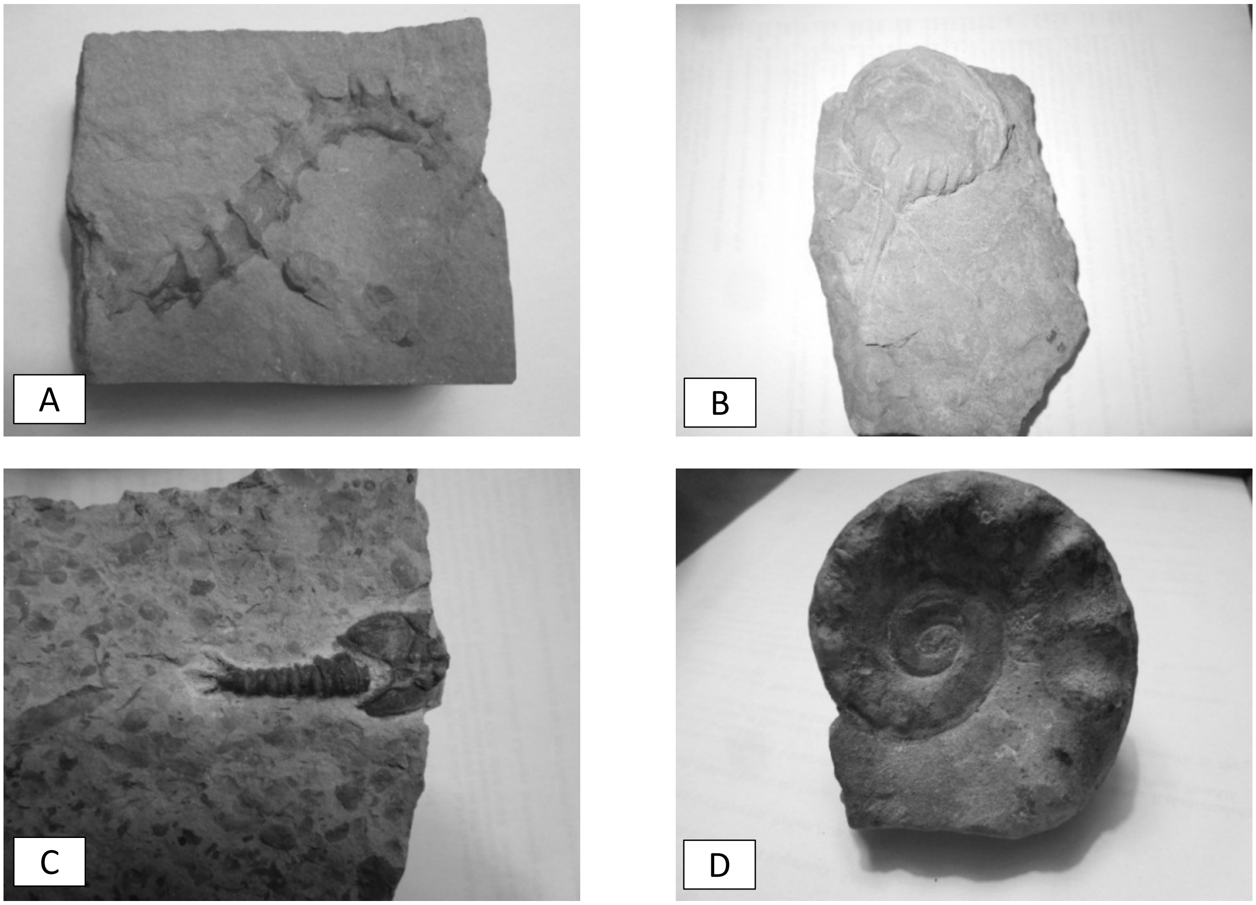

Figure 9: Important fossils from the Chadakoin and Drake Well formations. A, *Titusvillia* from the Drake Well railroad cut exposure (STOP 4), S. C. McKenzie collection. B, *Protolimulus eriensis*, a resting trace from a horseshoe crab found in the tri state area and at the Union City Dam spillway. Size 9 cm, S.C. McKenzie Collection; C, *Echinocaris randallii* from Drake Well showing a nearly complete individual 5.5 cm in length. S. C. McKenzie Collection, counterpart in the Carnegie Museum; D, *Porcellia nodosa* gastropod 7 cm-wide from a Drake Well Formation exposure near Riceville, PA S. C. McKenzie collection.

Possible regional astrogeological features. There are three unusual structures in our study area that may be impact craters (Pees and Palmquist, 1983). The first is the Western New York Chautauqua structure that appears as a vague depression with Chautauqua Lake in the center. Some roads run along a ridge that partly defines the rim of the deeply buried structure. NASA astronauts photographed some ring like features partly circling the structure and extending as far as Lake Erie. The second feature is in Warren Co. PA and is centered on the community of

Scandia. This structure is partly defined by a noticeable semicircular bend in the Allegheny River. The last is Pymatuning Reservoir, easily seen as a compressed but well defined circular area. Moreover, the Late Devonian Cussewago Sandstone is regionally quite thick in that region. Although these features may pre- or post-date Devonian events and be of non-impact origin, a possibility still exists that one or more may be the result of a bolide event.

Return to vehicles and retrace route back to intersection of routes 8 and 97 in Union City.

4.0	64.5	Turn right (south) onto Route 8 from Route 97 and proceed through Union City. PA Route 6 intersects Route 8 in the middle of town. Continue straight on Route 8.
0.8	65.3	PA Route 6 splits off of Route 8 at south edge of Union City. Turn right onto Route 6.
9.0	74.3	Intersection of westbound Route 6 with southbound Route 6/19. Turn left (south) onto Route 6/19.
6.0	80.3	Drive through town of Cambridge Springs, PA. Continue southbound on Route 6/19. Road follows valley of French Creek.
8.0	88.3	Drive through village of Saegertown, PA. Continue southbound on Route 6/19 to Meadville, PA.
7.0	95.3	Exit Route 6/19, turning east onto Arch Street in Meadville.
0.2	95.5	Turn right (south) onto Park Avenue.
0.1	95.6	Turn left (east onto Pine Street. Proceed eastward up the hill to Cora Clark Park.
0.7	96.3	Parking area for Cora Clark Park on the right. Turn right into the parking area and depart vehicles. STOP 3: Cora Clark Park creek section:

STOP THREE: Riceville Formation-Orangeville Shale Succession in Cora Clark Park, Meadville, PA.:

Depart from vehicles and proceed to trail bordering stream. One of us (Baird) will first deliver a brief overview on the Geology and stop-set-up before leading the group to the stream. We will descend by trail from the downhill (west) corner of the grassed park area to the creek bed. The group will, then, turn right at the creek and proceed to the downstream (west) end of the creek bedrock section. Be careful walking as the bedrock surface may be wet and slippery. The stratigraphic succession presented below is in ascending order of units encountered as one proceeds upstream.

Riceville Formation. The basal 5-meter (16.5 foot) succession on this stream is developed in the upper part of the Riceville Formation. Based on measurements by White (1881) and Caster (1934), the Riceville is about 26 meters (80 feet)-thick at this meridian. However, some of this aggregate thickness includes strata included by us in younger divisions (West Mead Bed, Bennyhoof Shale, and Drake Well Formation) which we will see upstream. The visible (restricted) Riceville interval on this creek is interpreted to be the eastern, upslope phase of the Chagrin Formation in Ohio. At this locality, the Riceville is expressed as an interval dominated by tabular to lenticular, grey, slabby siltstone beds and grey-green shale interbeds. The siltstone beds weather to a grey-brown color and display sharp, erosional sole marks along their bases. Sedimentary structures observed include: ripple marks on some bedding planes, scour surfaces (sole marks) along bases of beds, and disarticulated brachiopods, bivalve, and echinoderm debris.

"West Mead Bed". Above the Riceville interval is a compact bundle of siltstone beds which we, herein, designate the "West Mead Bed" for exposures along Bennyhoof Creek north of Meadville (Figure 6). At this creek, this unit includes 1.2 meters (3.6 feet) of resistant, closely-spaced, variably bioturbated, siltstone layers. The base of this unit is marked by a 4-6 cm (2-3 inch-) thick, very dark grey, silty mudstone bed which is floored by a lag of reworked pyrite and conodont/fish bone debris interpreted to mark the horizon of the Skinner's Run Bed (Figure 7 A). This is succeeded by 25 cm (10 inches) of grey siltstone beds and soft shale. This unit is succeeded by 0.75 meter (2.5 feet) of hard, brown-weathering siltstone beds. The parts of this interval display dark, silty shale partings as well as dark grey siltstone beds which are intensely bioturbated (Figure 6). In particular, the ichnotaxon Helminthopsis has been observed in this interval at several Meadville area sections; this trace fossil is characteristic of basal Mississippian dysoxic deposits and is abundant in the Bartholomew Bed, a division that we will see upstream at this locality (see below). Other fossils present include the brachiopods Cyrtospirifer , Syringothyris , productids, gastropods, and the problematical conical taxon Coleolus (Figure 7 B). We believe, on the basis of conodont yields to date, as well as lithologic features, that this unit is the upslope equivalent of the black Cleveland Shale in Ohio.

"Bennyhoof Shale". Continuing upstream, we cross a 2.4 meter (8-foot)-thick interval of soft, grey-green mudstone with associated, thin siltstone beds and lentils. We, herein, provisionally refer to this unit as the "Bennyhoof Shale" for good exposures on Bennyhoof Creek north of Meadville (Figure 8). The lowest 0.3 meter (12 inches) of this unit is heavily bioturbated, distinctly silty, and transitional with the underlying West Mead division. The middle of this unit is very shaley with only thin siltstone bed development. The top 0.7 meter (2 foot) portion of

this unit is marked by a return of thicker siltstone beds; these are distinctly lenticular (channelized?) and are associated only with trace fossils.

"Drake Well Formation". The Drake Well Formation is a name herein assigned to strata between the Bennyhoof Shale and the sub-Cussewago disconformity between the French Creek Valley region and the meridian of Union City (Figure 5 A, B). It is observed to appear in a few sections west of French Creek as a feather-edge deposit, followed by eastward thickening as younger beds appear progressively beneath the base-Cussewago contact across the study area. Although the upper part of this unit is concealed at Cora Clark Park, the lower four feet of the interval is well exposed in the creek floor above the Bennyhoof succession. The base of the Drake Well succession at this locality is marked by a diastemic contact, above which is localized development of a channelized lag bed (Figure 6). Along this contact, fish teeth and conodonts occur at the base of a concretionary siltstone lentil on the right-hand (south) side of the creek as we continue upstream. This contact and associated lag deposit appears to be coextensive with a brachiopod- and bone-rich unit in Oil Creek Valley sections which Caster (1934) had called the "Syringothyris Bed" (Figure 7 C), marking the base of Bedford Shale-equivalent deposits. Preliminary conodont information indicates that the base of the Drake Well falls in the M-U expansa zone age-range (Baird, et al., 2009a, b).

Lateral to-, and immediately above, the concretionary lentil, is a change to fossiliferous, burrowed, muddy siltstone which is well exposed in the floor of the creek. Several types of disarticulated brachiopod taxa (Cyrtospirifer , Syringothyris , and an unidentified rhynchonellid) can be seen on some bedding planes. More significantly, a large cluster of articulated and partially articulated echinoids, identified as Hyattechinus pentagonus, is visible on the right-hand (south) side of the creek (Figure 7 D). The echinoids occur in association with complete and partial spicule skeletons of glass sponges which were buried with the sea urchins in the same storm event. The sponges can be seen as moldic rectilinear patterns on bedding surfaces.

Cussewago Sandstone. Following a 28-31 meter (90-100 foot)-long concealed interval along the creek, involving only a small vertical gain, an interval of disturbed strata is visible on the left-hand (southeast-facing) cutbank and in a sloped, falls ramp in the creek floor immediately upstream from the cutbank. Although these beds are highly deformed, they appear to belong, in part, within the Cussewago Sandstone succession.

The Cussewago Sandstone has been traced regionally from the Grand River Valley area in Ohio, eastward to the meridian of Union City (Caster, 1934; Pepper, et al. 1954; Pashin and Ettensohn, 1995). The present authors agree with Pashin and Ettensohn (1995) that the Cussewago is the eastern equivalent of the lower (main) part of the Berea Sandstone succession in Ohio. Although the Cussewago is much thinner than the Ohio lower Berea overall, both units display locally display large-scale cross-bedding, a complex internal stratigraphy, and both structural and soft-sediment bedding deformation. Pashin and Ettensohn (1995) further speculated that the sub-Cussewago disconformity was the regional signature of the end-Devonian glaciation-related eustatic drawdown event. Although shelly fossils are generally absent from most sections, plant debris and palynomorph are common on some bedding surfaces. The Cussewago is unusual for its often extreme friability; it usually weathers to soft, wet, sloped banks where groundwater exits from this unit.

The deformed interval in the southeast-facing bank is quite problematic in that two lithologies are caught up in the disturbance and that the relationship of the disturbed interval with the underlying Drake Well Formation is concealed here. A sharply-bounded block of massive, friable Cussewago Sandstone appears to be bordered or surrounded by green-grey shale which is also deformed. It is uncertain at this time whether this shale is a pre-Cussewago unit or whether it is part of the Cussewago succession. Similarly, the adjacent, ramped falls surface may be in the topmost Drake Well Formation or it too may be part of the Cussewago as well. For perspective, the basal part of the Cussewago often displays deformed greenish shale at its base in association with sandstone ball-and-pillow structures. Patterns of internal soft-sediment deformation within the Cussewago as well as pronounced spatial thickness variability for this unit accord well with the idea that the Cussewago represents transgressive backfilling of a paleovalley system. Deformed beds in the Cussewago may, thus, may be the record of local sediment-slumping events within coastal channel networks. Proceeding upstream, one can view additional, undeformed Cussewago in the north-facing, right-hand cutbank and in the low waterfall in the creek bed below the overpass of the transverse park path over the creek. An approximate total of 5 meters (16-17 feet) of Cussewago Sandstone is exposed in Cora Clark Park.

Shellhammer Hollow Formation. This is a term erected by Pepper, et al. (1954) for a succession of undifferentiated shale and sandstone units between the underlying Cussewago Sandstone and the overlying, basal Mississippian Bartholomew Bed. It is, herein, understood to include, in upward-ascending order, equivalents of Chadwick’s (1925) Hayfield Shale, an upper siltstone division of the Berea Sandstone, and an interval of silty shale below the Bartholomew Bed as discussed in greater detail in Baird et al. (2009a). At Cora Clark Park, the Shellhammer Hollow interval is 6.3 meters (20 feet)-thick. It is well exposed in a small, steep, south-facing side gully adjacent to the top-Cussewago waterfall below the park path overpass. Cora Clark Park is unusual for poor development of the Berea upper division siltstone unit; most of the 6.3 meter succession is very shaley, but a thin bundle of flaggy, partly deformed, siltstone beds in the middle of this interval appears to be what is left of the Berea siltstone division in this area.

Bartholomew Bed. The base of the confirmed Mississippian succession in the Meadville area is marked by the discrete Bartholomew Siltstone Bed (Figures 4, 5, 8 C, D). The Bartholomew Bed, ranging from 0.15-0.3 Meter (5-12 inches) in thickness across western Crawford County is an important regional marker to stratigraphers which is usually easily located in sections (Pepper, et al., 1954; Schiner and Kimmel, 1972). It is typically expressed as a falls-capping ledge of dark grey bioturbated siltstone which weathers to a rusty color in sections (Figure 8 C). The base of this bed is sharp and marks an erosional discontinuity. It is also notable for intense bioturbation by the ichnotaxon Helminthopsis which is characterized by distinctive, curved, hook-shaped markings. Helminthopsisis widely understood to be a deposit-feeding trace associated with dysoxic, offshore, Mississippian deposits. We will observe the Bartholomew Bed upstream from the park path over the creek (Figure 8 C).

Orangeville Shale. Continuing upstream past the thin and compact Bartholomew Bed we, finally, encounter a bank of dark, fissile shale exposed in south-facing cutbank. This is the basal part of a thick succession of dark grey shale, grey shale, and tabular siltstone beds known as the Orangeville Shale of Lower Mississippian age which is a widespread division across northeast Ohio and northwest Pennsylvania (Figure 5). The basal 13 meters (40 feet) of the Orangeville consists of fissile dark grey shale in the Meadville area. In this cutbank, we see only the basal few meters of this greater interval. Body fossils are scarce in the Bartholomew Bed and lower part of the Orangeville Shale. Disarticulated Lingula and orbiculoid valves can be found at this locality.

		Return to vehicles. Exit park westbound on Pine Street.
0.4	96.7	Turn right (north) onto Grove Street.
0.4	97.1	Turn right (east) onto PA Route 27.
0.3	97.4	PA Route 77 splits off from Route 27. Stay on east-bound Route 27 toward Titusville, PA. This road passes through a number of small towns and go-slow zones.
25.8	123.2	Intersection of Route 27 with Route 8 in Titusville. Turn right (southeast) onto PA Route 27/8 and proceed eastward into the middle of Titusville.
0.4	123.6	Route 8 turns right, away from Route 27. Turn right (south) on Route 8.
0.3	123.9	Cross Oil creek and take an immediate left onto Bloss Street at the light. Proceed east on Bloss Street for one mile.
1.0	124.9	Cross Oil Creek on one-lane bridge and take an immediate right turn at the east end of the bridge.

0.2 125.1 Enter Drake Well Park. Park and depart vehicles.
STOP 4: Drake Well Park and Museum and "type"
"Drake Well Formation":

Stop 4 A: The Story of the Drake Well (history as contingency):

Many people assume that Edwin L. Drake showed up in Titusville, Pennsylvania, one day, drilled his well, and single-handedly ushered in the modern petroleum industry. Actually, there were many people involved in the effort. Drake was only part of the story, a very important part, but his place in history would not have existed were it not for a fascinating series of events, and the people involved in those events.

Samuel W. Kier (Figure 10 A), a Pittsburgh-area entrepreneur who dabbled in various enterprises, entered the salt business in 1847 and bought some property in the premier location of western Pennsylvania's salt-well industry about 32 km (20 mi) north of Pittsburgh. He drilled two wells to the Pennsylvanian Pottsville Formation, a well-known brine-producing sand at a depth of 122 m (400 ft) (Hughes, 1933). Although the wells produced a substantial amount of brine, they also produced an annoying amount of crude oil, a contaminant. According to legend, Kier's wife developed tuberculosis in 1848 and the attending physician prescribed "American Medicinal Oil" from Kentucky (Miller, 1974). Kier recognized the medicinal oil and the salt-well contaminant were the same fluid. He turned his wife's misfortune into a new and profitable enterprise by packaging the oil as medicine in half-pint bottles and selling them for 50 cents each. In 1850, following the advice of a prominent Philadelphia chemist, Kier set up a small still in Pittsburgh and experimented with distilling the oil. He eventually was able to distill a form of kerosene and began production of "carbon oil" for use in lamps. He also invented a lamp burner that would fit any lamp of the day and burn the "carbon oil" with little or no smoke. Single-handedly, Samuel W. Kier turned the lighting business upside-down. He was soon selling his "carbon oil" and his lamp burners in New York.

At about the same time, Dr. Francis Beattie Brewer (Figure 10 B), a Dartmouth College-educated physician and son of the president of a Titusville lumbering operation called Brewer, Watson and Company, became interested in crude oil. The company owned the Hibbard farm along Oil Creek about a mile south of Titusville. Like many areas along the creek, the farm had numerous oil seeps. Francis experimented with oil he collected on the farm and pioneered the use of crude oil for legitimate medical purposes. In 1851, he convinced his father to gather the oil for sale. On July 4, 1853, Brewer, Watson and Company signed the first petroleum development lease in the U.S. with J. D. Angier of Titusville (USGS, 1980). Angier set up some wooden cribs to trap the oil and some inexpensive machinery to separate the oil from the water, allowing him to collect between 11 and 23 l (3 and 6 gal) a day, most of it used for lighting and lubrication in the sawmill (Flaherty, 2003). That fall, Brewer showed a small sample to Dr. Dixi Crosby of the Dartmouth Medical School and Professor 0. P. Hubbard of the Dartmouth Chemistry Department, both of whom examined the sample and decided it had great value. Professor Hubbard, however, said the oil would never be commercially viable because it could not be obtained in large quantities.

Figure 10. Historical photographs of the men who were instrumental in ushering in the modern petroleum age. A, Samuel W. Kier, Pittsburgh-area businessman and entrepreneur; B, Dr. Francis Beattie Brewer, Titusville physician and son of one of the former owners of the land where Drake drilled his well; C, George H. Bissell, New York City lawyer and businessman; D, Professor Benjamin Silliman, Jr., Yale College professor of chemistry; E, James M. Townsend, president of the City Savings Bank of New Haven, Connecticut; F, “Colonel” Edwin L. Drake, ailing former railroad conductor and one of the most important men of the 19th Century; G, William A. “Uncle Billy” Smith, the tool maker who was in charge of drilling Drake’s well.

Another Dartmouth graduate, New York lawyer and businessman George H. Bissell (Figure 10 C), saw an advertisement for Kier's lamp oil, which caught his interest. He also saw Brewer's little bottle of oil in Crosby's office while visiting. He immediately put two and two together and had the Brewer, Watson and Company oil springs inspected. The resulting report was very positive, so Bissell and his partner, Jonathan G. Eveleth, decided to organize a company, buy the land, develop the oil springs, and sell the oil for lighting. They bought both the 100-acre Hibbard farm and an adjacent 1,200-acre tract from Brewer, Watson and Company in November, 1854. A month later, they formed the Pennsylvania Rock Oil Company of New York, the world's first oil company. Prospective New York investors were unfamiliar with crude oil, however, and were unwilling to invest in a commodity of unknown commercial value. Worried about the lack of interest in their company, Bissell and Eveleth hired Yale College chemistry professor Benjamin Silliman, Jr. (Figure 10 D) to analyze some crude oil and suggest ways it could be put to economic use. Silliman, who was arguably the country's foremost chemist, performed a series of experiments on the oil and, in April, 1855, wrote a glowing report of its value. It was superior to most oils he had examined; it did not harden on exposure to air, produced a good flame, and could be distilled into eight useful and economically viable products.

With Silliman's report in hand, Bissell and Eveleth were able to interest James M. Townsend (Figure 10 E), president of the City Savings Bank of New Haven, Connecticut, in their venture. Townsend and some of his associates were willing to buy into the Pennsylvania Rock Oil Company, but only if Bissell and Eveleth reincorporated the company from New York to Connecticut. The changeover occurred on September 18, 1855 (Giddens, 1948) and Townsend was elected president of the new company. Because Bissell and Eveleth were still in debt as a result of the cost of obtaining the land and incorporating the company, they decided to sell the land to the Pennsylvania Rock Oil Company and then lease it for oil production. By chance, just a few days before the sale, Bissell learned that Pennsylvania law required property owned by non-Pennsylvania corporations to be forfeited to the state of Pennsylvania (Flaherty, 2003). So, instead of selling the land to the company, Bissell and Eveleth convinced two of the stockholders to buy it, and then leased the land from them for 99 years. It was discovered, however, that the stockholders in question had used worthless securities in the transaction. Bissell and Eveleth already had a strained relationship with Townsend and his New Haven associates; this latest fiasco only caused the company to lapse into inactivity for several years. Townsend, however, continued to be enthusiastic about the Titusville prospect.

Townsend lived in the same New Haven hotel as a 38-year-old railroad conductor and jack-of-all-trades named Edwin L. Drake (Figure 10 F). Drake knew Townsend very well and actually invested $200 in the Pennsylvania Rock Oil Company. In 1857, he became ill and resigned as a railroad conductor. Knowing that Drake was still eligible for free railroad transportation, Townsend convinced him to go to Titusville and Pittsburgh to take care of some necessary legal matters. In advance of Drake's arrival in Titusville, Townsend mailed all the legal papers and several letters to "Colonel E. L. Drake" in care of the Brewer, Watson and Company. Drake was never in the military, but the title "Colonel" carried great weight with the locals, and it stuck. He investigated the Oil Creek area, visited the oil springs and observed oil being used for lighting and lubrication at nearby sawmills. He then traveled to Pittsburgh to complete his legal business and, while there, visited the salt works north of the city. Upon returning to New Haven, Drake told Townsend all he'd seen and suggested that oil could be obtained in commercial quantities at Oil Creek. Townsend and a majority of the board of directors of the company were favorably impressed with Drake's report. They formed the Seneca Oil Company of Connecticut on March 23, 1858. Drake was named president and leading stockholder, and a few days later he was elected general agent.

Drake moved his family to Titusville in May, 1858. At first, he tried to dig a well on the Hibbard farm, but the workmen were flushed from the hole by a gush of water. In frustration, Drake abandoned these works and decided that it would be cheaper to drill in the fashion of Pittsburgh's salt wells. Because no one in Titusville understood drilling, he traveled to Pittsburgh to consult with salt-well owners and hire a driller. When he returned to Titusville, he ordered a six-horsepower steam engine and a "Long John" stationary tubular boiler to furnish power for drilling, and then designed an engine house and derrick (the outside of the derrick was boarded over because Drake expected to drill through the snowy northwestern Pennsylvania winter). By August, 1858 everything was ready for a driller, but the driller he had hired didn't show up. Drake later learned that the driller thought he was crazy and only agreed to drill for oil to get rid of him. Several other drillers were hired, but none of them appeared at Titusville. Drake was about ready to abandon the idea of drilling when Lewis Peterson, one of Drake's salt-well-operator friends, recommended William A. Smith (Figure 10 G), a tool maker who was known locally as "Uncle Billy". He agreed to work for Drake for $2.50 per day, and threw in the services of his 15-year old son for free. "Uncle Billy" arrived in Titusville with his son and daughter in mid-May, 1959 and the rest of his family followed in July. Because the initial hole that was dug for drilling kept caving in due to flooding from Oil Creek, Drake bought 3-m- (10-ft)-long segments of iron pipe in Erie and drove them 10 m (32 ft) through the glacial outwash of Oil Creek Valley until they hit bedrock. Finally, in mid-August 1959, they began using the steam engine and drilled at a rate of about 1 m (3 ft) per day.

Meanwhile, in New Haven, the company stockholders were losing their enthusiasm for the project, and even Townsend was getting discouraged, despite continuing to support Drake financially. Finally, in frustration, Townsend decided to end the operation. He sent Drake a final remittance and told him to pay all outstanding bills and return to New Haven. In one of the more serendipitous moments in history, Townsend's message and money failed to reach Drake until after that momentous day in late August, 1859.

On Saturday afternoon, August 27, 1859, the drillers were about to quit work until Monday when the drill bit dropped into a crevice at 21 m (69 ft), and then slipped down another 15 cm (6 in). The men put their tools away and went home without further thought. On Sunday afternoon, "Uncle Billy" visited the well and saw oil floating on top of the water. He lowered a tin container into the hole and pulled it up filled with oil. His son ran shouting, "They've struck oil! They've struck oil!" On Monday morning, Drake arrived to find "Uncle Billy" and his crew guarding the well as well as several tubs and barrels already full of oil. Unfortunately, no one bothered to gauge the production. Still, it has been estimated that the well probably produced between 0.95 and 1.2 kl (8 and 10 barrels) of oil per day.

Although the original engine house and derrick were destroyed by fire on October 7, 1859, a rebuilt version served as the backdrop of the iconic 1866 photograph of Colonel Drake (Figure 11) by John Mather that is iconic to the history of petroleum exploration.

The Aftermath. Just a few years after Drake's success, he lost everything, and a serious bout of neuralgia kept him confined to an invalid's chair for the remainder of his life. Destitute and seriously ill, he moved to various locations trying to find a cure, but it was not forthcoming and he died in November 1880 in Bethlehem, Pennsylvania. Although he was buried in Bethlehem, his body was removed to Titusville in 1901 and a large monument was erected to his memory.

In 1904, on the 45th anniversary of the Drake Well, the Canadohta Chapter of the Daughters of the American Revolution (DAR) acquired the land where Drake's well had been drilled, and, subsequently, the American Petroleum Institute (API) established a museum and library on the site. In 1934, on the 75th anniversary of the Drake Well, API formally turned it over to the state of Pennsylvania as a historical park. In 1945, a full-scale reproduction of Drake's engine house and derrick, including a boiler, steam engine, and other machinery of the sort that Drake used to drill his well, was built on the original well site (Figure 12). You can watch museum personnel pump oil with the working machinery; this oil is supplied by the McClintock # 1 well drilled in 1861. It is the oldest continuously producing oil well on Earth, which can be seen at Rouseville about 21 km (13 mi) to the south.

Today the 219-acre park is maintained by the Pennsylvania Historical and Museum Commission. It includes the museum building, a gift shop, the working replica of the Drake Well, pre-Columbian oil pits, and numerous examples of historical oilfield equipment. The museum building houses indoor exhibits, as well as a research library of about 3,500 books and 10,600 photographs among its many interesting holdings.

Figure 11. John Mather's famous 1866 photograph of the Drake Well, taken when Drake returned to Titusville. Drake, in the stovepipe hat, is shown with his good friend Peter Wilson, a Titusville druggist. Photo courtesy of the Drake Well Museum (DW676).

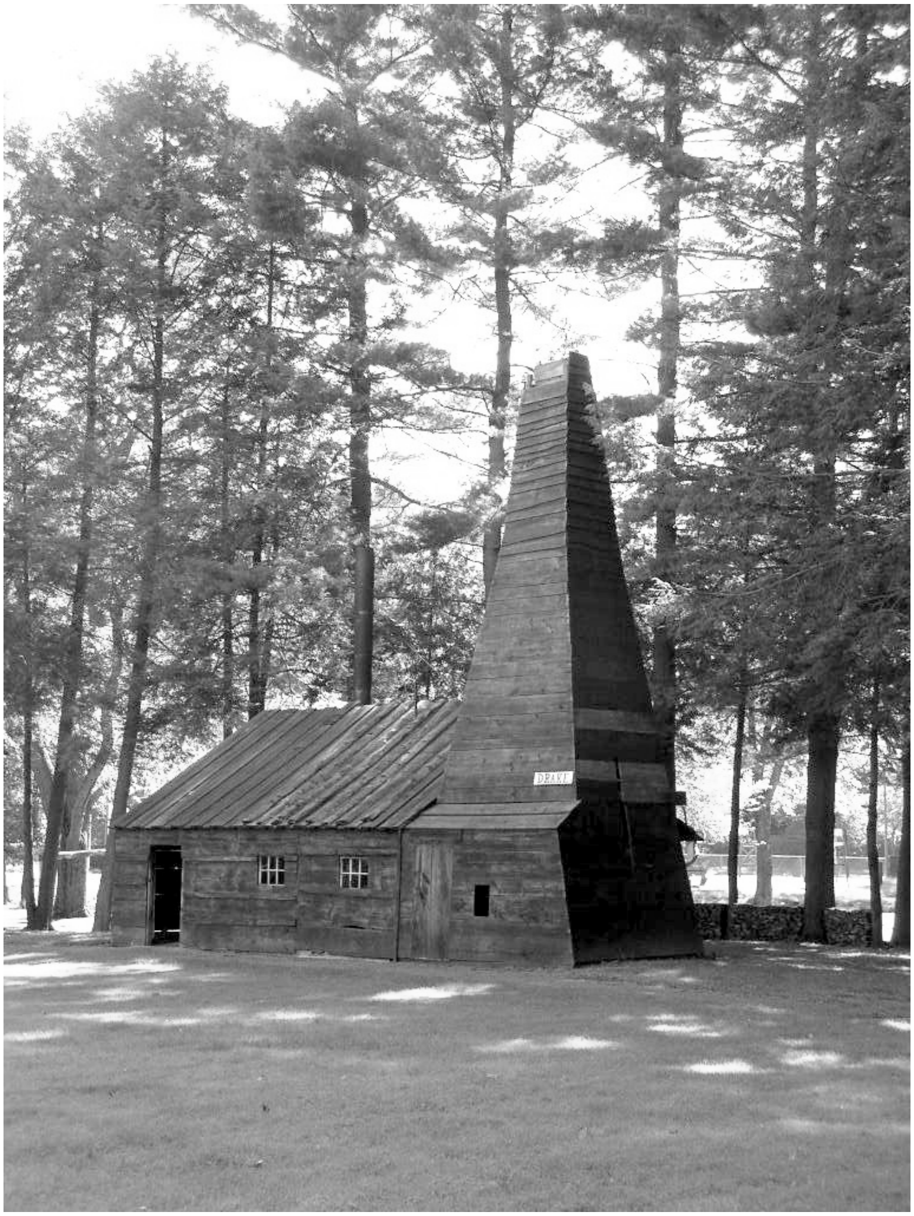

Figure 12. Recent photograph the Drake Well replica at the Drake Well Museum.

Proceed on foot from the Drake Well Museum back across the museum parking area. You must also cross the track of the Oil City and Titusville Railroad, adjacent to the station platform, to west-facing rock exposure visible from the parking area.

Stop 4 B: “type” “Drake Well Formation” section: a northwest Pennsylvania paleontological “gold mine”:

This provisional unit was defined by one of us (Harper) following detailed comparisons of his subsurface work on this interval with earlier studies (see Harper, 1998; Baird et al., 2009a). As understood herein, the name “Drake Well Formation” is an approximate replacement of earlier terms “Kushequa Member” (*sensu* Caster, 1934) and “unnamed member” (*sensu* Dodge, 1992) for the western, distal, part of the Knapp Formation, which is normally characterized by coarser conglomeratic beds in its eastern area of occurrence (see review in Baird et al., 2009 A).

This railroad cut displays 7.5 meters (24 feet) which is only a lower-medial subset of the 18 meter (60 foot) total thickness of the “Drake Well” succession (Harper, 1998). The lower 3.5 meters (10 feet) of this outcrop (now partly covered) is predominantly shale with thin, tabular siltstone beds. The upper 4 meters consists of more resistant sandstone and siltstone beds which are distinctly rich in fossils (see below).

“Drake Well Formation” Fossils. The exposure near the railroad station at the entrance to the park is where the Memorial Museum and the Commonwealth of Pennsylvania have designated a place where fossil collecting is permitted. To avoid injury, please do not dislodge heavy rocks from the cut and do not place rocks on the railroad tracks.

The upper Devonian rocks exposed at the railroad cut have been most recently called the “Drake Well Formation” (Harper 1998; Baird, et al 2009a). The discontinuous 9 inch sandy section, approximately 4 meters above the tracks, near the top of the exposed cut has produced excellent specimens of the Phyllocarid shrimp *Echinocaris randallii* (Figure 9 C) and *Tropidocaris* as well as another undescribed phyllocarid related to *Ohiocaris* (McKenzie 2009c. The formation contains angular fragments of a lingulid brachiopod. Similar fragments are also seen in the Chagrin Shale in north eastern Ohio in association with several *Echinocaris* species. *Echinocaris* had molar like mandibles that would have been ideal for shell crushing (duraphagous) feeding, which may explain the fragmental brachiopod hash in both locations.

The tabulate coral *Pleurodictyum*, brachiopods, gastropods and occasional specimens of *Porcellia* (Figure 9 D), a gastropod with coiling superficially similar to a Mesozoic ammonite, are found at this site in the sandier upper beds in association with crinoid and branching bryozoan sections (McKenzie, 2009b). *Porcellia* was first observed here in 2011. A chondrophore hydrozoan has also been found at this exposure. Pelecypods, bryozoans and crinoid ossicles are frequently preserved as orange cavities in the sandstone. Presumably those fossils were originally preserved in pyrite or a similar replacement which has altered. Beds with a similar lithology and faunal content have been reported in the Warren, Pennsylvania area (Waverly Fm.) and in Forest County near Hunter Run. For a Drake Well formation faunal list, see Harper et al. (2009; p. 129) in the 74th Annual Pennsylvania Conference guidebook.

Titusville hosts the iconic, and enigmatic, fossil *Titusvillia drakei* (Figure 9 A), which was originally described from the Drake Well interval nearby (Caster, 1939). Although originally identified by Caster as a glass sponge, recent work has cast doubt on this assignment (McKenzie

2009a). *Titusvillia* is most likely a trace fossil and is a junior synonym of *Armstrongia oryx*, another trace fossil.

		Return to vehicles. Exit park and retrace route to the intersection of Routes 8 and 27 in the middle of Titusville.
1.5	126.6	Turn right (east) onto Route 27 and proceed eastward through Titusville.
1.1	127.7	East edge of Titusville. Continue eastward up the hill toward Pleasantville, PA on Route 27.
2.8	130.5	Turn right (south) on County Road 1013. This becomes Route 227 to Rouseville, PA.
6.9	137.4	Turn left on County Road 1006 at sign for Pithole City.
2.3	139.7	Pithole City Park on your right. Turn into parking area and depart vehicles. Pithole City Museum and relict city grid plan:

STOP FIVE: Pithole Historical Museum:

Anatomy of a Ghost Town – Pithole (a cautionary tale). Originally, the area that was to later become the prosperous town of Pithole, consisted of forest and a few farms owned by Thomas and Walter Holmden and a few other farmers (Lytle, 1959). Aware of the drilling action along nearby Oil Creek, two speculators, I.N. Frazier and James Faulkner, leased a number of acres from the farmers and teamed with two other men to form the United States Petroleum Company in 1864.

Pithole oil field was discovered in January, 1865, following the advice of a dowser who told Frazier and Faulkner to drill on a corner of the Thomas Holmden lease. The Frazier well, as it was called, was drilled first by spring pole then by steam engine (Darrah, 1972). At about the same time the Frazier well was being drilled, two men named Kilgore and Keenan, who had subleased part of the Holmden lease, were drilling two wells they called the Twin wells. On January 7, 1865, the Frazier Well began to flow oil at 250 barrels of oil per day (BOPD). Less than two weeks later, the Twin wells came in. When the news got out, the throngs began to arrive en mass (Darrah, 1972; Burchardt, 1989b; Flaherty, 2003). The stock of the United States Petroleum Company jumped from $6.25 to $40 a share (Lytle, 1959). In April 1865, a Boston company completed the Homestead Well 250 BOPD just 100 feet outside the boundary of the Thomas Holmden farm (Lytle, 1959), establishing that the Holmden farm was not the only productive acreage.

One of Pithole's more interesting investors was a dashingly handsome actor named John Wilkes Booth (Figure 13). Booth and a real estate dealer named Joseph H. Simonds arrived in Venango County in June 1864 and roomed in Franklin (Michener, 1997). Simonds had acquired an interest in an oil lease of three and a half acres for Booth in December 1863 or January 1864. Booth had also purchased a 1/3rd undivided interest in a lease on the Allegheny River near Franklin that was drilled by the Dramatic Oil Company, and an undivided 1/30th of a contract in the Homestead well at Pithole (Giddens, 1947; Lytle, 1959; Michener, 1997). According to Simonds, "The whole amounted invested by him in this Allegheny River property, in every way, was about $5,000, and the other investment was about $1,000, making $6,000 in all." (Giddens, 1947, p. 258). As it turned out, all of the investments turned sour. The Dramatic Oil Company drilled only dry holes, and the Homestead well had not yet been drilled. Booth lost interest in his investments, pulled up stakes, and left Franklin on September 27, 1864. In April 1865, the Homestead Well was completed with a flow of 250 BOPD (Lytle, 1959). That same month, the Civil War ended and President Abraham Lincoln was assassinated at Ford's Theater in Washington, DC. Imagine how history might have been different if Booth's investments had paid off and stimulated his interest even further!

Following the discovery of Pithole field, the United States Petroleum Company divided its holdings into half-acre leases and sold 60 of its 80 leases at an average of $3,000 (Lytle, 1959; Darrah, 1972). As many as four wells were drilled to an acre. Suddenly the production of the Homestead Well jumped to 500 BOPD and that of the Frazier Well to 1,200 BOPD (Lytle, 1959; Pees, 2001). At the end of June 1865, the wells along Pithole Creek were producing 2,000 BOPD, or 1/3rd of the total world production of oil. Speculation in oil became a huge business. Tens of thousands of dollars were made and lost by selling and reselling oil leases. In July, 1865, the Holmden farm was sold for $1,300,000, the largest sum ever paid in the oil region for a single tract of land (Lytle, 1959).

Pees (2001) tells of the Grant well, which appeared to be a dry hole when drilling ceased in August 1865. The drillers were coaxed into running some tubing in the hole to increase speculation that it was, in fact, a producing well, and after pumping for four hours, the well suddenly began producing as much as 800 BOPD. The owner of the half-acre lot next to the Grant Well paid $1, 600 for it that spring; after the Grant well came in, he sold it for $16,500, the highest price on record for a half-acre lease (Lytle, 1959). Also in August, the Pool well, which was not far from the Frazier Well, came in at 300 BOPD and jumped to 1,500 BOPD. It was the largest producer at Pithole.

By September 1865, Pithole field was producing 6,000 BOPD. As Lytle (1959) pointed out, there are any number of wells being drilled and produced in the world today that produce 6,000 BOPD by themselves. But, in the oil territory of northwestern Pennsylvania in 1865, this was an incredible amount of oil. The Holmden Farm alone had 96 wells either producing or being drilled and the daily rate was 4,000 BOPD. Then, the people who had bought the Holmden farm were unable to meet the terms of the sale; the sellers took back the farm and resold it to someone else for $2,000,000! After Pithole became a ghost town, the Venango County commissioners bought the Holmden farm in 1878 for $4.37. The commissioners then sold it to a private owner in 1886 for $83.76!

Figure 13. John Wilkes Booth, Lincoln's assassin, dabbled a bit in oil leases in Venango County, Pennsylvania, in 1864, including the soon-to-be-famous Homestead well in Pithole. He left Venango County before any of his holdings saw any profit and was not heard from again until that fateful day in April 1865.

The Rise and Fall of Pithole City. The Thomas Holmden farm became Pithole City, planned and laid out in May 1865, with land available for development through three- or five-year leases (Stephens and Bobersky, 2007). The town was laid out on the hill in 500 lots along some 22 streets, with lots being only 33 feet wide, whereas the oil wells were sited on the flat land of the creek valley south and east of the town (Figure 14). New construction began immediately as oilmen, professional and amateur alike, stampeded to Pithole Creek to grab what they could. The Civil War had just ended, the country was flush with people anxious to invest in oil, and soldiers discharged from the army were eager for jobs, and many people were willing to lease or buy any scrap of land that held even the remotest prospect of having oil on it. The Pithole area began to see a land rush unheard of; thousands came in search of Oildorado. The forest disappeared quickly as trees were cut and shaped for lumber as the building frenzy took hold. Many buildings were dangerously flimsy; many were built and ready for occupancy within a week. Only the leading hotels, theaters, churches, and finer establishments were constructed properly. However, not a single brick or stone was used in any of this construction (Lytle, 1959).

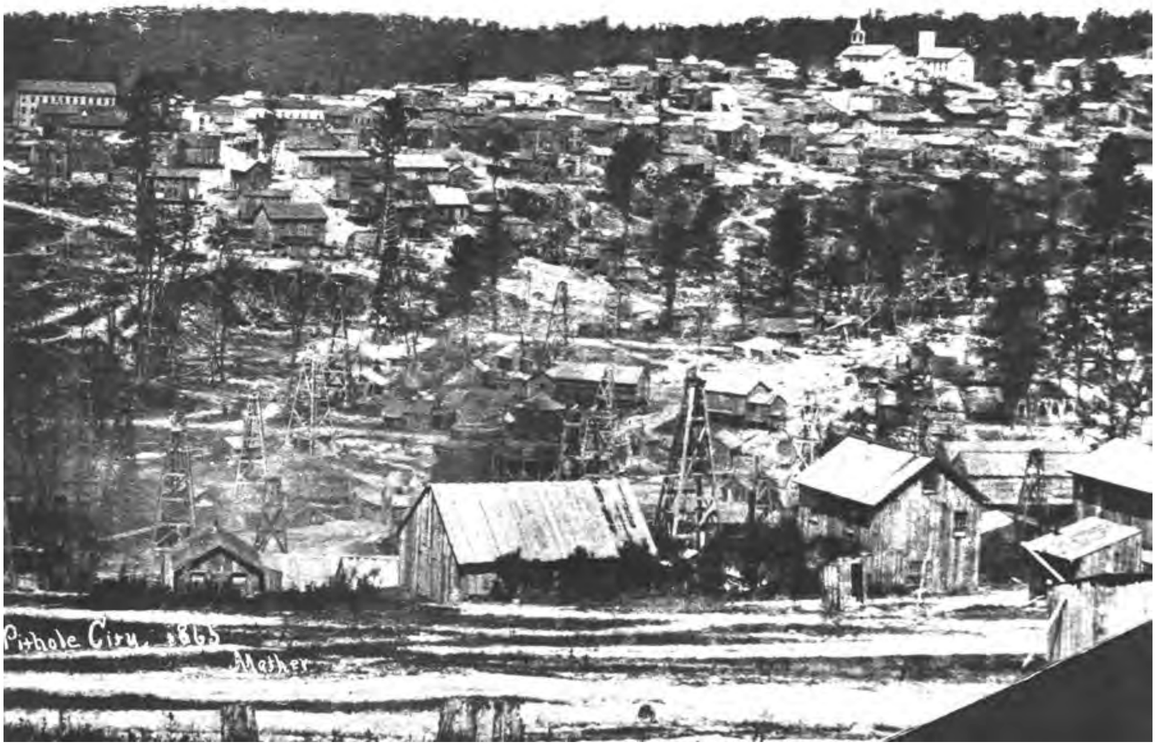

Figure 14. John Mather photograph of Pithole in 1865. The photo was taken from the flats of Pithole Creek looking northwestward across the oil producing flats to the town on the hill. Photo courtesy of the Drake Well Museum.

Potable water was scarce in the early days, so it became a profitable business to haul water to the town it from distant wells and sell a drink for 10 cents. As a direct result, the business in "distilled spirits" flourished. Finally, in December 1865, a water system reservoir was completed and pipes were laid along the main street. Since Pithole had no sewage system, the larger hotels had dry wells used for sewage disposal. As a result, many first-time visitors came and went with a first impression of unassailable odor – both human waste and crude oil mixing in a very unpleasant smell.

In September 1865, Pithole had reached its zenith. It had a population of 15,000, a newspaper, a post office, two banks, two telegraph offices, a fire department, an opera house, and a huge number of hotels – more than 50 by most counts (Stephens and Bobersky, 2007). One of these, the Danforth House, a large, elegant and comfortable hotel that furnished its guests with all the conveniences of a metropolitan hotel, stood at the corner of Holmden Street and First Street (Figure 15 A). The Chase House was the finest of Pithole's hotels. It could accommodate 200 guests, and seated 100 in its dining room. The telegraph offices were located there, and it was the general headquarters for the stage lines. It boasted a saloon on the ground floor that was furnished with a luxurious bar and numerous pictures. Murphy's Theater on First Street, the largest building in Pithole, could seat 1,000 people. Four religious denominations, Methodist, Episcopalian, United Presbyterian, and Roman Catholic conducted services at Pithole. The city boasted a social life with balls, concerts, strawberry festivals, and church socials.

Pithole was a town of law-abiding citizens early on, despite the lack of formal government, law, or jails; strangers were surprised how little drunkenness they saw on the streets (Lytle, 1959). It took until December 1865 before Pithole was incorporated as a borough and held its first election. But by the end of that year, Pithole saw the coming of ruffians and drifters. Among Pithole's more notorious citizens were Ben Hogan and French Kate who operated a variety of brothels during the oil boom (Giddens, 1947; Lytle, 1959; Darrah, 1972; and Burgchardt, 1989a).

By August 1865, just a few short weeks before Pithole City attained its record population of 15,000, the Homestead well suddenly stopped flowing and had to be pumped. At about the same time, several wells on the Holmden Farm caught fire and burned. A fire in October 1865 destroyed $1.5 million worth of oil and properties on the flats. The Frazier and Island wells stopped flowing in November 1865, but a new completion on the Holmden Farm came in at 1,000 BOPD and spurred new interest in the area. But in January 1866, the daily production of wells drop sharply, followed in February and March by fires on Holmden Street and Brown Street that destroyed two livery stables, a brothel and two dwelling houses, among other establishments (Lytle, 1959). By February 1867, as Pithole production dropped to less than 1,000 BOPD, people began to desert Pithole for the next big thing. By the end of 1867, the town was essentially dead. Only a small handful of people stayed behind, and by 1870 nothing was left except the odd piece of discarded lumber and holes where cellars and foundations used to be. In the end, the pool of oil that brought so much excitement to the area turned out to be only 100 acres in size (Pees, 2001).

Pithole is now a National Historic Site administered by the Drake Well Museum (Pennsylvania Historical and Museum Commission). It is open to visitors, and many of the sites of the principal buildings have been identified and are marked with signs. Today, Pithole is gone, completely covered in grass and trees, so it is difficult to realize that so much excitement and activity once took place at this remote and isolated spot. “Streets” are kept mown, and many buildings seen in historical photos can be found as simple holes in the ground (Figure 15 B). The town is quickly approaching the state the area was in when Frazier and Faulkner first came and leased the wilderness farm of Thomas Holmden.

The First Oil Pipeline. One of Pithole’s claims to fame was the building of the first oil pipeline. Teamsters were the primary oil transporters of the day, transporting oil by wagon from Pithole to Titusville, Oil Creek, or Oil City where it would then be loaded onto railroads for shipment. The teamsters charged $3 per barrel to take the oil 5.5 miles Oil Creek. The market price of a barrel of oil at that time was about $3, so the cost of getting oil to a refinery was $6 per barrel, twice what the oilmen were getting! In the fall of 1864, Samuel Van Syckel (Figure 16) and two other men formed the Oil Transportation Association and constructed a 2-inch pipeline from Pithole to the railroad depot on Oil Creek (Figure 17). The pipeline was successful from the beginning, despite the objections of the teamsters. The pipeline was well-designed and well-built and when finished, it could transport 81 barrels of oil per hour, cutting the cost of transporting from $3 to $1 per barrel. Van Syckel’s pipeline is considered to have been the beginning of the end for the oilfield teamsters. The idea caught on immediately and soon pipelines were built from all of the principal producing fields to the refining centers in Franklin, Oil City, and Titusville. At its operational peak, the Van Syckel pipeline consisted of two 2” pipelines. With the decline of Pithole, both were dug up and salvaged. The trench was never back-filled and can still be seen in some areas along its course.

Figure 15. Photographs shot at the corner of First and Holmden Street, Pithole City, 145 years apart . A, The Danforth House was built on a lot that cost $100 plus a $14,000 bonus. This hotel could house 140 guests. Photo courtesy of Drake Well Museum (DW10). B, Photo taken in 2008 from the same vantage point as in A. Nothing remains of the Danforth House now but a hole where the foundation used to be.

Figure 16. Portrait of Samuel Van Syckel.

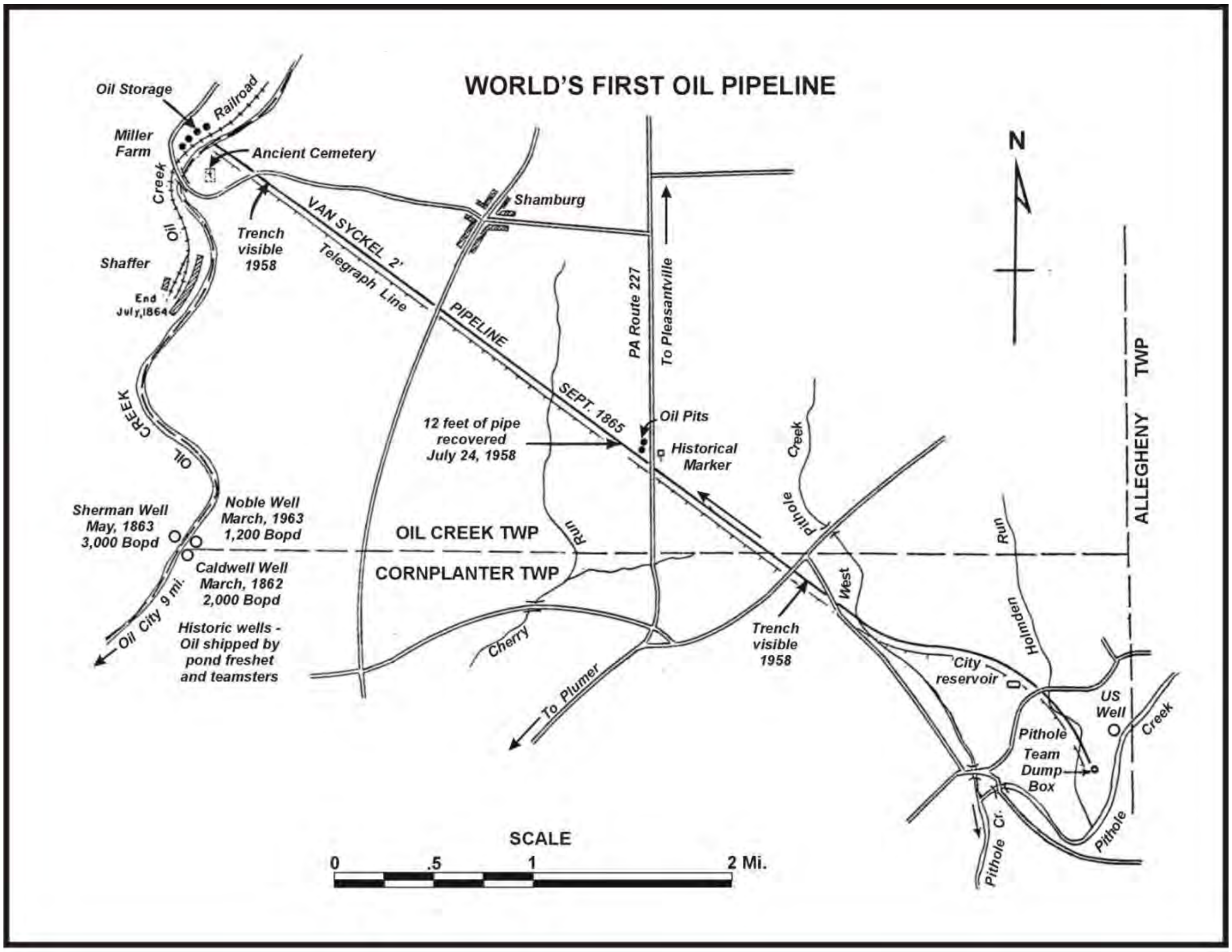

Figure 17. Map of Samuel Van Syckel's pipeline that carried crude oil from Pithole wells to the railroad terminal at Miller Farm (modified from Lytle, 1959).

		Return to vehicles. Retrace route back to intersection where Route 8 splits off northward from Route 27 at the west edge of Titusville = beginning of 76.1 mile return trip to Fredonia.
16.5	156.2	Route 8 splits off of Route 27. Turn right (northward) on Route 8. Continue north through Centerville, PA, Union City, and Wattsburg on Route 8.
30.0	186.2	Route 8 splits off of Route 80/89 at Lowville, PA. Continue north on Route 89 to I-90.
12.0	198.2	Route 89 junctions with I-90. Enter onto I-90 eastbound to Fredonia.
34.1	232.3	Dunkirk exit off of I-90. Continue straight through toll to red light on Route 60.
0.4	232.7	Red light at busy intersection at Route 60. Continue straight (west) on Millard Fillmore to a T-intersection and light on Central Avenue.
1.1	233.8	Red light at T-intersection of Millard Fillmore with Central Avenue. Turn left (south) on Central Avenue.
0.3	234.1	Entrance to SUNY Fredonia. End of field trip.

THE PENN DIXIE PALEONTOLOGICAL AND OUTDOOR EDUCATION CENTER: AN INTERNATIONALLY RENOWN MULTIDISCIPLINE EDUCATIONAL, CULTURAL, RECREATIONAL AND TOURIST ATTRACTION

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The Hamburg Natural History Society, Inc. (HNHS) is a nonprofit educational corporation that owns and operates The Penn Dixie Paleontological and Outdoor Education Center in Hamburg, New York (Fig. 1). The HNHS was founded in 1993 to promote the study of the natural sciences, with a particular emphasis on field activities associated with the geological and biological sciences. The HNHS offers a wide variety of hands-on educational programming to students of all ages, both at the Penn Dixie Site and off-site at local schools, libraries, and civic group meetings. Since its inception, the HNHS has expanded its educational curriculum to include public educational programming in astronomy and ornithology to complement its core study in geology and fossil collecting and identification. Unlike conventional museums or research facilities, the Penn Dixie Site is a hands-on outdoor educational facility—one at which visitors of all ages are encouraged to actually collect and keep 380-million-year-old fossils – ***"Where Science Comes Alive".***

Penn Dixie is he site of a former quarry operation that was the source of calcareous shale excavated and used for cement aggregate by the Penn Dixie Cement Company. A majority of the 57-acre site was quarried until the late 1960s, during which time 9 to 10 feet of shale was removed from the surface. A gray, somewhat flat "desert-like" or "lunar landscape-appearing" surface now occupies a majority of the site. After quarry operations ceased, weathering forces began to expose 380 million-year-old Devonian fossils preserved within the Windom Shale. This highly fossiliferous unit underlies the entire site and provides an inexhaustible supply of fossils. In addition to the Windom Shale, several limestone units - the Genundewa, North Evans, and Tichenor are exposed on the surface. The Wanakah Shale also outcrops, underlying the Tichenor Limestone, in a tributary that flows into Rush Creek and in cliffs along Rush Creek on the northern section of the site. All of these units contain a variety of fossils.

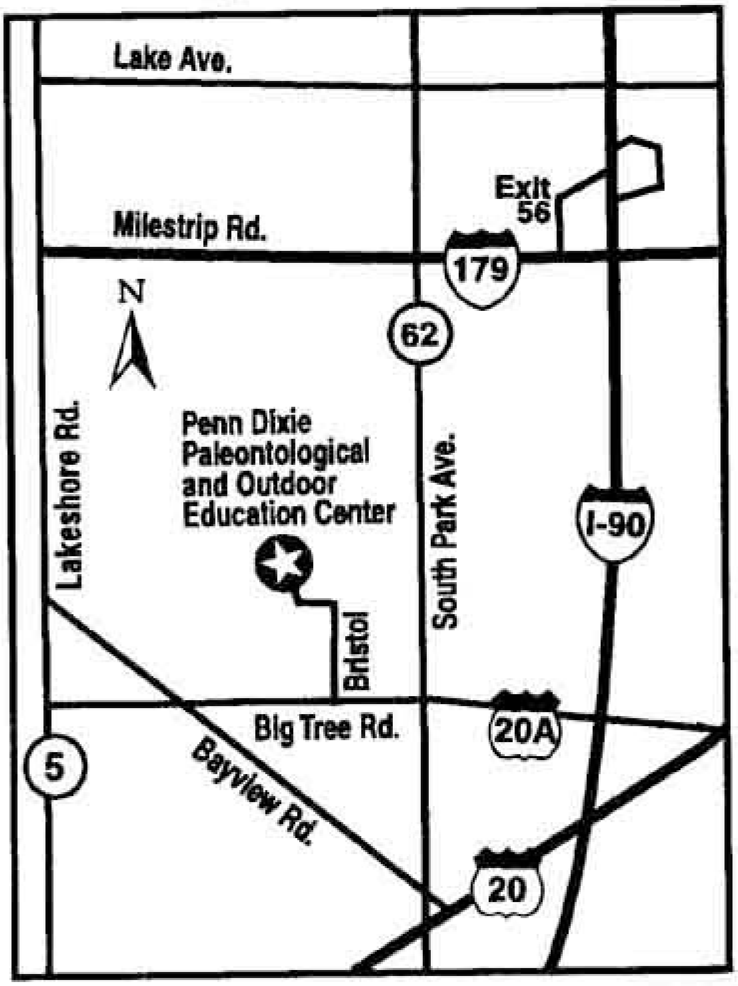


Figure 1. Penn Dixie location in Hamburg, NY.

PRESERVATION OF THE PENN DIXIE SITE

In 1989 and 1990, the site was under the threat of light industrial development, but citizens from the community had other ideas for preserving it for future generations. A group of local residents and geologists collaborated on acquiring and preserving this area for future outdoor educational use. This group worked with members of the Hamburg Town Board to purchase the property. In December 1995 the Town of Hamburg completed the purchase of the property and in January 1996 deeded 32.5 acres to the HNHS. The preservation and development of the Penn Dixie Paleontological and Outdoor Education Center had begun.

The HNHS administers and maintains the Penn Dixie Site, the former shale quarry that was purchased by the Town of Hamburg in 1995. The first 32.5-acre tract of land was deeded to the HNHS in 1996. The HNHS then took immediate steps to clean up the site and establish plans for its transformation into a truly world-class outdoor educational resource center.

In 2004, the HNHS purchased 16.75 acres of adjacent land from the Town of Hamburg, increasing the site to 49.25 acres. In 2008, the HNHS completed the purchase of an additional 5 acres of property that will provide a new entrance to Penn Dixie off Jeffrey Boulevard on the western perimeter of the site. This five acres will serve as the location for the proposed and much needed outdoor education center building. The two additional tracts of land were acquired with support from local foundations and the HNHS/Penn Dixie membership. The HNHS/Penn Dixie has installed 5 shelters and over 4,100 feet of paved trails for handicap accessibility at the site. In 2008, Penn Dixie was the recipient of a 2.24-acre wetland mitigation project, which has enhanced the former ponds on the site, increased the wildlife habitat, and provided an added educational feature. The HNHS' efforts to preserve the former quarry and its associated wetlands saved one of the richest sites of 380-million-year-old Devonian Era fossils in the eastern United States.

Fossil collecting and the study of the local geology were the initial intent for the preservation of this former quarry. After acquisition of the property in early 1996, the HNHS reexamined the other resources available for outdoor education programs in the other natural sciences. Penn Dixie began evening and daytime astronomy programs, with volunteer astronomers, and have grown these programs into an important segment of the educational programming. With over 143 nesting and migratory birds at the site; the deer, turkey, coyote and other animals; the spacious area for viewing the Penn Dixie Skies with telescopes; and the potential for expanding the wetlands, this is a unique location to provide a diversity of programs in the natural sciences. The HNHS also has installed over 2,100 feet of barrier-free paved trails with grants from the East Hill Foundation, the New York State Senate, and Erie County. Eventually, the plan is to install paved and boardwalk trails throughout the entire site. With all these wonderful features and opportunities, the goal continues to be to make the Penn Dixie Site an outdoor education center and not a museum.

The HNHS hired a full-time Executive Director in 2003 and a full-time educator in September 2004 to manage and develop programs in the natural sciences. As a private non-profit organization, a volunteer board of directors, elected by its membership, governs the HNHS. HNHS staff, volunteer educators and field trip leaders are actively involved in bringing educational programming to the Western New York community. For example, in 2012 alone, the HNHS sponsored or participated in more than 408 programs that were attended by more than 103, 901 children and adults. In 2013, to date, visitors from 38 different states, Washington, D.C., and 9 countries visited the Penn Dixie Site. Penn Dixie has over 1,100 memberships in over 30 states, Canada, England and Germany.

GEOLOGY, STRATIGRAPHY, AND PALEONTOLOGY

The Penn Dixie Site contains an extensive exposure of 380-million-year-old fossiliferous Middle Devonian shales and limestones, serving as an excellent outdoor classroom for introducing students to the local geology and paleontology. The Genudewa Limestone, North Evans Limestone, Windom Shale, Tichenor Limestone, and Wanakah Shale at this site are readily accessible and have the most extensive exposure available for study in western and central New York. Figure 2 illustrates the stratigraphic units present at the Penn Dixie Site and prepared by Dr. Rick Batt and is provided to visitors to the site. Prime exposures of these units are present (except for the West River Shale, which is mostly covered by overburden at the south end of the site). Brett (1974) and Baird and Brett (1982), along with Beuhler and Tesmer (1963), provide a detailed discussion of the stratigraphy and paleontology of these units. The warm tropical seas that covered this region of Western New York 380 million-years ago, when the region was 20 to 30 degrees south of the equator, provided an environment conducive to a variety of invertebrate and vertebrate animals. The shales and limestones that formed during this time period preserved the remains of the diverse and abundant fauna that occupied these seas. The following brief discussion of the units present on the site begins with the lower Wanakah Shale at the north end through the West River Shale to the south.

Wanakah Shale

The Wanakah Shale is a medium-gray to light-blue gray calcareous shale that weathers to a sticky clay. The Wanakah is exposed in the northeast section of the site in a tributary to Rush Creek and in the high banks on the south side of Rush Creek. The tributary is a popular area for fossil collecting, viewing the large calcareous concretions, and some pyritized burrows, rather than the steeper cliffs along Rush Creek. Brachiopods, bryozoans, trilobites, gastropods, pelecypods, echinoderms, corals, sponges, ostracodes, and some pyritized fossils may be found. Limited area in the tributary does not provide access for large groups.

Tichenor Limestone

The Tichenor Limestone overlies the Wanakah Shale and outcrops at the northern end of the site. Pyrite coating the surface of the Tichenor has weathered, exhibiting a reddish-rusty color that stands out from the surrounding overlying gray Windom Shale. At the northeast section of the site, an unexplained domal feature of the Tichenor, with several feet of relief, is present. This feature is not believed to be a result of the quarrying operation, but possibly from glacial rebound. A large exposure of the eroded limestone surface is adjacent to this feature and extends north to one of the on-site ponds. This area is often referred to as “crinoid heaven” due to the countless number of pelmatozoan columnals that are found lying on the surface. The Tichenor Limestone contains corals, brachiopods, pelecypods, trilobites, bryozoans, and echinoderms, all of which are difficult to remove from the hard limestone. The Tichenor Limestone is approximately 1.5 to 2 feet thick and underlies most of the site, dipping to the south-southwest along with the other units on site.

Windom Shale

The Windom Shale is a medium to dark gray, variably calcareous mudstone with several thin argillaceous limestones, concretionary beds, and pyrite horizons (Beuhler and Tesmer, 1963). In addition, at the southwest portion of the site there is an excellent exposure of phosphate nodules covering the surface. The Windom also weathers to a sticky clay. The Penn Dixie site has the most complete and best exposure of Windom Shale in New York State, approximately 42 feet thick. Brett and Baird (1982) described 14 subdivisions within the Windom that could be recognized at this location. Fossil assemblage zones were described in Brett (1974) and Brett and Baird (1982). A disconformable basal contact with the Tichenor Limestone is exposed in the domal outcrop in the northeast section of the site. The upper Windom beds have been scoured, and shale clasts can be observed in the overlying North Evans Limestone. The Windom contains a variety of corals, brachiopods, pelmatozoan columnals, bryozoans, trilobites, gastropods, pelecypods, cephalopods, and more rarely fish remains, plant material, and blastoid and crinoid calices. The upper Windom has a variety of pyritized fossils, burrows, and most-likely fecal remains weathering out on the surface. Some of the pyritized fossils include brachiopods, pelecypods, cephalopods, trilobites, and blastoids. The weathering shale exposes thousands of specimens lying on the surface, waiting to be found after 380 million years. Enrolled trilobites can be commonly found washed out of the shale after a good rainstorm, along with horn corals, brachiopods, and pelmatozoan columnals. Multiple complete trilobites on a slab (Fig. 3 & 4) have been collected from the Lower Windom and complete specimens of *Phacops rana* keep collectors returning for their perfect specimen. Sections of the Windom are not as fossiliferous as others, but careful study of the stratigraphic subdivisions identified by Brett and Baird (1982) will yield some interesting discoveries. In addition, Penn Dixie staff and volunteer guides will direct visitors to the better collecting areas on the site.

North Evans Limestone

The North Evans Limestone is a buff-colored, weathered dark-gray crinoidal limestone that is 1.5 to 4 inches thick and contains angular clasts derived form the underlying Windom Shale. Erosional lag concentrations of hiatus concretions, pelmatozoan fragments, conodonts, fish plates, teeth, and mandibles, along with some brachiopod valves, are present (Brett and Baird, 1982). Carbonized plant remains are also found in this unit. Although a variety of fish remains have been found at the Penn Dixie Site, they are difficult to find even with the good exposure of North Evans present. The buff-colored weathered surface of the North Evans and bone material make this unit easily recognizable.

Genundewa Limestone

The Genundewa Limestone is a nodular, medium dark-gray, poorly bedded limestone

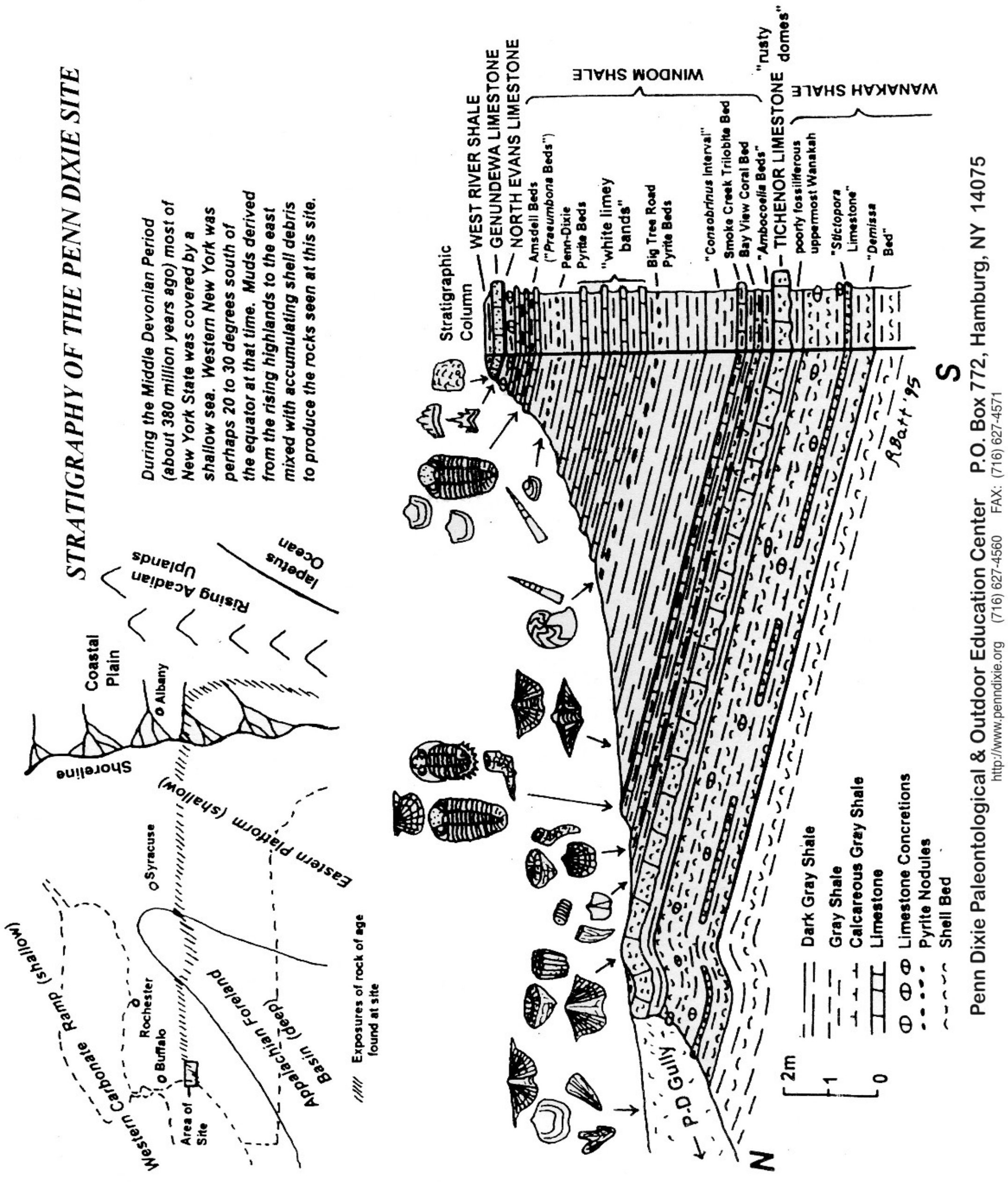


Figure 2. Stratigraphy of Penn Dixie. Prepared by Dr. Rick Batt in 1995.

that weathers to a light gray, which has been referred to as the "Styliolina Limestone" directly overlying the North Evans Limestone (Buehler and Tesmer, 1963). Carbonized wood can be frequently found, but other examples of the fauna are more difficult to obtain.

West River Shale

The West River Shale is dark gray to black in color and overlies the Genundewa Limestone. Most of this unit is covered by overburden at Penn Dixie. Eighteen Mile Creek provides a better opportunity to view this unit. Conodonts, cephalopods, pelecypods, and fish remains have been reported from the West River Shale at other localities in Western New York (Buehler and Tesmer, 1963). The preservation, diversity, abundance of fossils, and the extensive bedrock exposures at the Penn Dixie Site make this an excellent outdoor classroom for students, as well as amateur and professional paleontologists, to be introduced to Western New York geology and paleontology. In addition, students and possible future scientists from pre-school through college are being introduced to the rich geologic history of Western New York by the thousands each year. Weathering of the Windom Shale results in many corals, brachiopods, pelmatozoan columnals, and trilobites being continually exposed on the surface. Those who extend the effort to dig into the shale are rewarded with an extensive introduction to the variety of fossils preserved within the Windom. The northern section of the site provides an

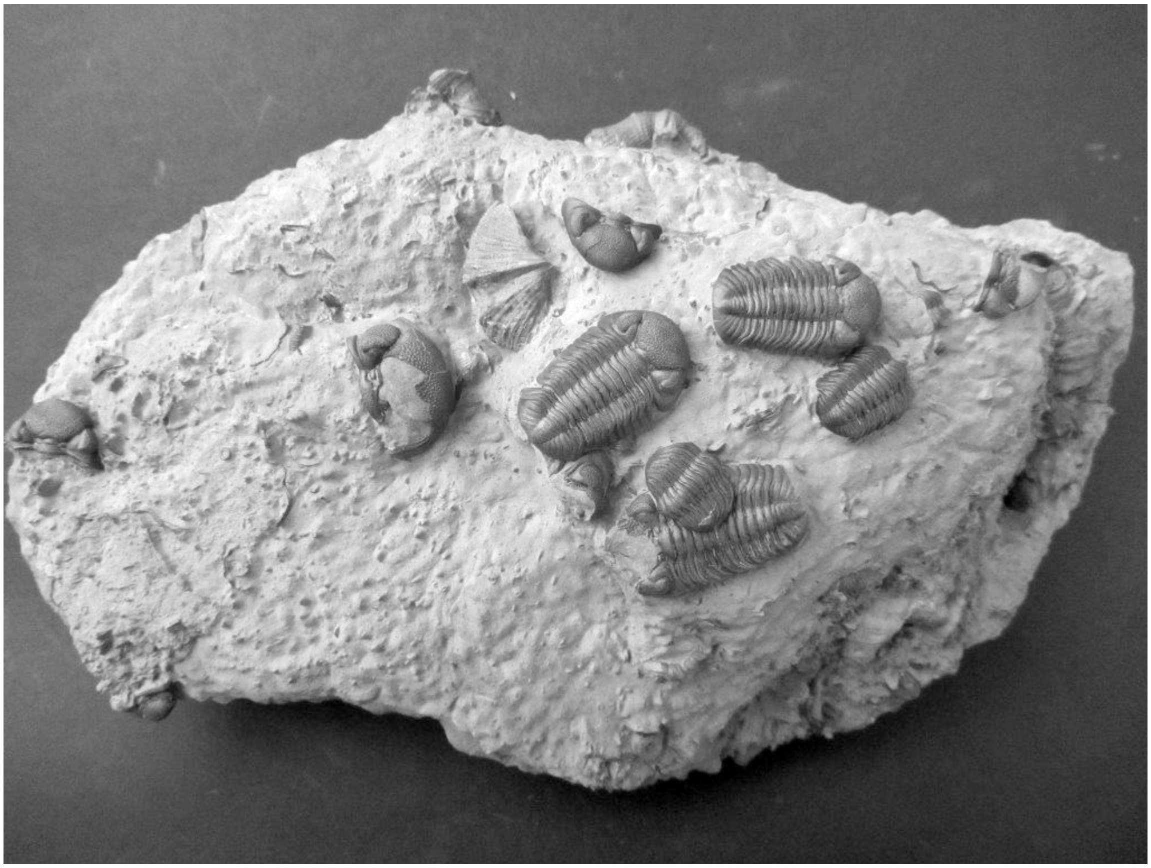


Figure 3. *Phacops rana* group collected by Roger Furze, of Germany, in August 2013, one of many multiple slabs that have been found in the Lower Windom Shale Smokes Creek Bed in 2013 and recent years.

excellent outdoor classroom for students and visitors to be introduced to fossils and the local geology. Many specimens found at Penn Dixie can be viewed on the web site at www.penndixie.org under Fossil Photos.

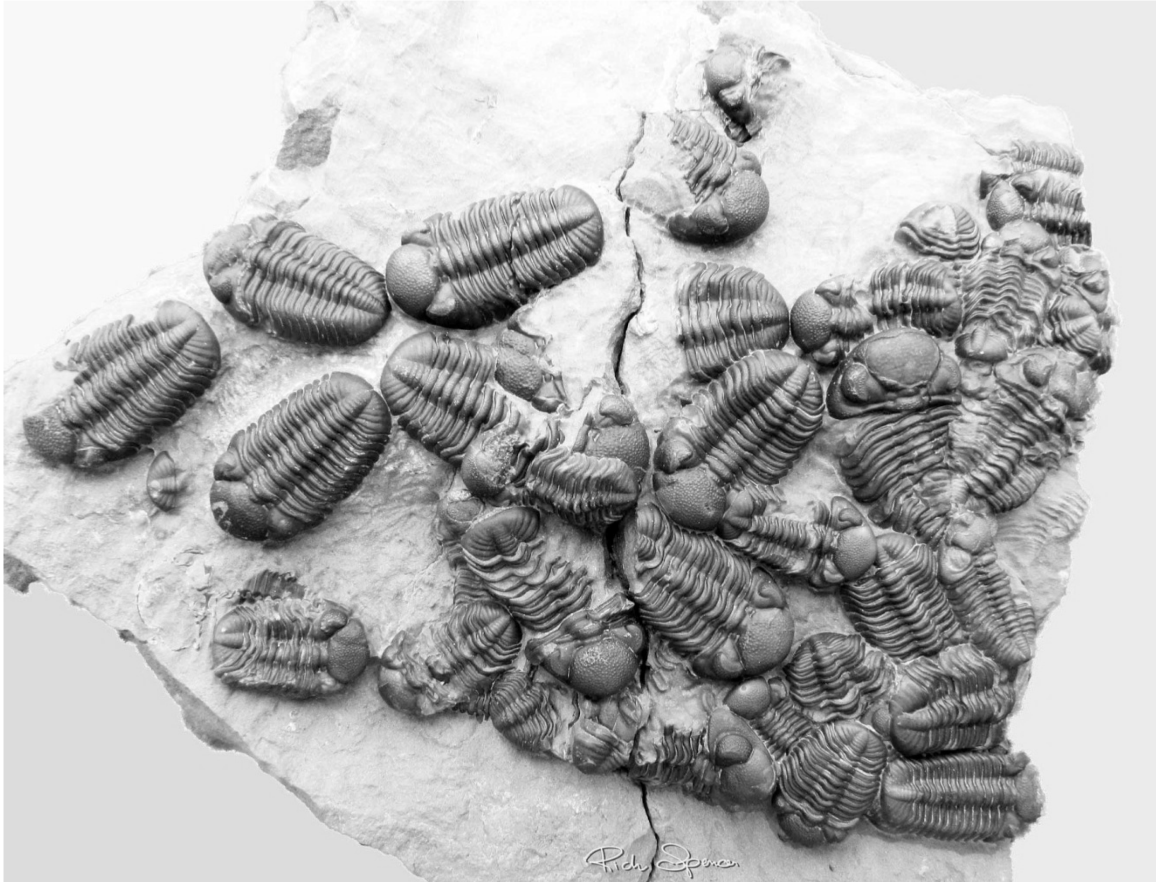
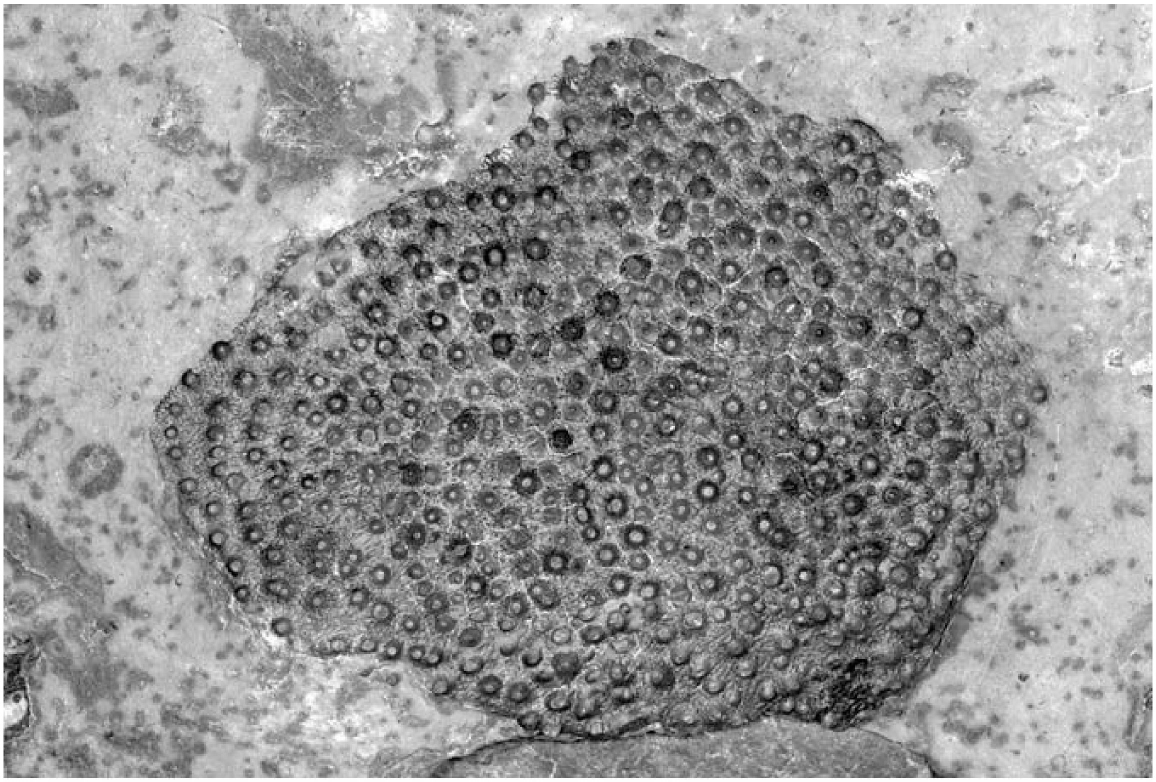


Figure 4. Mortality group of *Phacops rana* trilobites collected by Matt Phillips, Martinsville, VA, from the Lower Windom Smokes Creek Bed in May 2011.



Fish Plate, 6.6 cm long, found by Jim Brochu of Staten Island
in the lower Windom, June 21st 2008

Figure 5. One of the rare fossils that can be found at Penn Dixie.

PENN DIXIE RANKED THE NO. 1 FOSSIL PARK IN THE U.S.

The Geological Society of America Special Paper 474, June 2011, **"Geobiological opportunities to learn at U.S. Fossil Parks,"** by Renee Clary, of Mississippi State University, and James Wandersee, of Louisiana State University, evaluated seven fossil parks and the **Penn Dixie Paleontological and Outdoor Education Center in Hamburg, NY is ranked No. 1.**

The authors analyzed the seven fossil parks on key variables that influenced visitors opportunities to learn geobiology concepts at fossil parks which included (1) authenticity of the experience, (2) age of the fossils, (3) fossil-collection training facilities, (4) availability of on-site paleontological mentors, (5) fossil identification via signage and brochures, (6) site organization and way-finding signs, (7) accessibility of site, including safety. The authors visited and ranked the seven U.S. Fossil Parks against these variables evaluating these variable criteria to the effectiveness as science education sites.

The HNHS/Penn Dixie is pleased to have been included in this study and it reinforces the importance of our goals and objectives in providing an outdoor educational facility where children and adults can have a 'hands-on' experience in geology, fossil collecting and the natural sciences. Penn Dixie's preservation for future generations is critical for the study of the sciences providing a safe, easily accessible, and rich resource for all.

HNHS/PENN DIXIE HAS REPRINTED THE *GEOLOGY AND PALAEONTOLOGY OF EIGHTEEN MILE CREEK*

The HNHS/Penn Dixie has reprinted Amadeus W. Grabau 1898-1899 ***Geology and Palaeontology of Eighteen Mile Creek*** publication which is available for purchase. The book is selling for $34.95, plus 3.06 in sales tax and $5.00 shipping and handling. The book will sell, with sales tax included, for $38 plus $5 shipping in the U.S. An order form is available on the website at www.penndixie.org and it also may be purchased at Penn Dixie. This is the second reprinting of this publication and the revenues will go to help support the operations and programs at Penn Dixie.

CURRENT PROGRAMS AT PENN DIXIE

The opportunity to actually find and collect ancient creatures that roamed the seas of Western New York 380 million-years ago fascinates children and adults alike. Children are amazed that these fossils are older than the dinosaurs and their parents and that they can keep what they find! Penn Dixie has an inexhaustible supply of fossils and the opportunity to find new and rare specimens. The Penn Dixie Site provides an opportunity to open a whole new world of geology and paleontology, along with the other natural sciences, to students, scouts, senior citizens, and the general public. It has provided an outdoor educational experience for many hearing impaired, visually impaired, blind, and physically challenged individuals. The preservation and continued development of this site is extremely important. Commercial and residential development, along with landowners restricting property access, have made many fossil- collecting sites extinct or no longer accessible. For example, earlier this year a new landowner posted the property along the north side (Hamburg side) of Eighteen Mile Creek restricting access to the mouth of Eighteen Mile Creek along the frequently used trails. In addition, Penn Dixie can accommodate large groups, whereas many streambeds, road and railroad cuts, and shoreline exposures cannot or are impractical. Attempts to preserve collecting sites, such as Penn Dixie, must be made, or many classic collecting and geologic locations will be lost for future generations to visit and study.

Students, scouts, families, summer day camps, amateur and professional geologists find this classic geologic site an ideal place to study geology, collect fossils, observe over 143 nesting and migratory birds, view the WNY skies and explore nature. Guided tours, astronomy programs, birthday parties, Boy and Girl Scout activities, corporate and civic picnics, and family outings are available by reservation. The 4,100 ft. of paved trails provide wheel chair, walker, stroller and wagon access for handicap individuals, elderly, and young families with strollers.

The HNHS has scheduled a variety of programs throughout the year. Currently, the Penn Dixie Site is open to the public every May through October, Saturdays 9 AM-4

PM and Sundays 11 AM-4 PM; during Spring Break Monday-Saturday 9 AM-4 PM and Sunday 11 AM-4 PM, and 7 days a week mid-June through Labor Day, Monday through Saturday, 9 AM to 4 PM, and Sundays 11 AM-4 PM to collect fossils. Visits may be scheduled at other times for schools, scouts, pre-schools, universities, birthday party, corporate groups or other events by calling (716) 627-4560. Events are held rain or shine. Special Events, evening astronomy programs, bird walks, summer day camps, group and family tours are held throughout the year. Some of the Special Events and activities held annually include:

- Lecture programs in the natural sciences in the Gateway Executive Office, 3556 Lake Shore Road, Blasdell, NY.
- "Dig with the Experts" the third weekend in May
- Annual Children's Day the first Sunday in June
- Annual Miss Buffalo Nature Cruise and Buffalo Lighthouse Tour in June and September
- "Big Toys, Trucks & Bikes Event" in early July
- Mid-Summer's Night Adventure in August
- Special Event in September
- Annual WNY Earth Science Day Celebration in October
- Members Only field trip to various collecting localities and museums

Evening astronomy programs are held at Penn Dixie one Saturday night once a month March through October. Visits may be scheduled at other times by calling Penn Dixie at (716) 627-4560. Additional on-site and off-site events are open to the public, which are listed on the Penn Dixie website www.penndixie.org.

A GROWING MEMBERSHIP ORGANIZATION

The HNHS has experienced phenomenal growth since its inception in 1993. While many of the HNHS members come from Western New York, the society counts among its membership residents from over 30 states, and Canada, England, and Germany. Over 1,100 memberships, at a variety of levels, contribute to the daily operations of the HNHS and the Penn Dixie Site, along with increasing the HNHS endowment fund. Visitors from all over the U.S. and from Algeria, Australia, Brazil, Canada, China, England, France, Germany, Israel, Italy, Japan, Lebanon, Mexico, Mongolia, New Zealand, Pakistan, Scotland, Spain, Sweden, Switzerland, and United Arab Emerates have found the Penn Dixie Site a tremendous educational resource. **Penn Dixie was ranked No. 19 by attendance of the Top 25 Tourist Attractions in WNY in 2005** by Business First of Buffalo, NY.

OUR PLANS FOR GROWTH

The first priority is to obtain funding to hire two-full time staff - a Director of Education and a Director of Development to work closely with the Executive Director to generate revenues to help make the Penn Dixie Site fully sustainable. The HNHS/Penn

Dixie is submitting requests to foundations to help fund these two positions.
The second priority is to secure funding to construct an outdoor education center building to provide facilities, utilities, and shelter from inclement weather conditions that affect programs, attendance, and revenues. The Penn Dixie Site revenues are affected by weather and the building will provide an opportunity for year-round programming. A building on-site will increase programs, attendance, a larger gift shop, and opportunities for new and expanded programs. The proposed building will consolidate all the Society's resources and property at one location. It will provide an opportunity for the site to be open year-round and for programs like astronomy even during inclement weather. The HNHS Board is searching for sources of funding from a variety of opportunities in the government, foundation, corporate, private sector, and membership support. Information on the building plans are available on the Penn Dixie website www.penndixie.org. The HNHS/Penn Dixie welcomes any suggestions, leads or contacts that could possibly result in funding.

The HNHS/Penn Dixie has preserved a classic, unique resource for the region in which schools, amateur and professional geologists, fossil collectors, families, pre-schools through university level students, and visitors rely on it for the educational, cultural, recreational and tourism aspects of the site.

HOW YOU CAN HELP

The HNHS has some ambitious plans to further develop this site into a world class outdoor educational, recreational, and tourist attraction for the Niagara Region. In completing the first phase, the HNHS has effectively preserved a unique educational and green space resource for future generations. With the completion of the next phases of development, the HNHS will maximize the educational opportunities afforded by the Penn Dixie Site for all of Western New York and the region. The Penn Dixie Site is already proving a powerful draw for visitors from all across North America and, indeed, the world. Completion of the site's educational facilities will only enhance this draw and bring increased numbers of visitors to the site.

The difficult economic conditions in Western New York continue to impact the HNHS and the Penn Dixie Site. The HNHS (a non-profit organization) needs to secure additional funding to keep our current level of public programs at Penn Dixie**.** The HNHS is attempting to raise funds by increasing memberships, admissions, programs, donations, grants, and seeking corporate support. The HNHS' goal is to become self-sustaining. Many members and donors, who have not even been to Penn Dixie, are willing to support our cause to preserve and develop this classic site for future generations.

You can help continue the tremendous advances and accomplishments that have been made to date by:

- Sending a donation.
- Taking out a membership.

- Recruiting a new HNHS member.
- Bringing visitors to Penn Dixie.
- Recruiting a Corporate member.
- Enrolling your family in a program or summer day camp.

The HNHS is actively seeking financial support from a variety of sources to attain its goal of transforming the Penn Dixie Site into an educational resource that fully utilizes and shares the unique resources contained within the site. If you are interested in learning more about how you can help support the HNHS and the Penn Dixie Site, please call the HNHS at 716/627-4560. Visit our web site www.penndixie.org for program and membership information. We look forward to having you visit Penn Dixie.

ACKNOWLEDGEMENTS

I thank my wife, Linda, for her review of this manuscript, Stan Martin for proof reading the article, Dr. Rick Batt for use of the Penn Dixie Stratigraphic Column, Roger Furze for his photo of multiple trilobites, and Matt Phillips for his multiple mortality slab. I also thank the HNHS/Penn Dixie Board, Penn Dixie members, and volunteers who have unselfishly provided their time and talents to the preservation and development of the Penn Dixie Paleontological and Outdoor Education Center.

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ROAD LOG FOR PENN DIXIE SITE VISIT

Total Miles	Miles from last point	Route Description
		Take NYS Thruway to Exit 56 Blasdell, after the tollbooth, turn right onto Rt. 179 north.
0.0	0.1	Proceed to first traffic light and turn left onto Rt. 62 South Park Avenue.
0.1	1.2	Proceed 1.2 miles to the traffic circle at Big Tree Road
1.3	0.2	Turn right and proceed west on Big Tree Road to Bristol and turn right.
1.5	0.3	Proceed to the end of Bristol and turn left on North Street.
1.8	0.1	The Penn Dixie entrance is directly ahead. Enter the gate and meet at the Penn Dixie shelter on the north side of the parking area.

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

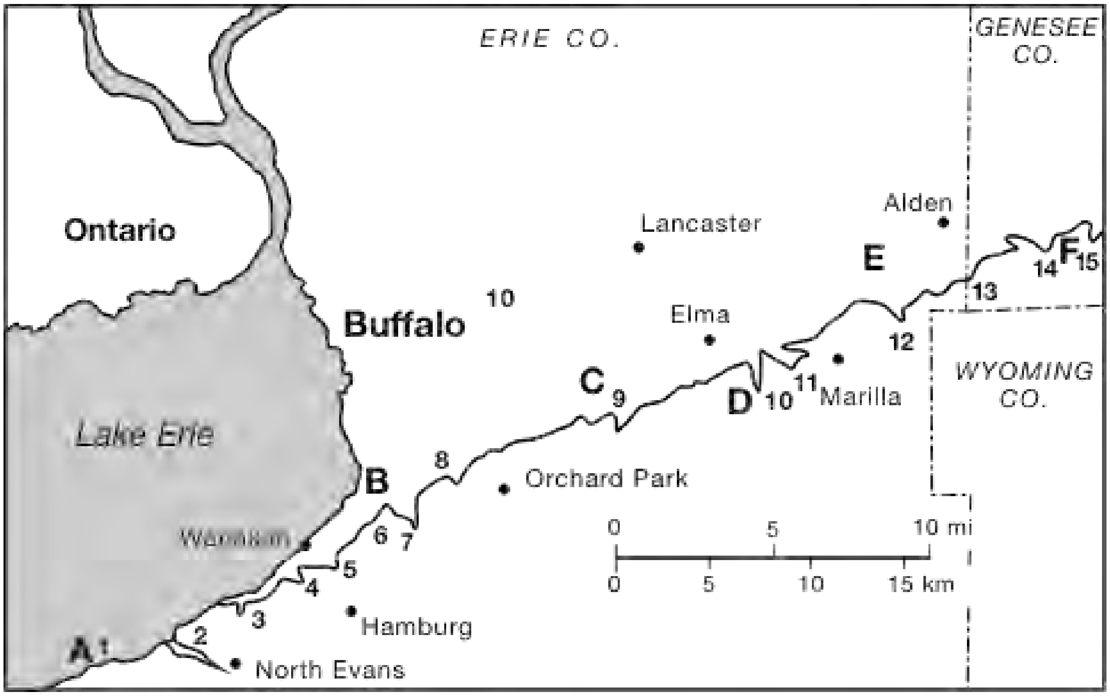


Figure 1. Location map for sections in Erie County, NY. Key localities, identified by numbered sections include: 1) Pike Creek; 2) Eighteen Mile Creek; 3) unnamed creek near Weyer; 4) unnamed creek next to

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,

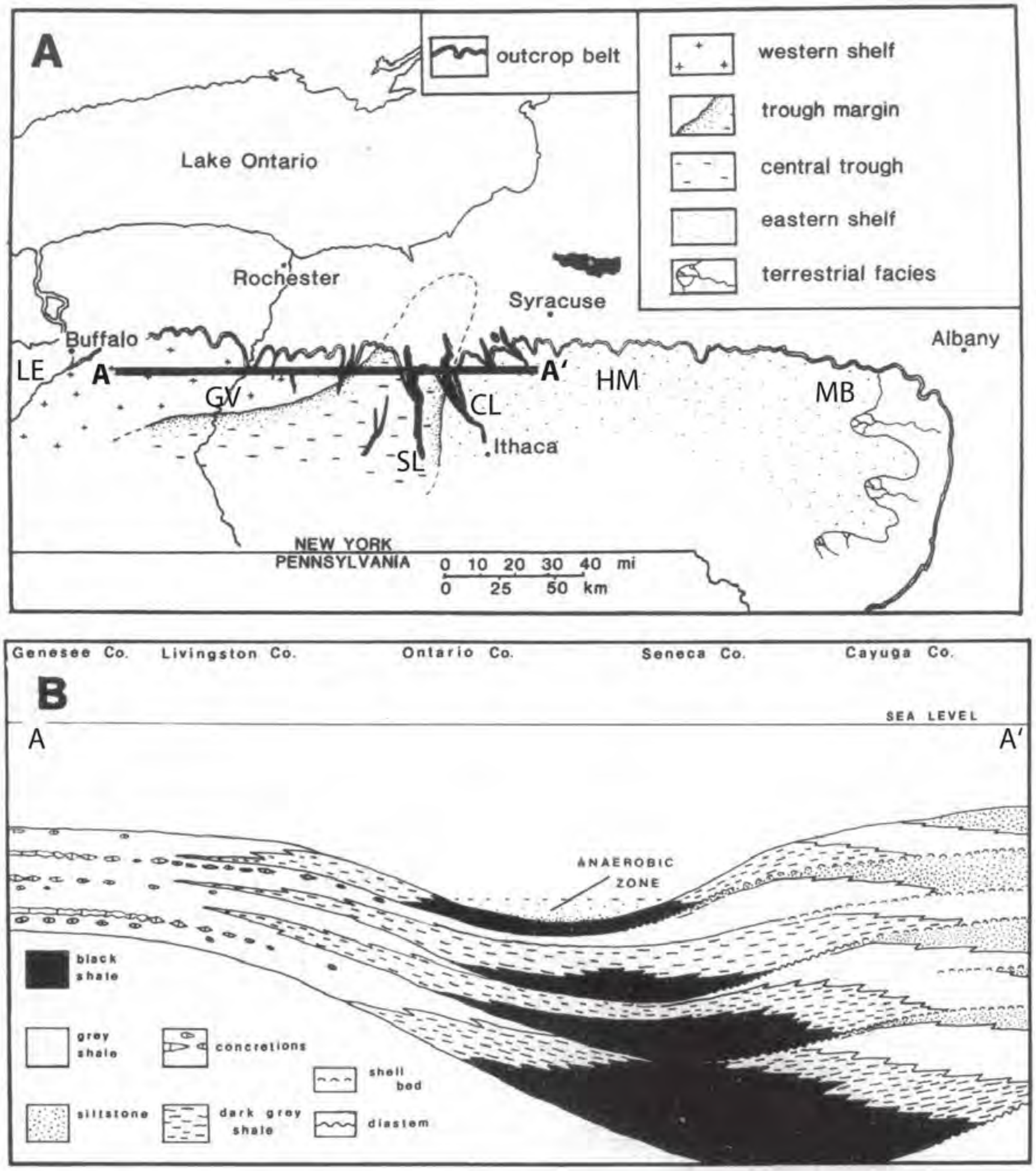


Figure 2. Paleogeography of the western New York area during Middle Devonian time showing foreland basin axis extended obliquely into central New York State. Abbreviations: LE: Lake Erie; GV: Genesee Valley; SL: Seneca Lake; CL: Cayuga Lake; HM: Hamilton type area; MB: Middleburg, the approximate eastward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

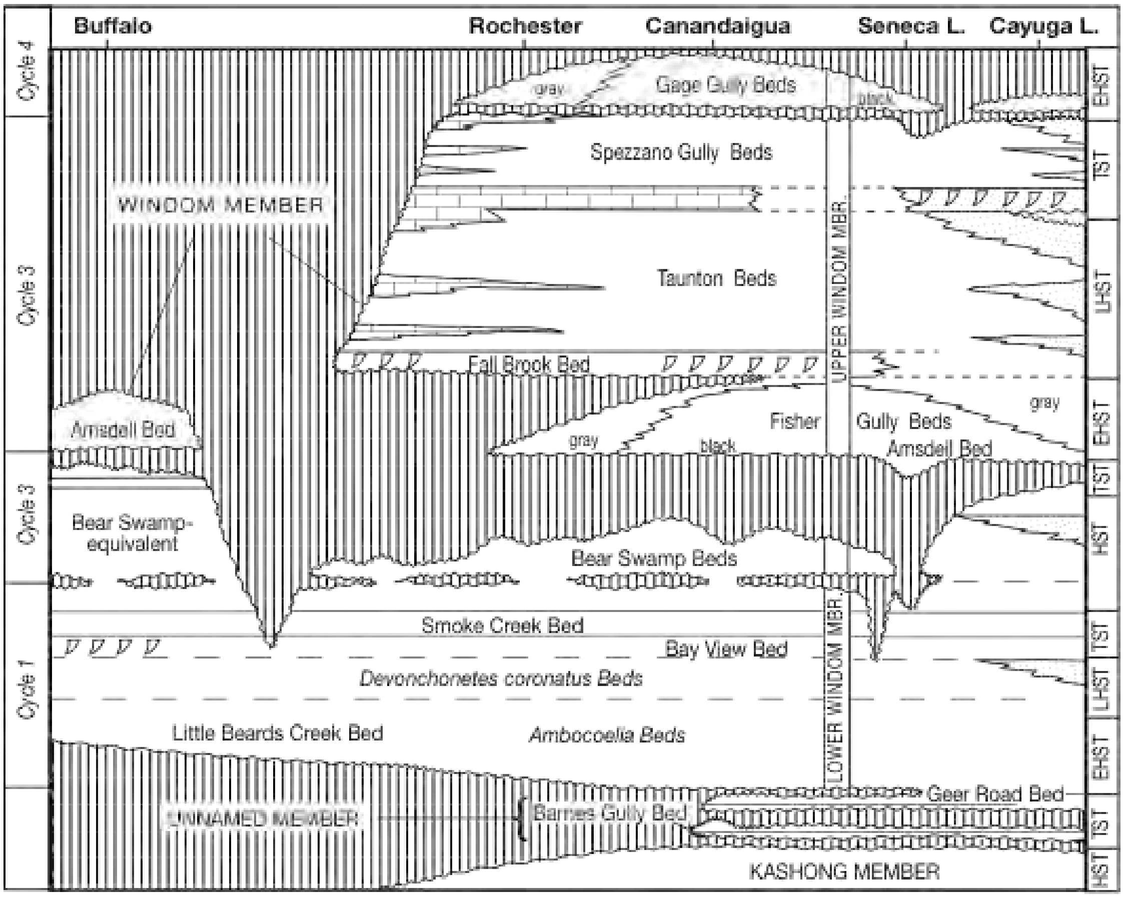


Figure 3. Time-rock diagram of Middle Devonian Windom Member of Moscow Formation showing sequence stratigraphic interpretation; abbreviations: EHST: early highstand; HST highstand systems tract; LHST: late highstand (regression); TST: transgressive systems tract. Modified from Brett and Baird (1994).

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.

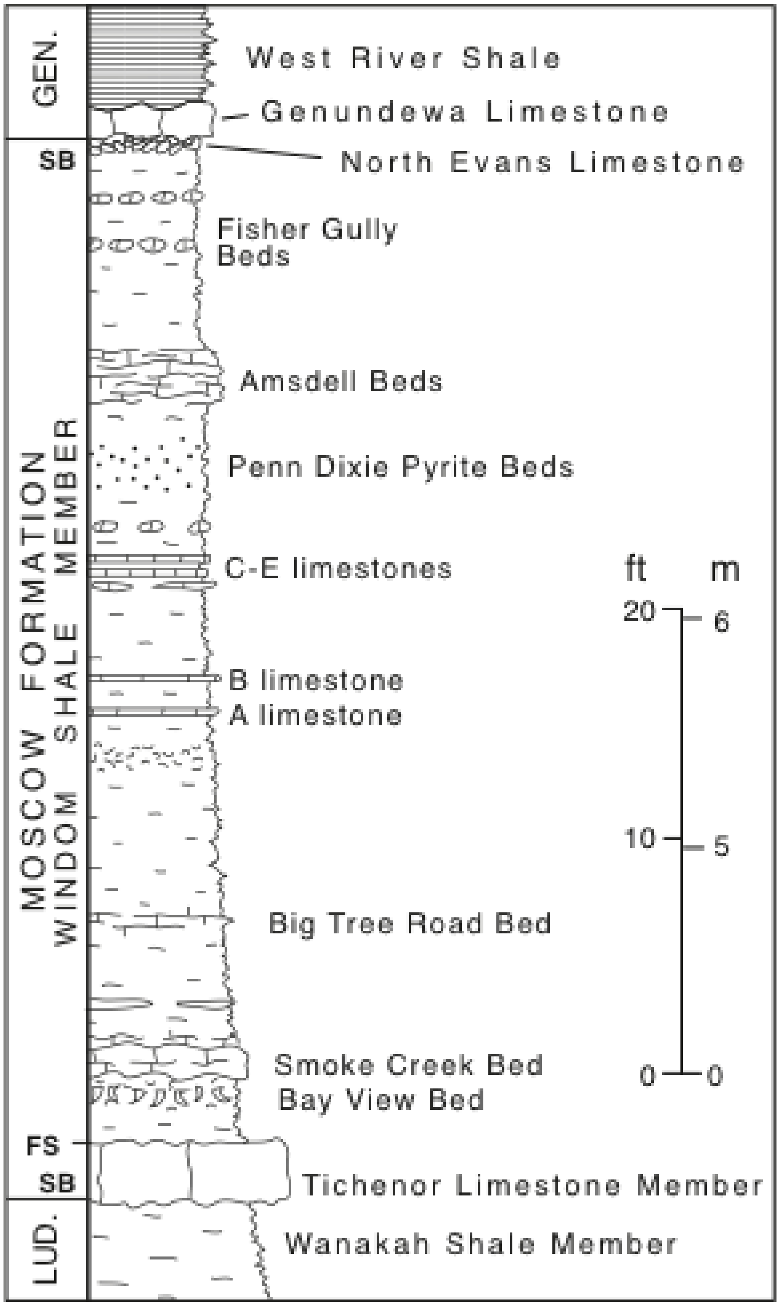


Figure 4. Generalized stratigraphic column for Penn Dixie shale pit, Blasdell, NY showing major beds of the Windom Shale. Modified from Brett and Baird (1982). Abbreviations related to sequence stratigraphi c surfaces. FS: flooding surface; SB:sequence boundary. GEN = Genesee Group; LUD = Ludlowville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

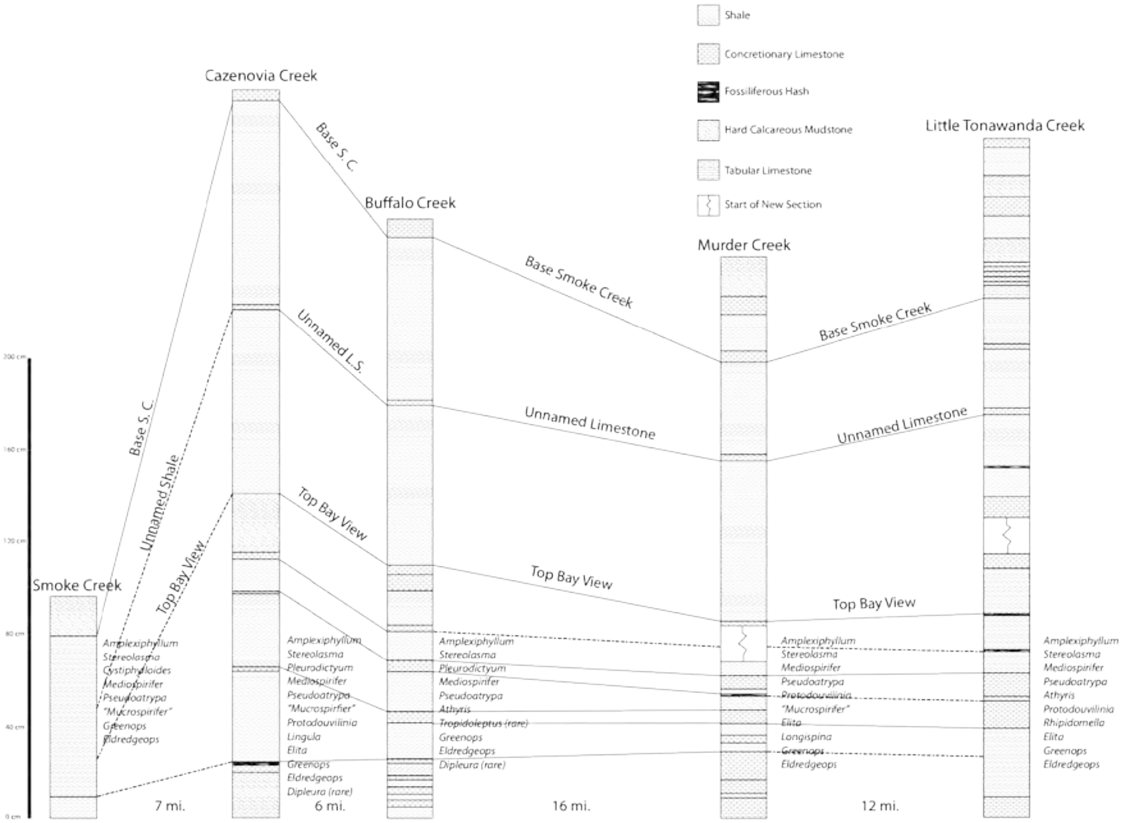


Figure 5. Detailed correlation of the Bay View to Smoke Creek bed interval in Erie and western Genesee counties. Approximate mileage between sections is given between columns; also see Figure 1 for locations.

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.

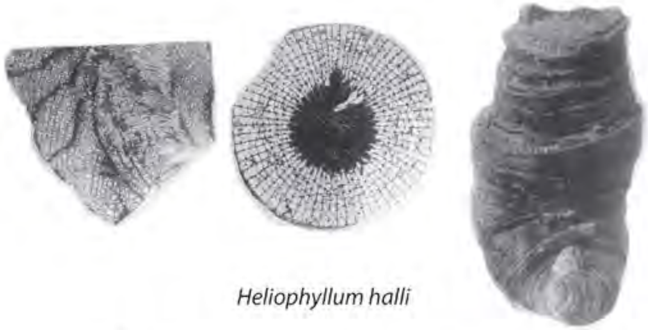
Smoke Creek bed: Brett and Baird (1982) named a distinctive trilobite-rich calcareous interval the Smoke Creek bed for exposures along the south (and north) branch of Smoke Creek in the village of Windom. The Smoke Creek bed is a relatively consistent interval of indurated concretionary, light gray calcareous 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 *Schizobolus* 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,



Heliophyllum halli

Cystiphylloides americanum

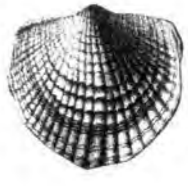
Stereolasma rectum

Amplexiphylluym hamiltonae

Mediospirifer audaculus

Pleurodictyum americanum

Pseudoatrypa devoniana



Spinatrypa spinosa

Rhipidomella vanuxemi

Mucrospirifer consobrinus

Athyris spiriferoides

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

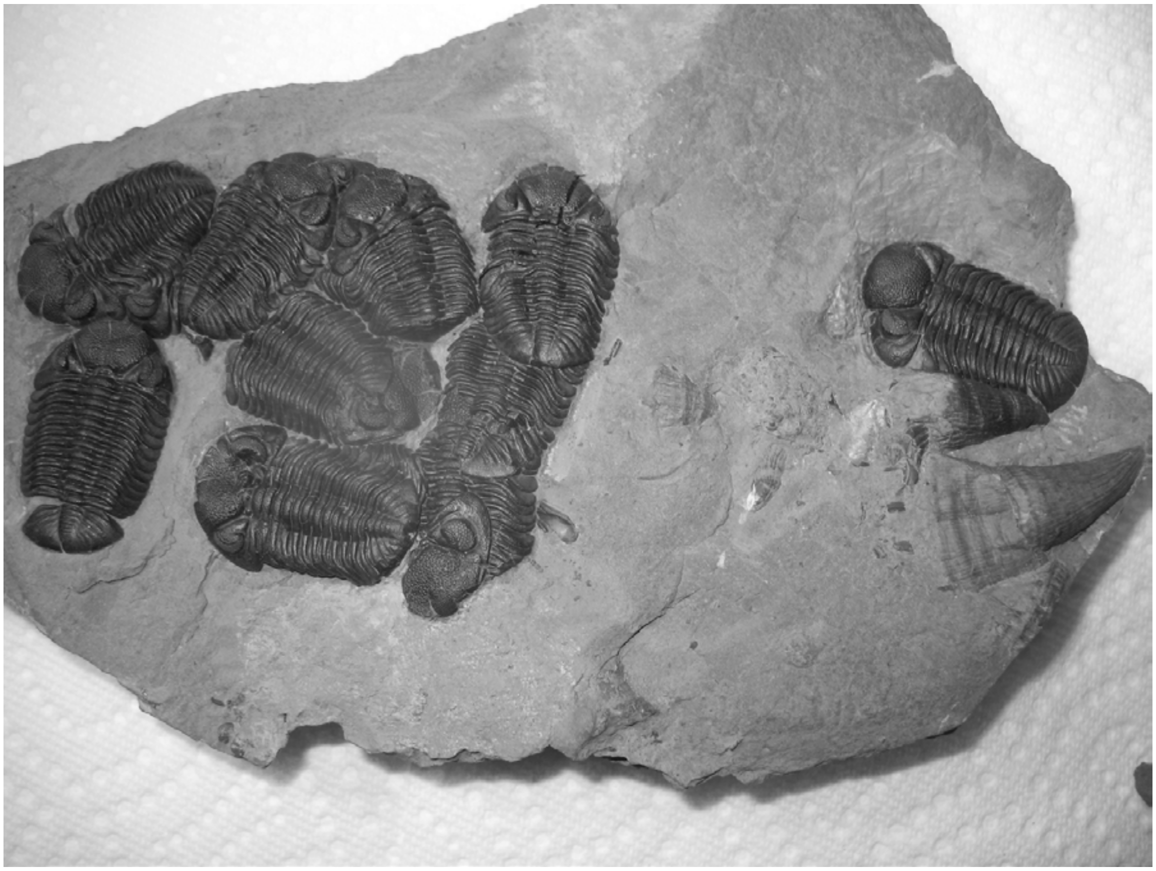


Figure 7. Cluster of articulated specimens of the trilobite *Eldredgeops rana* (Green) and the rugose coral *Stereolasma rectum* from Smoke Creek bed, lower Windom Shale at the Penn Dixie shale pit. Specimens are approximately 1.5 cm in length. Note slight disarticulation suggesting minor decay prior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

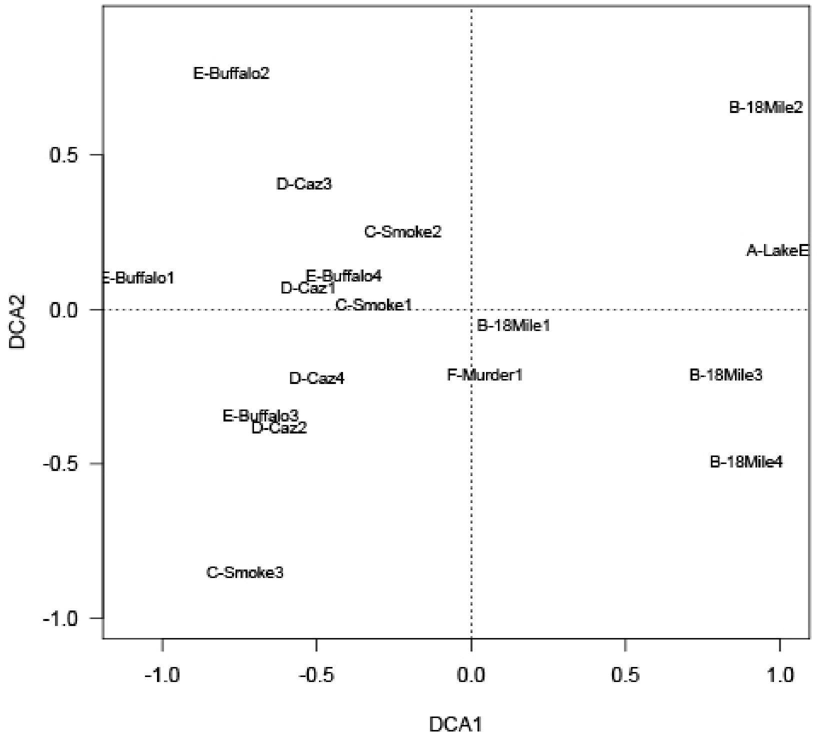
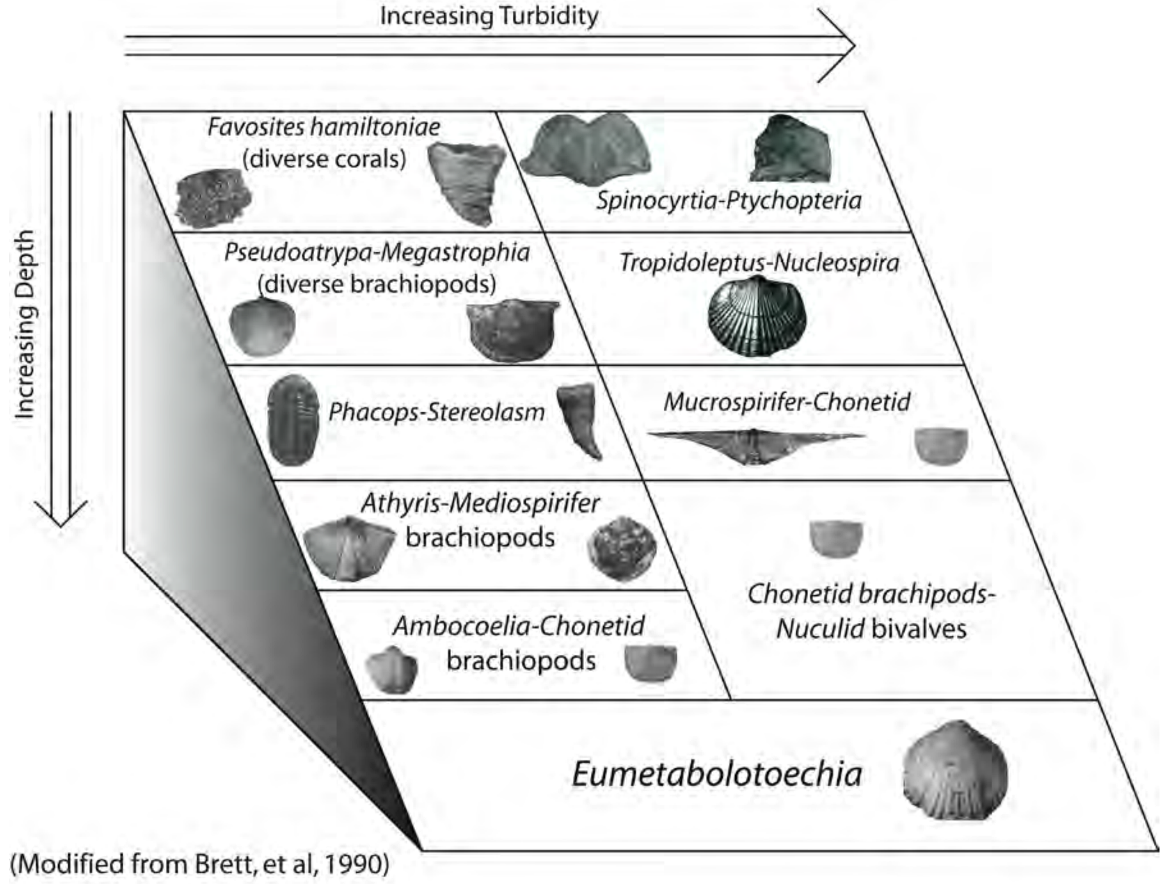


Figure 8. Plot of detrended correspondence analysis (DCA) axis 1 vs. axis 2 scores for samples of Bay View bed at six locations in western New York. Letters on locations indicate geographic position, from west to east these are A) Lake Erie shore Highland on the Lake, B) bank of Eighteen Mile Creek, 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.

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).



(Modified from Brett, et al, 1990)

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.

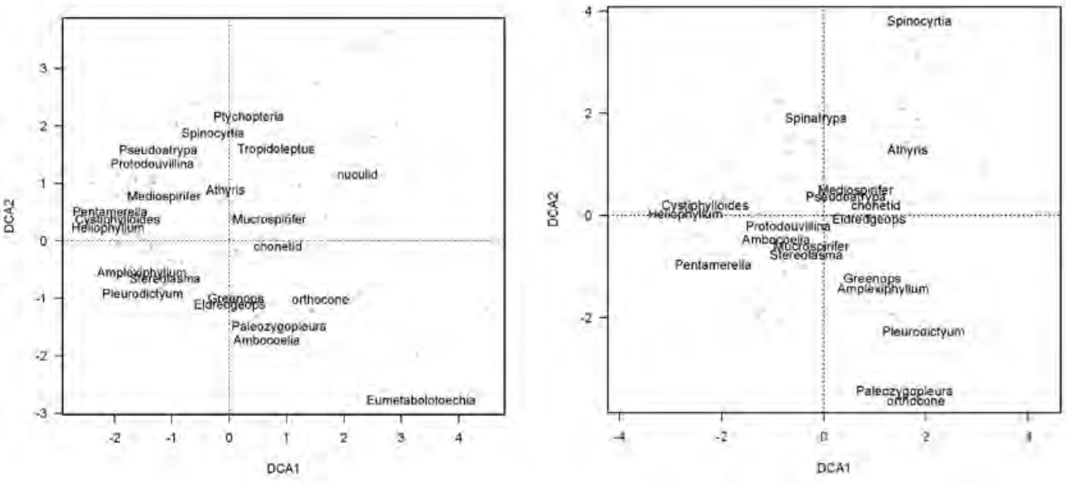


Figure 10. Plots of detrended correspondence analysis (DCA) axis 1 vs. axis 2 scores for genera of fossils from various samples. (Left) Plot of the entire Ludlowville Formation as a proxy for the "generic" Hamilton. The progression of taxa closely follows the qualitatively defined biofacies of Brett 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

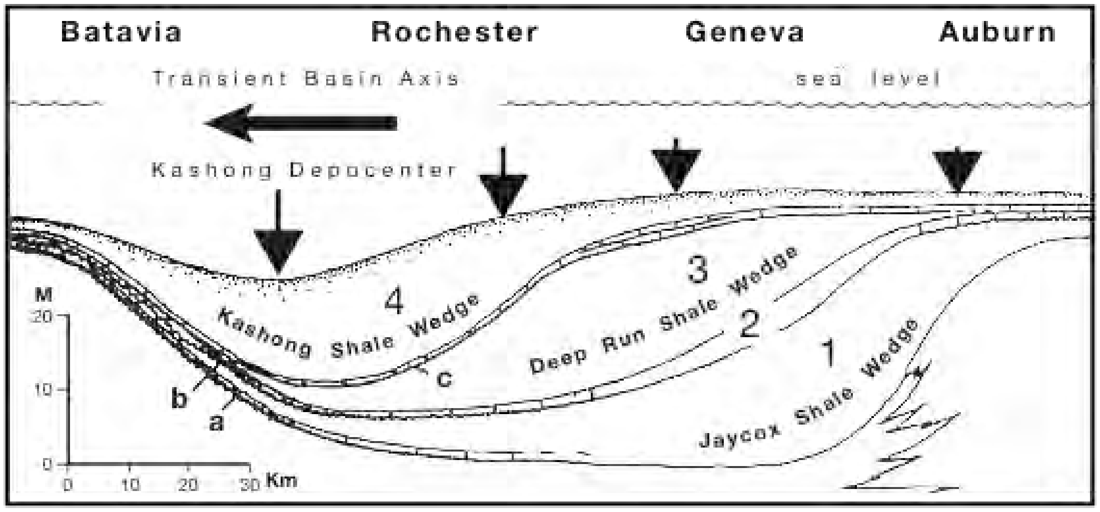


Figure 11. Generalized diagram showing westward migration of basin axis and depocenters through the lower Moscow Formation.

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.

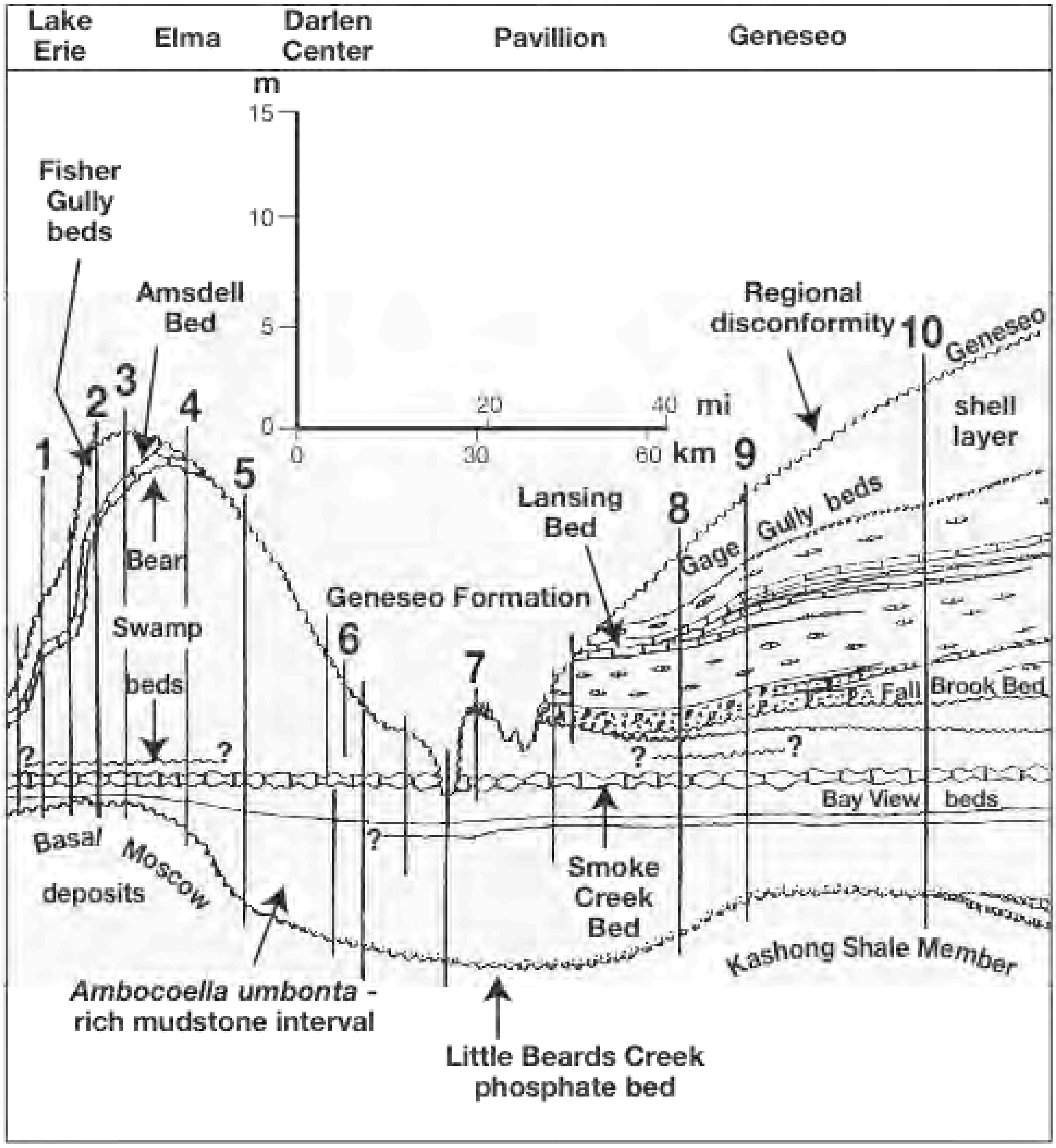


Figure 12. Stratigraphic columns of Windom Shale at various locations in western New York showing differential thickening of the lower Windom to the east and regional northeastward truncation of the upper Windom beds in central Erie to eastern Genesee Counties. Columnar sections are as follows: 1) Eighteen 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).

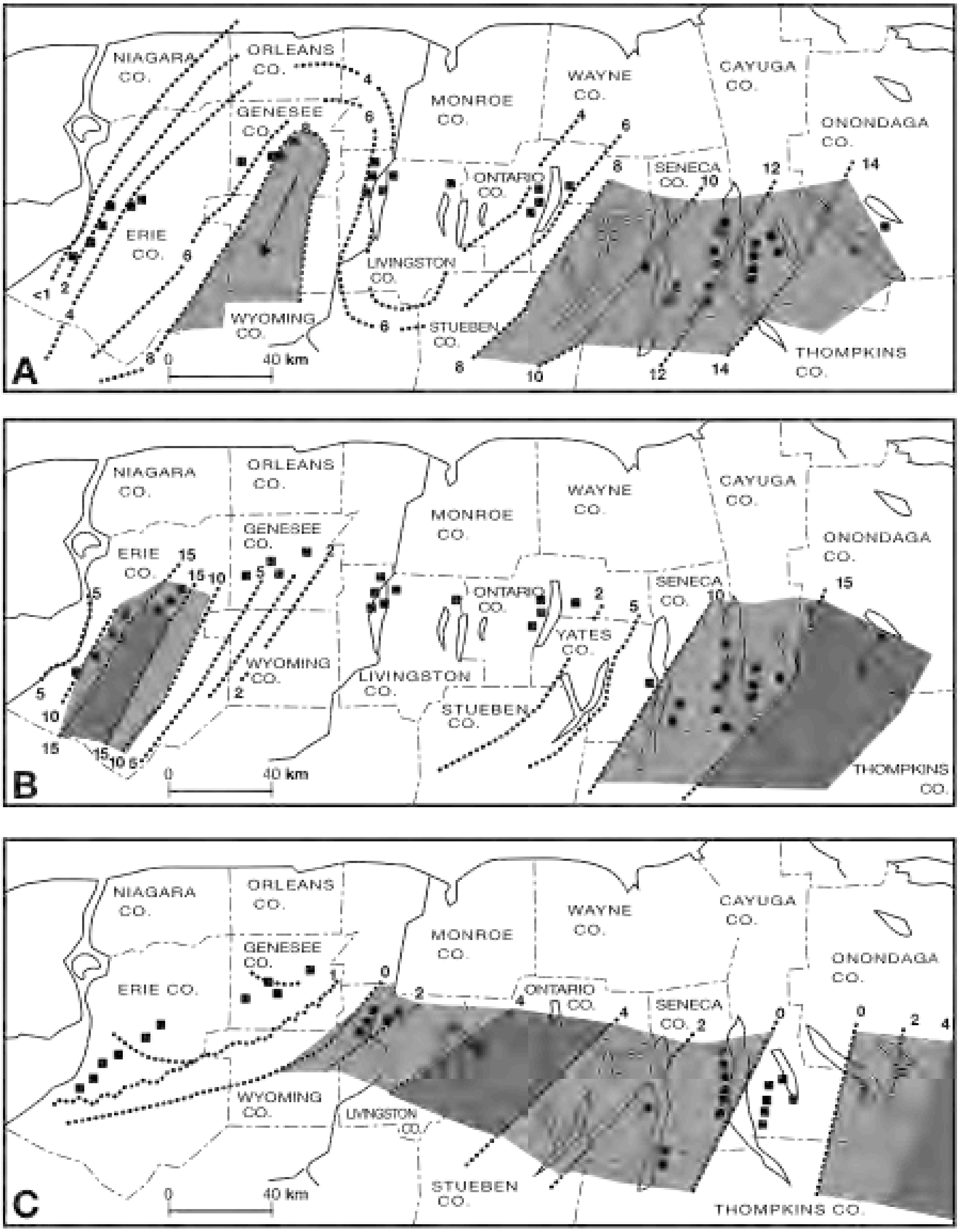


Figure 13. Isopach maps showing approximate position of basin axis during deposition of the Windom Shale; contour intervals in meters; darker areas show basins. A) lower Windom up to Smoke Creek bed; note presence of two depocenters, including western sub-basin; note migration to a position in Genesee 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

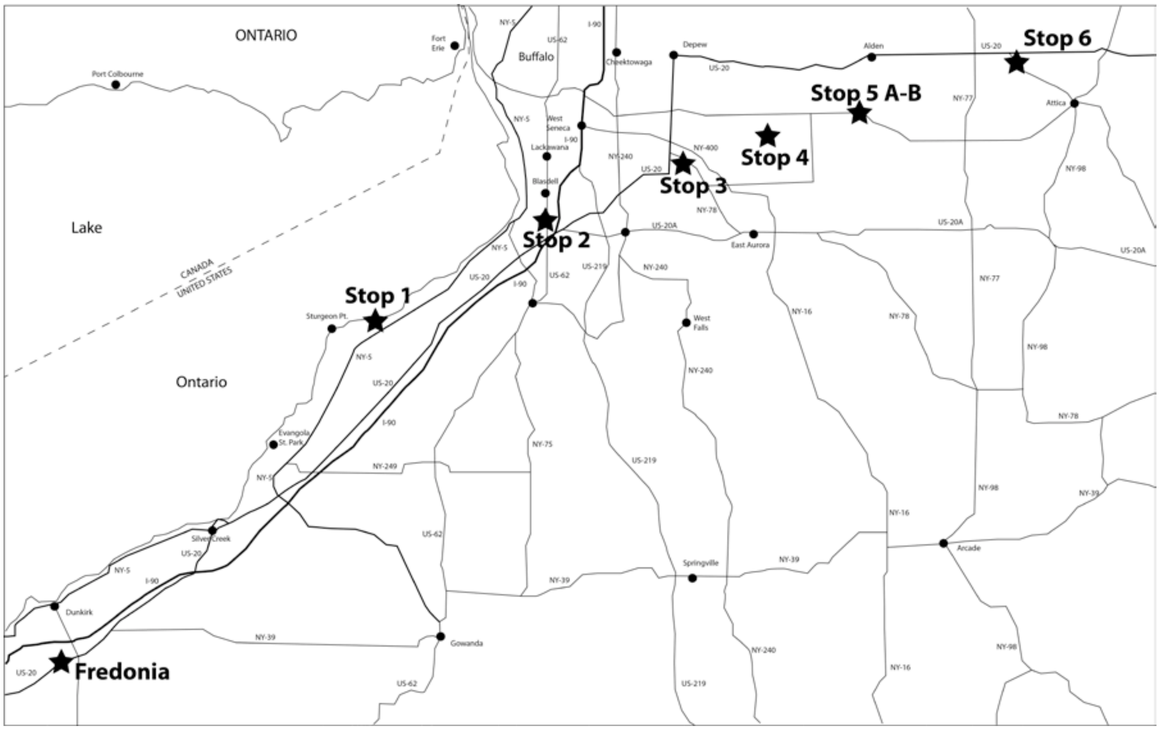

Figure 13. Location of stops for field trip relative to major highways in western New York.

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.

Hindcasting, forecasting, and controlling erosion at the Western New York Nuclear Service Center

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INTRODUCTION

The Western New York Nuclear Service Center (Center), comprising 3,340 acres approximately 30 miles southeast of Buffalo, New York (Figure 1), is the site of the only commercial nuclear fuel reprocessing facility that has operated in the United States. As a result of reprocessing activities and shallow-land disposal of radioactive waste, significant inventories of long-lived radioactive materials are present at the site. Although significant decontamination and decommissioning of site facilities has occurred over the past two decades and continues today, the state and federal agencies managing the site are evaluating a range of options between in-place closure and removal of the remaining facilities and contamination. In order to evaluate decommissioning options for the site, the agencies are working to better understand how erosion has shaped the site in the past and how it will continue to do so far into the future. Given inherent uncertainties in hindcasting/forecasting of erosion and the dynamic nature of the local upland stream systems, it is appropriate that the current focus of erosion controls be on the near-term (decades) in areas close to critical site facilities.

GLACIAL GEOLOGY

The Center is located almost entirely within the 29 mi^2 watershed of Buttermilk Creek (Figure 1), a tributary to Cattaraugus Creek that empties into Lake Erie approximately 40 miles downstream of the Center. The watershed generally occupies a shale and sandstone valley scoured by glaciation of the area. Repeated glaciations have veneered and filled the valley with tills, lacustrine sediments, morainal deposits and outwash. The till buries the bedrock valley to a depth of up to 500 ft (150 m) along the valley axis. The till is thinner on the hillsides and bedrock is nearly exposed on the hill summits peripheral to the watershed.

THE ONSET OF INCISION

Post-glacial incision of Buttermilk Creek and its tributaries is thought to have begun in the Late Wisconsinan, shortly after the retreat of the Lavery ice, although direct evidence obtained in the vicinity of the Center has been elusive. Lafleur (1979) dated a high stream terrace suggesting incision of Buttermilk Creek was underway by about 11,500 years before present (YBP). Organic material associated with Defiance-Lake Escarpment outwash to the north of the Center suggests final ice retreat in the area occurred no later than 17,700 YBP (Calkin and Miller, 1977; note ^{14}C [radiocarbon] years are corrected to calendar years before present following Fairbanks et al., 2005). Recently, wood fragments found near the surface of the till plateau adjacent to Buttermilk Creek (Figure 2) indicate a meltwater environment may have still been present until about 14,000 - 14, 600 YBP. These particular wood fragments were not found in fluvial deposits; they were located approximately 0.5 - 1.0m below the surface within homogenous clay deposits. The wood fragments were colocated with very thin, horizontal deciduous leaf mats, suggesting deposition in meltwater/backwater. Once the ice retreated, thus opening northern (Buttermilk Creek) drainage, it is unclear what other mechanism could have emplaced these materials in such a manner at this particular location. Given this information, the onset of incision of Buttermilk Creek may have occurred between 14,000 and 15,000 YBP. As ice retreated further out of the Erie and Ontario Basins, the lowering lake levels would have occasioned the final dissection of the regional plateau drainage by the west-flowing Cattaraugus Creek, which serves as the current local baselevel for the Buttermilk system.

DENUDATION RATE(S)

The timing of ice retreat and onset of incision of Buttermilk creek is important to understanding downcutting rates within the system. Buttermilk Creek has eroded approximately 55m (180 ft) near its confluence with Cattaraugus Creek. Previous estimates using Lafleur's (1979) radiocarbon date of a high stream terrace put average downcutting at approximately 4.8 m/1,000 yr. Given the upper bound date described above (~14,500 YBP) yields a slower average rate of 3.7 m/1,000 yr. These limited data, while constraining to some degree the timing of incision onset, provide no information about changes in the incision rate through time, possible variability in incision rate throughout different parts of the watershed, or about the watershed's baselevel history near its confluence with Cattaraugus Creek (Trip Stop 6). While the existing conceptual model for landscape evolution at the site assumes a constant rate of downcutting, Lafleur (1979) notes that incision rates are expected to slow over time, particularly in reaches where the glacial sediment substrate becomes increasingly armored by clast lag buildup. Further, quartz-based optically stimulated luminescence (OSL) data collected at various terrace elevations along Buttermilk Creek suggest the incision of Buttermilk Creek was much more rapid early in its development (as much as 20x as rapid) than occurs today (USDOE, 2010).

A prominent feature of the Buttermilk Creek watershed topography is a hanging abandoned meander on the west side of the valley near the Center, ~ 20m below the till plateau and ~30m above the valley floor (Trip stop 5, Figure 2). The elevation of the meander suggests it represents a point in time when approximately 40% of the total incision observed today had occurred. OSL dated samples from the top of the till plateau and within the abandoned meander date both features to ~17,000 YBP. Recently collected ^{14}C samples date the top of the plateau at ~14,000 YBP and the meander at ~5,200 YBP. While the OSL data implausibly suggest the first 40% of incision occurred instantaneously, the ^{14}C data suggest the first 40% of incision occurred over a 9,000-year timeframe, the remaining 60% of incision having occurred in the last 5,000 years. It is obvious that additional dating studies are needed to better constrain both the onset of incision and changes in the incision rate over time and space. Samples near the watershed outlet could be particularly valuable for understanding baselevel history.

AGGRADING AND DEGRADING STREAM TERRACES

An interesting follow on discussion is the apparent absence of any net incision at locations within the Buttermilk Creek watershed and neighboring Connoisarauley Creek watershed over the past 1,000 to 2,000 years. This conclusion is drawn from age-dating a number of eroding stream terraces at the valley floor. As the channel sweeps laterally within the valley, remnant stream terraces are exposed and eroded. Within these terraces, exposed wood at the present day level of the stream consistently dates to approximately 1,000 to 2,000 YBP (Trip Stop 7, Figures 4 and 5), indicating that while the stream system may have migrated laterally a great deal during that timeframe, it has not appreciably incised (net incision). Moreover, the terraces being eroded at present stream level appear to be of a much larger scale than those being created within the system at present (Figure 6). These eroding terraces appear to be valley-filling aggradational units of sorted fluvial material, suggesting that while these materials were deposited by flowing water (not landslide or mudflow deposits) it was deposited in a fluvial regime not resembling the one we see today.

DISPOSAL AREA IMPLICATIONS

The large tributaries to Buttermilk Creek have dissected and incised the Lavery till plateau and generally occupy steep, deep V-shaped valleys lacking any floodplain. The discussion that follows focuses on the large Buttermilk Creek tributary known as Frank's Creek and its smaller tributary Erdman Brook (Figure 7). The convex longitudinal profile of Frank's Creek/Erdman Brook (Figure 8) is interpreted to mean that the system is inherently unstable and will continue to incise even if the baselevel at the confluence does not change. The instability is evidenced by the continued headward incision and dissection of the landscape, coupled with valley widening. The development and migration of knickpoints appear to drive much of the development of Buttermilk Creek's tributaries. As knickpoints incise the stream, adjacent slopes are over-steepened, and mass wasting in the form of small slides, slumps, and rotational failure serves to widen the valley (Trip Stop 4 to active landslide).

Near the headwaters of many of Buttermilk's tributaries, there is a sharp transition from a deep V-shaped valley to a more broad U-shaped valley, which coincides with a change in the longitudinal profile of the stream to a gentler grade (Figure 8). In Erdman Brook and Frank's creek, this transition has generally mirrored the location of large knickpoints (Trip Stops 2 and 3, Figures 11 and 12). Upstream of the transition/knickpoints, the floodplains occupy a wide, flat valley bottom, and in many cases (typically in wetland areas), a defined stream channel is not evident. While the V-shaped reaches are incised in Lavery till, the upland U-shaped reaches have been filled with 1 m to 3 m of fine-grained sediment in the recent past, evidently by beaver dams (Figures 11 and 12). Beaver dams are common in the area and effectively result in deposition of large amounts of sediment in these upland stream reaches. Beaver dams/ponds also serve as a natural means of erosion protection, providing grade control and energy dissipation. In order to monitor and manage the streams in a stable condition, beavers (and their dams) have been removed from Frank's Creek and Erdman Brook since the development of the Center (1960s). In the absence of beaver dams to hold the deposited sediments in place, knickpoints moving upstream out of the V-shaped reaches have encountered the highly erodible deposits, and over the past ~50 years have incised more than 100 m of both Erdman Brook and Frank's Creek. As these knickpoints have moved closer to the radioactive waste disposal areas, the state and federal agencies managing the site have taken steps to control the erosion.

On both Erdman Brook and Frank's Creek a number of grade-control structures have been installed during 2009-2013. The structures are typically based on a pool-riffle design with incorporated anchored grade control (Trip Stops 2 and 3, Figures 13 and 14). At knickpoint brinkpoints, interlocking subsurface concrete block walls have been installed perpendicular to the stream valley and keyed into the Lavery till that underlies the more erodible surface deposits. These walls extend outward from the center of the valley to the extent of the 100-year floodplain. Immediately downstream of these grade-control walls, the knickpoint scour pools have been reshaped and armored, and designed to outflow into engineered rock riffles. These structures, while relatively new, have functioned as designed with minimal maintenance, and should protect these localized reaches from erosion over the next several decades -- an appropriate nearby and near-term focus for erosion control, absent a better understanding of the system over millennial timeframes.

CONCLUSION

Converging lines of evidence suggest the existing simple conceptual model of Holocene landscape development may not adequately describe the evolution of the Buttermilk valley in a manner that allows for meaningful long-term erosion forecasts. As the state and federal agencies at West Valley continue to safely manage the site and conduct decommissioning activities, we are also focusing effort on developing a better understanding of the history of the Buttermilk Creek basin. This work may eventually lead to the development of longer-term, basin wide erosion forecasts and broader erosion control strategies. In the meantime, the agencies will continue to deploy, monitor, and maintain decade-scale, local controls, which are proving to be effective at mitigating erosion in the tributaries adjacent to critical site facilities

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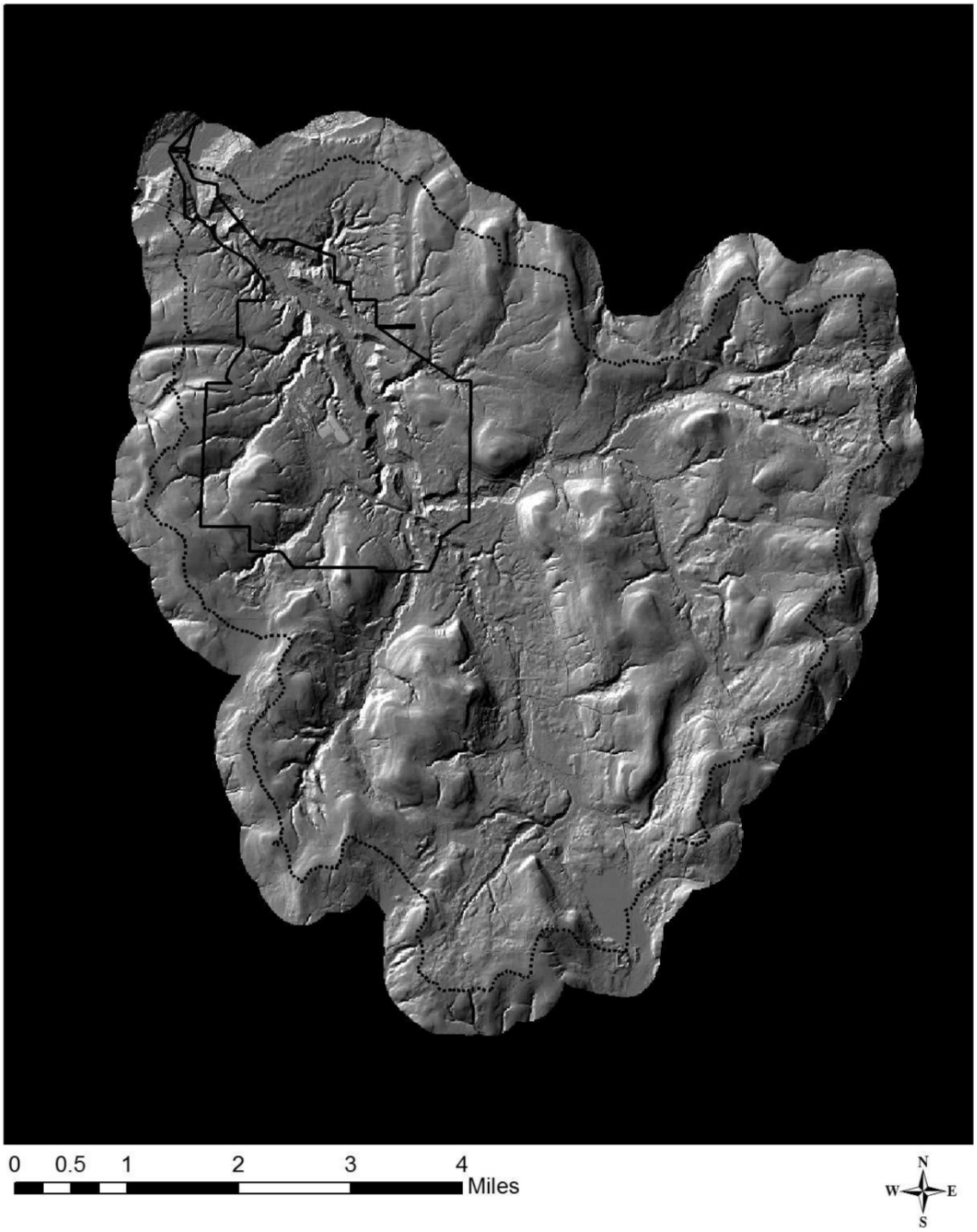
United States Department of Energy, 2010. Final Environmental Impact Statement For Decommissioning and/or Long-Term Stewardship at the West Valley Demonstration Project and Western New York Nuclear Service Center (DOE/EIS-0226).

Figure 1: LiDAR-derived hillshade relief of Buttermik Creek watershed (outer dashed line) and Western New York Nuclear Service Center (inner solid line).



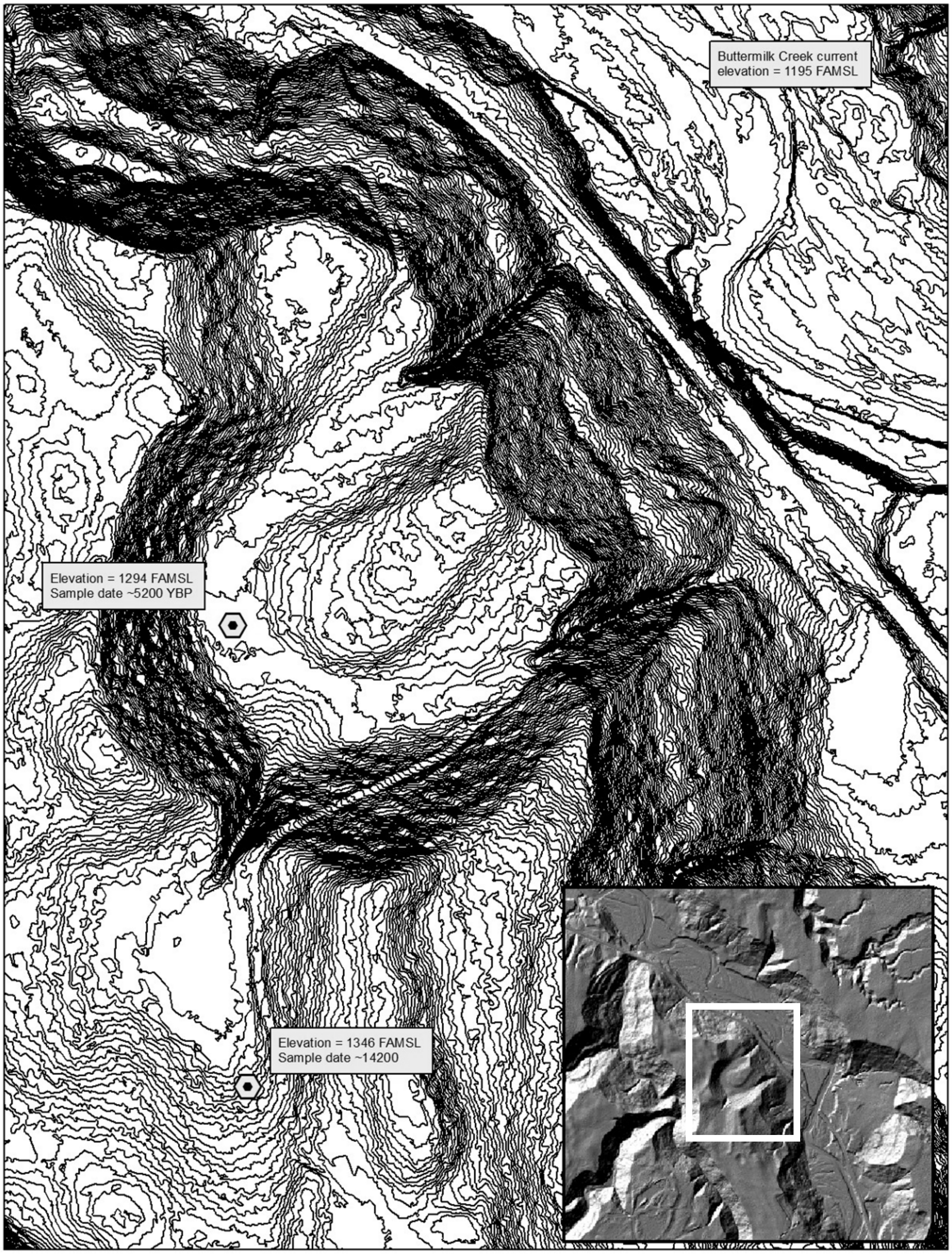


Figure 2 - LiDAR l.Oft contour lines depicting hanging cutoff meander on Buttermilk Creek valley wall. Two dated wood sample locations are identified.

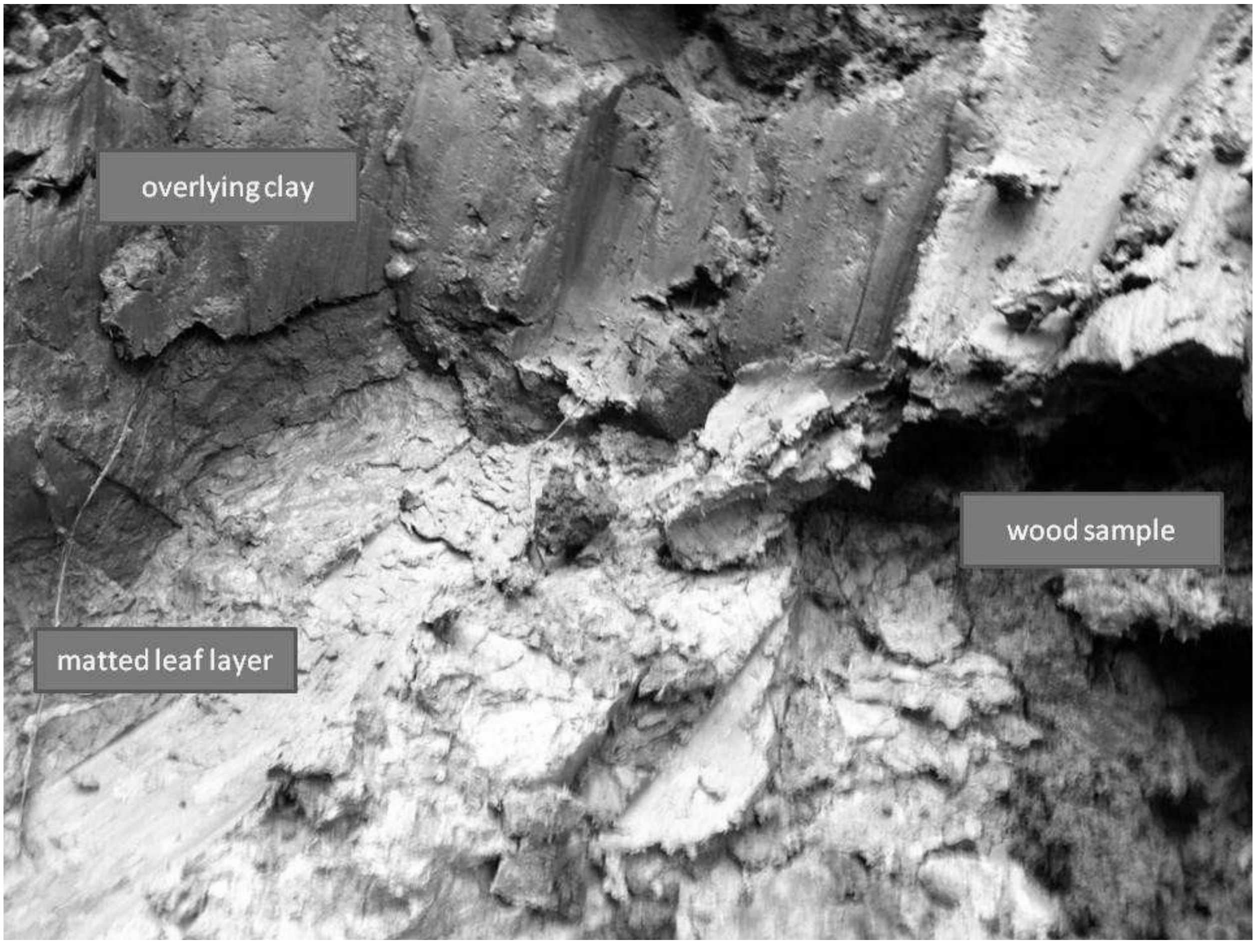


Figure 3 - Wood sample collected near top of till plateau at 0.89m deep (bottom). Samples were found in homogenous clay deposits colocated with mats of deciduous leaves. Three samples date to ~14,200 YBP.

Figure 4 - Large wood sample at base of ~3m terrace at interface between Lavery till and fluvial cobbles. Wood sample dated to ~2,300 YBP. Sample in Connoisarauley Creek, which occupies the next watershed to the west of Buttermilk Creek.

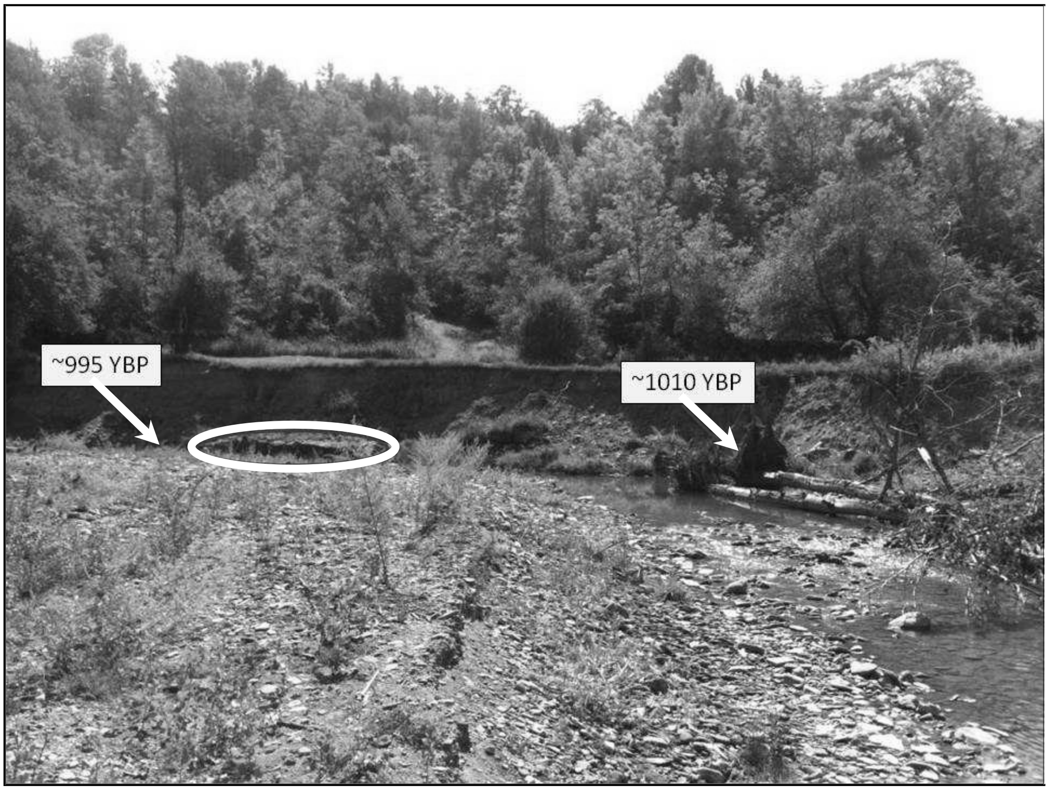


Figure 5 - Eroding terrace in Connoisarauley Creek. Two wood samples from the base of the terrace date to ~995 YBP and ~1010 YBP. A Lavery till outcrop is circled.

Figure 6 - "Valley-filling" fluvial terrace on Buttermilk Creek, a ~4.0m high aggradational feature. Intact lavery till can be found at the base of the terrace. A wood sample excavated at the base of the red pole dates to ~520 YBP.

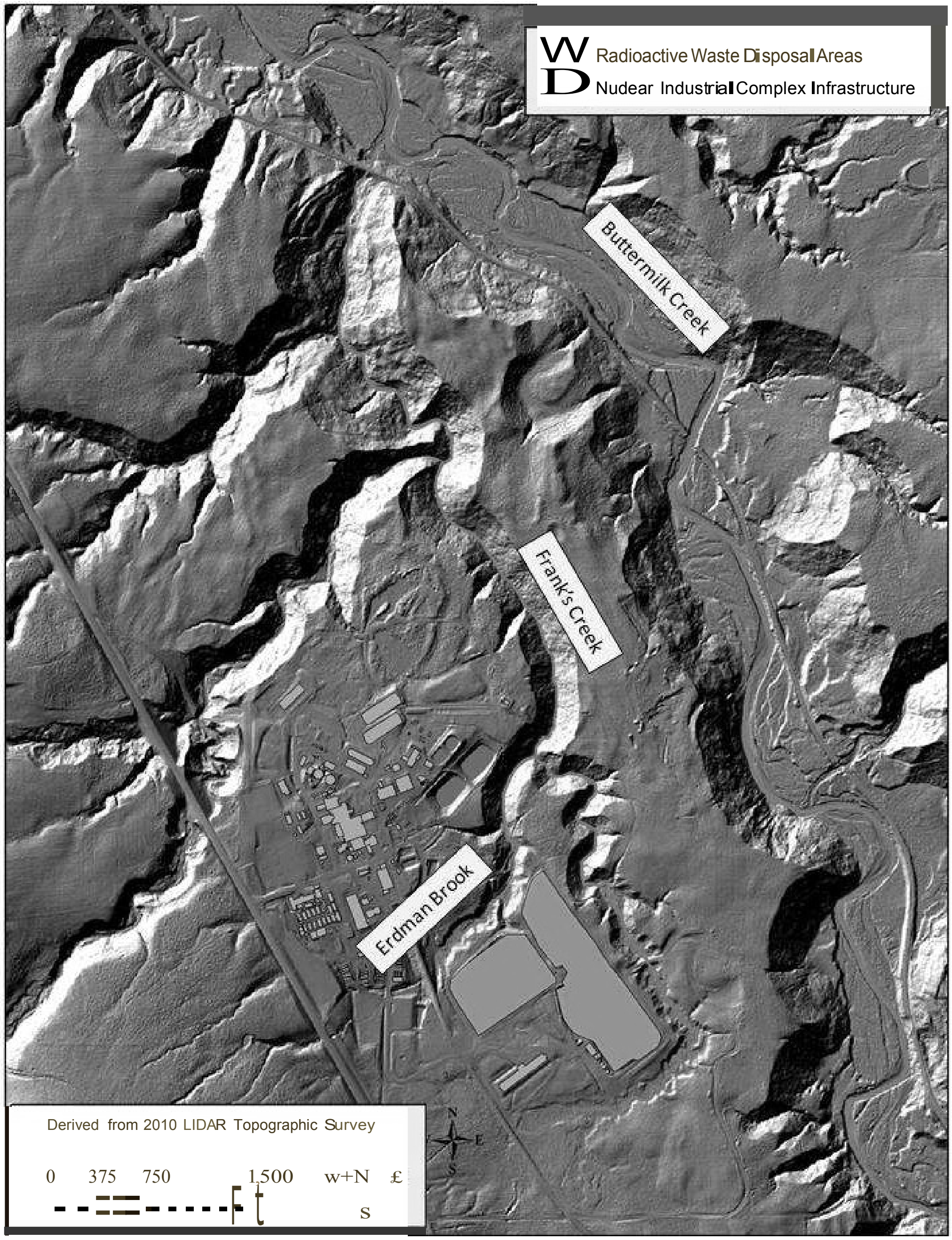


Figure 7 - Hillshade topography highlighting Buttermilk Creek and tributaries Frank's Creek and Erdman Brook and their proximity to the radioactive waste disposal areas and the infrastructure of the industrial complex

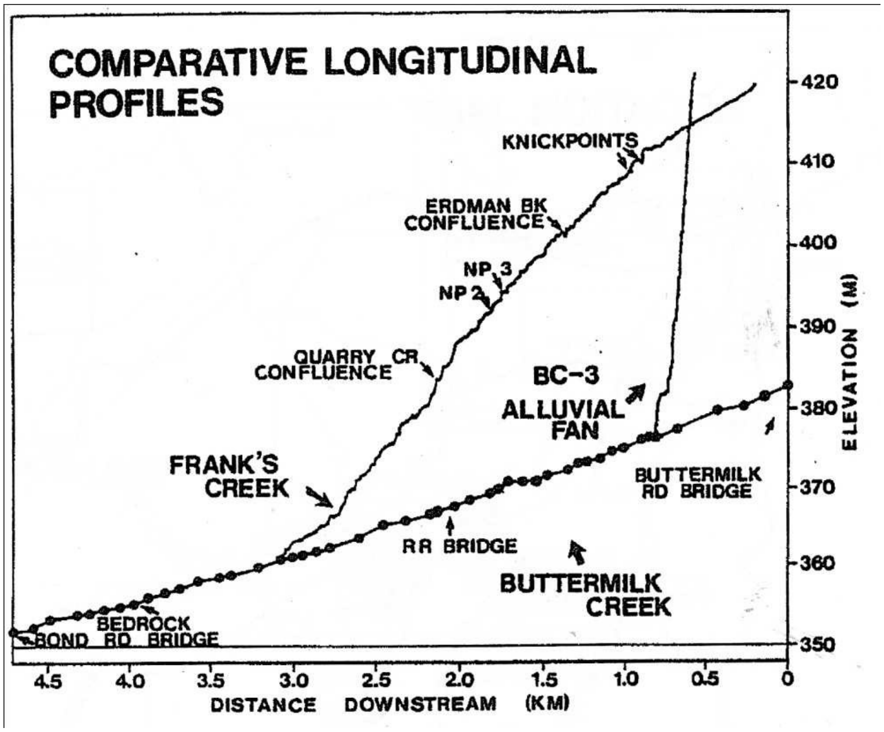


Figure 8 - Longitudinal profiles of Buttermilk Creek, Frank's Creek, and a small valley wall alluvial fan (Boothroyd et al., 1982)

Figure 9 - Active knickpoint on Erdman Brook. Stained gravel layer at waterline marks interface between fine-grained fluvial deposits (above) and Lavery till (below). Exposed branch below waterline dates to ~400 YBP. Total knickpoint height is ~1.5m.

Figure 10 - Active knickpoint on Frank's Creek. Stained gravel layer marks interface between fine-grained fluvial deposits (above) and Lavery till (below). Exposed branch dates to ~180 YBP. Total knickpoint height is ~2.5m.

Figure 11 - Beaver dam constructed on Frank's Creek near the radioactive waste disposal areas.

Figure 12 - Log exposed by migrating knickpoint in Frank's Creek shows evidence of having been felled by beavers. Log had been covered by approximately 2 meters of fine-grained deposits and was resting on intact Lavery till. Log dates to approximately 220 YBP.

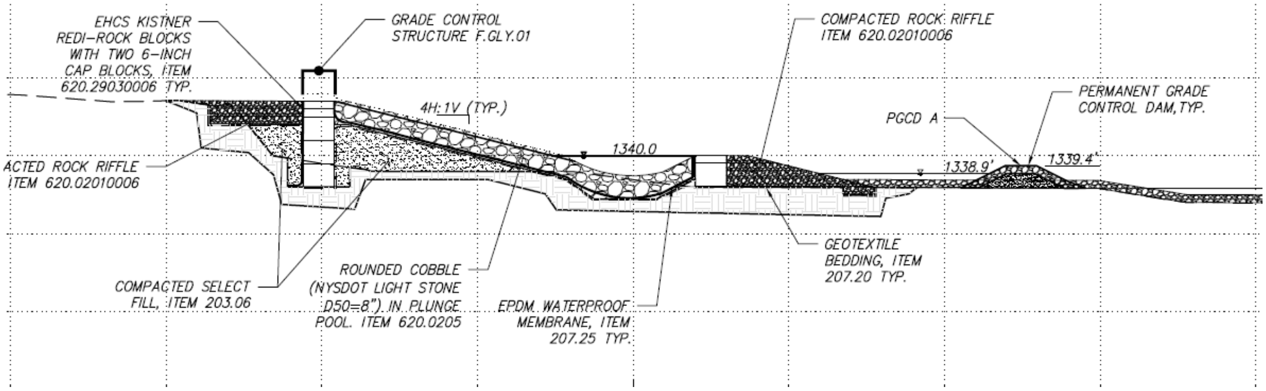


Figure 13 - Typical erosion control structure design with anchored grade control wall and pool-riffle sequence.

Figure 14 - Erosion Control Structures Installed on Erdman Brook. Shown are a series of pools and riffles. Looking downstream.

Trip Stops

Stop #1. The Ashford Office Complex, 9030 Route 219, West Valley, NY (Lat: 42.396014, Long: -78.674458): Trip participants will meet at the office of the New York State Energy Research and Development Authority to sign visitor forms and watch a safety video.

Travel to and enter **West Valley Demonstration Project (WVDP) and Western New York Nuclear Service Center (WNYNSC), 10282 Rock Springs Rd., West Valley, NY 14171** (Lat: 42.448975, Long: -78.657178): **Note: In order to enter the WVDP and WNYNSC, you are required to be escorted at all times by a NYSERDA employee.**

Stop #2. Erdman Brook Erosion Controls: Grade control and armored pool-riffle sequences for mitigating knickpoint erosion. Installed 2009-2012.

Stop #3. Franks Creek Erosion Controls: Grade control and armored pool-riffle sequence for mitigating knickpoint erosion. Installed 2013.

Stop #4. Buttermilk Creek Active Landslide: 180' landslide on west bank of Buttermilk Creek. Last major slide event during flood of August 9, 2009. Exposures of glacial till and lacustrine sediments.

Stop #5. Abandoned Hanging Meander: A 5,000-year old cutoff meander high on the valley wall.

Leave WVDP/WNYNSC.

Stop #6. Scoby Dam, Scoby Hill Rd., Springville, NY (Lat: 42.481144, Long: -78.700192): Visit Cattaraugus Creek near the confluence with Buttermilk Creek for discussion of baselevel control.

Stop #7. Connoisarauley Creek, Connoisarauley Rd. North, West Valley, NY (Lat: 42.448189, Long: - 78.715517) : Visit large stream terraces for discussion of aggradation/degredation over past 1000 years.

Field Musings on Glacial and Geo-Political Boundaries in Western New York

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INTRODUCTION

Glaciation was literally a heavy influence on the topography in Chautauqua County, New York's westerly and southerly boundary with Pennsylvania. We will visit relic shorelines of pro-glacial lakes that occupied the Erie basin as ice near the Buffalo area dammed easterly flow; we will see that the shorelines are now tilted from post-glacial isostatic rebound and how geodetic evidence suggests the rebound continues. We will visit ice marginal features such as eskers, sub-glacial meltwater channels and deltas, and an apparent sub-aqueous recessional moraine. We will visit one or more "pop-up" structural features in the otherwise flat-lying Devonian stratigraphy, possibly the result of glacier-weight unloading. We will visit the inter-state boundaries to explain how George Washington, Benjamin Franklin and other early American leaders strategically determined the geographic interface between New York and Pennsylvania, to see the field challenges facing government surveyors who marked the lines, and learn how glacial-related geologic features defined the westerly line of New York.

BACKGROUND

This trip is an extension of the NYSGA field trip, "Paddling Up a Meltwater Channel: A Late-Wisconsinan Ice-Marginal Cruise Near Fredonia, New York" (Woodbury and Jensen 1990) by including work within the MS thesis, "A Proposed Ice Margin for Late Lake Arkona or Early Lake

Whittlesey and Geodetic Evidence for Continuing Post-Glacial Uplift in Western New York" (Woodbury 1992). Additionally, stops are included to give a wider and more general view of the glacial history of Chautauqua County, and the rides between stops will be narrated between vehicles by radio so that even the traveling views will be mental stops for geologic and geo-political thought. For more detail on glacial items, see the references already cited and the excellent summaries with references in "New York Glacial Geology, U.S.A." (Cadwell and Muller 2004) and "The Glaciation of Pennsylvania, U.S.A." (Braun 2004 and 2011). For enlightening and extensive detail on western New York's geo-political boundaries see "Report of the Regents' Boundary Commission Upon the New York and Pennsylvania Boundary" (Clarke 1886) and "Andrew Ellicott, His Life and Letters" (Mathews 1908). Also, an illustrated color brochure will be supplied to the participants on this trip and will be pdf-available by email request to supplement this publication.

STOP ONE:

During either a period during a stage of late Lake Arkona or a period during an early stage of Lake Whittlesey, a long series of high-volume sub-glacial meltwater channels drained the southerly edge of ice that advanced southwesterly in the Erie basin to the area now Chautauqua County. The lowest of these meltwater channels carved out large amounts of local Devonian inter-bedded shales and siltstones as it emptied into, and formed a large delta in, either late Lake Arkona or early Lake Whittlesey. See Figure 1 for locations of the channel, the delta, and the delicate eskers likely formed near a wasting ice margin. We will observe evidence that waves washed the northerly ends of the eskers at the beach elevation of the pro-glacial lake that drained the Erie basin westerly during this glacial stage. At Stop Ten we will see apparent sub-aqueous recessional moraines that seem to correlate with glacial events forming the meltwater channel, the delta, the beach ridge, and the eskers.

At Stop One we will stand at the former water level – as surveyed by differential leveling for this project with the help of graduate student Bobbi Jo Gibbons – that snubbed the esker noses about 14,000 years ago, then walk the sinuous top of the esker and muse on what the feature contains within. We will get lucky as the grape-farmer owner has cut a cross-sectional path through the esker and we can take out our rock picks to better examine the core of mostly local and angular material with some sorting and stratification.

STOP TWO (with restrooms also available here):

Luensman Overview Park sits atop the Lake Escarpment End Moraine. Views northerly give a glimpse of current Lake Erie and the higher and older relic shorelines of Lake Warren which United States Route 20 generally follows here, and of the even higher and older Lake Whittlesey which Webster Road follows here. Author Gilman assisted in the development of this gem in the county parks system by authoring a brochure on its geologic history, and he will give another of his hilltop lectures from the site. A nature trail, with its own guidebook at the trail head, is a nice addition to the original park and is highly recommended for those who can re-visit this stop at a more leisurely pace.

STOP THREE:

We will cross and ride the ridge of the continental divide between the Great Lakes Drainage Basin and the Mississippi Drainage Basin as we move to this stop. We will pass Bear Lake, a kettle lake at the northerly end of a broad outwash plain. We will then cross perpendicularly across a drumlin field along a town line road surveyed and cut through wilderness more than 200 years ago. Our stop is at the summit of one drumlin at a spot offering great views toward Buffalo, the area thought to be the source of the most recent glacial lobe advance southwesterly in the Erie basin and also views to the northwest, the orientation of the drumlin field and the likely source of an older pulse of glaciation that traveled across the continental divide and beyond the southerly end of what is now Chautauqua County. After this stop, we will drive through the quaint village of Cassadaga and see its three inter-connected kettle lakes as we move southerly down the easterly side of a wide valley of outwash – a filled-in finger lake perhaps?

STOP FOUR:

An excellent perch for pensive musings on geology, this is a stop above the pioneer settlement of Ross Mills with a breathtaking panorama of the wide outwash-filled valley below and the hills in Pennsylvania unreached by glaciers many miles to the south.

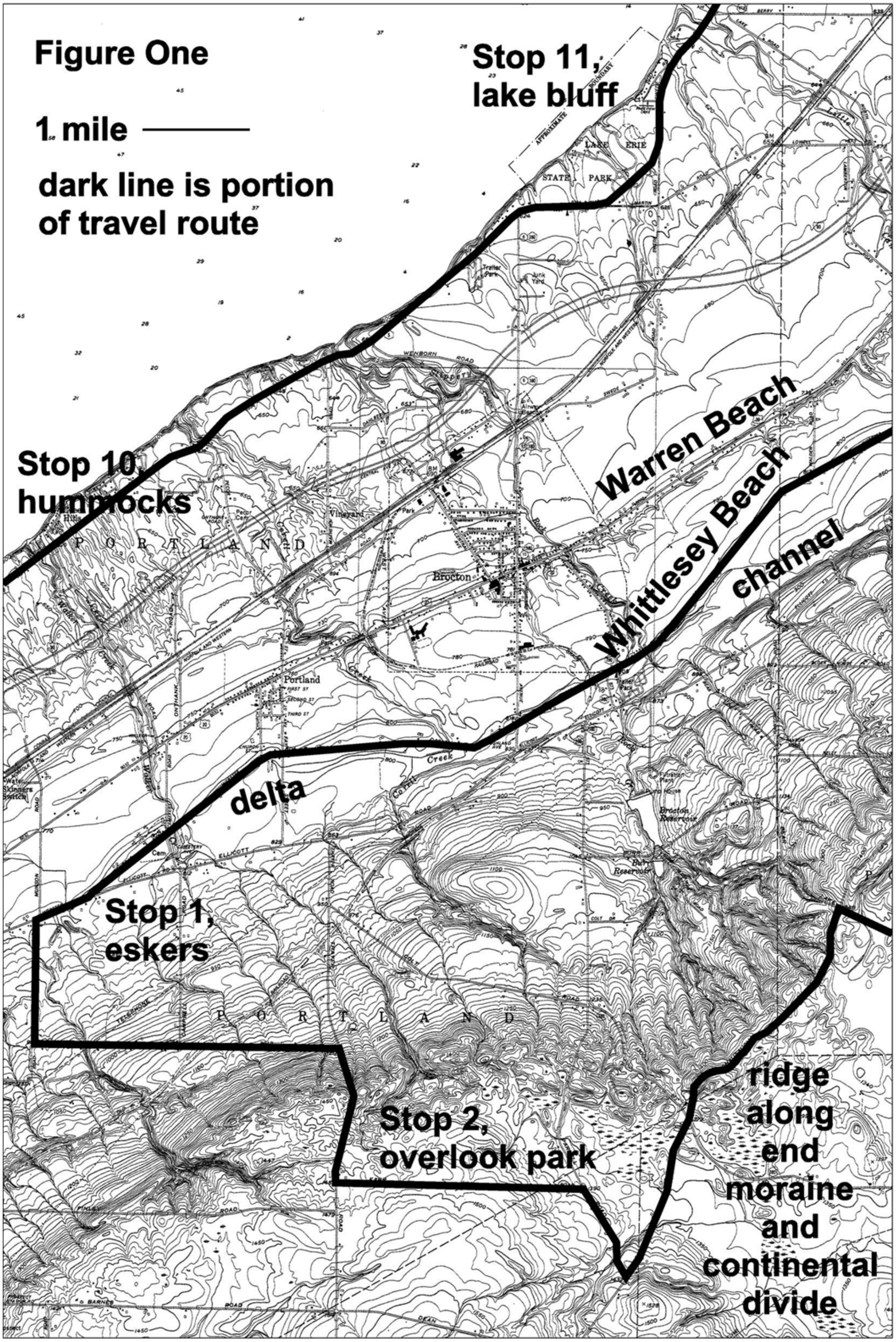
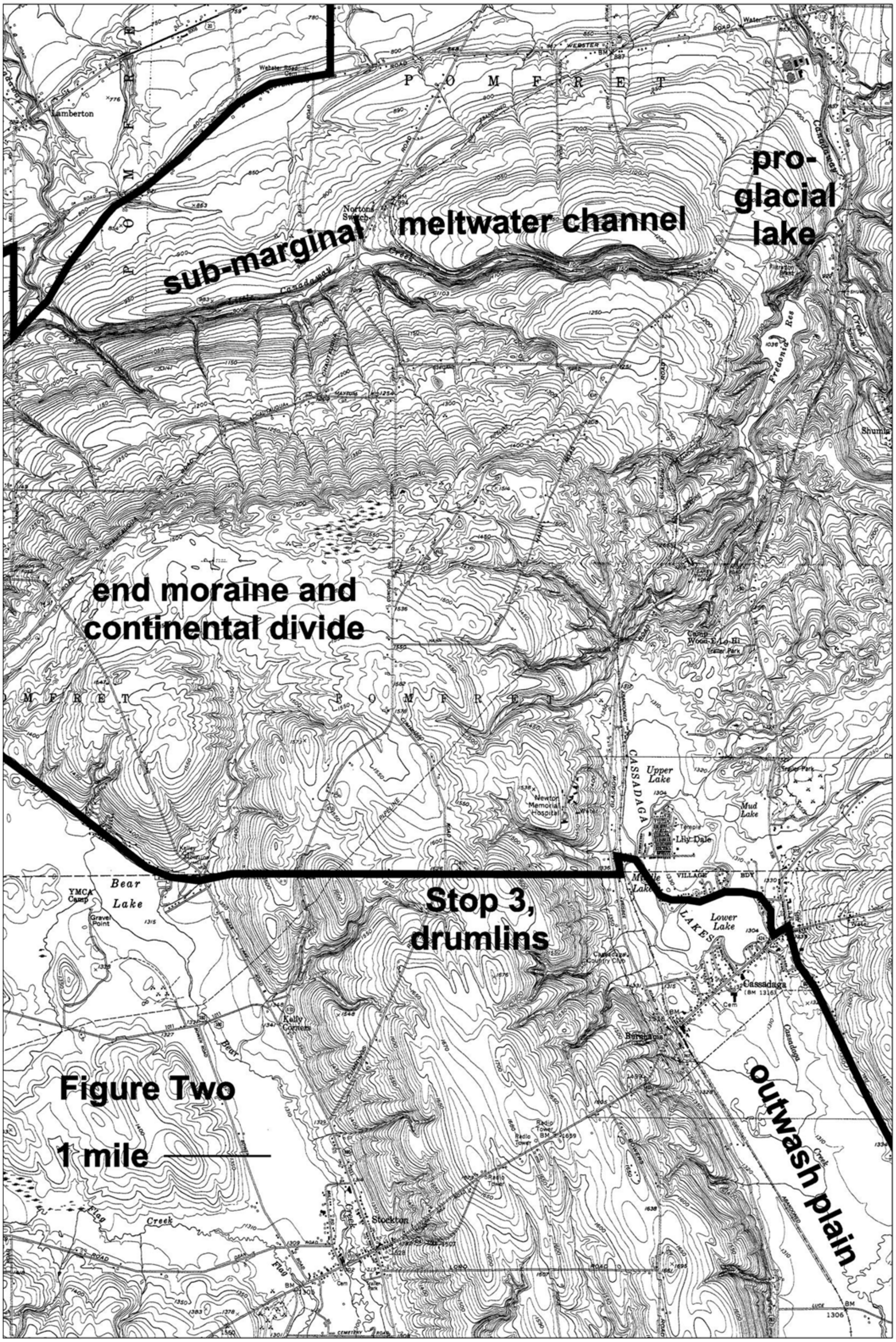
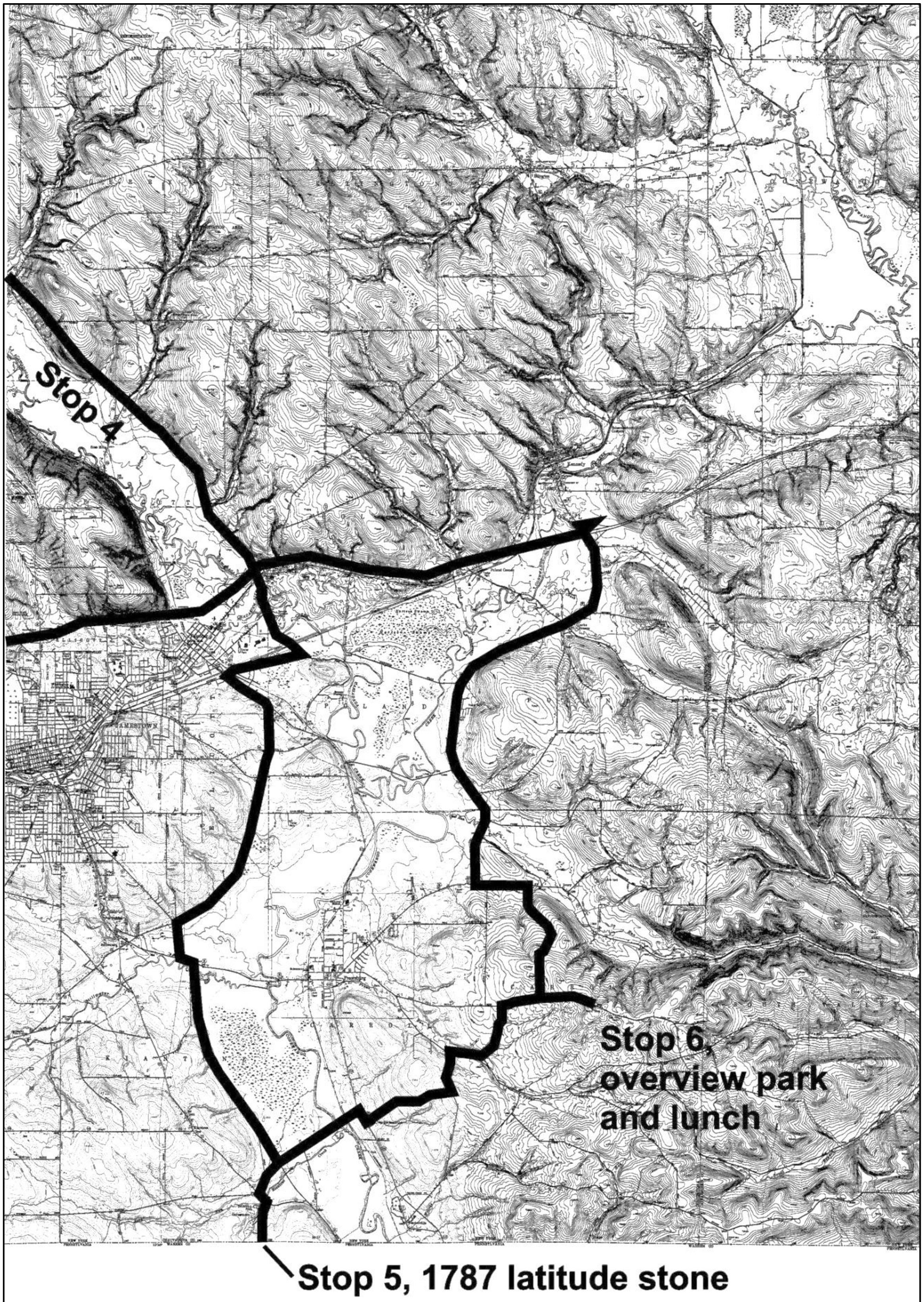


Figure One
1 mile
dark line is portion of travel route
Stop 11, lake bluff
Stop 10, hummocks
Warren Beach
Whittlesey Beach
channel
delta
Stop 1, eskers
Stop 2, overlook park
ridge along end moraine and continental divide
PORTLAND
Brocton
Portland
LAKE ERIE STATE PARK
Brocton Reservoir


sub-marginal
meltwater channel
pro-
glacial
lake
end moraine and
continental divide
Stop 3,
drumlins
outwash plain
Figure Two
1 mile
POMFRET
CASSADAGA
Upper Lake
Lower Lake
Lily Dale
Cassadaga
Bear Lake
Stockton
Kelly Corners
Mud Lake
Newton Memorial Hospital
Lamberton



Firgure Three
one mile ▬

STOP 5:

In 1786 and 1787, brothers Andrew, Joseph, and Benjamin Ellicott represented "Pennsylvania President" Benjamin Franklin – others represented New York – to blaze a survey line to Lake Erie along 42 degrees North Latitude, the boundary between the two states. About every 20 miles, astronomic readings were made by Andrew Ellicott and stones were there marked and set. We will visit a rare remaining stone. In 1781, New York had ceded lands west of the meridian through the west end of Lake Ontario to the United States, although that boundary was not established until US President George Washington ordered it surveyed in 1789 and 1790 when the Ellicott brothers represented the United States for that task. Pennsylvania hoped Chautauqua Lake would be in Pennsylvania. Figure Four is a map sent to Washington from the 1787 work of the Ellicotts for which Washington returned a letter of hope that Chautauqua Lake might indeed go to Pennsylvania, but Figures Five and Six are maps drawn by Andrew Ellicot filed, respectively, with the Holland Land Company in Amsterdam and with the Commonwealth of Pennsylvania, showing Chautauqua Lake and its surrounds were found by his survey completed and marked in 1790 to be in New York.

STOP 6 (with restrooms also available here):

Lunch at the Erlandson Overlook Park, where we have views of glacial-carved and outwash-filled valleys, including the former valley of a northerly flowing Allegheny River, and views toward the un-glaciated Salamanca Re-entrant where the river now flows south.

STOP 7 (not mapped, but location is on road log, and restrooms also available here):

The northwesterly corner of New York is marked by granite stones set in 1884 to replace the 1790 marks placed by Andrew Ellicott. Another large stone monument is near here and we will read its ornate and elaborate markings. For this fieldtrip, modern geodetic surveying was used to establish the latitude and longitude of the stones tied to the current reference ellipsoid to field-discuss the accuracies of the original surveys done centuries ago.

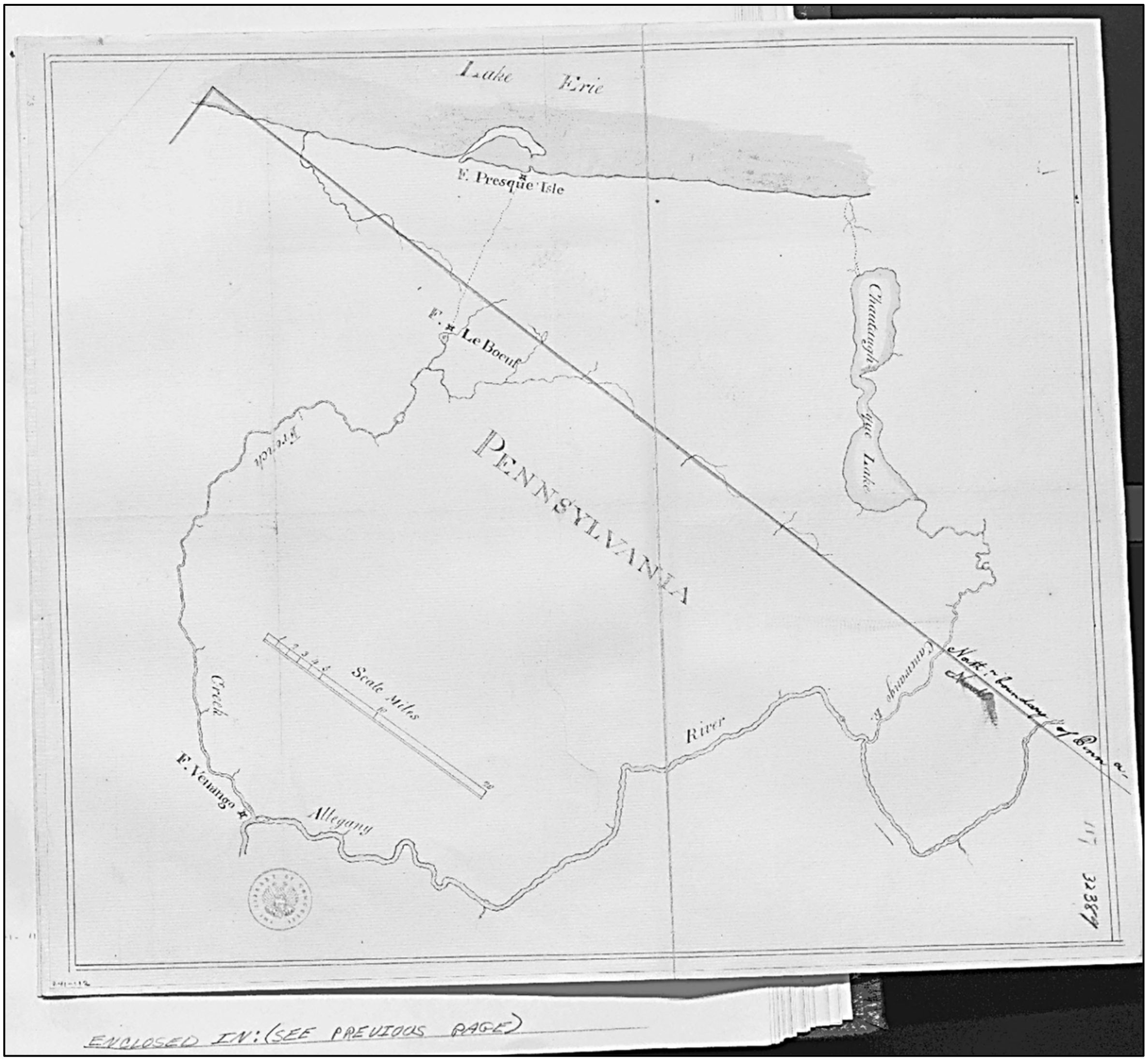
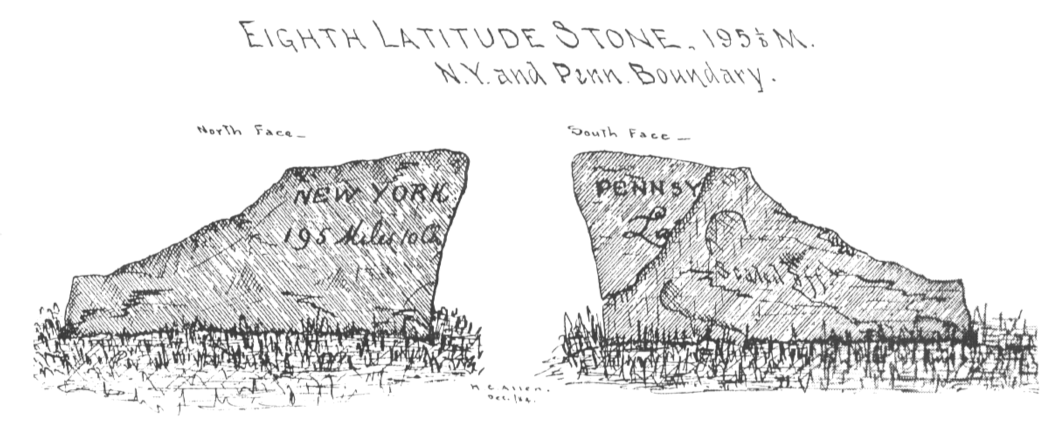
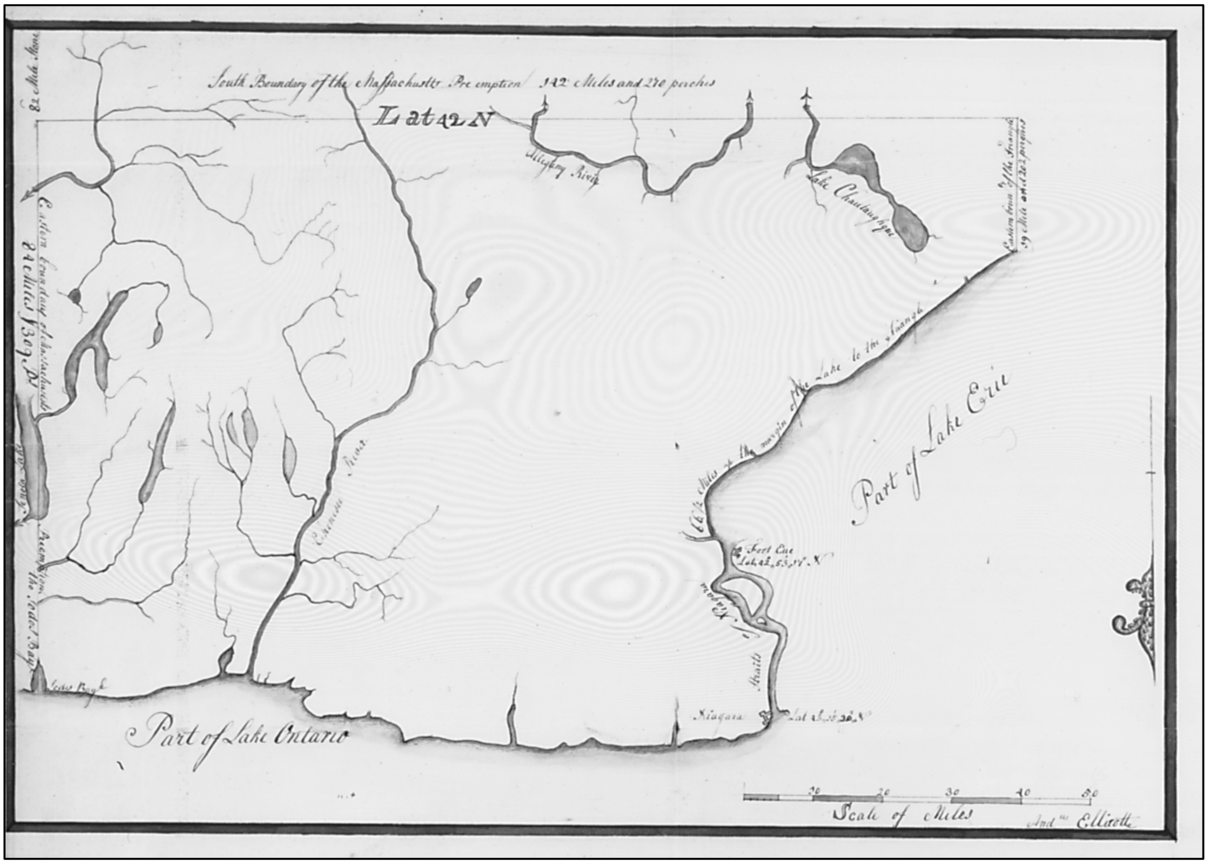
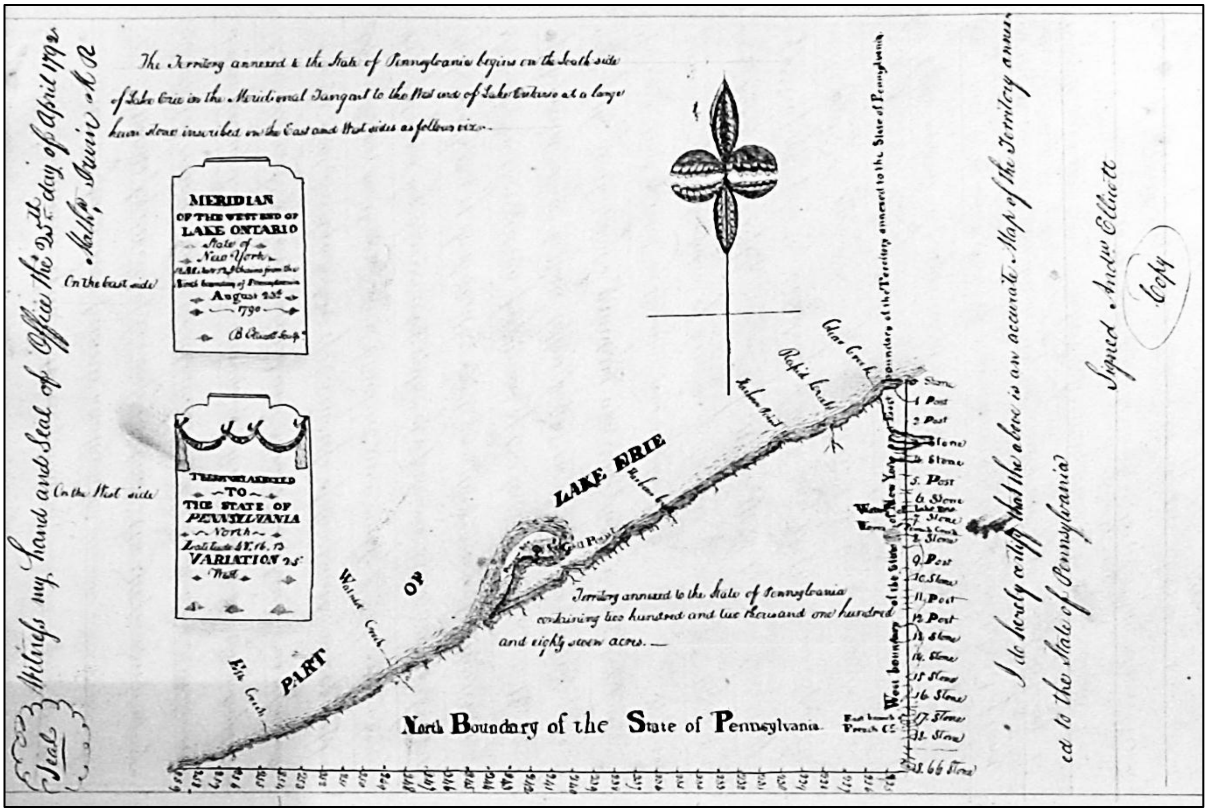


Figure Four above is a gracious scan for this research by the Library of Congress, from the original letter books of George Washington. Figure Five below is an 1884 drawing of the 1787 latitude stone set south of Chautauqua Lake. Map and stone to be discussed in the field along with Figures Six and Seven at the right that are Andrew Ellicott survey maps of the western boundary of New York.


EIGHTH LATITUDE STONE, 195⅛ M.
N.Y. and Penn. Boundary.
North Face –
South Face –
NEW YORK
195 Miles 10 Ch
PENNSY
Lat
H C Allen
Dec. 184


South Boundary of the Maſsachusets Pre emption 142 Miles and 270 perches
Lat 42 N
82 Mile Stone
Allegany River
Lake Chautaughque
Eastern boun. of the Triangle
39 Mile and 202 perches
Eastern boundary of Maſsachusets
84 Miles 309 P
Geneseo River
Part of Lake Erie
66½ Miles up the margin of the Lake to the Triangle
Fort Erie
Lat 42.53.17. N
Niagara Straits
Niagara
Lat 43.15.20 N
Part of Lake Ontario
10
20
30
40
50
Scale of Miles
Andw Ellicott



STOPS 8 AND 9 (not mapped, but locations are on road log):

These stops show fascinating structural features as the usually flat-lying Devonian strata in Chautauqua County near Lake Erie has “popped up” – and perhaps due to glacier-weight unloading. Geodetic leveling research (Figure 10, Woodbury 1992) shows continuing local post-glacial rebound, so is present isostatic adjustment a key to these past effects?

Figure 8, left, “pop up” along Lake Erie bluff near Ripley wastewater plant, Stop 8.

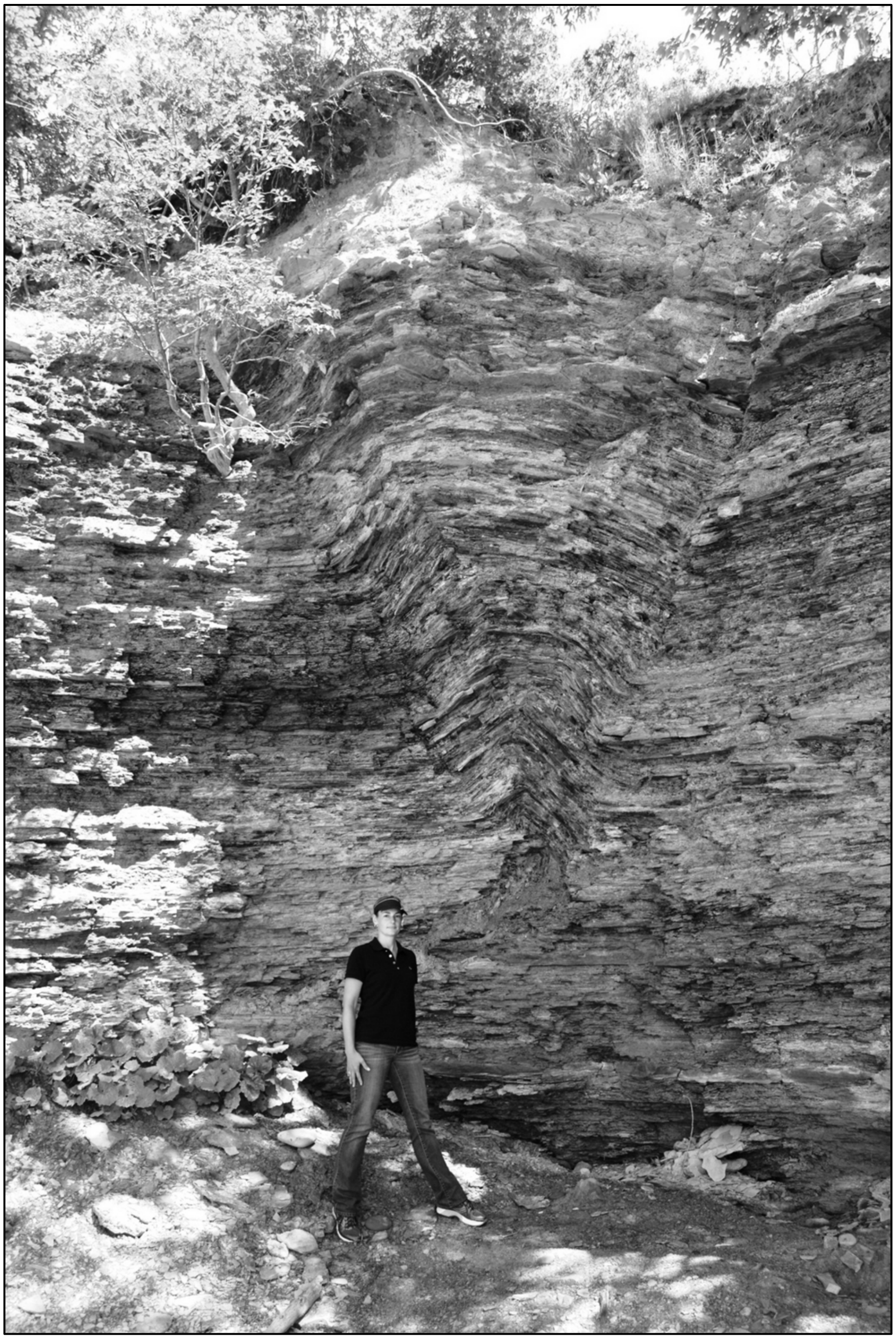


Figure 9, left, “pop up” along Lake Erie bluff at Ripley Beach, Stop 9.

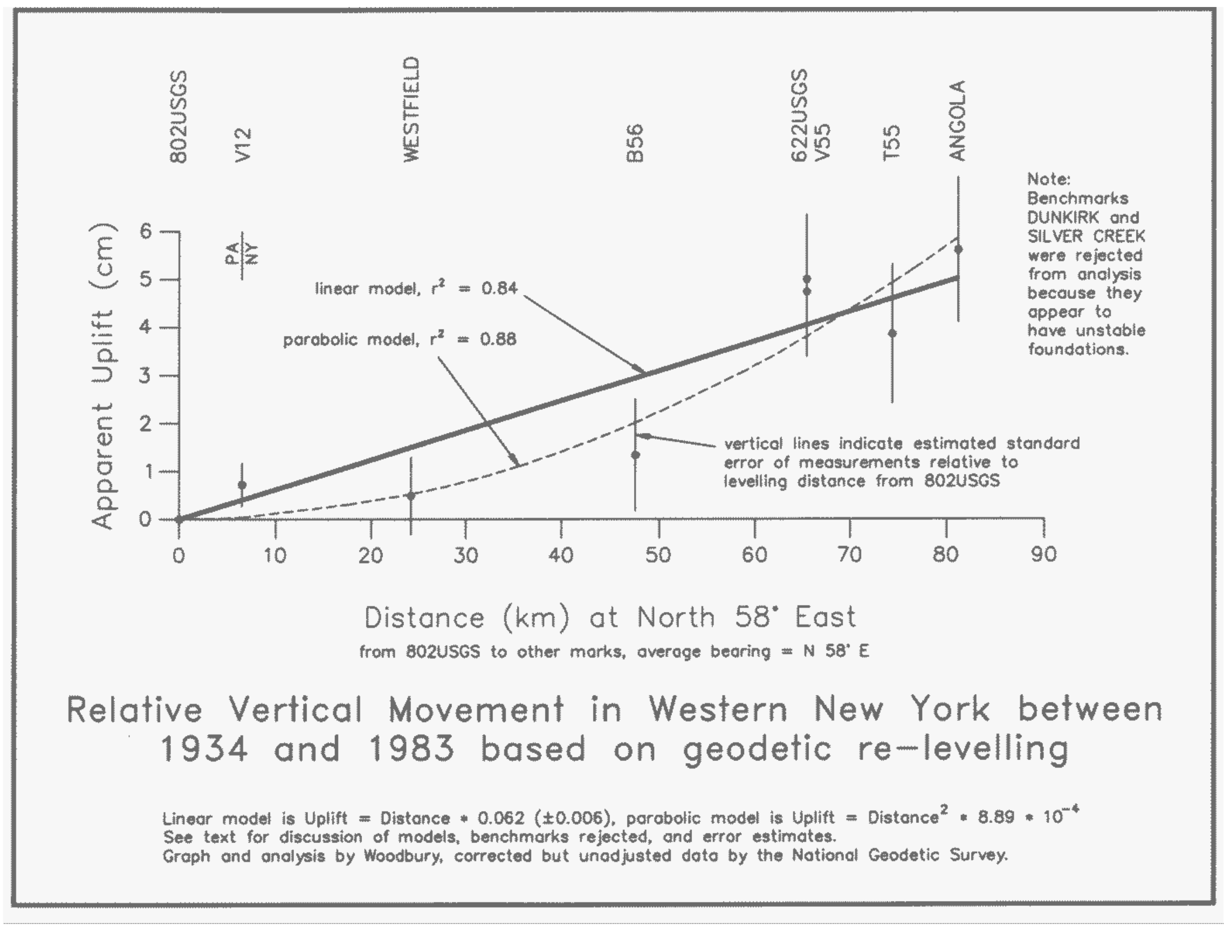


Figure 10, Geodetic Evidence for Continuing Post-Glacial Uplift in Western New York. The National Geodetic Survey (division of NOAA and successor to the US Coast and Geodetic Survey) provided this investigation with unpublished and unadjusted (not tilted to conform to a datum) survey data. The two epochs of data were identically computer-processed by NGS and corrected for systematic errors from level collimation, rod scale imperfections, atmospheric refraction, curvature of the Earth, tidal accelerations, and gravity effects (from Woodbury 1992).

STOPS 10 AND 11 (and with restrooms also available at Stop 11):

Heading back to campus we will stop to see hummocky terrain that seems to correlate with the eskers we first visited, and the research theory in progress is that these mounds are sub-aqueous recessional moraines formed as ice calved away in a westward flowing Lake Whittlesey. Lake Erie State Park takes us to a dramatic glacial stratigraphic section, a yearly adventure for geomorphology students and a pleasant Pleistocene place for our closing muse.

Figure 11: Hummocky Terrain, possible sub-aqueous recessional moraine at time of eskers

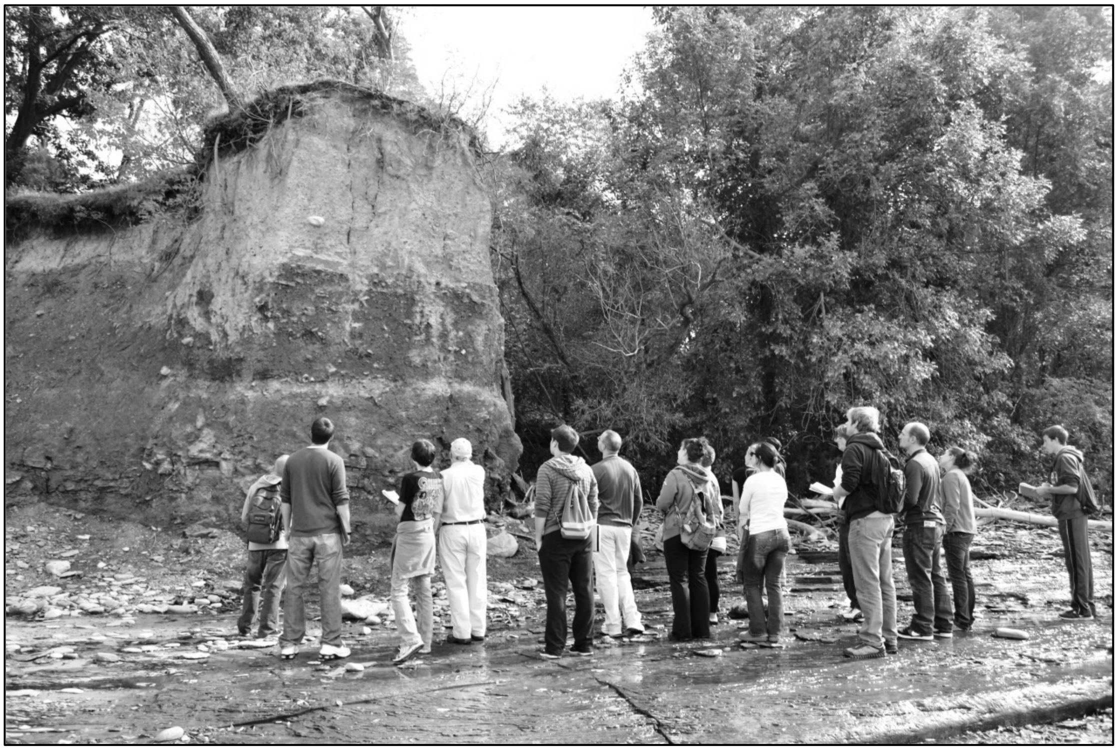


Figure 12: Lake Erie State Park, a classic classroom to study glacial-related stratigraphy

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Woodbury, R.J., and Jensen, M.D., 1990, Paddling Up a Meltwater Channel, a Late Wisconsinan Ice-Marginal Cruise Near Fredonia, New York: in Guide Book, 62nd annual meeting, New York State Geological Association, Fredonia, New York, pp. G1 – G16.

Woodbury, R.J., 1992, A Proposed Ice Margin for Late Lake Arkona or Early Lake Whittlesey, and Geodetic Evidence for Continuing Post-Glacial Uplift in Western New York: Unpublished MS Thesis, State University of New York at Fredonia, Fredonia, New York, 74 p.

SPECIAL THANKS FOR FIGURES AND MORE

Julie Miller, Historian of Early America at the Manuscript Division of the United States Library of Congress, was exceptionally gracious to provide the scan of Figure Four which she emailed with this insight to the rare and special service: "Your question was forwarded to me in the Manuscript Division since we have the George Washington papers here. The Washington papers are mounted in volumes and, as you guessed, the map was folded in half at the time it was microfilmed. We normally do not make scans from the George Washington papers since digital and microfilm images are already available, because they're fragile and irreplaceable, and because we get so many requests. However, since this image is not digitally available, I made an exception. The scan, in pdf form, is attached. Thanks for telling us about this oversight - I will try to get the full map included in the American Memory Washington papers."

Barbara Kittle, Librarian at Reed Library of SUNY Fredonia, graciously provided the high-resolution scan of Figure Six from the remarkable archives of Holland Land Company Records at Reed.

Pennsylvania's Archives provided a web link for their Erie Triangle map by Andrew Ellicott, Figure Seven.

Thanks also to Dr. Deakin and Dr. Lash in SUNY Fredonia Geosciences for encouraging this project and for editing the guidebook. Both professors bring Fredonia incredible distinction for science, both nationally and internationally. They inspire students in the ways of wise and careful science and they inspire their colleagues as well. Of course with this year not only being a NYSGA host year for SUNY Fredonia Geosciences but also the 50th anniversary reunion to celebrate the start of the department, the homecoming gathering will remind us all of the so many talented professors who created generation after generation of excellent Earth scientists starting with their careful and caring education at SUNY Fredonia Geosciences. So a special thanks too to everyone involved with and who help support the excellent programs – especially Dr. Baird and Dr. Wilson who organized all NYSGA events and alumni events this year.

ROAD LOG -- NYSGA 2013 Guidebook – Road Log for Trip A-5

This field trip will depart at 8:00 a.m. from the Services Complex at SUNY Fredonia. It is intended to only use two university vans with room for 15 visitors total in addition to four leaders and faculty. Please use restrooms before you arrive at the trip launch site. Please pick up your FSA lunch if you bought one, or go to a store before the start time and carry a bag or box lunch with you as our lunch area has nothing for sale or vending. Restrooms are at several stops on this trip, and those stops are noted in the main stop descriptions.

Miles from last point	Cumulative mileage	Route description
0	0.0	SUNY at Fredonia President's Drive (set trip miles here)
0.1	0.1	Turn right onto Central Avenue
0.5	0.6	Veer left onto Temple Street at Light
0.2	0.8	Turn right onto U.S. Route 20
0.5	1.3	Crossing Chestnut Street Following old Early Lake Warren Beach
1.4	2.7	Turn Left onto Adams Road Possible offshore bars approaching Lake Whittlesey Ridge
0.7	3.4	Turn Right on Webster Road
0.1	3.5	Passing Webster Pioneer Cemetery. This is an undisturbed Lake Whittlesey high water mark.

0.5	4.0	Crossing Farel Road Profile in Guidebook To the south is a channel
0.7	4.7	Veer Left at split onto Ellicott Road Channel visible to the right between Ellicott and Webster Road to the North.
0.9	5.6	Crossing Little Canadaway creek
0.2	5.8	Turn Right on Harmon Hill Road Crossing channel that was parallel and under the ice front
0.5	6.3	Turn Left on Webster Road Following Lake Whittlesey Ridge
2.2	8.5	Jogging into State Route 380. Bare to the right at Webster Road
1.3	9.8	Passing a grape vineyard to the right that was relocated while many cubic yards of gravel was removed to build to prisons in Portland, New York
0.3	10.1	Farmhouse on wave washed delta deposits reached by Lake Whittlesey waters. Antenna to the South is next to Luensman Overlook.
1.3	11.4	Passing Cemetery Road between roads toward distal part of the delta which contains the Portland Pioneer Cemetery.
0.6	12.0	Ellicott and Webster Roads join at foreslope of delta. Local farmer confirmed that the soil was very sandy in these fields.

Stop 1 – Eskers, get your rock hammers out here

0.2	12.2	Turn Left onto Munson Road Profile in Guidebook where all levels of Lake Warren were crossed.
0.3	12.5	Rise onto Whittlesey beach. Possibly due to the exposure of the Shumla Siltsone at this location. Crossing recessional moraines as we head up the hill.

0.6	13.1	Turn Left onto Wolebon Road
1.7	14.8	Turn Right on Thayer Road.
0.3	15.1	Turn Left into Luensman Overlook Park

Stop 2 Luensman Park (Lake Escarpment End Moraine, overlook of the Lake Plain)

0.1	15.2	Turn Left onto Thayer Road
0.4	15.8	Turn Left on Farr Rd Notice the hummocks on both sides of the road.
1.5	17.4	Turn Right onto Parcell Rd.
0.5	17.9	Turn Left onto Chautauqua Route 37
1.0	18.9	Cross State Route 380 and proceed straight onto Chautauqua Road Old road commissioned by the Holland Land Company which passes right over the continental divide.
1.6	20.5	Turn Right on Bear Lake Road.
1.0	21.5	Kettle Hole Lake Clever Store run by one of the original Geology Graduates from S.U.C. at Fredonia
0.7	22.2	Cross Kelly Hill Road Crossing Drumlins
1.0	23.2	Cross Fredonia-Stockton Road Proceed to Stop 3

Stop 3 Pioneer Cemetery at top of Drumlin on Holland Land Company Town Line

0.9	24.1	Turn Left on Frisbee Road
0.1	24.2	Turn Right on Dale Drive

		3 Kettle Hole Lakes Lily Dale Spiritual Center
1.0	25.2	Turn Right on Park Avenue
0.3	25.5	Turn Left onto Maple Avenue
0.1	25.6	Turn Right onto State Route 60 Ridge on Right covered by Drumlins.
1.7	27.3	Kame on Left
2.0	29.3	On Town Line Road You can see several miles ahead as this road was also commissioned by the Holland Land Company in 1798.
7.9	37.2	Continue Straight through light onto Gerry-Levant Road
1.3	38.5	Stop 4

Stop 4 Ross Mills Overlook

1.3	39.8	Cemetery in Valley Fill
2.9	42.7	Straight ahead the outlet of Cassadaga, Chautauqua, Conewango, and Chadakoin Rivers all came together
0.5	43.2	Proceed Straight ahead
0.9	44.1	Turn Right on New York Avenue (?) Storage facilities for the Jamestown aquifer
0.9	45.0	Turn Left onto State Route 380 (Work Street)
4.2	49.2	Turn Left onto Martin Road
0.6	49.8	Turn Left onto State Route 60
0.1	49.9	Turn Right onto U.S. Route 62
3.0	52.9	Turn Right onto Riverside Road
0.7	53.6	Turn Left on Kiantone Road

0.2	53.8	Turn Right onto Sturdevant Road
0.5	54.3	Turn Right onto Honey Lane

Stop 5 Shale Latitude Stone Established by Andrew Ellicott in 1787

0.6	54.9	Turn Left on Sturdevant Road
0.1	55.0	Turn Left on Kiantone Road
0.2	55.2	Turn Right on Riverside Road
0.5	55.7	Continue on Riverside Road and Cross U.S. Route 62
1.3	57.0	Turn Right on Chautauqua Route 53
0.2	57.2	Turn Left on Austin Mill Street.
1.3	58.5	Turn Left on Bain Road.
0.6	59.3	Turn Right on Frew Run Road.
0.4	59.7	Turn Left on Peterson Road Salamanca re-entrant to the right.
0.5	60.2	Turn Right onto Oak Hill Road.
1.5	61.7	Turn Right into Erlenson Park.

Stop 6 Erlandson Park Overlook (Lunch Stop)

0.0	61.7	Turn Left onto Oak Hill Road.
0.8	62.5	Turn Right onto Scott Road.
1.7	64.2	Turn Left onto Ivory Road.
0.8	65.0	Turn Right onto U.S. Route 62
6.1	71.1	Turn Right onto circular entrance ramp for I-86
27.1	98.2	Turn Right onto Sherman Exit 6

0.3	98.5	Turn Right onto Route 76N Kipp Street
0.3	98.8	Bear left at fork staying on Route 76N
0.1	98.9	Turn Right onto Route 76N
11.1	110.0	Passing Ripley Water Treatment Plant
0.6	110.6	Passing Lavurus Road (Crossing Lake Whittlesey Beach)
0.4	111.0	Stay on Route 76N
0.1	111.1	Turn Left onto State Route 5
2.3	113.1	Proceed along Route 5 to the trailer park near the Pennsylvania State Line which is Stop 7

Stop 7 Three boundary monuments with an excellent story.

0.1	113.4	Turn Around (Left) out of Trailer Park onto Route 5 East
2.3	115.7	Return to Ripley Wastewater Treatment Plant for Stop 8

Stop 8 Pop-Up at Lake Shore by Ripley's Wastewater Treatment Plant

2.9	118.6	Turn Left onto Ripley Beach Road
0.2	118.8	Proceed to the Lake Shore

Stop 9 Pop-Up at Ripley Beach

0.2	119.0	Turn around and proceed South on Ripley Beach Road to State Route 5
0.0	119.0	Turn Left onto State Route 5 East
10.2	129.1	Turn Right into Small Driveway to Stop 10

Stop 10 Hummocky Terrain where there should be lake bottom sediments.

1.0	130.1	Passing Walker Road
4.0	134.1	Turn Right into Entrance for Lake Erie State Park, bear right by the gate house and park near bathrooms at far left (westerly side) of the last parking lot.

Stop 11 Lake Bluff Exposure at Lake Erie State Park

1.0	135.1	Leaving Lake Erie State Park and Proceeding back onto State Route 5 East
0.9	136.0	Turn Right onto Van Buren Road
3.4	139.4	Proceed onto Matteson and turn soft Left onto Brigham Road at Temple Street
0.2	139.6	Proceed Right onto Athletic Fields Road
0.1	139.7	Proceed Left onto Ring Road
0.6	140.3	Turn Left onto University Parkway
0.1	140.4	Turn Right on Academic Avenue
0.1	140.5	Turn Left onto President’s Drive

Avulsion by Chautauqua Creek

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INTRODUCTION

During December 2005 Chautauqua Creek cut through a high (10 to 30 meters) interfluve abandoning an oxbow of about 100 meters diameter. Sections of the interfluve were composed of glacially-deposited and buried outwash and shale bedrock, originally photographed by Dr. Ernie Muller ca.1960 (Muller 1963). The 1999 NYSGA trip to this site examined pre-avulsion features. The features of the 2005 break-through and 5-to-8 meter drop in stream-bed elevation are visually crisp. The location is an outstanding example of directly-juxtaposed, temporally-contrasted features. Interfluves preserve the contents of a glacially buried-valley that was cut obliquely by modern Chautauqua Creek; shale-sediment buried-valley contacts are preserved in modern valley walls. The approach to this site involves splash-hiking the shale creek-bed for a mile or more. The route begins down a gravel trail with switch-backs, about 300 feet of relief. Cone-in-cone structures, pop-up folds and fossils can be viewed in the creek-bed shale along the way. In addition, Chautauqua Creek serves as the primary drinking water source for the Village of Westfield. Water supply history, watershed protection and current/future source water issues will also be discussed. This trek is very scenic, having been considered as a possible location for a state park in contention with Allegheny State Park. Above-the-ankle soft boots or other foot-wear that can get wet are good options for the creek walk.

BEDROCK GEOLOGY

Although not part of our immediate objective, we will bring with us copies of the 1990 NYSGA Guidebook article by Gilman and Berkley. Their article included one of the stops that we will visit (our Stop 2). Their trek down Chautauqua Creek (and other parts of their article) paid particular attention to brittle structures in the bedrock. We will point these out while we hike to our Stop 2. We have been especially interested in the timing of the development of the pop-up folds. In scanning cliff walls of western and central New York streams, we note the absence of these folds. On the other hand, pop-ups occur routinely at quarter or half mile intervals in stream beds or Lake Erie cliffs. Also noteworthy is that one-meter amplitude folds are very commonly associated with basal tills. The non-glacial pop-ups are apparently related to erosional unloading.

SURFICIAL GEOLOGY

While looking at buried valley fills in northern Chautauqua County we have noticed that the fills are not internally deformed unless involved in modern landslides. The exception to this scenario occurs where the fills include near-surface outwash and lacustrine sediments among the Lake Escarpment and Lavery Moraines (Wilson and Boria 1999). These settings show ample evidence of deformation from the melt of underlying ice. Surface land morphology shows well-defined kettle holes and gently undulating surfaces with 10 or more meters of relief. Gravel pits show dips that range to between 50 and 90 degrees. Outcrops show folded and faulted sediments.

This trip will provide an opportunity to discuss recent meander incision across a buried valley wall (Figure 1). Our sketches and photography, in addition to published information, allow for a nearly complete reconstruction of meander movement during recent decades, and final avulsion of the meander by Chautauqua Creek.

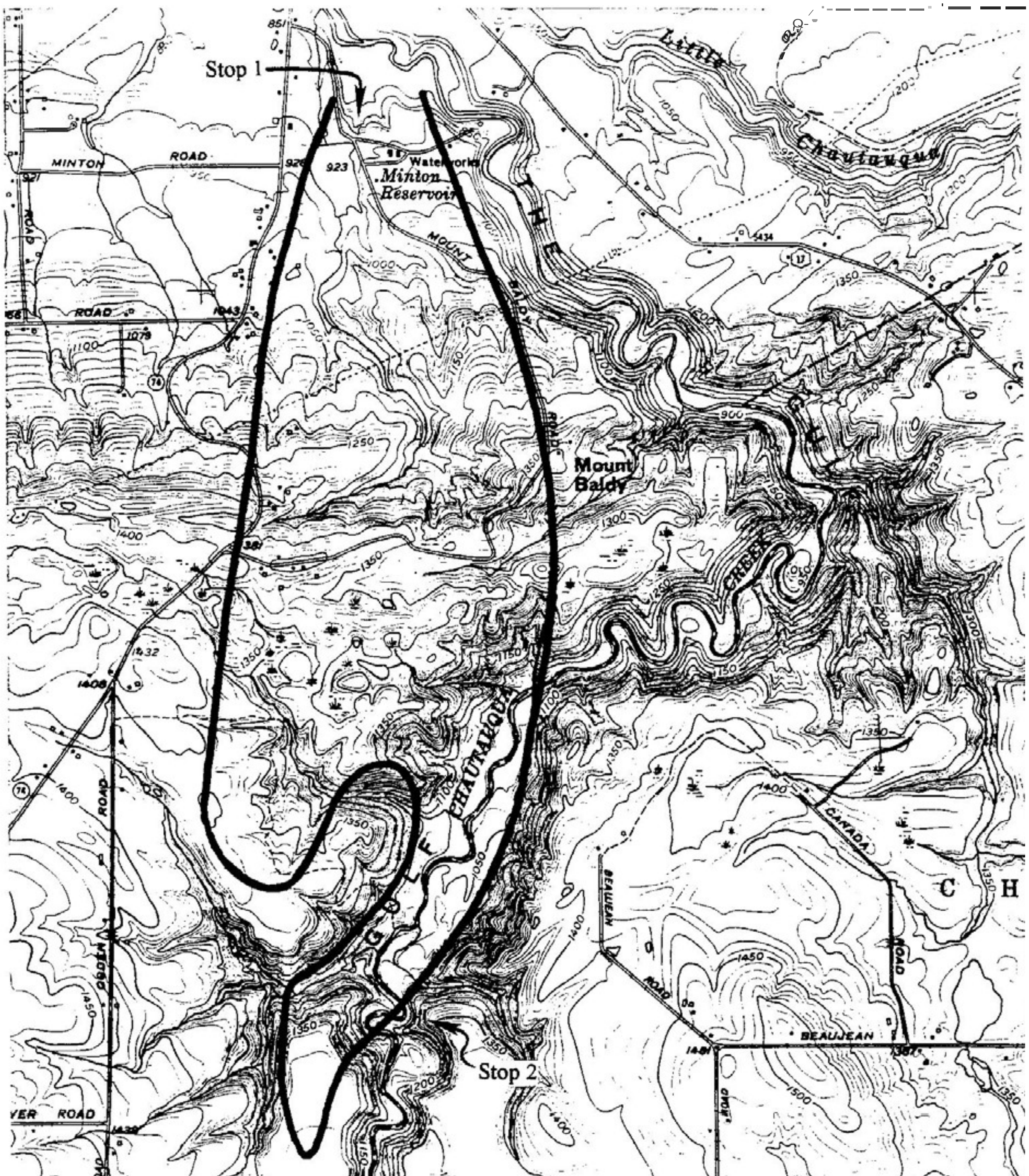


Figure 1: Topographic map of the region, showing stop locations and approximate boundary of deeply buried bedrock. This is based primarily on mapping of the elevations of exposed bedrock in tributaries (courtesy of the late Ken Fahnestock). Approximate Scale 1" = 2,000'

Figures 2 and 3 show the historic positions of the meander loops at Stop 2 (the undeformed sediments at Stop 1 are exposed by a combination of natural gully growth and reservoir outlet erosion). From the dates it can be seen that the stream alternates periods of erosion between the two faces of the meander loop, which led to the avulsion of the deposit in 2005.

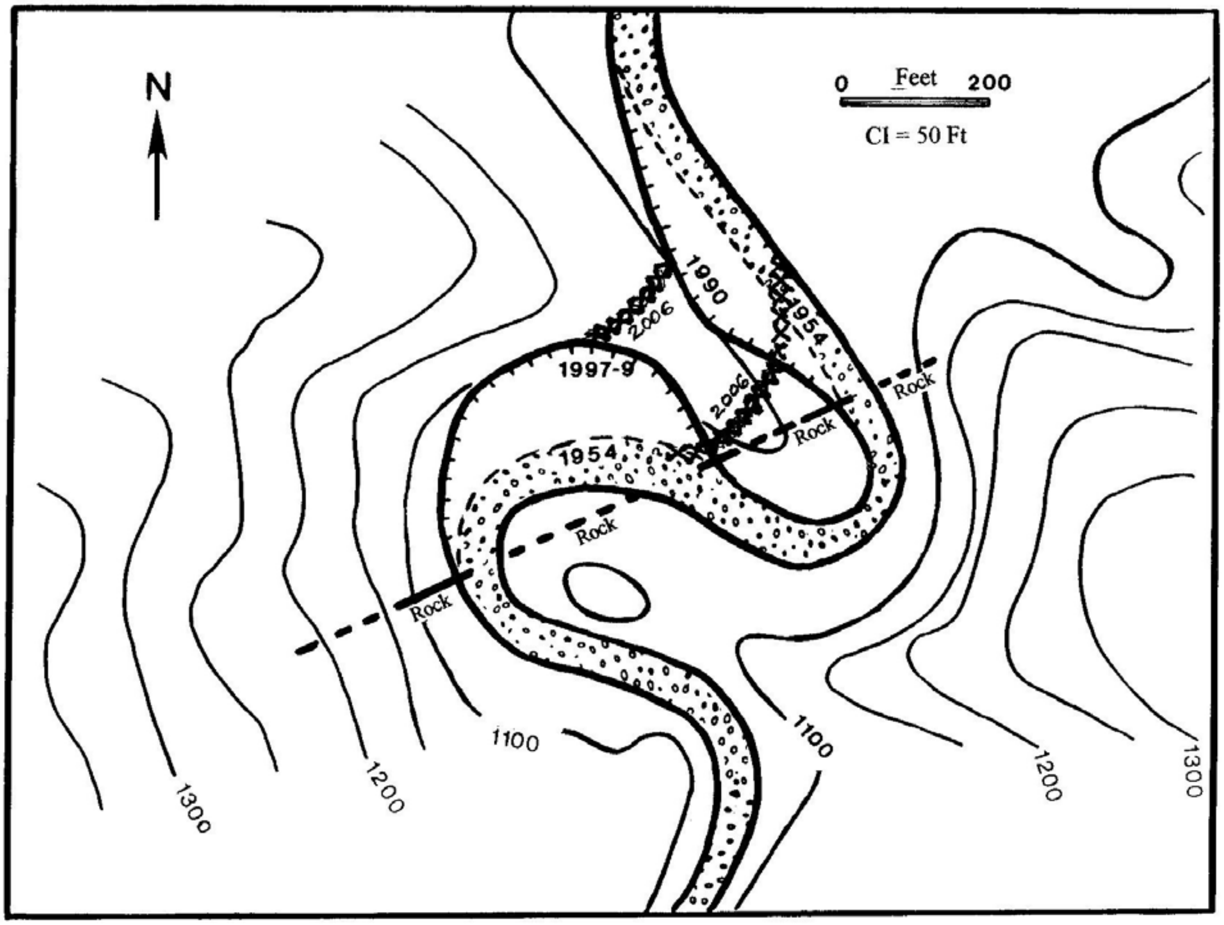


Figure 2: Map showing 1954 location of Chautauqua Creek with locations and dates of lateral erosion since then, followed by final avulsion of the deposit which occurred in December 2005 and photographed in February 2006. Further erosion has occurred since then.

Figure 4 presents a sketch compiled from our periodic visits since 1988. Figure 5 gives some food for thought. To what extent did Lake Escarpment glacial oscillations create this outcrop as opposed to a more complicated history that could include earlier glacial episodes? Lack of radiometric or other dates makes the answer difficult. Another idea for discussion … are the gravels at the base of the outcrop from subglacial processes?

Figure 3: Post-avulsion aerial photograph taken in 2008. The position of the center line of the creek in 1954 is shown with a single heavy dashed line. The position of the creek in 2000 is shown with thin continuous lines that depict the approximate water channel. (Source: Chautauqua County GIS)

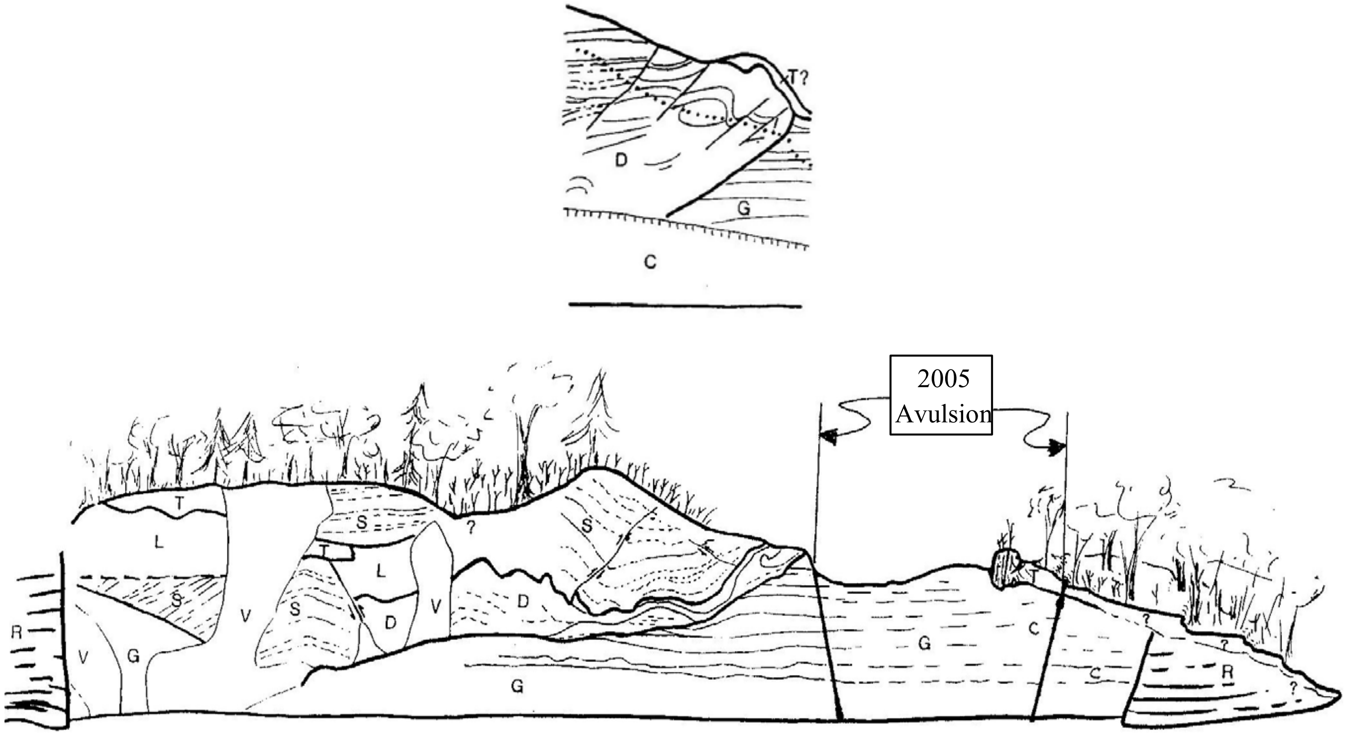
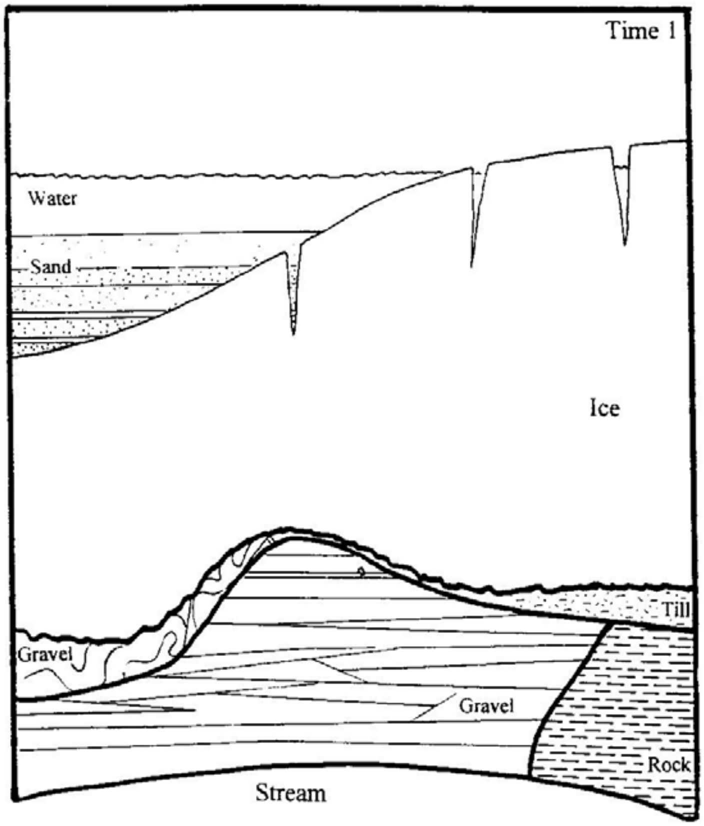


Figure 4: Composite section of the south face, primarily representing sediments as exposed in 1997, and showing the approximate location of the 2005 avulsion. Upper drawing is central section as exposed in 1988 (dotted line matches 1997 skyline). Symbols are: G = Gravel; D = Disturbed gravel; S = sand; L = lake sediments; T = till; V = vegetation; C = covered.

Time 1 shows the glacier stagnant after deformation of underlying gravel (left) and deposition of till (right).



Time 2 shows subsequent let-down of sand layers as they would have been seen prior to avulsion. Till at upper left post-dates deformation (and till at upper right may also).

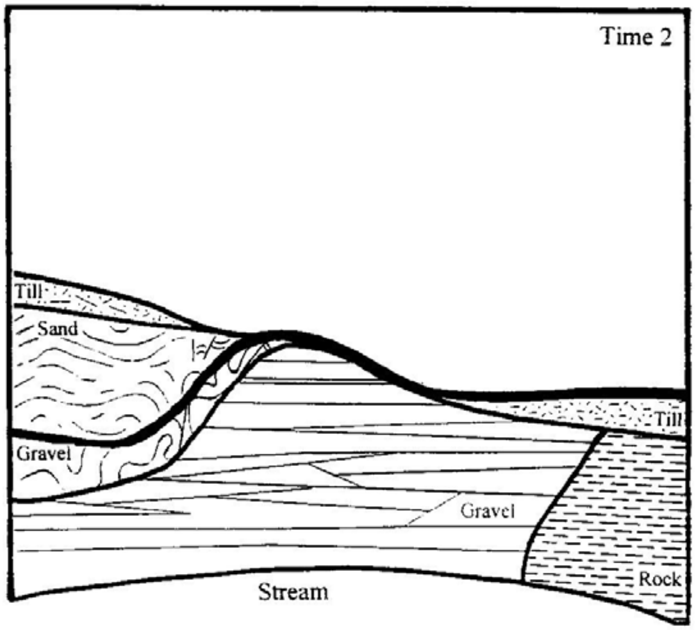


Figure 4: Schematic diagram of the central and eastern portions of the south face.

Figure 5: 1988 photograph of the south face

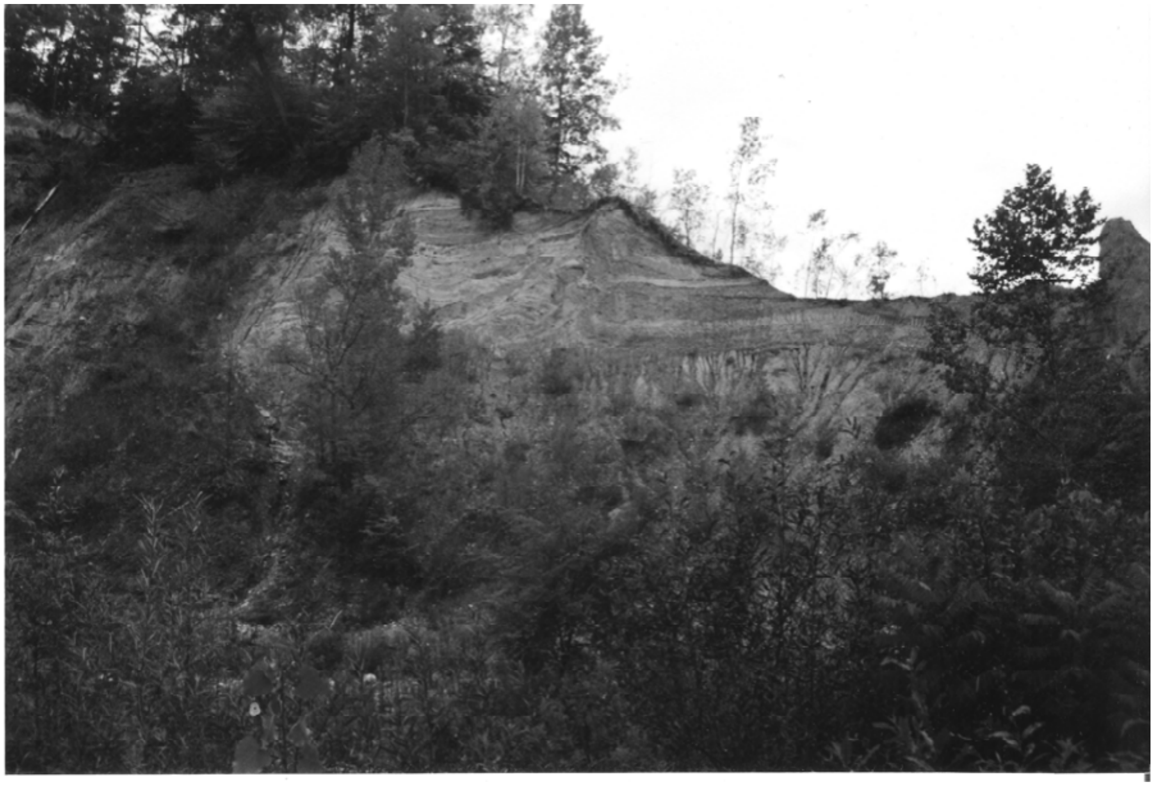


Figure 6: 1993 photograph of the south face. Note lack of vegetation on right side of photo compared to 1988

DRINKING WATER SOURCE

The Village of Westfield relies on the Chautauqua Creek watershed for drinking water. They serve a residential population of 4,000, a number of commercial businesses, three fruit processing plants, the Westfield Central School and the Westfield Memorial Hospital. The village is situated along the Lake Erie plain on and between glacial Lake Warren and Lake Whittlesey beach ridge deposits. Micro-climates created by the proximity of Lake Erie, along with the presence of the sand and gravel beach ridge deposits, make the Lake Erie plain an excellent grape growing location. Average daily water demand is approximately 0.5 MGD but, in the fall during grape processing season, it increases to over 1.0 MGD.

The first public water supply and distribution system to serve the village was constructed in the early 1890's. This system conveyed water from Chautauqua Creek to the village through a gravity pipeline whose intake was located several miles upstream from the present day water treatment plant. Much of the pipeline was laid along the creek bank and was subject to breaks caused by stream erosion, making it a high maintenance system. Water flowed from the source, through the village distribution system and up to an uncovered reservoir where it was stored for later use. The drinking water received no type of treatment until 1915, when a water-borne typhoid fever outbreak occurred in Westfield creating a serious need for chlorination. Eventually this system could not meet village water needs so, in 1939, the Minton Reservoir was built on a tributary to Chautauqua Creek. The watershed area of this 55 MG reservoir is just 0.7 square miles (448 acres), and was designed to provide only a portion of the water demand. The primary source of water to the village continues to be from Chautauqua Creek, which has a watershed area of approximately 27 square miles (17,280 acres). A low-flow diversion dam fitted with high capacity pumps transfers water from the creek to the reservoir when creek turbidity is relatively low.

In 1951, a conventional filtration plant was constructed consisting of coagulation, sedimentation, rapid sand filtration, chlorination and fluoridation. Increasingly stricter drinking water turbidity standards have been established by EPA and NYSDOH (prior to 1962: 10.0 NTU, 1962: 5.0 NTU, 1977: 1.0 NTU, 1988: 0.5 NTU and 2005: 0.3 NTU). These increasingly stringent standards along with sporadic high turbidity events in the source water caused the village’s drinking water to be frequently out of compliance with the turbidity regulation.

By the mid-1980s the Minton Reservoir had lost about 15% of its original capacity to sedimentation (Wilson and Boria 1999). Two approaches were taken to address these issues. The first is improved watershed management; the second is construction of a new filtration plant in 1995. Improved watershed management included:

- Activities within the Minton Reservoir and Chautauqua Creek watersheds that contribute to the problem (i.e., logging, oil and gas exploration, etc.) are more carefully managed, especially on the 1,400 acres of watershed land owned by the Village.
- The Village updated its Watershed Rules and Regulations (10NYCRR, Title 10, Part 105) to address changes in land use and modern issues unforeseen when the original regulations were enacted in 1933. Watershed Rules and Regulations give the Village legal authority to address violations uncovered during watershed inspections.
- Causes of turbidity including landslides and stream down-cutting in the creek feeding Minton Reservoir were treated using direct structural controls (bank protection and grade stabilizers).

Reduction of stream erosion, improved watershed management and major upgrades to the Westfield Water Treatment Plant dramatically reduced raw and finished water turbidity. Prior to 1995, finished water turbidity often violated NYS Health Department standards, increasing the risk of exposing water customers to microbiological contaminants, which required immediate public notification and sometimes boil water orders.

Since watershed and filter plant improvements have been made, the Village has been in significant compliance with turbidity standards. Finished water turbidity is now consistently below 0.1 NTU.

REFERENCES

Gilman, R.A. and Berkley, J., 1990, A few of our favorite places, *in* New York State Geological Association 62nd Annual Meeting Field Trip Guidebook: SUNY Fredonia.

Muller, E.H. 1963, Geology of Chautauqua County New York part II, Pleistocene geology: New York State Museum and Sciences Service Bulletin No. 392, Albany, NY 60p.

Wilson, M.P., and W. Boria, 1999, Holocene meander incision imposed across a buried valley wall, *in* New York State Geological Association 71st Annual Meeting Field Trip Guidebook: SUNY Fredonia.

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ROAD LOG: AVULSION BY CHAUTAUQUA CREEK

Miles from last point	Cumulative mileage	Route description
0	0.3	From the intersection of Route 20 and Route 394, drive west on Route 20 crossing over the bridge over Chautauqua Creek then turn Left (south) onto Chestnut Street (County Route 21).
1.2	1.5	Turn Left (southeast) onto Mt. Baldy Road.
0.4	1.9	**STOP 1**. Outlet ravine of Minton Reservoir. Park on the roadside. This will be a brief stop to peer into the ravine and observe the nature of the buried valley fill and contrast these materials to those at Stop 2 and to see the Village of Westfield's Minton Reservoir.
		Backtrack (northwest) down Mt. Baldy Road.
0.4	2.3	Turn Left (south) onto Chestnut Street (County Route 21).
2.2	4.5	Turn Left (south) onto Ogden Road
1.5	6.0	Turn Left (east) onto Taylor Road
0.6	6.6	Parking at end of Taylor road (remains of gravel pits in kames).
		STOP 2. Wet foot trek into Chautauqua Gulf (approximately a 1.3 mile hike one way).

Stop 1: Minton Reservoir (Lat: 42.2980; Long: -79.5750)

Stop 2: Avulsion by Chautauqua Creek (Lat: 42.2633; Long: -79.5742)

MICROBIALITES WITHIN THE EURYPTERID-BEARING BERTIE GROUP OF WESTERN NEW YORK AND ONTARIO, CANADA.

Samuel J. Ciurca, Jr., Rochester, New York

Figure 1. Large stromatolite mounds in upper beds of the Ellicott Creek Breccia, Fiddlers Green Formation, Bertie Group at the Ridgemount Quarry South (RQS), Niagara Peninsula, Ontario, Canada. The reefs (note 28 cm. rock hammer in upper middle of photo) are comprised of "topographic waterlime" and breccia.

The Bertie Group is well known throughout the world as the repository of a fantastic suite of relatively rare arthropods – the eurypterids, and specimens have found their way into museums worldwide. Eurypterid specimens have been collected by the thousands ever since their discovery in 1817, but some aspects of their occurrence have gone mostly unnoticed. Increasingly, in recent years, I have noticed more and more that many (if not most) occurrences are associated in one way or another with a variety of microbialite morphotypes.

The occurrence of the eurypterid-bearing waterlimes is part of a little-understood cyclic sequence (Ciurca, 1973 and later) and it is now obvious that the newly observed microbialites (stromatolites, thrombolites and algal mats) are inherently involved with this cyclicity. Researchers should find the Bertie Group ripe for study in what otherwise sometimes looks like a boring sequence of dull, relatively unfossiliferous rocks.

The Bertie Group, of course, probably inherited part of its depositional regime from the earlier Salina Basin where previously very thick redbeds (Vernon-Bloomsburg), dolostone and evaporites (Syracuse Fm.) and dolomitic and argillaceous beds (Camillus Fm.) were laid down. Judging from what we see in upstate New York, the outcrop belt follows a northern shoreline and some of the units within the Bertie Group even appear like strandline deposits (upper beds of some of the waterlime units).

Bertie Group

FORT HILL WATERLIME

Algal Mounds - Microbialites

The Fort Hill Waterlime (Wl.) occurs at the base of the Bertie Group and is overlain by the Oatka Formation, a shaly dolomitic sequence with no known fossils, but with relict evaporite structures, especially salt hoppers (as at Morganville and Akron Falls). See Ciurca, 1973, 2011 for further descriptions.

The Fort Hill has lower and upper parts – the lower is the eurypterid-bearing, straticulate waterlime with salt hoppers up to six inches in size. This waterlime can be considered a planar stromatolite. The upper unit is more massive, irregularly-bedded, finely crystalline dolostone, but little is known at present about the nature of the mounding observed. Only small ostracods and salt hoppers have been observed within the mounds. The distribution of the Fort Hill is from at least the type area (Fort Hill and Buttermilk Falls north of LeRoy) east to Phelps, New York. It is a marker bed for the region (See Ciurca, 1973).

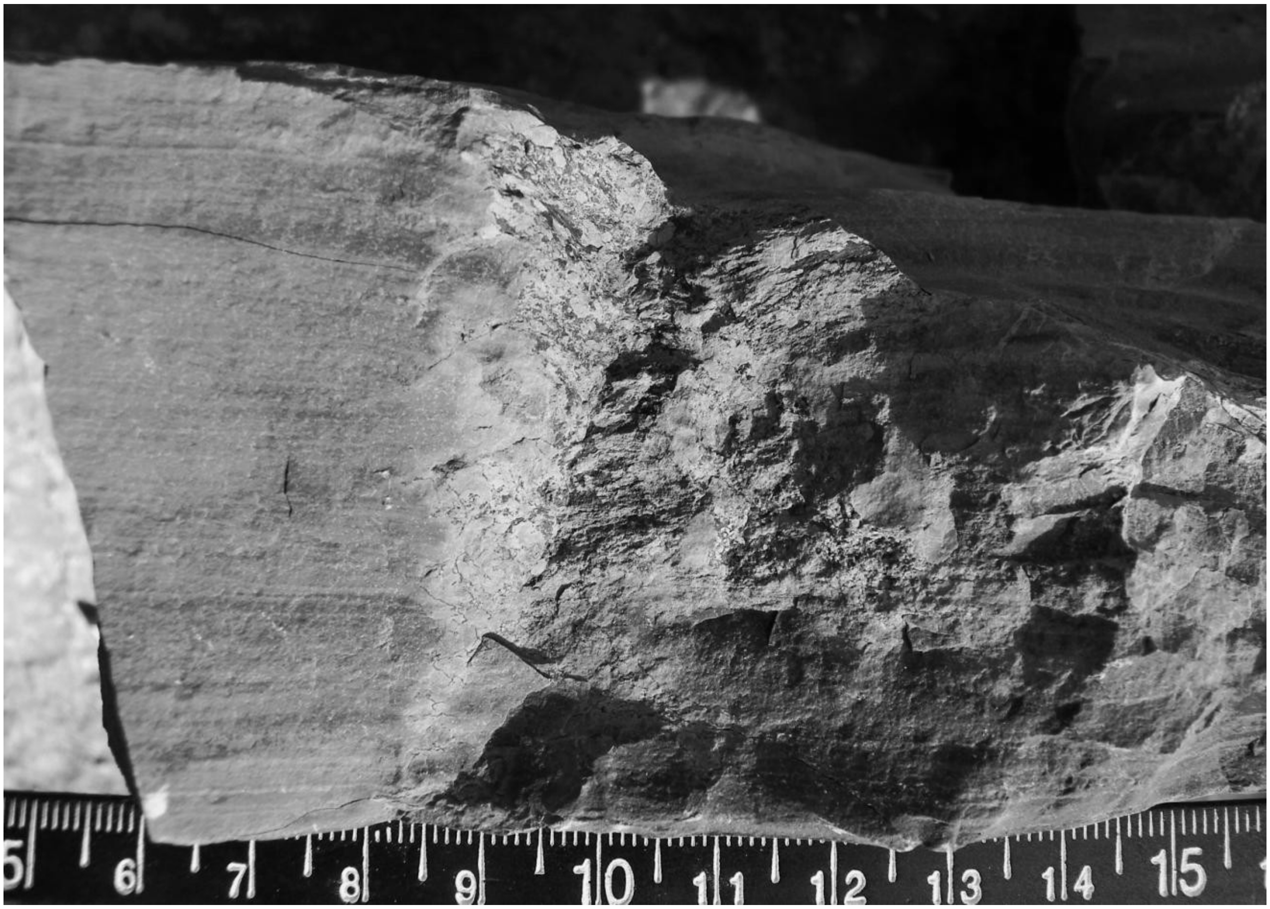

Figure 2. Lower Fort Hill Waterlime, finely straticulate (planar stromatolite) grading into disruptive halite pseudomorphs at right. This is the eurypterid bed (*Eurypterus* sp.) with ostracods and cephalopods.

Marking the base of the Bertie Group in western New York, the Fort Hill Wl., at the type section, is underlain by several meters of the Camillus Formation with mudcracked horizons and little or no fossils.

FIDDLERS GREEN FORMATION

Most of the microbialites observed within the Bertie Group are now recognized in nearly all of the Members and are of several types. The areal distribution is amazing as the microbialites occur, following the outcrop belt, over a distance of more than 300 miles. The most impressive structures are the great stromatolite mounds of the Ellicott Creek Breccia and the thrombolites of the Victor Member.

Morganville Waterlime (Member)

At the type section at Morganville, New York (Black Creek), the Morganville Waterlime is only 4 feet thick and simply a typical waterlime but with few fossils, mostly ostracods. However, it appears to thicken eastward and includes, possibly, a eurypterid fauna at Cayuga Junction on the east side of Cayuga Lake.

In 2012, I was able to view strata below the Victor Member at RQS in Canada for the first time in years as they were blasting the main mass of the Fiddlers Green Fm. away revealing the lower strata. I found the Morganville Waterlime again in what looked initially like the typical waterlime I expected, but with large circular mounds revealed at its top see below)

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Figure 3. Circular stromatolitic mound, one of several, located on newly exposed quarry floor below the Victor Dolostone. The hammer is 27.5 cm. long. The floor is now flooded, but may become available in the future.

The mound was very resistant to sampling, but a chunk was finally released with a little prodding. The chunk from the mound revealed the stromatolitic nature of the mounds and is shown in the photo below - note the dark rind at top (the specimen, 120712, is in the PMNH).

Figure 4. The sample from the circular stromatolitic mound, fine-grained waterlime typical of the Morganville Member of the Fiddlers Green Fm.

Recent observations by the author with Carlton Brett and Matt Vrazo, reveal additional microbialite structures at Phelps, New York associated with the Victor 'A' Member.

Victor Member

In Canada, large thrombolites occur within the Victor Member (see photo, page 474 in Ciurca, 1994) and microbialites of one form or another can be seen throughout the distribution of the member. At Phelps, New York, the Victor Member is distinctive with a limestone at its base (A), typical massive dolostone in the middle (B), and an upper limestone unit (C,D). Current research is revealing additional fascinating and large structures within this interval.

Much of the Victor Dolostone seems to consist more of algal mat material, irregular bedded strata with low amplitude stylolites and occasional eurypterid pieces preserved, especially within the more micritized beds as shown in the photo below. At Black Creek, Morganville, massive crystalline dolostone contains a eurypterid fauna early-recognized in Clarke and Ruedemann, 1911-1912. They recognized a peculiar kind of Eurypterus, now known as E. laculatus a form now known to be prolific within the Fiddlers Green Fm. across the state.

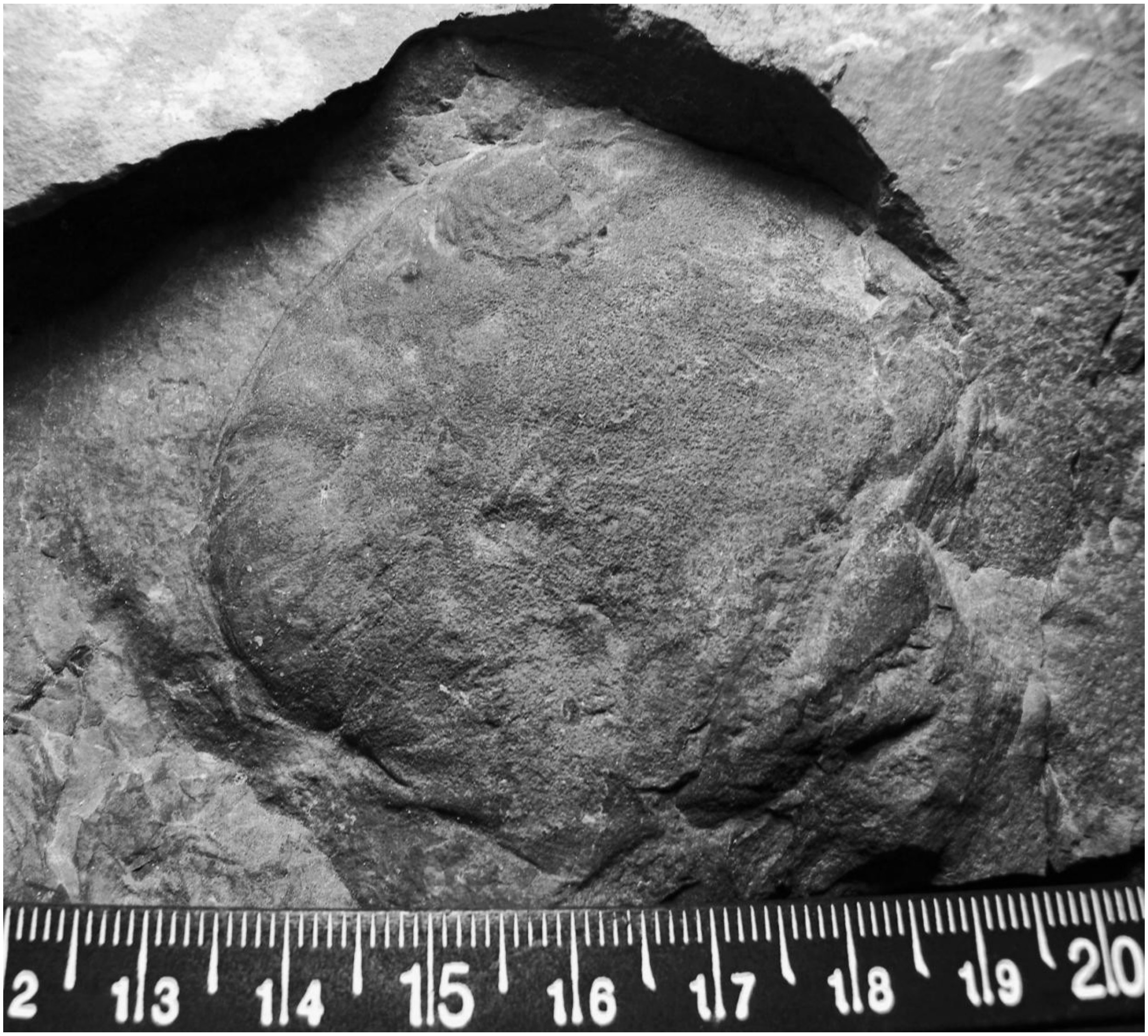


Figure 5. Relatively large pterygotid carapace (note large bulging eyes) from algal mat facies, Victor Dolostone, Manchester, New York.

Below the now famous eurypterid beds (Phelps Waterlime), in the roadcut opposite the Litchfield Town Hall, occur finely-crystalline, brown dolostone (Victor Dolostone) with much eurypterid material, black carbonaceous bedding planes (presumably of algal origin) and abundant ostracods, *Lingula* , trace fossils, *Eurypterus remipes*, and rarely pterygotid specimens are found here.

The Victor Member also forms the caprock of several waterfalls in western New York due to the extremely resistant nature of the 'reefy' phase of this dolostone. It is exceptionally evident along Murder Creek at Akron Falls (lower) at Akron, New York:

Figure 6. The caprock of the lower Akron Falls in June of 2012 when it was quite dry. The massive beds are Victor Dolostone (interpreted as constructed by microbialites) underlain by Morganville Waterlime.

The thrombolitic nature of the reef is shown in a closeup photo (Fig. xx). Following the outcrop belt, facies changes reveal microbial reefrock (enormous regional biostromes) grading into interreef beds and what appear to be shoals consisting primarily of the brachiopod, *Whitfieldella*. In the Marcellus Valley, crinkled stromatolitic beds with low amplitude stylolites and micritized Whitfieldella have been observed (Ciurca, 2011). At a few localities, waterlime with eurypterid remains appear to fill channels in the reefy facies. At other localities, the Victor Member exhibits more of an algal mat facies, perhaps indicating the more shallow portions (back reef) of sedimentation.

Salt hoppers occur in many of the beds, usually near the top of the succession as at Indian Falls. Hypersalinity seems to have played a strategic role in the development of many of the Bertie Group units and may have been necessary for the formation of some of the dolomitic units, especially the waterlimes. Salt hoppers are intimately associated with stromatolites and algal clasts and many eurypterid fragments and algal clasts appear to have been nuclei for the growth of halite crystals. It is obvious that all of the sediments that contributed to the formation of the Bertie Group were peculiar in one way or another. There is such variation in lithology, sedimentary structures, textures and preserved biota that make the group a fascinating subject for research – there is not only so much to learn, there is still so much to observe.

Figure 7. A closeup of the massive beds of Victor Dolostone at the lower Akron Falls. It takes a sledge hammer to examine the extremely resistant beds here. Stylolitic seams are common.

In the Niagara Peninsula (Ontario, Canada), the top of the Victor Member is overlain by the Black Shale Marker Bed (BSMB) which varies, within RQS itself, from ~0 to 6 inches in thickness. It is an anomaly within an otherwise carbonate depositional sequence.

Elsewhere, the Victor Member consistently shows evidence of microbial structures and/or bedded forms with only a slight change in faunal content. In easternmost localities, a lingulid brachiopod is commonly associated with abundant ostracods and trace fossils, but still with plenty of eurypterid remains. Over a broad expanse, the Fiddlers Green Fm. is a shallowing-up unit with most of the stromatolites in the upper beds when present (as in Canada).

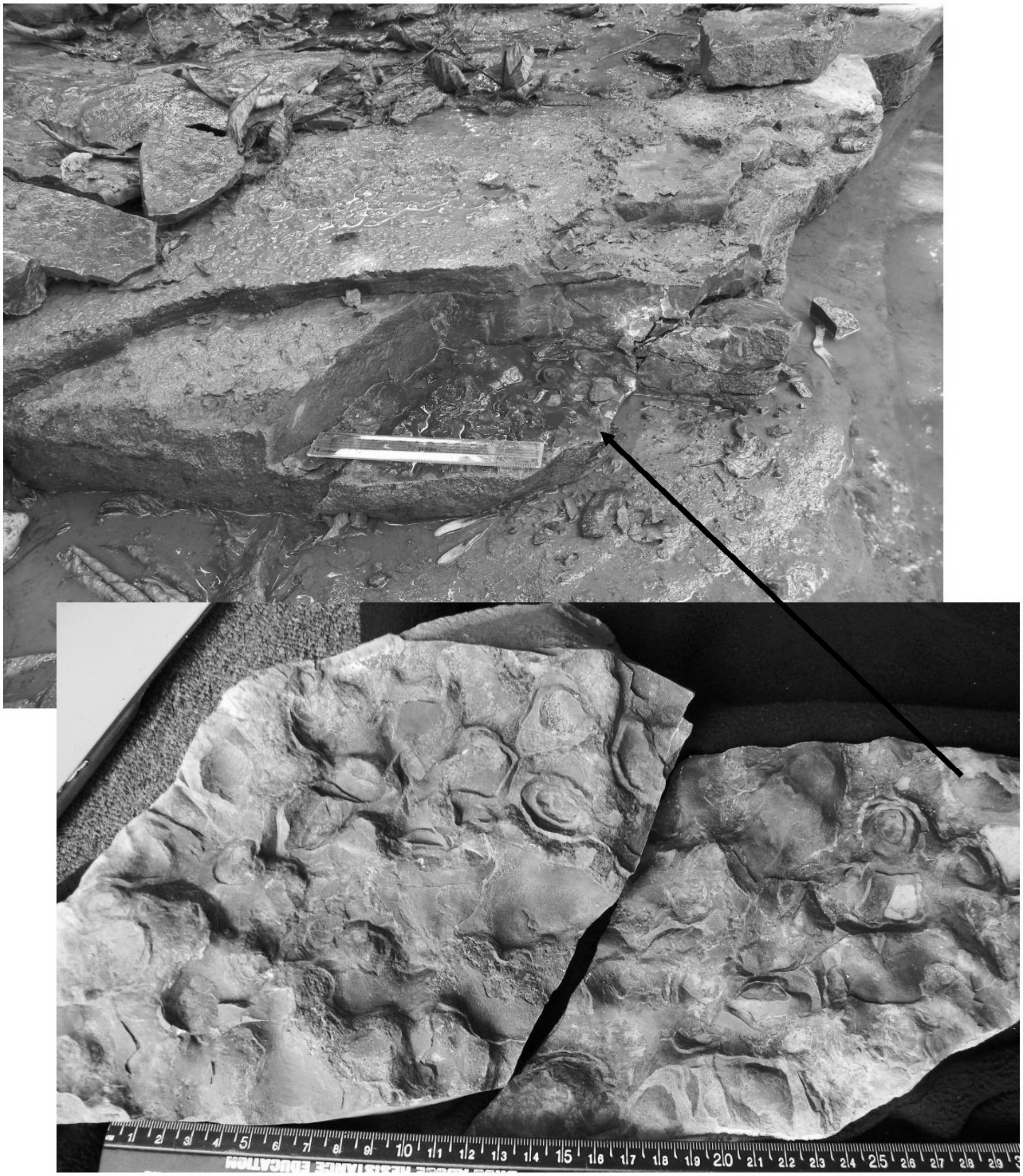
Phelps Waterlime (Member)

One of the most important of the Silurian waterlimes of New York is the Phelps Member, only because it is so well known for the famous *Eurypterus remipes* Fauna, especially in the east (Passage Gulf and the Lang Quarry). In general, microbialites have not been too important within the unit, but a recent observation sheds much light on important facies changes within the unit. A very large collection of fossil remains and sedimentary structures from this unit is available for study at the Peabody Museum of Natural History.

The Phelps Wl. has been traced from its type locality at Phelps, New York eastward to Passage Gulf (Millers Mills Quad.) where he collected hundreds of specimens from the *E. remipes* biota in a massive waterlime with mudcracks at the top. The Phelps is ~1 to 1.5 m. thick. Just a little westward, at a roadcut opposite the Litchfield Town Hall, he also collected (over many years) a large sample from the unit but found that the mudcracks were associated with layers of LLH stromatolites (Ciurca, 2005). This type of stromatolite was also observed at Mud Creek, East Victor, New York, but at most sections of the Fiddlers Green Fm. these are not evident.

Amazingly, within about a mile south of the type section of the Phelps Waterlime, at Flint Creek in the village of Phelps, essentially the entire Phelps Wl. is stromatolitic. This discovery provides for a different interpretation of the distribution of this important eurypterid-bearing waterlime. The outcrop belt seems to follow a near-shore distribution of the waterlime with more off-shore facies (to the south) appearing now and then. The occurrence of the eurypterid fauna, in this case at least, is behind shallow-water biostromes of stromatolites (essentially back-reef). To the south, there were probably larger stromatolite/thrombolite complexes like those of the Victor Member grading perhaps even farther south into pure limestone facies.

Figure 8. Type section of the Phelps Waterlime, New York State Thruway north of Phelps. The massive beds in the uppemost part of the photo are the Phelps Member, Fiddlers Green Fm. Below this are limestones and dolostones of the Victor Member and lower strata – this is an exceptional exposure in this part of the state. This waterlime has yielded abundant eurypterid remains and associated fauna, most of the collection of which is now in the Peabody Museum of Natural History. Large salt hoppers, up to 6 inches on a side, have been found here and also abundant eurypterid remains with relict salt crystal impressions.



Figures 9 and 10. Phelps Member (stromatolite facies) at Flint Creek, Phelps, N.Y. Photos of outcrop of LLH stromatolites (laterally linked hemispheroidal) in creekbed and samples removed (080711-5). The Phelps here is overlain by very resistant beds of the Ellicott Creek Breccia. Rapid facies change occurs here -about one mile north, very little of the stromatolites are evident at the type section where the unit is simply eurypterid-bearing waterlime.

Ellicott Creek Breccia (Member) -ECB

ECB encompasses a variety of lithologies and textures including characteristic breccia, topographic waterlime, small and very large stromatolites, carbonaceous bedding planes and smooth interbeds of waterlime. Eurypterid remains (and other fossils) are common at certain sites (e.g. Niagara Peninsula, Ontario, Canada). In Canada, huge stromatolites cover some benches in a quarry (see Figure xx) documenting huge mounds that no longer exist as they have been converted to crushed stone.

Figure 11. ECB type section, Ellicott Creek, Williamsville, N.Y. The heron's rear end points to the reentrant at the base of the ECB. Below are upper beds of the Victor Member with prolific brachiopods (*Whitfieldella* sp.). Note: the heron had just caught a fish and that is why its head is down.

The arching beds in the figure are microbialite mounds in ECB-B, underlain by ECB-A. ECB-C is higher in the section and below the Scajaquada Fm. The lower, middle and upper beds of ECB can all become microbialitic depending on locality (facies changes can be rapid).

The reentrant is believed to be the BSMB (the Black Shale Marker Bed so prominent in Ontario, Canada). In general, ECB ranges from ~1.5 – 2.0 m. in thickness and is observed at numerous sites across western New York. At the Neid Road Quarry northeast of LeRoy, large mounds similar to those in Canada occur, but also smaller compact mounds (see page 91 in Nudds and Selden, 2008). A ramus from one of the largest pterygotids that ever lived was found associated with these mounds here.

At Flint Creek, Phelps, N.Y., ECB is prominent along a lengthy portion of the creek, above the Phelps Member but microbialites are not prominent. Brecciation is well-developed here and it has been suggested that the beds may represent a widespread paleoseismite (http://eurypterids.net/EurypteridMonth18.html).

WILLIAMSVILLE WATERLIME ‘A’

Algal Mounds - Microbialites

In recent years, a number of small mounds (1 foot plus) have been encountered within the Williamsville ‘A’ Waterlime at RQS, Niagara Peninsula, Ontario, Canada. The section of the quarry floor where the largest mound was observed is shown below. The stick in the photo is 0.5 m. Note the corrugated sides of the part exposed.

Figure 12. Large circular mound discovered within Williamsville ‘A’ – see text above.

Microbialites within the Williamsville Formation do not seem to be common and, indeed, none have been identified to date in the wonderful exposures of the unit eastward to the central New York region. It is the fortuitous situation at the RQS, where a bench was left in part of the quarry right at the contact of Williamsville ‘A’ with Williamsville ‘B’ (lower benches expose the top of the Fiddlers Green Formation and still lower, the base of the Fiddlers Green Fm.).

Microbialite (Thrombolite) Mats

Also recently observed were small areas that may represent thrombolitic mats, i.e. the structures are generally thin and matlike rather than mounds. Williamsville ‘A’ is generally 18 -24 inches thick in this quarry and is the repository of countless eurypterid (and other) remains and the observed mats also contain eurypterid parts.

The possible newly observed thrombolite mat occurs within a few centimeters of the top of Williamsville ‘A’ and parts of it were dismembered (samples collected) and are shown in photographs below. The size of the mat was around a meter, but its margins, where it contacts the general waterlime, were not seen. Besides the eurypterid carapace shown in the photo, another specimen showed a large phyllocarid spine on the underside of the mat.

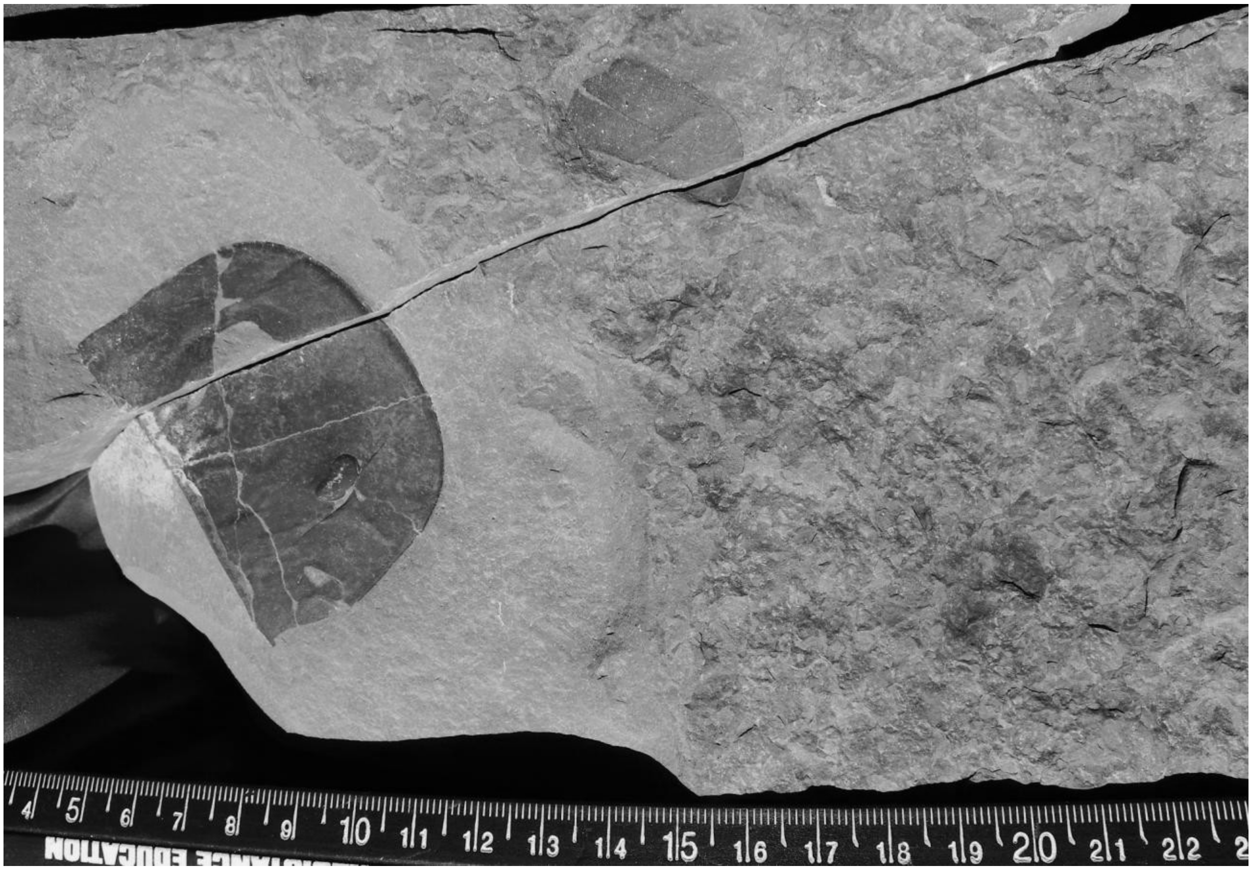


Figure 13 Slab of waterlime (underside) showing carapace of *Eurypterus lacustris* (dorsal down) with suggested thrombolite mat to the right (and with eurypterid fragments on the mat).

Very few other examples of similar microbialite structures were observed in the Williamsville Formation during over 40 years of observations, but representative samples are to be reposited in the collections of the Peabody Museum of Natural History at New Haven, Connecticut.

‘Blotch’ Horizon

One of the more interesting discoveries at RQS was the “Blotch Horizon” just a few centimeters down from the ‘A – B’ contact (aka, A-B Event Horizon, Brachiopod Pavement). The horizon is just above the Trackway Horizon (see Ciurca, 2002) and consists of countless small, but complex structures resembling *Parka decipiens* and may represent an algal bloom that occurred only once during the deposition of the ‘A’ unit. They mostly seem to be randomly distributed on the bedding plane, but some may have been collected into windrows and depressions and many eurypterid specimens have also been encountered on the same bedding plane.

Thus far, the only event horizons recognized in Williamsville ‘A’ are the two mentioned above (Blotch Horizon and the Trackway Horizon) and these occur within the upper third of the unit. None have been recognized below as it is difficult to dig much farther down into the 18 inch waterlime. It is known, however, that eurypterid remains occur throughout lower layers, even just above the underlying Scajaquada Fm.

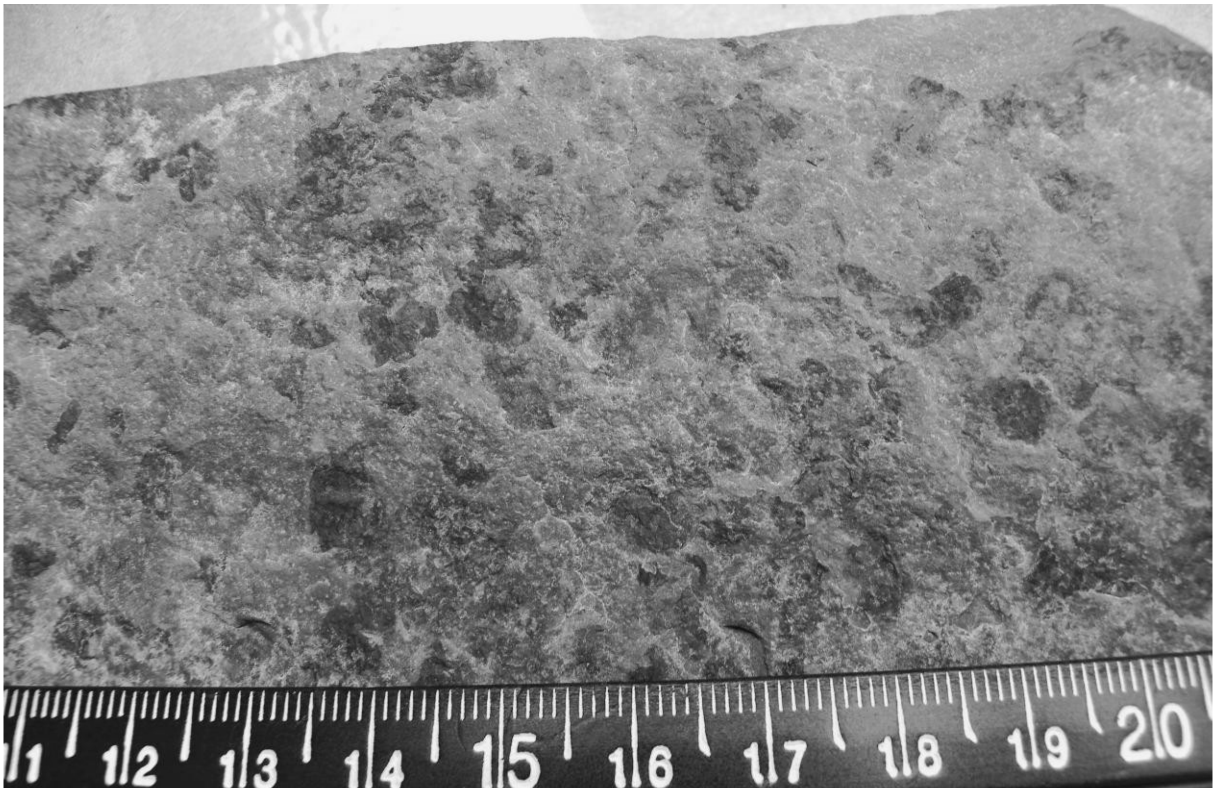
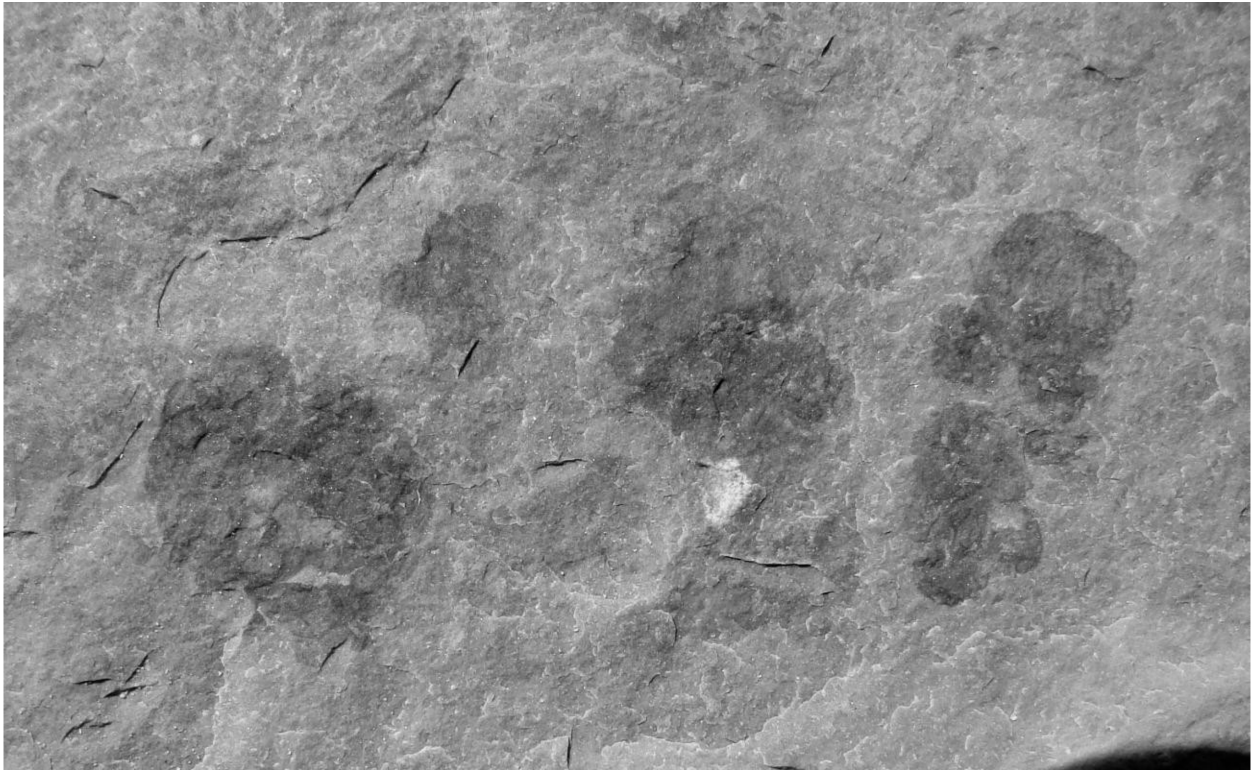


Figure 14 (above). Small area of the Blotch Horizon occurring in the upper third of Williamsville 'A' Waterlime at RQS.
Figure 15 (below) A closer view of blotches showing 'cells' (with ?spores).



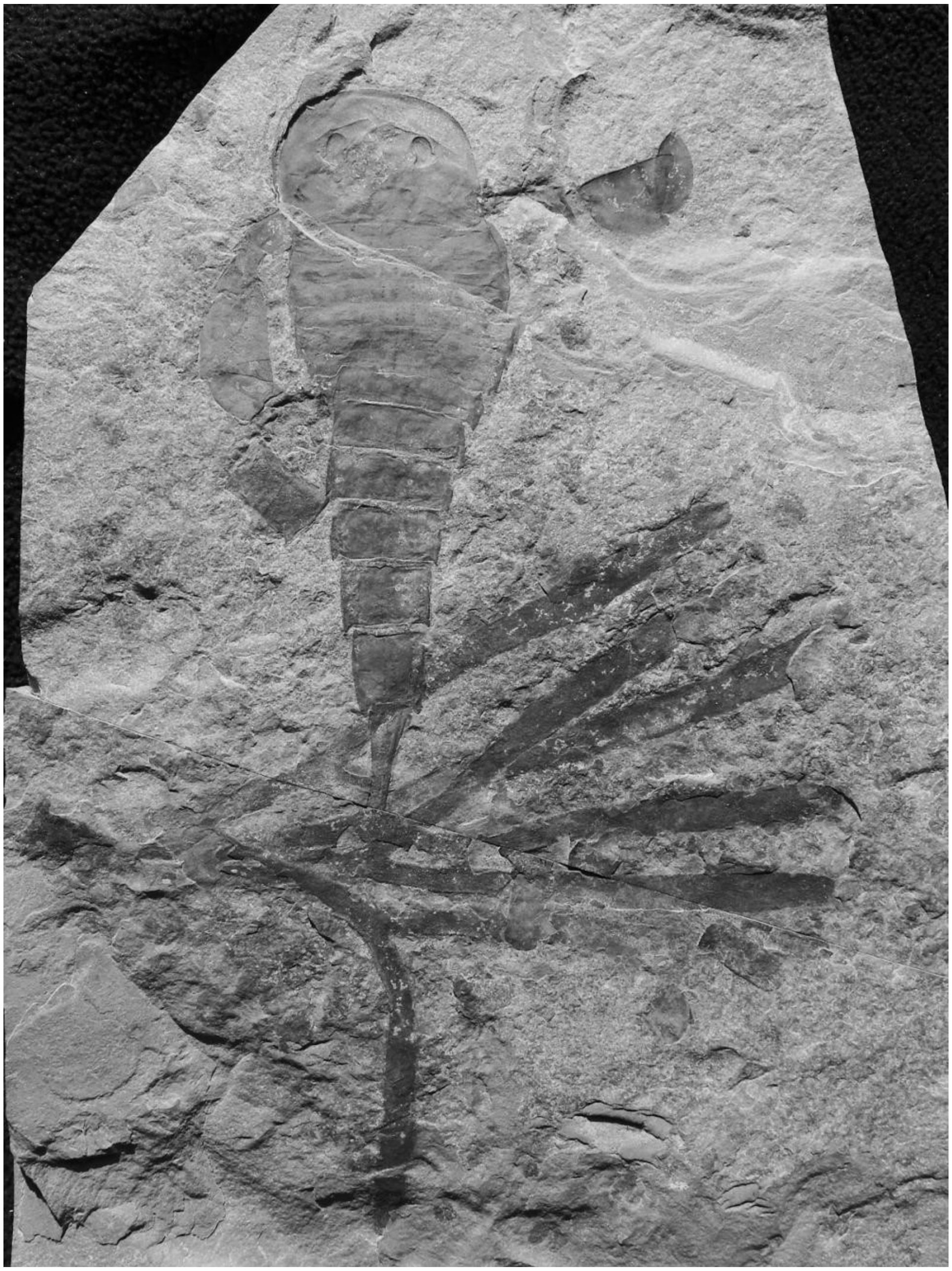


Figure 16. Small depression (scour) at the Blotch Horizon where many blotches were preserved along with *Inocaulis* (the "finger plant"), *Eurypterus lacustris* (040900-8) and eurypterid fragments. Eurypterid is ~17 cm. long, carapace is ~4.0 cm. wide. Note, this is the underside of the slab removed from the quarry floor – the eurypterid was preserved dorsal up.

Algal Clasts

Within the Bertie Group, occur irregular patches that appear to be algal clasts ripped up, transported and deposited from nearby or distant sources of microbialite activity. Such structures are most prevalent in the waterlimes of the Ellicott Creek Breccia (member) of the Fiddlers Green Formation, especially within the upper half of the unit.

In contrast, only occasionally are such structures observed within the Williamsville Formation (Williamsville 'A' submember) where microbialites are rarely observed, but eurypterid specimens are abundant.. Examples of such structures are shown below.

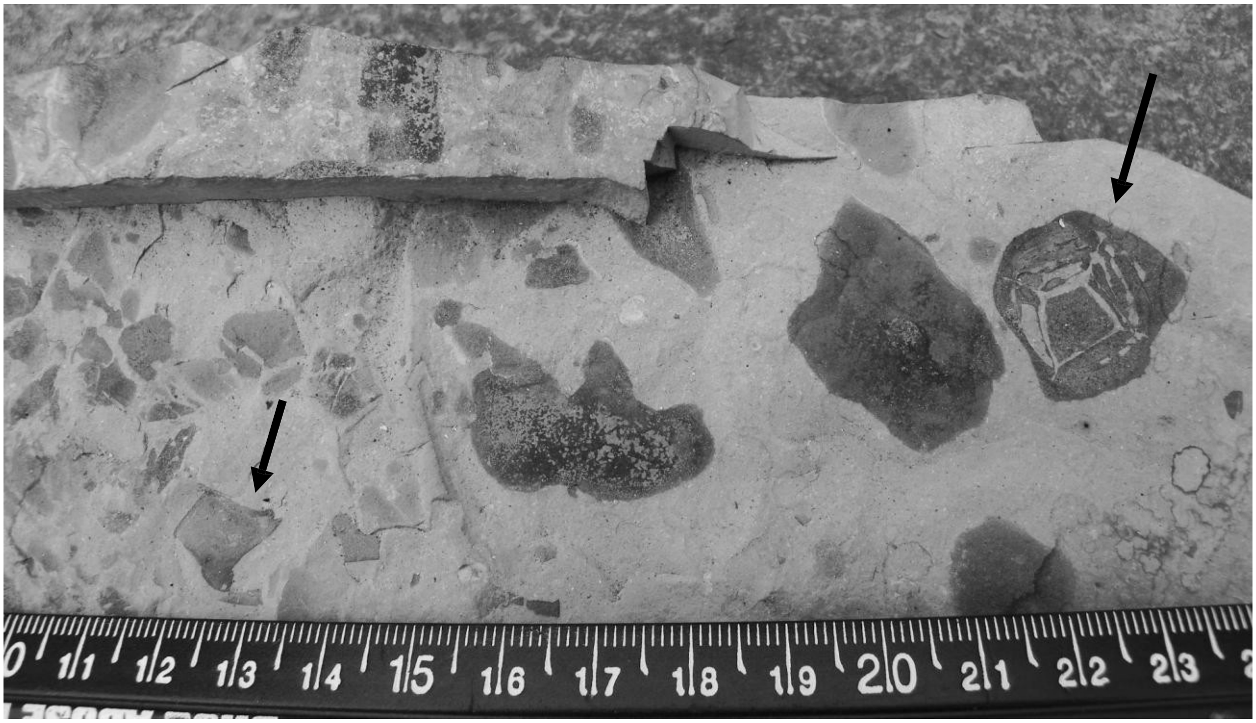


Figure 17. A small slab (flat pebble conglomerate) of upper ECB showing many clasts. At upper right, the clast bears an intrusive salt hopper structure. At lower left is an isolated coxa of the eurypterid *Eurypterus* sp. This specimen is from the Ridgemount Quarry South, Niagara Peninsula, Ontario, Canada. Such algal clasts are observed eastward to at least the Neid Road Quarry northeast of Le Roy, New York where they are also associated with small and large stromatolites/thrombolites.

The *Eurypterus lacustris* Biota dominates Williamsville 'A' Waterlime stratigraphically higher in the section, above the ECB, and irregular patches of apparent algal nature are not often encountered. Nevertheless, over a period of years, many have been observed as isolated clasts. Perhaps most interesting is the fact that some of them, too, show that hypersalinity played an integral part of sedimentation during deposition of this important eurypterid-bearing unit. Relict halite structures are superimposed on some of them as shown in the example below.

There is also a specific horizon just a few inches below the top of Williamsville 'A' that is literally covered with small blotches (Blotch Horizon) that also may be algal in nature and resemble *Parka*, small structures well- known in England (see above). A good representative collection of specimens has been reposited in the Peabody Museum of Natural History. Eurypterid remains are also found associated on the same bedding plane. The distribution of the blotches seems to be completely limited to this horizon, and these have not been observed in New York outcrops of the Williamsville Formation. Note: The Blotch Horizon occurs just above the so-called Trackway Horizon (see Ciurca 2002).

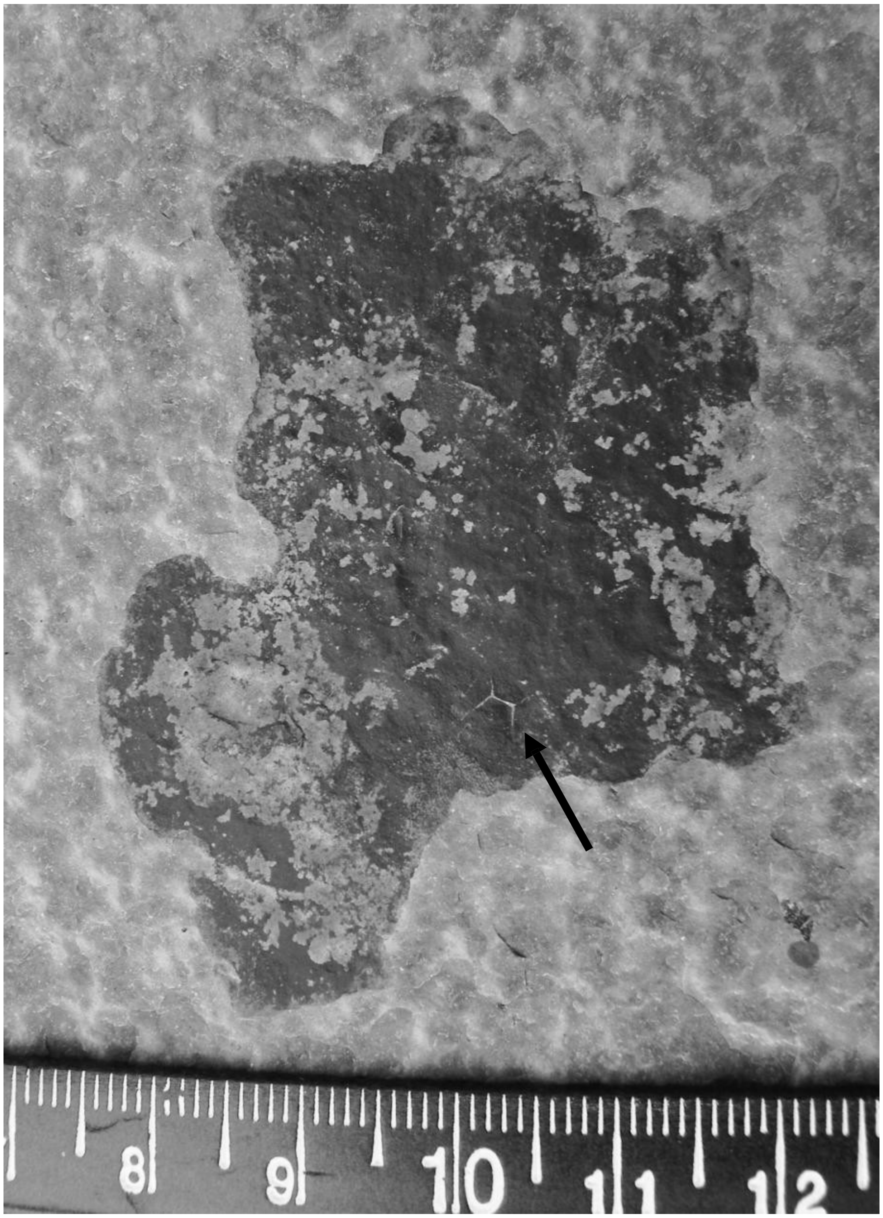


Figure18. A large, irregular patch of apparently carbonized material showing at least one relict halite structure on the patch. Perhaps this is a broken-off piece of a floating algal mass from a shallow, hypersaline lagoon. Similar relict salt structures are also found on eurypterid parts (i.e. carapaces, tergites, etc.).

AKRON FORMATION

Origin of a Massive Dolostone Complex

The Akron Fm. is generally regarded as a fine-grained, mottled dolostone heavily bioturbated. While this is certainly true, it may be that the formation owes its existence, again, to the little guys – the microbes that formed an immense sheet of carbonate mud across western New York and Canada. While it is not generally easy to access the irregular bedding planes of the unit, fortuitous encounters with weathering of enormous blocks of the Akron at RQS have revealed many structures and even a supportive fauna of ostracods, gastropods and a few brachiopod species suggestive of the microbialite origin of the unit.

Irregular and often undulating bedding planes preserve a variety of carbonaceous structures that seem to indicate a variety of algal mat types, but not of typical stromatolitic nature. At some sites, the mats seem to be interlocking suggesting that sediment was trapped and formed a network that slowly built up over time to produce up to ~5 m. of Akron Dolostone.

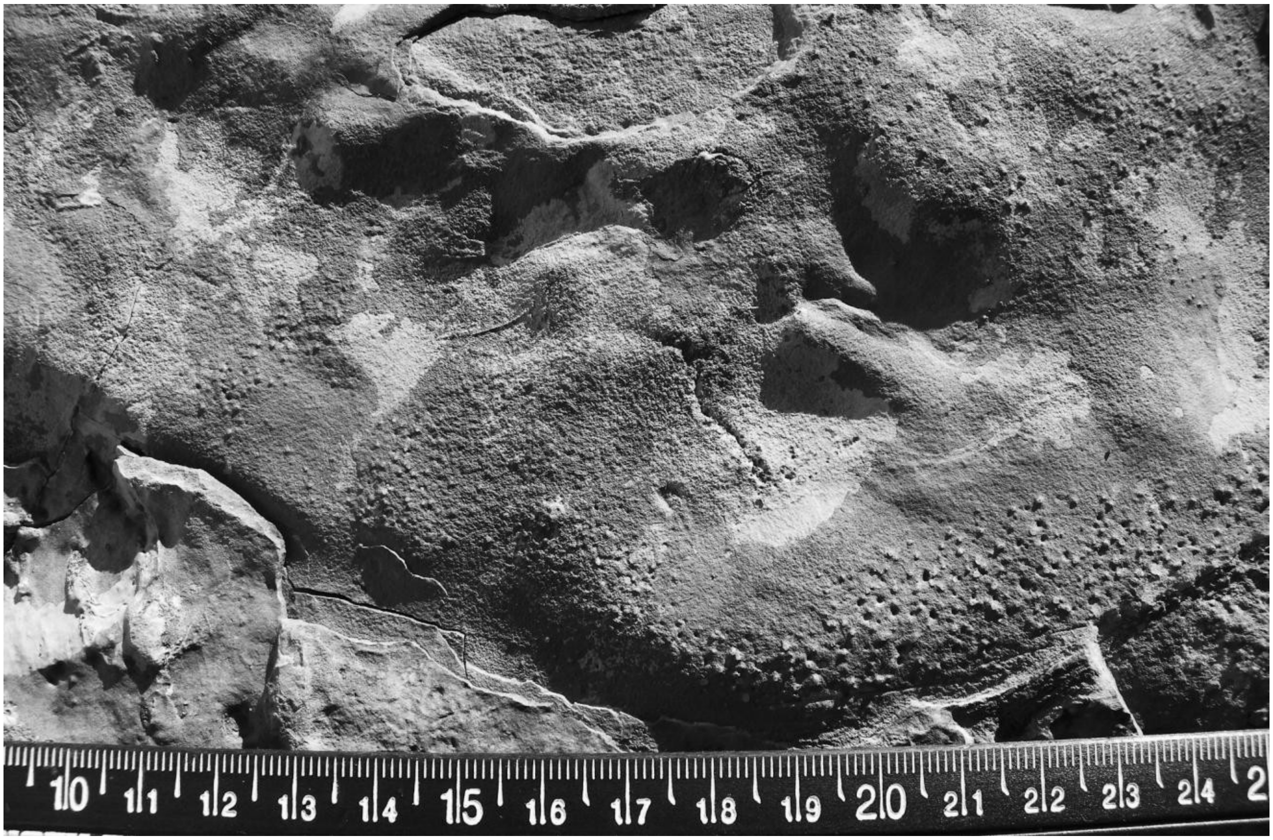


Figure 19. Crustose surface suggestive of peculiar algal mat type, Akron Formation at RQS.

Additional Examples

The Akron Fm. is exposed at many places in western New York, often at localities near the Onondaga Escarpment. Other places include quarries, especially abandoned old quarries some still available for observation (e.g. Glen Park at Williamsville, Neid Road Quarry northeast of LeRoy).

Of special note are exposures at the Clarence Sanctuary where much of the Bertie Group is preserved, perhaps one of the best sites for what the nearly complete Bertie Group looks like. At this site there are at least 3-4 m. of Akron Dolostone preserved below the Onondaga Limestone.

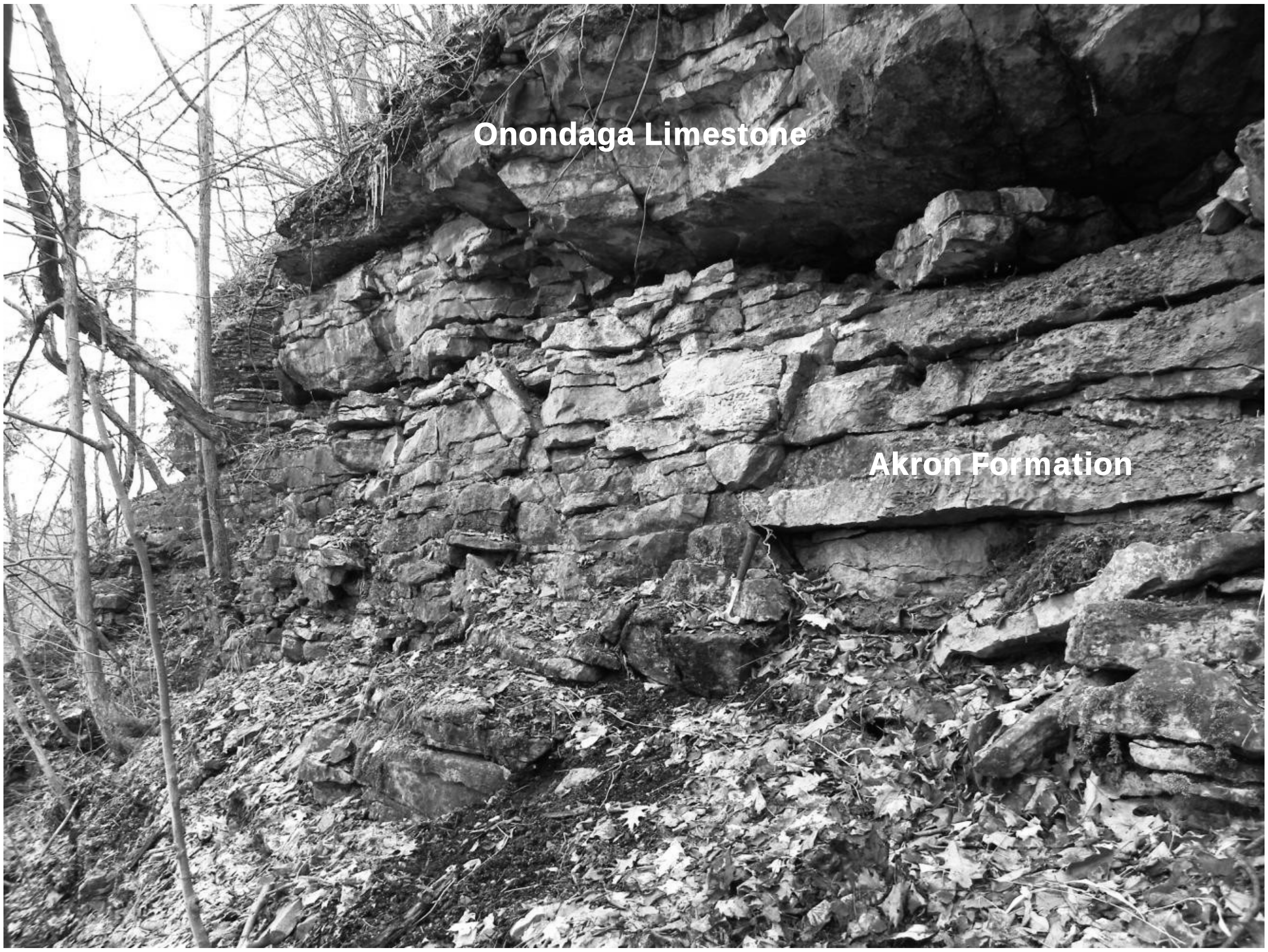


Figure 20. The Akron Fm. below the Onondaga Limestone at the Silurian/Devonian boundary. The unit has a thickness here of at least 3 - 4 m. Note rock hammer (37.5 cm.) center right in photo.

From near Honeoye Falls eastward, stromatoporoids make their appearance in the Akron Fm. (see Stock 1979) and occur sporadically to Jamesville and beyond generally forming thin biostromes (sometimes associated with tabulate corals and an assortment of brachiopods).

Eastward, beds appear to become thicker and more massive as at Mud Creek (East Victor) and seem to be more similar to the thick beds of Victor Dolostone below in the Fiddlers Green Fm. (in the past, these units caused confusion in stratigraphic interpretations). Precise correlation of the Akron Fm. with supposed eastern equivalents is not yet possible, mostly due to what Ciurca (2011) called the Auburn Seneca Falls Anomaly (ASF Anomaly). There are at least three different lithologies in the region that have been termed “Cobleskill” but that seem to occur at various stratigraphic positions.

It may be that the Akron Fm. was the more onshore facies with biostromes (stromatoporoids) and reefy masses (perhaps the “Martisco Reef Complex”) farther out and finally genuine limestone (e.g. at Frontenac Island) being still farther out, these facies forming bands around the margin of the basin. It is in the Auburn, Seneca Falls region that all three facies appear to be present and a good region for further research. Just getting the stratigraphy elucidated would be an accomplishment.

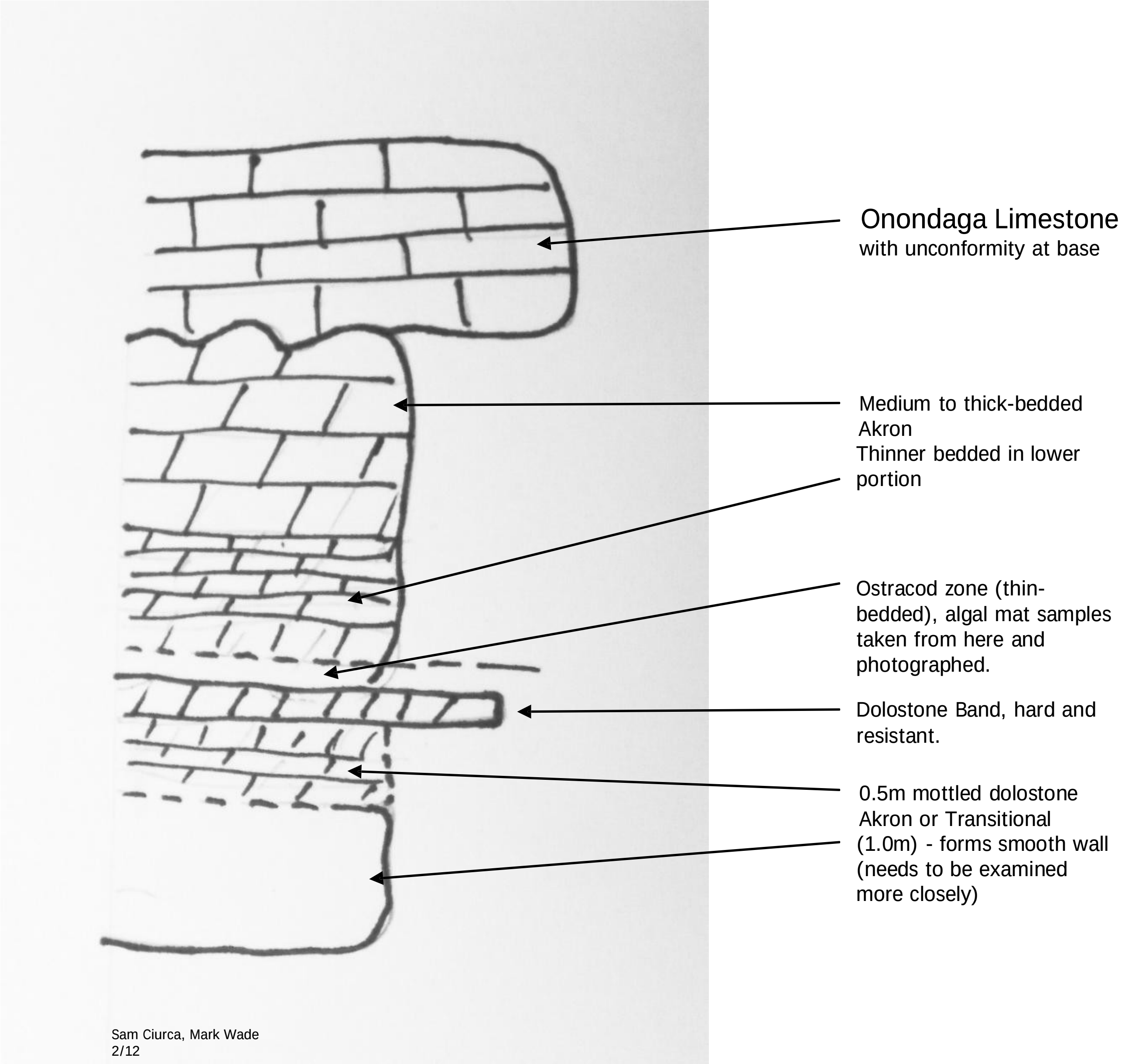
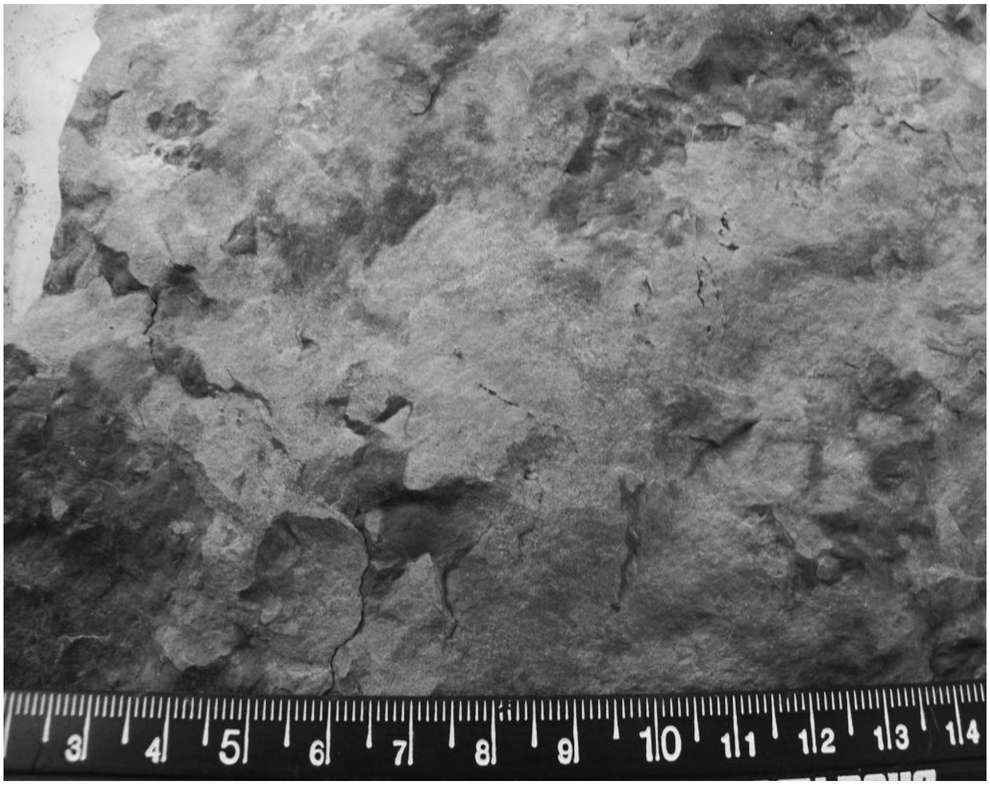
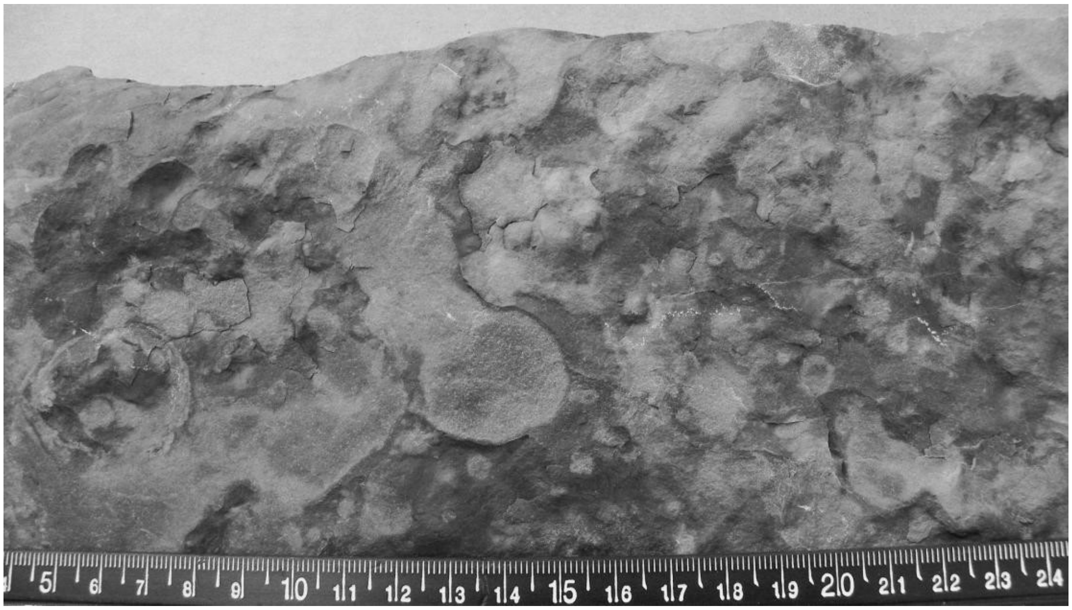


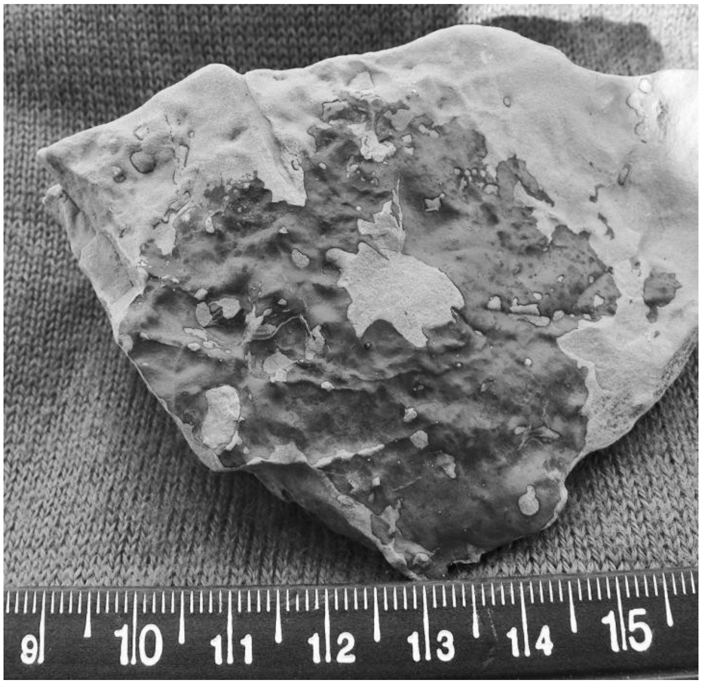
Figure 21. Notes on part of the section at the Clarence Sanctuary. The algal mat samples mentioned above are shown in the figures below. Beneath the transitional beds, the Williamsville Formation makes its appearance as a waterlime with shaly intervals intercalated. Data February 5, 2012.

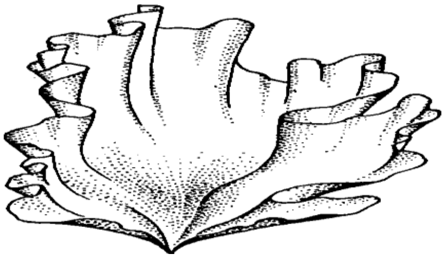


Figures 22 and 23. Specimen 020512-1 Foliose, presumably carbonized algal mats are thoroughly distributed throughout the matrix with abundant ostracods and a few brachiopods (to date). Below is another example (020512-2) from the ostracod zone near the base of the 10 feet (~ 3.5m) of Akron Ds. exposed in the upper cliff (below the Onondaga Limestone).



Another type of algal structure is observed at the type section – it may be a form resembling modern sea lettuce. Burrowing within the Akron is almost ubiquitous, and this presumed alga seems to show evidence of the burrowing.





Figures 24 (left) and 25 (above). Specimen 030312-1 Presumed alga, carbonized and surely compressed, Akron Fm., Akron Falls (upper), Akron, N.Y.
The drawing shows possible analog, a modern sea lettuce (see arthursclipart.org).

The Akron Dolostone, as interpreted here is a mottled, bioturbated dolostone with a variety of microbialites preserved in association with an abundant ichnofauna, gastropods, ostracods and a few brachiopods. In upper beds at RQS, salt hoppers are found with much mineralization evident (calcite, dolomite, celestite crystals), especially in rocks just below the Silurian/Devonian unconformity

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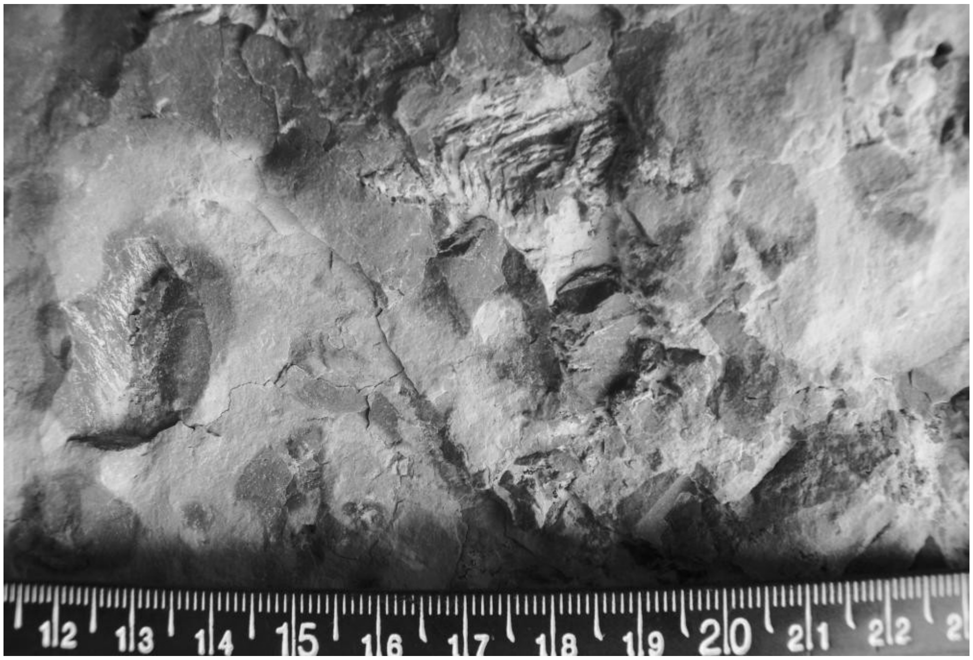

Figures 26. Specimen 051098: typical, mottled Akron with salt hopper structures scattered in the matrix.

One more example may be worth mentioning. At the Canandaigua Outlet (Manchester, N.Y.), above the eurypterid beds of the Williamsville Fm., the Akron bears heavily carbonized ?thrombolites in massive tan dolostone with micrite 'locked' in place to form the massive beds. The specimen was retrieved from a large mass of the dolostone and is shown below (Specimen 090213-1).

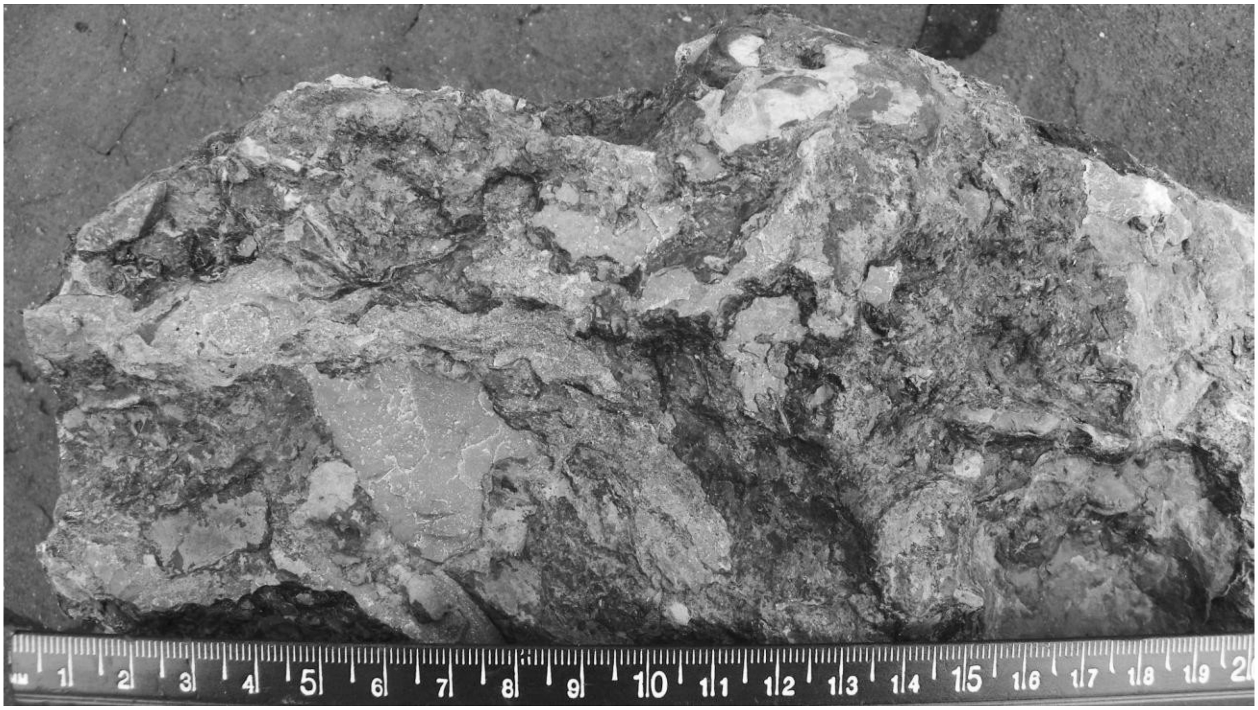

Figure 27. Akron Dolostone from Canandaigua Outlet as described above. Note the contorted carbonaceous material enclosing the fine micrite.

SUMMARY

While much is known about the eurypterids and associated faunas of the Bertie Group, a lot is yet to be learned about sedimentary structures and the paleoichnofauna of the group. Observations made over a period of over 40 years seem to indicate that microbialites also played a significant role in the development of a variety of lithologies that make up the group.

Succeeding the Salina Group, the Bertie Group was initiated in western New York by microbialites in hypersaline waters, presumably of shallow water origin. The nature of the microbialites may never be known but the fact that eurypterids make their early appearance in this basal unit, the Fort Hill Waterlime, is of importance in attempting to understand the evolution of the commonly known forms from upper beds of the Bertie Group, viz. the well-known faunas of the Fiddlers Green Fm. (*Eurypterus remipes* Fauna) and the Williamsville Waterlime (*Eurypterus lacustris* Fauna). If we are really to understand the environments in which eurypterids lived, we have to have all the facts. Microbialites within the Bertie Group may add additional facts if they can be analyzed and add to our understanding of all of the units that constitute the Bertie Group.

Lithologically, the Bertie Group is complex and part of this complexity can now be attributed to the modification of the sediments by stromatolites, thrombolites and what appears to be also a variety of algal mat types. There seems to be an evolution of microbialites through the sequence. Basic stratiform planar stromatolites start the sequence (Fort Hill Waterlime) immediately overlain by mound-types. An influx of sediment temporarily smothered this initial phase (Oatka Fm. – still hypersaline) but was succeeded by voluminous carbonates of the Fiddlers Green Fm. in which a variety of microbialites tried to dominate. Basal Fiddlers Green is simply another waterlime (Morganville) but recent observations show large circular mounds of stromatolitic nature. This is succeeded by massive, crystalline dolostone (Victor Member) with huge thrombolites and overlying stromatolites and 'interreef' algal mats irregularly-bedded with enormous quantities of brachiopods (*Whitfieldella*) that appear to have accumulated into shoals at some sites.

Shallowest water appears to have produced the LLH stromatolites of the Phelps Member at several localities. The stromatolites occur at the top of an important eurypterid-bearing waterlime (*Eurypterus remipes*) that may also preserve strandline deposits. The highest member of the Fiddlers Green Fm., i.e. the Ellicott Creek Breccia, bears at least three levels of stromatolite/thrombolite growth.

While little is known about microbialites in the Williamsville Fm., certain structures strongly suggest their presence, though they are not overwhelming as they are in lower strata. Finally, the Akron Fm. may owe its existence to the formation of a different suite of microbialites, but not of stromatolitic form. While dolomitization and intense bioturbation have obscured many features, closer examination of the horizontal and vertical burrows, the carbonaceous structures and the fauna that are preserved should allow for a better understanding of this peculiar mass of carbonates.

ACKNOWLEDGEMENTS

Over the many years, a lot of people have helped with field work and discussions on eurypterids and the Bertie Group – thanks to all of them.

Recently, Mark Wade (of Rochester) has provided invaluable help in the field including helping the author get out of a large creek bed (Tonawanda Creek) after suffering a ham string injury. Mark and I also explored new Bertie territory allowing for new observations of significance to our understanding of the group and the distribution of some of the microbialites suggested in this report. Mark also helped with the road log for this field trip. Thank you.

Tod Clements (of Rochester) is a well-known eurypterid collector and I have taken advantage of our friendship – he has given me many interesting specimens or sold them to me at reasonable prices, all material having been witnessed by me as we explored the waterlime layers, especially Williamsville 'A' Waterlime at the RQS. (Tod is the discoverer of the first well-preserved eurypterid to come out of the Rochester Shale and kindly donated the specimen to the Peabody Museum of Natural History). Many thanks, Tod.

I have not forgotten the hours spent with Linda Heffron at the Neid Road Quarry – while I was 'digging' the waterlime layers, she was either looking for the rare fossils, enjoying the reclaimed botany of the place or calmly relaxing on the bedrock while reading a book (as we both enjoyed watching the vultures over head or lined up, standing at the top of the quarry walls like black statues). Thanks Linda, who does not enjoy Georgia and misses the wonderful Silurian and Devonian sections we have in New York.

As a curatorial affiliate of the Peabody Museum of Natural History, many of the specimens retrieved from the many units of the Bertie Group will be available to other researchers for study in coming years. Thanks to Dr.;

Susan Butts for many interesting exchanges and help in making sure as much retrieved data gets associated with specimens (most of the author's notes are incorporated into the collections at PMNH).

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http://eurypterids.net/EurypteridLinkInxex.html

http://eurypterids.net/StromatolitesEurypterids.html

http://newsteadhistoricalsociety.org

ROAD LOG

MILES FROM LAST POINT	CUMULATIVE MILEAGE	ROUTE DESCRIPTION
0	0	JCT I-290; (Exit ramp 7) with NY5. (Head east into Williamsville).
0.4	0.4	McDonalds on left.
0.5	0.9	Turn left on Cayuga St.
0.1	1.0	STOP SIGN Turn right on Glen Ave.
0.1	1.1	Parking lot on left. STOP 1 Glen Park (Ellicott Creek, Williamsville).
0	1.1	Leave parking lot, Turn left.
0.2	1.3	Mill St., Turn Right.
0.1	1.4	NY5, Turn left and head east.
2.3	3.7	JCT NY78 and NY5, continued east.
8.6	12.3	Adassa Auto Auction on left, site of former Louisville Quarry.
1.3	13.6	JCT NY93 and NY5, continue east (McDonalds on left side).
1.1	14.7	Crittenden Rd., Turn left.
1.1	15.8	Skyline Drive, Turn left.
0.3	16.1	Orange Gate – ENTRANCE TO AKRON FALLS PARK (turn right at Fork).
0.2	16.3	Turn right and park in lower parking lot. STOP 2 Akron Falls Park (Murder Creek).
0.1	16.4	Leave parking lot, Turn left.
0.2	16.6	Orange gate, Skyline Drive.
0.2	16.8	Crittenden Rd., Turn left.
0.3	17.1	STOP SIGN – NOTE FIVE POINT INTERSECTION. Make second Right onto Indian Falls Road.
4.1	21.2	NY77, Turn left.
0.1	21.3	Gilmore Rd. Turn left (before bridge over Tonawanda Creek.
0.1	21.4	STOP 3 Indian Falls, Tonawanda Creek, town of Pembroke.
0.0	21.4	Turn left out of parking lot, back to NY77 (Turn right to NYST).
1.7	23.1	Turn right to New York State Thruway Toll booth (Pembroke). Head east on I-90 to LeRoy exit.
13.8	36.9	Roadcut in Onondaga Limestone and lower units of Bertie Group.
8.4	45.3	EXIT 47 Pay toll, right lane to ramp onto NY19 – head straight South on NY19.
2.3	47.6	Parmelee Rd., Turn left.
0.5	48.1	Oatka Trail, Turn left.
0.8	48.9	Circular Hill Road, Turn right.
0.4	49.3	Top of Onondaga Escarpment.
1.2	50.5	Gulf Rd., Turn left.
0.8	51.3	ON LEFT: 1911 Steamshovel, may have be used at Panama Canal.
0.5	51.8	Neid Rd., Turn left.
0.4	52.2	Turn left, entrance road to abandoned Neid Rd. Quarry. Park along left edge as there are homes on the right side. STOP 4 Neid Road Quarry in Onondaga Limestone and some portions of the Bertie Group (also Silurian-Devonian boundary).

Anthropocene

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INTRODUCTION

During this trip we will talk about ways to characterize sites concerning human impacts or interactions, thinking about spatial and temporal contexts. We will visit several example landscapes, discussing "Can we standardize anthropogenic characterization and will it help to plan the future?"

Southwest New York continues to undergo a great set of transitions. First the region was invaded and developed by Europeans beginning in mid-1700s, but especially during the 1800s. The climax of deforestation reached across the late 1800s into the early 1900s, similar to much of eastern North America. At the peak we had about 10% to 20% remaining forest cover. Secondly, for the past 70 or 80 years we have experienced erratic but sustained reforestation, mostly as a gradual succession, and much of the region is now 70% or more forest. Third, the region has undergone population loss and impoverishment for about a half century, with the contrast of an increase in rural estates. Much of the economy of the region is based on tourism.

For this field trip the locations and route will be finalized just before the trip and hand-outs provided. All sites will be accessed from vehicles by foot paths, but sturdy footwear is expected of participants.

TALKING POINTS

While we anticipate the discussions will vary widely, several questions will be promoted for discussion:

1. Doesn't biodiversity require geodiversity? Do we need to protect the diversity of environments of deposition and erosion? What constitutes a "geospecies"? Is there a simple proportionality constant between the number of biospecies and the number of geospecies?

2. What is the history of each site visited in the previous hours, days, seasons, decades, and centuries? What is our prediction for the same time frames in the future?

3. How do environmental ethics affect our past interpretation of the site and our future prognosis for the site: utilitarian, conservation, preservation?

4. We will characterize several of the climate features of the region, and ponder a possible future climate and its affects.

5. Economic considerations will be discussed.

MIDDLE – UPPER DEVONIAN STRATA ALONG THE LAKE ERIE SHORE, WESTERN NEW YORK

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INTRODUCTION

The Middle and Late Devonian succession along the New York State Lake Erie shoreline and exposures in adjacent creeks includes numerous dark gray and black shale units that record dysoxic to near anoxic marine substrate conditions near the northern margin of the subsiding Appalachian foreland basin. Contrary to common perception, this basin was often not stagnant; evidence of current activity and episodic oxygenation events are characteristic of many units. Lag deposits of detrital pyrite roofed by black shale, erosional runnels, and cross-stratified deposits of tractional styliolinid grainstone are evidence of episodic, moderate to high energy events within the basin. This trip will highlight the transitions in the basin from gray shales to dark shales, often characterized by pyrite-rich lag deposits, phosphate, conodont, fish beds, and concentrations of carbonate material, as well as the Naplesites epibole surface associated with the Belpre Ash suite in the lower Rhinestreet Formation. Three stops will showcase strata associated with Middle and Late Devonian extinction events – the Taghanic Onlap and the "Conodont Bed" of the North Evans Limestone that marks the Givetian-Frasnian boundary in western New York – a truncation of the more conformable transition to the east, and the Frasnian-Famennian boundary interval, one of several Late Devonian extinctions and the marker of a significant global crisis that led to the demise of the widespread and diverse Devonian reef community.

GEOLOGIC SETTING

During the late Middle Devonian western New York was located in the southern hemisphere tropical realm and covered by an epicontinental sea (Scotese, 1990). Strata seen on this fieldtrip accumulated on the northern margin of a subsiding foreland basin that periodically expanded and deepened during phases of oblique collisional overthrusting (tectophases) associated with the ongoing Acadian Orogeny (Ettensohn, 1987, 1998; Fig. 1). The most pronounced thrust loading event (tectophase three) coincided with the onset of the deposition of the Genesee Group; this flexural drowning event was also largely coincident with a major rise in sea level (within T-R cycle IIa of Johnson et al. 1985). In west-central New York this deepening is expressed by lithologic change from shelf carbonates of the Tully Formation into basinal black shale deposits of the Geneseo Formation (Heckel, 1973; Baird and Brett, 2003; Baird et al., 2003). In western New York the Tully Formation is absent due to erosional/corrosional processes, and progressively younger divisions of the Genesee Group: Geneseo Formation with Leicester Pyrite at its base, Penn Yan Formation, and condensed North Evans/Genundewa deposits, are observed to successively onlap the Taghanic Unconformity, a major regional disconformity, in a westward direction (Fig. 2). This disconformity, separating fossiliferous neritic facies of the late Middle Devonian (Late Givetian) Windom Member of the Moscow Formation, Hamilton Group from overlying dysoxic, pelagic limestone and lag debris of the North Evans/Genundewa deposits at the base of the Genesee Group, will be seen at STOP 1A. In west-central New York localities, the gradational transgressive change from Tully carbonate facies into black shale of the Geneseo Formation coincides with the beginning of the upper Givetian substage of the late Middle Devonian (Huddle, 1981; Kirchgasser et al. 1989). Proceeding westward along the Taghanic disconformity, the ages of the onlapping black shale deposits become progressively younger into eastern Erie County; this reflects the regional flexural-eustatic Taghanic event (Kirchgasser et al., 1989; Baird and Brett, 1986). A younger erosion surface, associated with the North Evans Limestone conodont – bone lag below the Genundewa Limestone, oversteps the Taghanic disconformity in Erie County, thus merging the two discontinuities into a composite unconformity (Fig. 2). Hence, at STOP 1A, the Late Devonian (early Lower Frasnian) North Evans Limestone rests directly on late Middle Devonian (middle Givetian, ansatus Zone) shales of the Windom Member (Moscow Formation; Hamilton Group) with several conodont chronozones missing or whose representatives were reworked and transported. The effective chronostratigraphic (taphonomic) age of the North Evans is early Frasnian upper MN Zone 2 (Figs. 2, 3).

Acadian orogenic uplift in New England and the central Atlantic region was associated with progradational developmemt of the Catskill Delta Complex which filled the foreland basin from east to west (Woodrow and Sevon, 1985; see Kirchgasser et al., 1997). Catskill Delta progradation began in earnest during deposition of the Middle Devonian Hamilton Group following the onset of the second collisional tectophase, but accelerated significantly during the third tectophase (Ettensohn, 1998). Not only do strata above the Taghanic disconformity thicken greatly to the east, but they also grade spectrally eastward and shoreward into variably fossiliferous neritic facies which are typically much coarser (Fig. 2).

Generally, the units seen on this field trip represent very fine grained detrital facies of the Catskill Delta representing deposition in deeper water slope and basin settings both at and beyond the delta margin (Fig. 2). Units such as the Rhinestreet Formation of the West Falls Group (Late Devonian, Frasnian) are typically expressed along Lake Erie as organic-rich, fissile to massive, black shale facies recording near-anoxia during phases of transgressive highstand (Rhoads and Morse, 1971; Murphy et al., 2000). However, thinner intervals of gray-green, typically bioturbated shale occur within the Rhinestreet (see STOPS 1C, 2). Shale of this type thickens greatly eastward toward the depocenter and sediment source. Black shale units, including the Rhinestreet, typically split into eastwardly splaying black shale tongues (Fig. 1). The black shale facies is often laminated, but actually, typically displays small flattened burrows, indicating the bottom setting was not exclusively anoxic.

Baird and Brett (1986, 1991) discussed a variety of mechanisms to produce coarse tractional lags in black shale settings in the context of a basinal, deeper-water setting interpreted for such facies. Processes including: deep-storm wave impingement, bottom current processes, and internal waves were examined as mechanisms capable of moving coarse particles at depth. We tentatively settled on a model of internal wave-shoaling against a sloped basin substrate as a possible traction mechanism; in this scenario by internal waves generated along the pycnocline

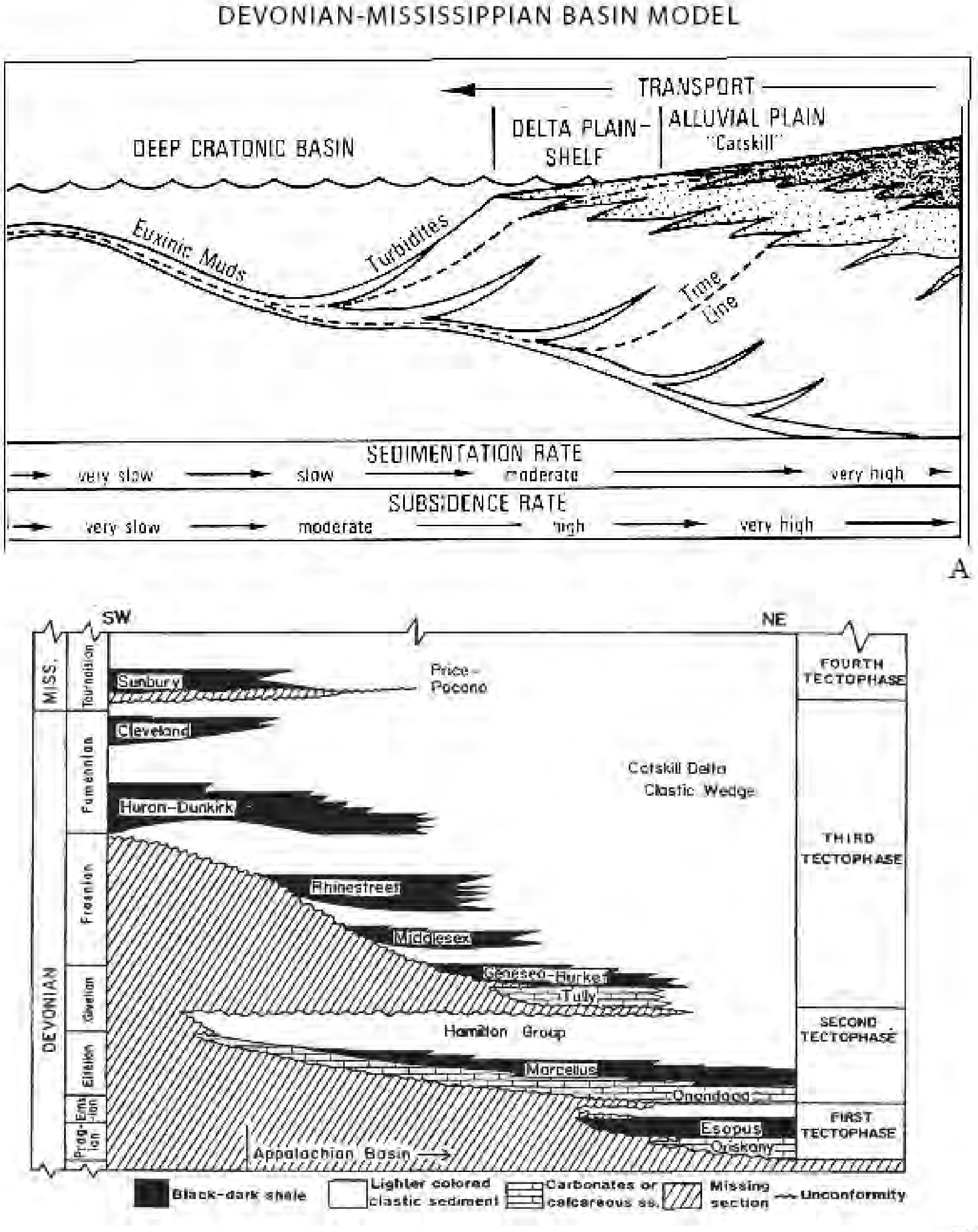


Figure 1. A. Idealized depositional model of the Catskill Delta complex (from Broadhead et al., 1982). B. Composite stratigraphic section from east-central New York to north-central Ohio in the northern Appalachian Basin showing distribution in time of pre-tectophase unconformities and unconformity-bounded flexural sequences of black shales and coarser clastic sediments attributed to four Acadian tectophases. Note progressive southwestward (cratonward) basin migration of successive black shale strata (from Ettensohn, 1994).

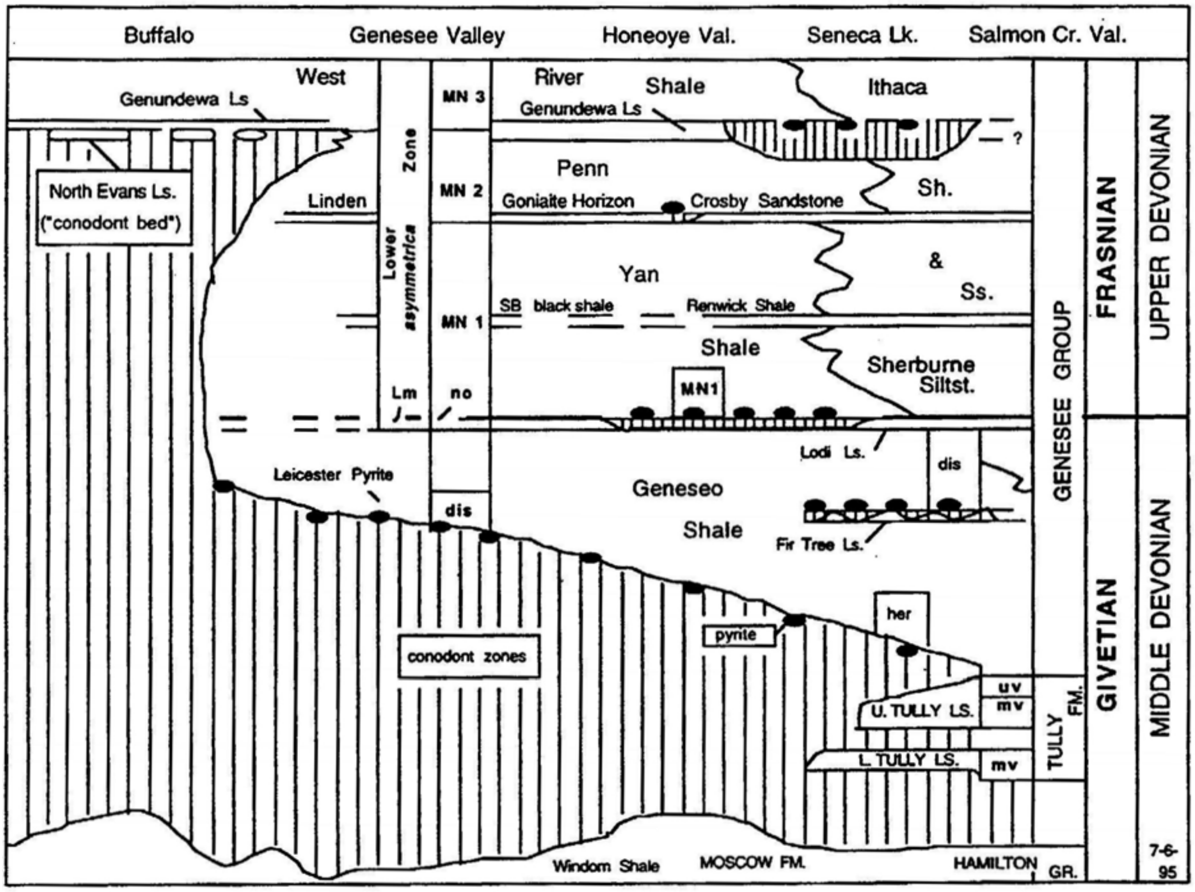


Figure 2. Generalized chronostratigraphic cross section of lower Genesee Group and subjacent Moscow Formation (Hamilton Group, Windom Shale Member). Large hiatus below Genesee Group marks position of compound Taghanic Unconformity, Genesee onlap succession and sub-Genundewa unconformity. The pre-Tully erosion- Hamilton erosion surface marks a major sequence and tectophase (III) boundary. The lenses of detrital Leicester Pyrite are derived from this erosion but were deposited through a long period of diachronous onlap of Genesee black muds from this discontinuity during the Taghanic transgression. The locally beveled beds with pyrite and fish debris include condensed styliolinid limestones and nodules (Fir Tree, Lodi, Abbey, Linden, Crosby, Genundewa) associated with surfaces of maximum sediment starvation formed during pulses of sea level rise. In this report, these horizons have been traced to the most highly condensed westernmost sections. The North Evans Limestone ("conodont bed") in the Buffalo area in western Erie County is a lag deposit of crinoid, fish and conodont debris that accumulated in shallow water over the peripheral bulge at the west margin of the basin where of the gap of the compound unconformity is greatest. Lenses of North Evans debris with ansatus Zone (Middle varcus) to upper MN Zone 2 conodonts and Frasnian goniatites (Koenenites) are traceable beneath the sub-upper Genundewa disconformity as far east as the Genesee Valley. (From Kirchgasser, Brett and Baird, 1997, fig. 7). See Fig. 3 for names of conodont zones.

SERIES	STAGE	CONONDONT ZONES		GONIATITE DIVISIONS		NEW YORK		
						UNITS	REGIONAL ZONES	
UPPER DEVONIAN	FAMENNIAN	? trachytera		Cheiloceras Stufe	III-VI II-H	Oswayo Cattaraugus	Maeneceras milleri	28
		marginifera			II-G	Chadakoin	Maenerceras aff. acutolaterale	27
		rhomboidea				North East & Westfield	?	
		crepida			II-C	Gowanda	Truyolsoceras clarkei	26
							Cheiloceras amblylobum	25
		triangularis				Dunkirk		
	FRASNIAN	linguiformis	13	Crickites	I-L	Hanover	? Sphaeromanticoceras rickardi Crickites lindneri	24c 24b 24a
		rhenana	12	Archoceras	I-K		Delphiceras cataphractum	23
						Pipe Creek	?	
		jamiae	11	Neomanticoceras	I-J	Angola	Sphaero. rhynchostomum	22b
				Playfordites	I-I		Playf. cf. tripartitus	22a
		hassi		Beloceras	I-H	Rhinestreet	Schind. chemungensis	21c
							Wellsites tynani	21b
			7 6	Mesobeloceras	I-G		Naplesites iynx	21a
		punctata	5	Prochorites	I-F	Cashaqua	Prochorites alveolatus	20
				Probeloceras	I-E		Probeloceras lutheri	19
		transitans	4	Sandbergeroceras	I-D	Middlesex	Sandbergeroceras syngonum	18
			3	Timanites	I-C	West River	Koenenites beckeri	17b
						Genundewa	Manticoceras contractum	17a
		falsiovalis	2	Koenenites	I-B		Koenenites stylio. kilfoylei	16b
						Penn Yan	Koenenites styliophilus styliophilus	16a
			1	Ponticeras	I-A		Chutoceras nundaium	15c
						Lodi	Ponticeras perlatum	15b
	GIVETIAN (pars)	norrisi disparilis hermanni		Pharciceras Stufe	MD III	Geneseo	Epitornoceras peracutum	15a
							Pharciceras sp.	14
						Tully	Pharciceras amplexum	13
		varcus		Maenioceras Stufe	MD II	Moscow	? Tornoceras uniangulare Maenioceras sp.	12

Figure 3. Late Devonian succession in New York State showing alignment to international conodont zones (Standard and Montagne Noire [1-13], goniatite cephalopod divisions, and New York regional zones (12-28). MN Zone assignments follow Kirchgasser and Klapper (1992),

Kirchgasser (1994), Klapper et al. (1995) and Over (1997, 2002). New data indicate MN Zone 8 is represented in Rhinestreet Shale (see text) From House and Kirchgasser (2008, fig. 63).

within the water column, eventually shoal against the basin margin slope resulting in erosion and sediment traction (Baird and Brett, 1991). This fits into the black shale onlap scenario in that this erosion occurs on the Taghanic Unconformity slope prior to slope burial by black mud; as water deepens, owing to sea level-rise and/or flexural subsidence, the zone of pycnoclinal erosion continually migrates westward in the upslope direction ahead of black mud onlap which takes place within a lower energy, lower dysoxic substrate regime below the pycnocline (Baird and Brett, 1986, 1991). Westward flexural basin expansion during Geneseo Shale deposition would account for east-to-west slope drowning and conveyor belt-type pycnocline migration and subsequent sediment onlap along a 100 km lateral distance across western New York. Calcareous fossils and diagenetic carbonate debris reworked from the underlying Windom Shale on the east-sloping, sediment-starved, Taghanic erosional ramp would start out as calcareous lag material in a shallower water wave-influenced, oxygenated regime. Subsequent slope drowning with consequent overspread of dysoxic water below the pycnocline was believed to explain the dissolution and transformation of the lag material to a residual placer of pyrite and other insolubles. Since the zone of pycnocline impingement was always upslope from the mud onlap limit during Geneseo time, the basal Geneseo lag would always be made up of insoluble material (Baird and Brett, 1986).

It is significant that the Leicester example is not isolated; coarse insoluble lags associated with Devonian black shale-roofed unconformities have been examined elsewhere (see summary in Baird and Brett, 1991; Schieber, 1994, 1998; Brett et al., 2003). Moreover, in the Rhinestreet Formation (STOPS 1C, 2), Angola Formation (Stop 3) and in the Hanover Formation (STOPS 4, 5), we will observe numerous gray-black shale alternations where thin black layers, some only millimeters-thick, rest sharply on gray shale units. Some of these contacts display thin lags of reworked wire-like, pyritic burrows, flattened goniatites, some with pyritized sutures, and geopetally pyrite-filled, spherical cysts of the algal taxon Tasmanites (Schieber and Baird, 2001). Lags flooring these thin black layers are much thinner and finer than those associated with the major contacts.

Juergen Schieber, by contrast, argues for a shallower water origin of these discontinuities and associated black shale facies based on his work on the Ohio, Chattanooga, and New Albany shales (Schieber, 1994, 1998). Coarse tractional siltstones, sandstones, and shell beds within the very condensed black, Chattanooga Shale are interpreted by him as being the result of storm wave impingement. Calculations of orbital wave velocities accounting for coarse sand and detrital pyrite transport, as well as the scouring of consolidated shale, yielded velocities in excess of 150 cm/sec. suggesting water paleodepths of as little as 10 meters (Schieber, 1994, 1998). These contrasting models revive the long-standing "black shale paleodepth controversy." Grit-grade popularipples and sheet sands occur within black shale facies of the Dowelltown Member of the Chattanooga Shale west of Nashville, Tennessee; not only does cross-laminated, grit-grade, quartz and phosphatic sand rest on the sub-Chattanooga disconformity, but this distinctive concentrate recurs at numerous overlying levels within the Dowelltown [G.C. Baird and A.J. Bartholomew (SUNY – New Paltz), unpublished observations]. Clearly, Schieber's storm model appears to have some credibility in explaining black shale features on the Nashville Dome. The coarse-grained Dowelltown beds, as well as the Leicester and its analogs, pose a key question;

how does one reconcile “basinal,” widely-distributed, and near-anoxic, organic-rich shale with evidence for high energy current activity? Are these units truly shallow with a pycnocline maintained just below the sea surface, to be disrupted intermittently by storms? Does a shallow-to-deep spectrum of Devonian black shale types exist within the Appalachian Basin and beyond? If shallow Devonian black shales exist, are these maintained by enormous surface productivity or by purely physical mechanisms? Until a good actualistic (modern) example of Leicester-type deposits is found forming, they will remain an intriguing enigma, but also a key insight in our overall understanding of sedimentary processes in the rock record.

The model of regional bed onlap and deeper-water pycnoclinal erosion can also be applied to the younger North Evans bone/conodont lag bed flooring the Genundewa Limestone (see STOP 1A; Fig. 4). The Genundewa Formation of the Genesee Group is a condensed pelagic limestone unit almost entirely composed of the conical microfossil Styliolina fissurella [Order Dacryoconarida Fisher, 1962], a problematic 1-2 mm-long calcareous conical shell of uncertain affinities. It was originally described erroneously from flattened material, hence the specific name “fissurella” (see Hall, 1843, 1879). Subsequent workers placed these organisms in a variety of groups: pteropod mollusks, tentaculitids, protista, and convincingly a form of lophophorate (see Lindemann and Yochelson, 1994; Lindemann, 2002; Vinn and Zaton, 2012). The abundance of this taxon in the Genundewa constitutes a major regional bioevent, or epibole; this organism appears to have been a form of extinct plankton that must have undergone periodic “blooms” in the epicontinental sea. In the Genundewa, these shells are uncompressed and are sometimes replaced or casted by pyrite. Although this unit is volumetrically almost entirely composed of Styliolina, other fossils include coalified plant material, the diminutive bivalve Pterochaenia, conodonts, and goniatites, including Koenenites.

This stratum seems to mark a transgression from a eustatic or tectonically induced lowstand event recorded by a regional unconformity marking the top of the Penn Yan Shale and an associated coarse lag unit known as the North Evans Limestone bone/conodont bed (“Conodont Bed” of Hinde, 1879; Fig. 2). The dysoxic Genundewa styliolinid carbonate grainstone facies onlaps the unconformity surface to the northwest, the inferred foreland basin margin, to the point of near bed-extinction in eastern Erie County. The North Evans Limestone, similar to the Leicester Pyrite, is very coarse; it contains reworked fish teeth, bones, spines, scales, abundant pelmatozoan debris, pyritized mollusks, including early whorls of goniatites, and a rich and famous concentration of conodonts, an amalgamation of late Givetian and early Frasnian elements spanning several conodont zones (Baird and Brett, 1982; Brett and Baird, 1990; Bryant, 1921; Huddle, 1974, 1981; Kirchgasser, 1994; Hussakoff and Bryant, 1918; Over et al., 1999). The important difference between the North Evans and Leicester is the dominantly carbonate nature of the former and the overwhelmingly insoluble character of the latter. We believe that the North Evans lag accumulated under conditions that were less dysoxic and, by implications, shallower than those applying to the Leicester. In essence, the North Evans lag is what the Leicester may have looked like at an upslope position on the Taghanic ramp prior to its subsequent dissolution at greater depth (Brett and Baird, 1982; Baird and Brett, 1986). The biota is of low diversity and suggests a dysoxic stressed environment, particularly, when compared to the rich, high diversity benthic fauna of the Tichenor Limestone, a carbonate unit of comparable thickness 6 meters below the Genundewa along Eighteenmile Creek, Erie County. Devonian styliolinid limestone facies is also known from European and North African sections where it is understood to represent condensed pelagic facies which accumulated in sediment-starved settings on the order of tens to hundreds of meters of water depth (see Tucker and Kendall, 1973; Tucker,

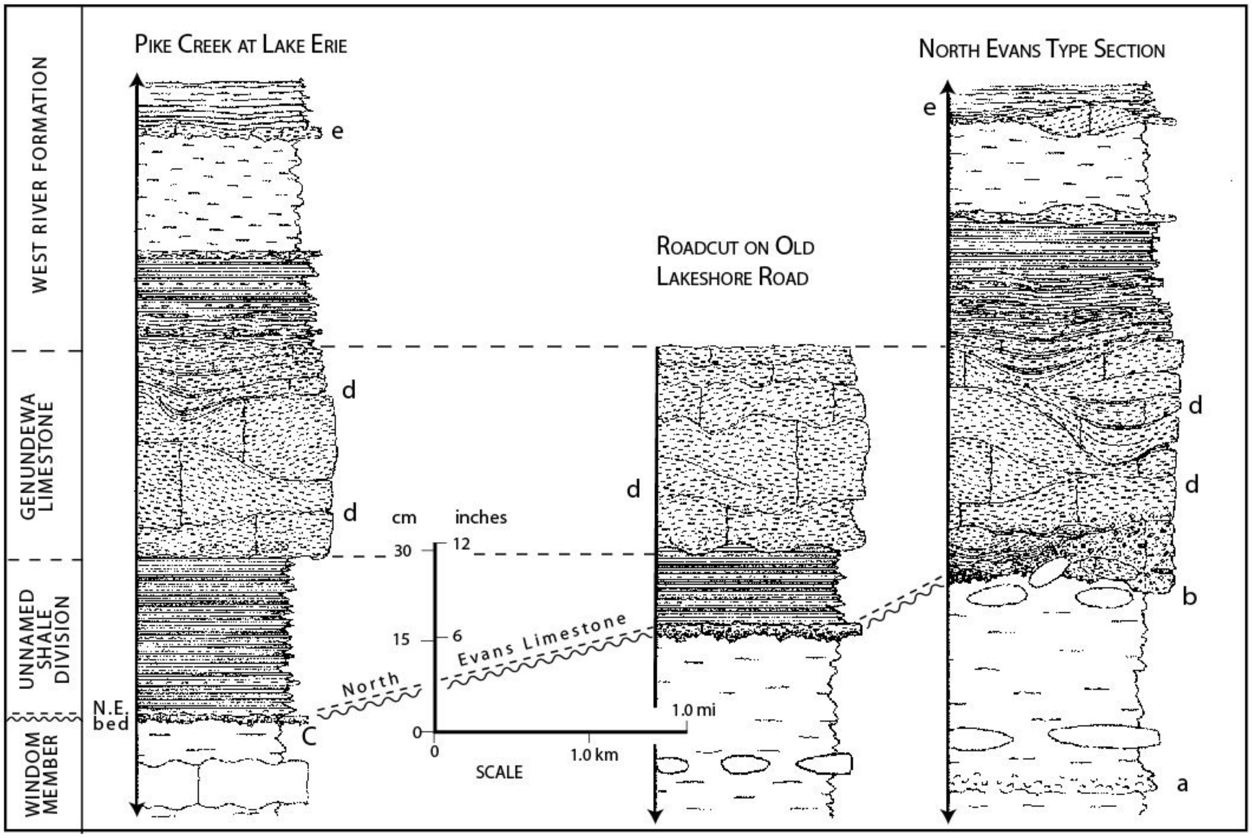


Figure 4. Genundewa Limestone and associated units in the vicinity of Lake Erie. Note prominent westward thinning of the North Evans lag deposit coupled with westward appearance of an unnamed black shale unit that separates the North Evans from the overlying Genundewa. Also visible is distinctive pinching and swelling of beds with associated localized channeling within the Genundewa. Lettered units include: a, Amsdell Bed of Windom Member yielding abundant Emanuella praeumbona; b, thick, pelmatozoan-rich subfacies of the North Evans Limestone; c, thin, pyrite-rich subfacies of the North Evans Limestone; d, Genundewa styliolinid grainstone-packstone carbonate facies; e, thin, lenticular, styliolinid limestone bed in the West River Formation yielding glauconite and abundant conodonts; this is sample-bed USGS 8122-SD Fall Brook, Geneseo (Livingston County) of Huddle (1981) and named the Huddle Bed in his honor (Baird et al., 2006).

1974; Bandel, 1974). The Genundewa compares most closely to the "cephalopodenkalk" (cephalopod limestone) facies of the German Rhenohercynian region; this carbonate accumulated on structural "highs" (schwellen) where styliolines, goniatites, diminutive bivalves, and ostracodes accumulated in a sediment-starved regime (Tucker, 1974; House and Kirchgasser, 1993). Basins between these swells received contemporaneous accumulation of thick shale units where turbiditic facies yield mainly ostracodes and little else. Compared to descriptions of the Rhenohercynian cephalopodenkalk, the Genundewa notably lacks micrite and is much more nearly a styliolinid grainstone (Fig. 4). However, it is locally packed with goniatite phragmocones in a manner typical of many cephalopodenkalk units. Acanthoclymenia, Koenenites, and Tornoceras , crinoid ossicles, and wood debris, can be found (see Kirchgasser et al., 1994, fig. 7, for sketches of the goniatites).

The Genundewa in Erie County is usually massive, but when weathered, the limestone typically splits apart into nodular and flaggy beds (Sass, 1951; Baird and Brett, 1982; Brett and Baird, 1982). Nodules occur as laterally linked to separate zones of sparry styliolinid limestone surrounded by muddy styliolinid partings. Bedding in the Genundewa is usually laminar with some evidence of bioturbation. Preparation for the present field trip led to discovery of cross stratification within the Genundewa along the Lake Erie shore bluffs southwest of Pike Creek and nearby on Eighteenmile Creek (Fig. 4). Several stacked sets of low angle cross stratified styliolinid grainstone can be seen with distinct thickening and thinning of beds in the cleaner, longer sections (Fig. 4). Locally, beds are distinctly cut out where channelization has occurred. This pattern resembles small-scale hummocky cross-stratification, suggesting the influence of deep-storm wave impingement at the substrate.

LATE DEVONIAN BASINAL FACIES AND EVENT HORIZONS

A sequence of alternating black and sparsely fossiliferous gray shale units, West River Formation-through-Dunkirk Formation, characterize the Late Devonian Frasnian and basal Famennian succession in southern Erie County. Inferred paleoenvironments range from nearly anoxic for portions of black shale units to more broadly dysoxic for the gray facies. No unit in this succession yields a significant benthos, though, as we will see, some strata yield a variety of pelagic taxa.

On the Lake Erie shore southwest of Eighteenmile Creek we will examine the lower part of the black Rhinestreet Formation, a major division of the West Falls Group (Fig. 6). Within the larger black shale interval is a 2.2-2.4 m-thick interval of predominantly gray shale with thin “pinstripe” black shale bands at several levels (Fig. 6). This is well exposed on the lakeshore (STOP 2) where a basal turbiditic? siltstone bed marks the base of the interval. Although some bioturbation can be seen in the gray shale, much of it is fine grained, conchoidal “satin shale,” suggestive of turbiditic or hemipelagic origin. Hence the gray shale complex appears to be the distal “toe” of prodelta sediments within the basin. At STOP 1C a 1.0 cm-thick K-bentonite can be seen about one meter below the gray shale unit (Fig. 6). The pyroclastic character of this bed is revealed by an abundance of mica-rich clay which is suffused with diagenetic pyrite. This K-bentonite was reported by Levin and Kirchgasser (1994) to be the Belpre Ash of Tennessee, since confirmed by Lanik et al. (2013) to have the same radiometric date and similar conodont fauna. Some 40 cm above the gray shale interval exposed northeast of Sturgeon Point (STOP 2) is a 4 – 8 cm-thick interval of Styliolina–rich black shale that yields the zonally significant goniatite Naplesites (Fig. 7B), previously known in New York from a few specimens, presumably from the Rhinestreet Shale, that were reported by Clarke (1898) from around Naples in Ontario County. The discovery of conodonts in Styliolina concentrations associated with the goniatites, offers an opportunity to link conodont, ammonoid chronostratigraphic, and zircon derived U/Pb radiometric age from the underlying ash bed. The goniatites are notable for their poor, ghost-like preservation in the black shale, suggesting that the aragonite of the phragmocone may have dissolved before significant mud compaction had taken place, but that the organic periostracum survived after compaction, leading to the flattened, composite impressions of these fossils; the edges of some of the septa (chevron-pattern suture lines) are replaced by pyrite. The goniatite clusters include a variety of ontogenetic stages from juveniles to adults with shell diameters exceeding 100 cm.

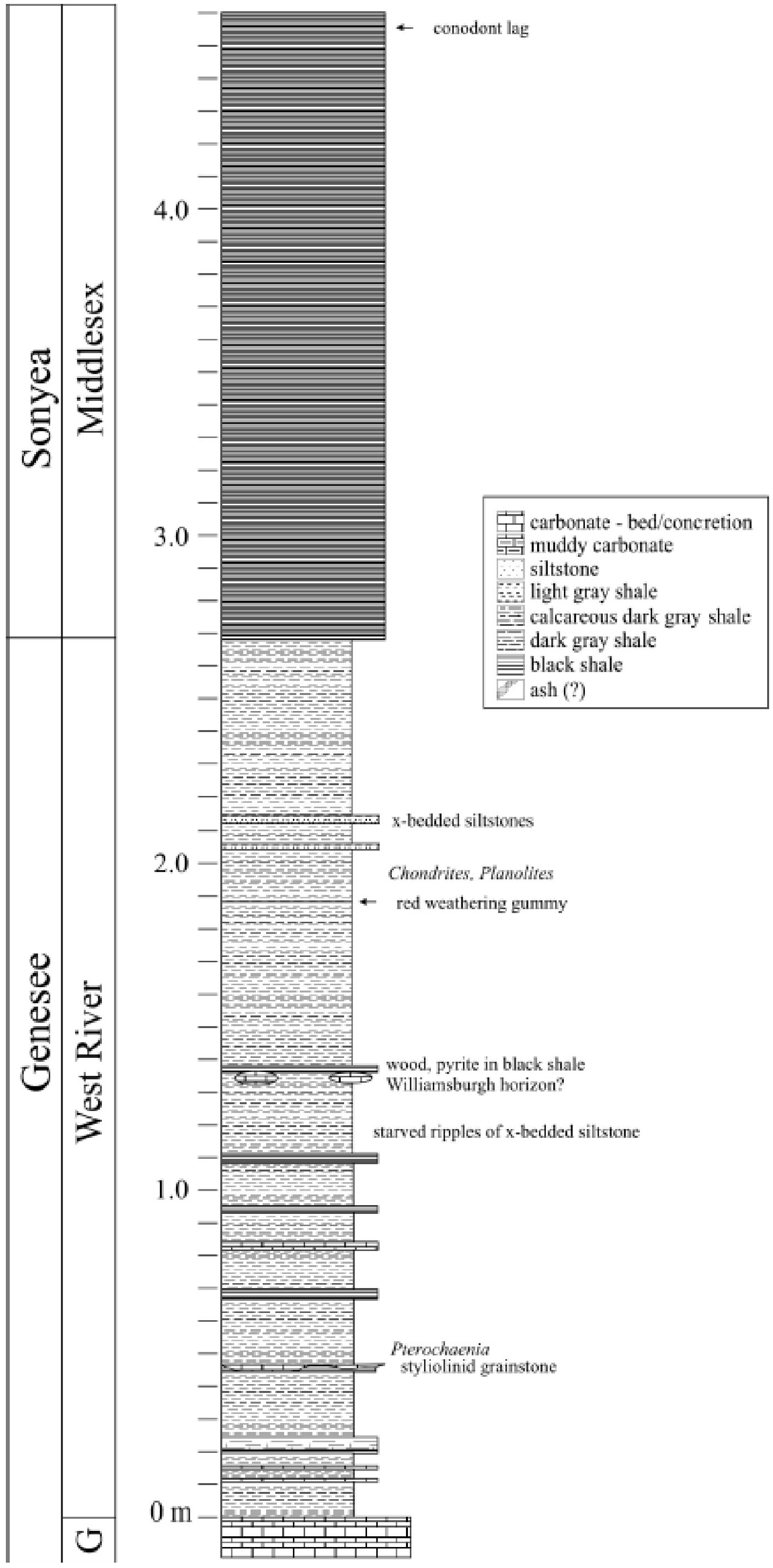


Figure 5. Stratigraphic section of the West River Formation and Middlesex Formation at Eighteenmile Creek. G = Genundewa Limestone.

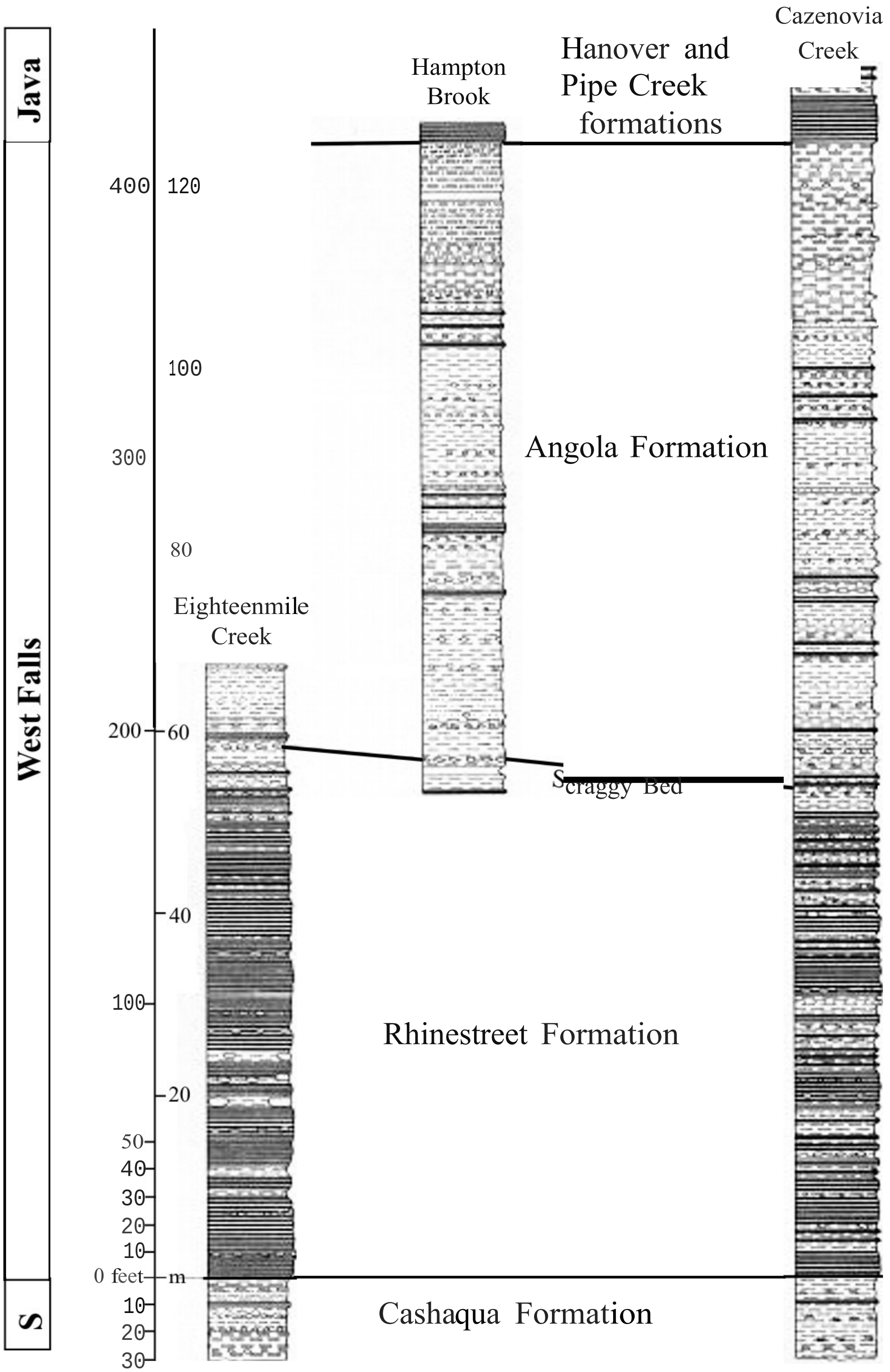


Figure 6A. General stratigraphy of the West Falls Group – Rhinestreet and Angola formations - on the Lake Erie shore and adjacent creek exposures, from Pepper et al. (1956). S = Sonyea Group. See Figure 5 for key to symbols.

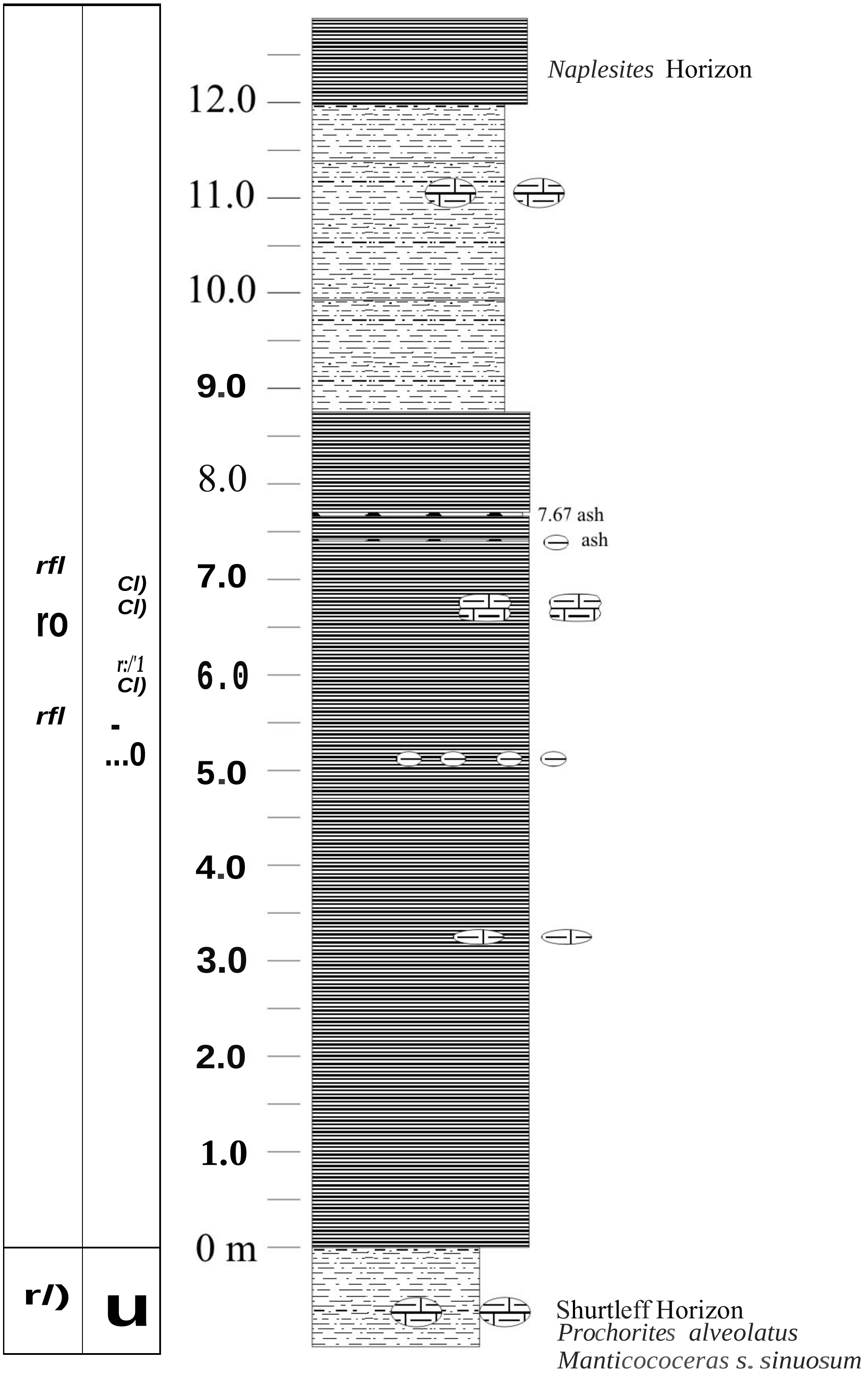
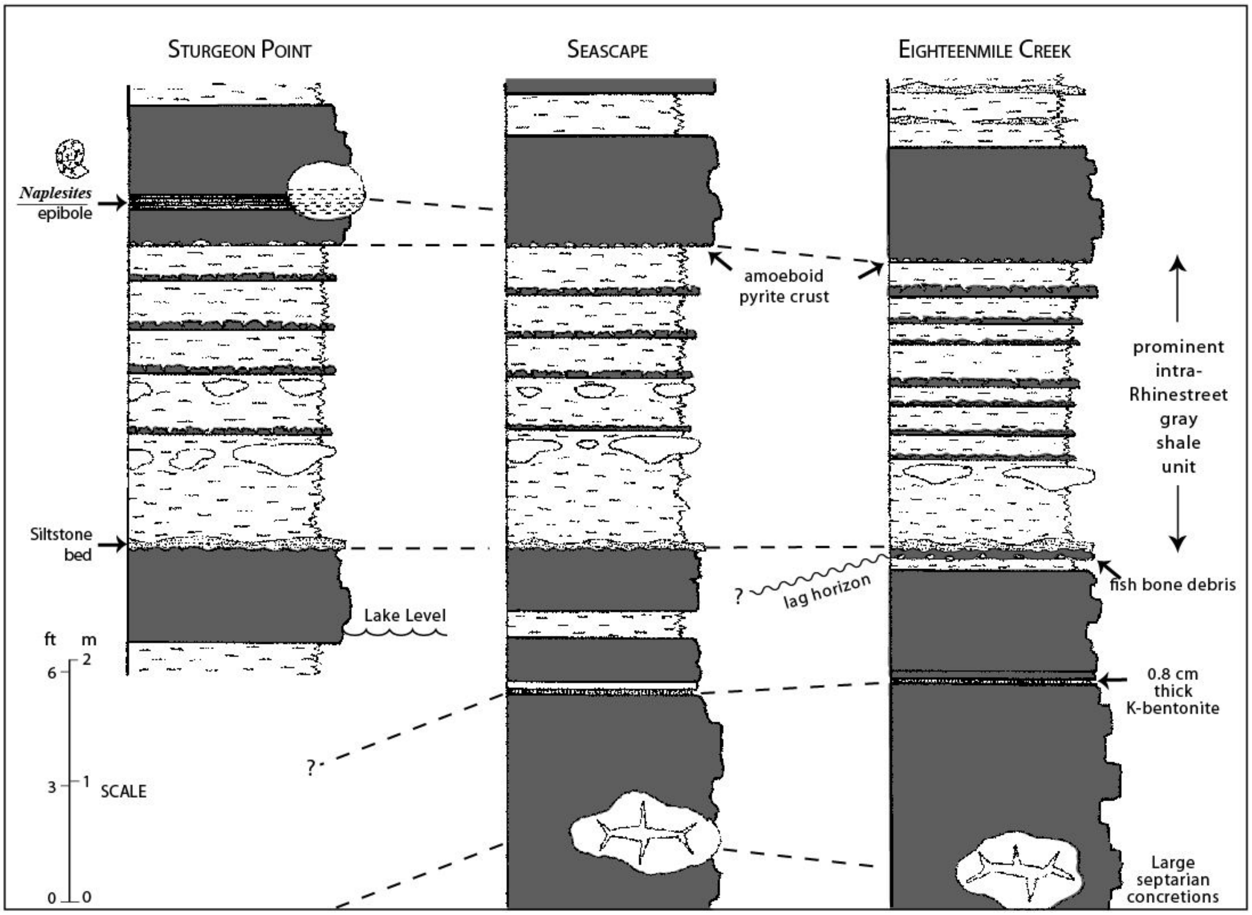


Figure 6B – Detailed section of the basal Rhinestreet Formation at Eighteenmile Creek. S = Sonyea Group; Ca = Cashaqua Formation. See **Figure 5** for key to symbols.



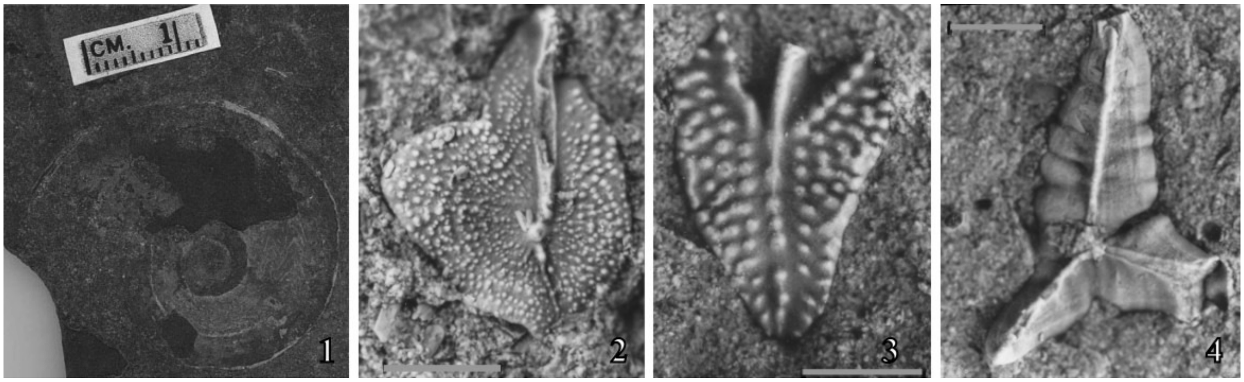


Figure 7A. Unnamed gray shale division within the lower part of the Rhinestreet Formation in the vicinity of Lake Erie in southern Erie County. Note the numerous gray-green shale alternations within the gray shale division, the K-bentonite bed below, and the Naplesites goniatite epibole above. B. 1. Goniatite Naplesites with characteristic chevron-pattern suture line preserved in pyrite from the Naplesites epibole. 2-4. Conodonts from the fish-conodont lag beneath the siltstone at base of gray shale division; 2, Palmatolepis punctata; 3, Ancyrodella nodosa s.s.; 4, Ancyrognathus sp. L of G. Klapper. Scale bar = 0.5 mm.

Southwest of the Sturgeon Point marina and car park is a low, resistant bench of Rhinestreet black shale. At the top of the bench and above a band of massive septarial concretions are two closely-spaced zones of small, 0.3 – 3.5 cm- diameter phosphatic nodules which occur interspersed among larger limestone concretions. Close examination of the phosphatic nodules shows that they selectively grew around fish bones, spines, and scales. The high proportion of fish- nucleated nodules in this location suggests a time of significant water column productivity and/or sediment condensation. This horizon may be one of many similar beds yet to be recognized in the Devonian basinal succession. Recently G. Baird reconnoitered past the phosphate-bearing outcrop and around the shore bend to the southwest. Outcrop commences again with appearance of gray-green shale, gray discoidal concretions, and thin black shale layers both at and below water-level. Capping this is a bench of black shale yielding numerous Naplesites. It seems that the northward-projecting Sturgeon Point brings up older strata and that the section, north of the marina, is repeated once again. This would mean that the phosphatic beds should be present at Seascape, at our Eighteenmile Creek stop, and, possibly, locally at lake-level northeast of the Sturgeon Point marina.

Overlying the Rhinestreet in westernmost New York is the Angola Formation, which represents a return to Cashaqua-like conditions of predominantly gray silty shales and interbedded black shales and concretionary beds (Fig. 7). Eastward the Angola interfingers and grades into the Gardeau and Nunda formations, which represent more near shore turbiditic and sandstone facies of the deep shelf and shoreface (Pepper et al., 1956; Baird and Jacobi, 1999). Along the Lake Erie shore the Angola is on the order of 60 m thick. We will look at a lower portion of the Angola at Point Breeze (Stop 3) where goniatite-bearing concretions – Pt. Breeze Bed of House and Kirchgasseer (2008) and a distinctive black shale are exposed, as well as the uppermost Angola at Walnut Creek (Stop 4). The sedimentary microcycles seen in the Rhinestreet are continued in the Angola; these cycles and key beds can be traced well into Wyoming County to the east (House and Kirchgasser, 2008, fig. 15). The concretionary beds in the lower Angola are rich in well preserved goniatites. The type materials of Sphaeromanticoceras rhynchostomum (Clarke, 1898) and Carinoceras sororium (Clarke, 1898) come from the lower Angola. Other goniatites from the Pt. Breeze Bed include Sphaeromanticocera oxy, Carnioceras vagans, Manticoceras lamed, M. aff. M. lamed, Playfordites cf. P. tripartitus, Linguatornoceras aff. L. linguum, Aulatornoceras pacistriatum, and Crassotornoceras aff. C. crassum. These place the lower Angola in Devonian Goniatite Division Neomanitcoceras UD I-J; conodonts from this interval have not provided a distinct zonation (House and Kirchgasser, 2008), but are probably in MN 11.

The closing of the Late Devonian Frasnian stage was marked by two major episodes of ecological disruption and faunal extinction. 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, south of the field trip area. In Europe, North Africa, and elsewhere the two extinction events are marked by black shale or black limestone beds within slope and basin successions. These are known respectively as the “lower Kellwasser Bed” and “Upper Kellwasser Bed” in the literature (see Over, 2002; Racki, 2005; Schindler, 1993; Schindler and Königshof, 1997). Recently, both the lower and Upper Kellwasser equivalent beds have been found in western New York on the basis of lithology correlated to conodont zonation (Over, 1997, 2002; Day and Over, 2002; Over et al., 1997). The lower Kellwasser event is now linked to the Pipe Creek Formation, marking the base of the Java Group; we will see this unit at Walnut Creek (STOP 4; Figs. 8, 9). The Upper Kellwasser event correlates to a black shale bed in the upper part of the Hanover Shale Formation near the top of the Java Group (Over, 1997, 2002); we will see this bed at Point Gratiot (STOP 5; Fig. 10).

The Pipe Creek Formation at Walnut Creek (STOP 4) is a 0.6 meter-thick, very hard, black shale that abruptly overlies the softer, gray Angola Formation (Fig. 8, 9). The laminated microfacies of the Pipe Creek contrasts dramatically with a subjacent zone of gray, pyritic Angola mudstone; this 15 cm-thick mudstone interval is thoroughly penetrated by networks of pyritic burrows which can be dramatically seen through x-ray imaging (Fig. 9). The Pipe Creek can be traced regionally southwestward into 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). The actual ecological reorganization-extinction event, best seen in neritic facies, is cryptic in Erie County; study of this faunal change will be the domain of work in equivalent silty-sandy facies in central New York. However, tentative discovery of a 1.2 cm-thick K-bentonite bed rich in pyroclastic micas in the Eighteenmile Creek section offers the possibility that this interval can be dated radiometrically. Given that the Pipe Creek Formation is succeeded by gray, goniatite-bearing nodular shales of the basal Hanover Formation (STOP 4 description; Fig. 8), the combined radiometric date and the goniatite - conodont information will constitute a key point for the global Lower Kellwasser Event.

The lower Hanover Formation shows distinct meter-scale cyclic packages of black shale - gray shale with concretion horizons that is seen elsewhere in the offshore faices of the Frasnian strata. The base of the black shales represents a starvation surface and condensed interval of a flooding surface, possibly accumulating pyrite – see Baird and Brett (1987) as well as volcanic ash. The black shales then represent the condensed early highstand and time of organic preservation under relatively deeper or quiet water conditions. The concretion horizons are believed to develop prior to significant compaction within the substrate, probably at the time of sediment starvation of the overlying black shale base (see Raiswell, 1971; Raiswell and Fisher, 2000).

The Upper Kellwasser Bed is exposed in upper Hanover Shale at numerous localities in western New York from the Genesee River Valley to Point Gratiot on the Lake Erie shore (Over, 2002). At Point Gratiot it occurs within the upper part of the Hanover Formation 0.15 m below the base of the Lower Famennian Dunkirk Formation. Along Eighteenmile Creek near New Oregon Road the bed is 2.4 meters below the base of the Dunkirk. Generally, the Hanover Formation is predominantly gray mudstone with a few rhythmic bundles of thin black shale units. Above the Pipe Creek and at several higher levels, this unit is spectacularly nodular with repeating bands of calcareous concretions and distinctive beds of irregular, closely crowded, beige nodules resembling calcrete (Fig. 8). Generally the Hanover yields only a low diversity fauna of ostracodes, small gastropods, bivalves, sparse goniatites, and small rugosans despite its light color, pervasive bioturbation, (including Zoophycos), and numerous carbonate layers. It appears to record relative sedimentary condensation under dysoxic conditions. However, compared to

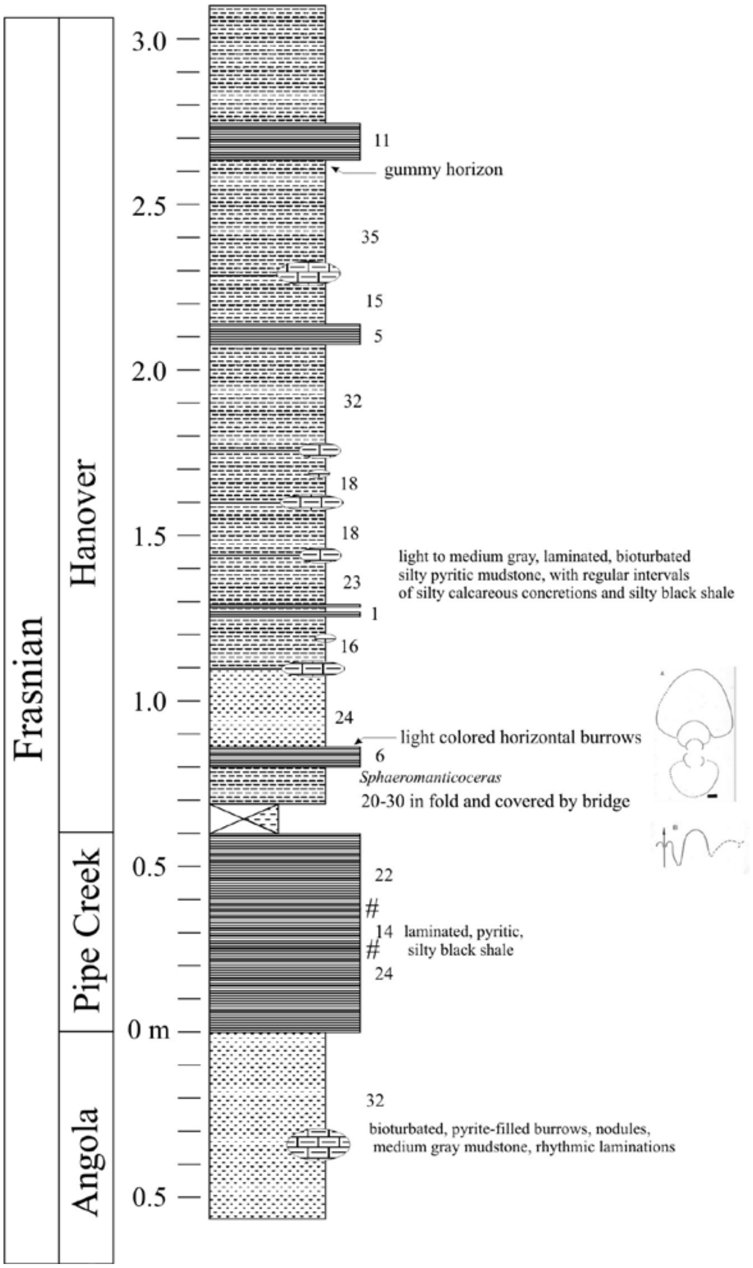


Figure 8. Pipe Creek Formation ("Lower Kellwasser Bed") and synjacent units at Walnut Creek (STOP 4). A, B are cross section and suture pattern of Crickities lindneri which enters at approximately 1 m in this section marking the base of the Crickites Geozone and Division UD I-L. Gummy horizon is a possible ash bed. See Figure 5 for key to symbols.

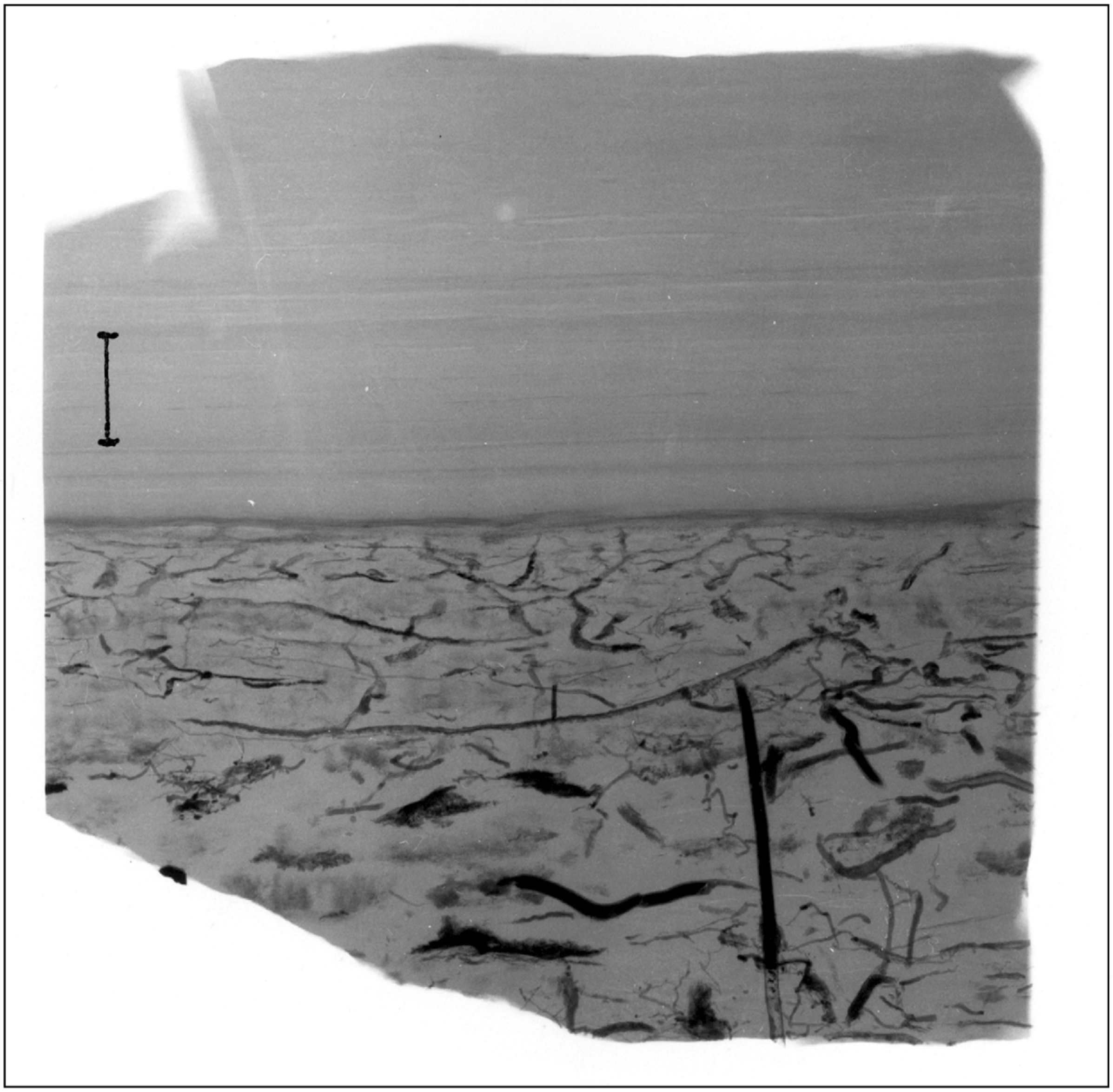


Figure 9. X-radiographic image of the contact between the Angola Shale and the overlying Pipe Creek Formation. Although this specimen is from the type Pipe Creek section near West Falls, Erie County, that contact is essentially identical to the one seen at STOP 4. Note the conspicuous vertical change from the bioturbated gray Angola into the laminated Pipe Creek lithology. Scale is 1.0 centimeter.

dysoxic – minimally oxic units in the Middle Devonian Hamilton Group (Levanna Member, Ledyard Member), the facies is markedly poorer in shelly benthos and richer in bands of small and irregular nodules. This suggests some dynamic geochemical-evolutionary changes across the Givetian and Frasnian that have yet to be identified or quantified.

The Upper Kellwasser Bed is expressed as a fissile black shale unit with some silty laminations in the upper part (Fig. 10). This bed is designated the Point Gratiot Bed for the excellent exposure along Lake Erie at Point Gratiot at the southwest edge of Dunkirk, Chautauqua County (Stop 5). This layer, which is 15 cm-thick at Point Gratiot, 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 the upper part of this layer has yielded articulated fish remains. At Beaver Meadow Creek, Spathiocaris, a probable cephalopod anaptychus, is 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 actually marks an apparent change to finer grained, more basinal facies within the upper part of the Hanover Formation [see revised schematic (Fig. 11) clarifying this relationship]. Between Point Gratiot and Java Village the interval between the Upper Kellwasser Bed and the overlying Dunkirk thickens from 15 cm to 7 meters with addition of numerous alternating black and gray-green shale beds (Fig. 11). 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 linguiformis (MN Zone 13)/Lower triangularis chronozonal conodont boundary and inferred Frasnian-Famennian contact (Fig. 3) 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. However, one of us, Jeff Over, has described a bed of shelly taxa containing earliest Famennian brachiopods and bivalves in a thin, anomalous layer only one meter above the extinction horizon near Java Village (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. Moreover, new fieldwork by Over in neritic deposits at this level further east near Hornell, by Boyer and students, and work by Baird in southern Chautauqua County, is shedding light on the more visceral effects of the extinction on shelly benthos and bioturbators in lower Famennian neritic deposits.

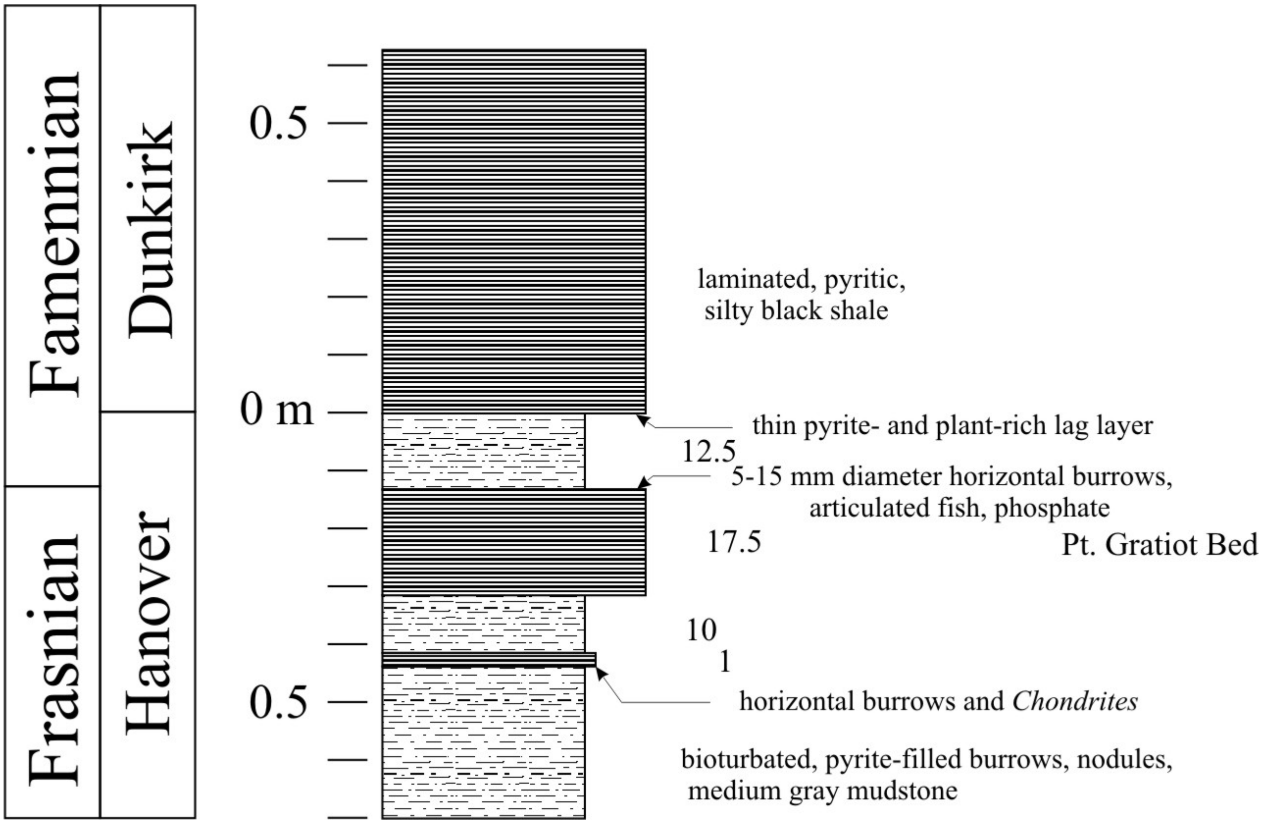


Figure 10. Frasnian-Famennian boundary horizon within the upper part of the Hanover Shale on the Lake Erie shore at Point Gratiot. Note that the local Frasnian-Famennian boundary unit, corresponding to the global "Upper Kellwasser Bed" of chronostratigraphic literature, designated the Point Gratiot Bed. See Figure 11 for lateral changes in the Hanover Shale, especially the inflation of the 12 cm interval between the Pt. Gratiot Bed and the Dunkirk Formation. See Figure 5 for key to symbols.

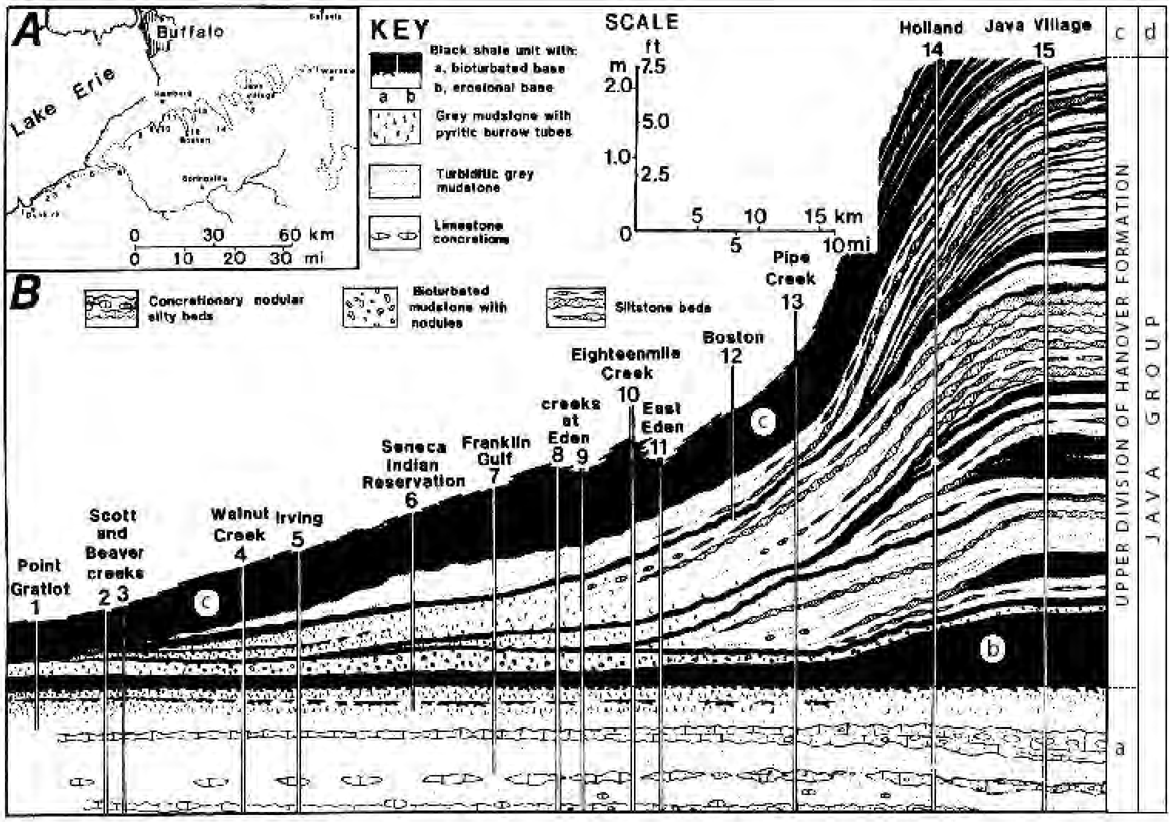
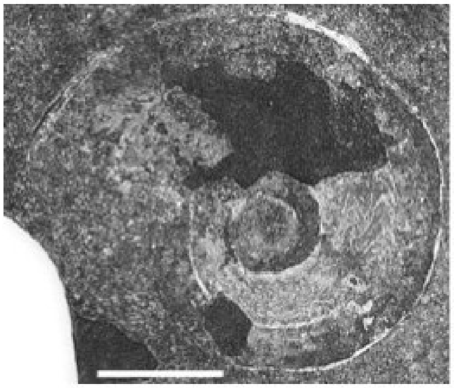


Figure 11. Regional stratigraphy of units within the upper part of the Hanover Formation across Chautauqua, Erie, and southwest Wyoming counties. Note conspicuous eastward thickening of the upper Hanover unnamed division of alternating thin gray and black shale with eastward splaying of units into a distal deltaic wedge and westward erosional overstep of underlying units by Dunkirk and upper Hanover black shale beds. Note also that the upper medial Hanover Formation below the newly named Point Gratiot Bed (= “Upper Kellwasser Bed”) is notably more calcareous, bioturbated, and lighter colored than overlying units (see discussion in text). This figure is modified from Baird and Lash (1990) and Baird and Brett (1991) in that the Point Gratiot Bed is shown to be a division within the upper Hanover succession rather than the base of the Dunkirk Formation as shown in these earlier reports. Lettered units include: a, calcareous bed in upper medial part of Hanover Formation; b, Point Gratiot Bed; c, basal strata of Dunkirk Shale.



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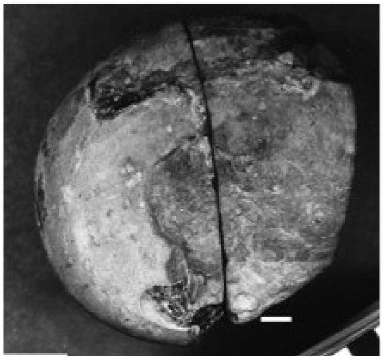

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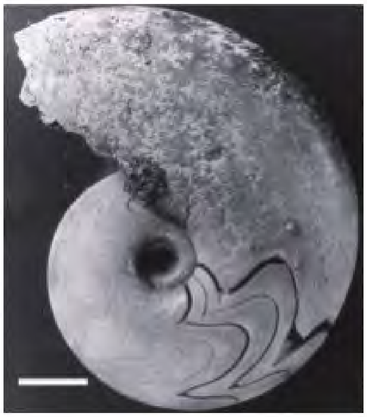

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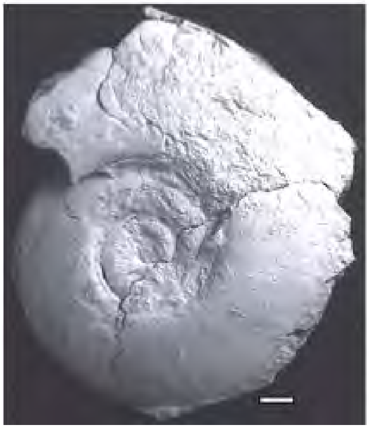

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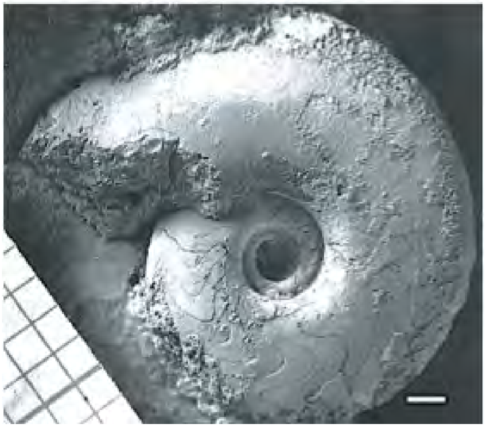

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Figure 12. Goniatite cephalopods from Late Devonian of western New York: in stratigraphic order [Givetian (1) and Frasnian (2-9)]. Specimens illustrated in House and Kirchgasser (2008) and reposited in New York State Museum, Albany. Bar scales: 1 cm. 1. Ponticeras perlatum, Lodi Limestone, Lodi Glen, Seneca Lake. 2. Koenenites styliophilus styliophilus, Penn Yan Shale, Sartwell Ravine, Keuka Lake. 3. Koenenites styliophilus kilfoylei, Genundewa Limestone, Bethany Center, Genesee County. 4. Probeloceras lutheri, Cashaqua Shale, Eighteenmile Creek, Erie County (pyrite replacement). 5. Manticoceras sinuosum sinuosum, Cashaqua Shale, Beards Creek, Livingston County (pyrite replacement). 6. Prochorites alveolatus, Cashaqua Shale, Honeoye Lake, Ontario County (barite replacement). 7. Naplesites naplesense?, Rhinestreet Shale, Sturgeon Point, Lake Erie shore, Erie County (pyrite replacement). 8. Sphaeromanticoceras oxy, Angola Shale, Kennedy Gulf, Wyoming County. 9. Crickites lindneri, Hanover Shale, Walnut Creek, Chautauqua County.

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ROADLOG AND STOP DESCRIPTIONS

Accumulated Miles	Incremental Miles	Road log description
0.0	0.0	Central Avenue at entrance to SUNY-Fredonia; turn south (right) and proceed to Temple Street; turn left (southeast) and proceed to E. Main Street/US 20. Turn east (left) and proceed on US 20 from Fredonia, through Silver Creek, to North Evans and the traffic signal at South Creek Road just before the bridge over Eighteenmile Creek.
28.4	28.4	Turn left (north), proceed under railroad overpasses and park on west side of road.
1.0	29.4	Stop 1A – Eighteenmile Creek at stone bridge.
1.1	30.5	Proceed south on South Creek Road, cross US 20 and park on side of road by cemetery. Stop 1B – Eighteenmile Creek at US 20 bridge.
0.6	31.1	Proceed south on South Creek Road/Shadagee Road to where gas line crosses road and park on east side of road. Stop 1C – Eightreenmile Creek at "gas line."

STOP 1A. Conrail Bridge over Eighteenmile Creek, South Creek Road near North Evans, south of NY 5, north of US 20. Proceed from parking area eastward on old railroad grade and down slope on south side to creek. This section exposes the upper Windom Shale, North Evans type section, very thin Penn Yan, Genundewa Limestone, West River Shale, Middlesex, Cashequa, and the lower Rhinestreet on either side of the stone bridge (Figs. 4-7).

This section shows the Windom Member-North Evans Limestone contact as a knife-sharp boundary separating gray Windom Shale bearing light gray concretions from dark, dysoxic beds of the Genesee Group (Fig. 4). The North Evans Limestone is a 6-12 cm thick lag accumulation dominantly composed of crinoidal debris, but also characterized by abundant conodonts, glauconitic grains, fish debris, and reworked concretions (Fig. 4). The North Evans grades into styliolinid grainstone facies of the overlying Genundewa, sometimes separated by thin styliolinid-rich shale assigned to the Penn Yan. However, further downstream from that bridge to the northwest, a succession of creek bank sections shows dramatic thinning of the North Evans Limestone with the appearance of the feather edge of the dark shale as a nodular parting above the lag unit. Moreover, the North Evans undergoes a lateral, spectral change from a thick crinoidal unit to a thin layer of mixed carbonate grains and detrital pyrite that is distinctly more "Leicester"-like (Fig. 4). In the next key section (Fig. 4) along the Old Lakeshore Road the intervening shale is 10-11 cm-thick and the North Evans Limestone is only about 2-3 cm-thick. This intervening shale unit is herein interpreted as being a local basinal facies of the Genundewa Limestone in that its upper contact is conformable (non erosional) with the Genundewa Limestone. The westward North Evans allochem transition from dominantly calcareous to largely insoluble grains, accords closely to the appearance of the overlying dark shale, and it suggests that carbonate dissolution of the exposed lag was more intense in the more basinal subenvironment of STOP 1 than at localities further to the northeast.

At STOP 1 the North Evans Limestone rests on the Taghanic Composite Unconformity, a disconformity of large time-magnitude. Based on comparison with more continuous Devonian sections further east, the section at Lake Erie is severely truncated; approximately one third of the Windom Member, the entire overlying Tully Formation, and all of the succeeding Geneseo and Penn Yan formation successions are absent at STOP 1 (Figs. 3, 4). The North Evans Limestone is a complex lag blanket famous for its fish material (Hussakoff and Bryant, 1918, Bryant, 1921, Turner, 1998) and conodonts (Hinde, 1879, Bryant, 1921, Huddle, 1974, 1981). North Evans conodonts are exceedingly abundant and diverse in species and types of elements. Elements of the North Evans fauna, both its fish debris and conodonts, can be traced from Erie County to the Genesee Valley. Preservation of the conodont elements is distinctive and varies from complete and pristine (light amber-colored) to broken, dark (almost black), and degraded (Color Alteration Index is 2 to 3). Colors of some of the fish debris are red, orange, gray and blue. The taphonomic history of the North Evans debris is complex and tests the limits of chronostratigraphic resolution (Kirchgasser and Koslowski, 1996; Kirchgasser and Vargo, 1998; Kirchgasser, 1994, 1998, 2001, 2002, 2004). The final taphonomic (burial age) of the North Evans material correlates to the youngest zone conodont in the mix, which is Ancyrodella recta of the upper part of Lower Frasnian MN Zone 2 (Kirchgasser, 1994); early whorls of the Lower Frasnian goniatite Koenenites (also MN 2 age) have been recovered from North Evans conodont residues at the type section at Eighteenmile Creek (Fig. 4) and in lenses within the Genundewa Limestone at Linden in Genesee County. The North Evans, as with most lag beds, poses a depositional paradox; even though the lag content records an enormous span of time, the actual final depositional event producing the bed may have been geologically instantaneous.

The Genundewa Limestone at STOP 1 is a 30-40 cm-thick ledge composed of styliolinid grainstone-packstone carbonate (Fig. 4). It is typically brownish gray, massive to nodular, limestone which sometimes weathers into thinner, flaggy beds. Aside from Styliolina and the small bivalve Pterochaenia, fossils are scarce, usually small, and of low diversity. The goniatites Koenenites, Acanthoclymenia, and Tornoceras, as well as Manticoceras at the very top, occur in the Genundewa, but are rare or poorly preserved here; the conodont Ancyrodella recta of upper MN Zone 2 occurs in the North Evans Limestone and at the base of the Genundewa Limestone at Linden in Genesee County (see Sunday illustrations). As noted, the Genundewa is a pelagic limestone that probably represents oxygen-stressed, sediment-starved, basin slope conditions. However, at this locality, local erosional channelization is evident locally within the limestone (Fig. 4). These channels, as well as pervasive small-scale hummocky cross-bedding and widespread alignment of Styliolina throughout the Genundewa, attest to significant current activity at the substrate, probably caused by deep-storm waves. The top of the Genundewa is gradational with the overlying shaley West River Formation; the topmost Genundewa becomes shaley and flaggy before giving way to the typical alternation of thin black and gray shale normally seen in the West River (Fig. 4). We herein interpret the interval from the sub-North Evans disconformity upward into the lower medial West River Formation is a Transgressive Systems Tract, starting with an erosional lowstand event recorded by the disconformity. The succeeding Genundewa is a condensed interval recording transgressive deepening within the basin and sediment-starvation on slope. A possible Maximum Flooding

Surface is represented by a recurrent conodont-glauconite-bearing styliolinid bed within the basal West River Shale (Fig. 4); this conodont-rich bed has been traced westward from the Genesee Valley and is Huddle (1981) sample horizon 8122SD at Fall Brook, Geneseo (Kirchgasser et al., 1994, A-4, STOP 1, Fig. 11); it has been named the Huddle Bed in his honor (Baird et al., 2006). Early highstand facies are represented by succeeding alternations of black and gray shale. This overall transgression probably represents a hybrid eustatic and flexural event within the basin.

Proceeding up-section the West River Shale is composed of 2.5 m of dark gray shales, black shale beds, and silty interbeds that are cross bedded (Fig. 5). Horizons rich in the the pelagic bivalve Pterochaenia are common, as are beds that preserve dacryoconarids and Planolites. The Williamsburg Bed, a carbonate, wood, and conodont-rich pyritic horizon in the upper 1.5 m of the West River marks a sequence boundary and condensed interval before the onset of persistent black shale deposition in the Middlesex. The Williamsburg Bed can be traced to the Finger Lakes region (Over et al., 2002).

The Middlesex is exposed upstream from the railroad bridge. Here the Middlesex is xx m thick, composed of dense silty black shales. A lamination of pyrite and conodonts in the upper 5 cm contains Ancyrodella gigas and the lowest Palmatolepis punctata, which marks the base of MN Zone 5.

In a narrow gully on the east side of the creek the entire Cashaqua Formation is exposed. The Cashaqua is 13 m thick, consisting of light gray shale and abundant concretions that contain goniatites and dacryoconarids. Toward the top are several thin black shales and an ash bed, which is possibly part of the Belpre Ash Suite, but this has not yet been tested. The Rhinestreet Formation sharply overlies the Cashaqua – Stop 1B.

Return to vehicles.

Cashaqua-Rhinstreet contact, Belpre Ash.

STOP 1B. Cashaqua Shale/Rhinestreet Shale contact and overlying Rhinestreet strata exposed on Eighteenmile Creek and on access road leading to that creek, town of North Evans, Erie County (see Fig. 6). Enter access path opposite from North Evans Cemetery. Proceed on foot down sloped path to valley bottom. Cross flat area to edge of Eighteenmile Creek.

The Cashaqua Formation of the Sonyea Group in southern Erie County is characteristically composed of gray fissile shale with a rhythmic succession of discoidal concretion bands (Buehler and Tesmer, 1963; Kirchgasser et al., 1997; Fig. 6). The fauna of this unit consists of small mollusks and brachiopods, indicative of a dysoxic setting. Most notable, is the occurrence of numerous, often poorly preserved, goniatites belonging to the genera Manticoceras and Probeloceras which are flattened within the shale and variably three dimensional inside of concretions (conodont Zone MN 5). Probeloceras is the ancestral genus of the family Beloceratidae and is followed by the genus Naplesites in the Rhinestreet Shale seen at Sturgeon Point, Lake Erie (Stop 2; Fig. 12 and Kirchgasser et al., 1994, fig. 7 for illustrations of Sonyea and West Falls Group goniatites). The prominent concretion layer with MN Zone 6 conodonts in the dark shales of the upper Cashaqua Shale is a septarian band with white or pink barite filling the shrinkage cracks and in places east of the Genesee Valley in Livingston County, replacing the shells of a rich molluscan fauna including the goniatites Manticoceras, Prochorites, Acanthoclymenia and Aulatornoceras; conodonts in the bed indicate MN Zone 6. The Prochorites is a species (P. alveolatus) known elsewhere only in Western Australia.

The Rhinestreet Formation is one of the thickest Late Devonian black shale divisions in western New York. The base is sharp and marked by a seam of diagenetic pyrite which weathers to a rusty band in bank sections. No detrital pyrite has been found on the contact, but a rich association of conodonts is reported from the basal few centimeters of black Rhinestreet shale (Huddle, 1968; Kirchgasser and Klapper, 1992; Klapper et al., 1995). Hard, well-jointed, black shale makes up most of this section. Less organic-rich, recessive weathering dark gray shale intervals, as well as, beds of greenish gray shale, can also be seen (Fig. 6, 7). Conspicuous at several levels within the black shale intervals are large, often massive, septarial concretions. The black shale facies within the Rhinestreet records intervals of severe dysoxia to near-anoxia within the Devonian basin associated with a broad time interval associated with global sea level highstand (Johnson et al., 1985). This organic-rich lithofacies accumulated in a relatively deep-water, stratified basin setting west of the prograding Catskill Delta in a foreland basin already maintained by collisional thrust loading (Ettensohn, 1998; see Fig. 1). Contemporaneity of Catskill Delta progradation is splendidly shown by the eastward splaying of Rhinestreet black shale divisions into the deltaic clastic wedge and by eastward passage of organic-rich basinal facies into shoreward, coarse, fossiliferous neritic facies and terrestrial red beds (Woodrow and Sevon, 1985; see deWitt, 1960; deWitt and Colton, 1959; Colton and deWitt, 1958; Sutton, 1963, and Kirchgasser et al., (1994) for evolution of correlations and unit terminology pertaining to eastern Rhinestreet and other West Falls Group subdivisions). The 2.3 meter to 2.4 meter-thick gray shale unit above the band of large concretions is the western distal "toe" of a progradational clastic pulse extending westward from the delta complex; this fine grained turbiditic or hemipelagic sediment was probably deposited during a sea level lowstand event which allowed prodelta muds to be exported far into the basin (Fig. 1). A turbiditic origin for part of this interval is suggested by the presence of a 2 – 5 cm-thick siltstone bed at its basal contact (Fig. 6, 7); the basal surface (sole) of this layer displays erosional groove cast impressions and the top of the bed fines upward into featureless gray shale, suggestive of a turbiditic event. At the Seascape section, the basal lag of the siltstone bed yields conodonts typical of MN Zone 7-8 (Levin and Kirchgasser, 1994; Kirchgasser et al., 1994; Kirchgasser and Klapper, 1992; Fig. 7B).

Upstream on the west bank - STOP 1C - about one meter below the green-gray shale units an excellent exposure of the Belpre Ash Suite. Two ash beds and a concretion horizon are exposed here. A third ash, possibly related, is found in the uppermost Cashaqua. The thickest altered ash bed is characterized by gray brown clays (kaolinite and mixed layered clays), bleached (pyroclastic?) micas, minor quartz, calcite, plagioclase and apatite, as well as secondary pyrite. The ash bed is graded with clay flakes in the upper part with even stronger parallel orientation than the clays in the overlying black shale. Lenses with the distinctive color and fabric of the ash occur intermittently for a few centimeters above the ash bed. The upper "thick" ash was recently dated using single zircon chemical abrasion U/Pb analysis at the facility at Boise State University to 375.32 +/- 0.14 Ma. This is statistically identical to the date from ash "6" at Little War Gap, Tennessee, of 375.40 +/- 0.13 Ma (Lanik et al., 2013). The shales between the ash beds in a 1 m interval at Little War Gap include Palmatolepis punctata, P. housei, P. ljaschenkoae, Ancyrognathus barba, and Ancyrodella nodosa, which indicate placement in MN Zone 8. Conodonts within a 4 meter thick interval from the adjacent shale and concretions in the Rhinestreet Shale above the ash horizons include Palmatolepis ljaschenkoae, P. punctata, Polygnathus dubius, Ancyrodella nodosa s.s., and Ancyrognathus sp. L? of Klapper (Fig. 7B). The conodonts and absolute dates indicate the middle Frasnian ashes in New York State are Belpre and provide a precise date for MN Zone 8.

Return to vehicles.

0.6 31.7 Proceed north on Shadagee Road to junction with US 20, turn west (left).

1.7 33.4 Procced west on US 20 to Sturgeon Point Road, turn northwest (right).

5.0 38.4 Enter Sturgeon Point Park and Marina, park on northernmost berm. Stop 2 – Lake Erie shoreline

STOP 2 and LUNCH. Rhinestreet Formation in Lake Erie shore bluff succession, both to the northeast of-, and southwest of, the Sturgeon Point marina and car park complex near Derby, Erie County (see Figs. 6, 7). We will, first, proceed on foot from the northeast end of the car park to the beach and follow the beach and continuous shale cliff section to a position near the outflow pipes from the Derby waterworks. The K-bentonite is not accessible here, but the gray shale unit is much easier to examine at this outcrop. Moreover, the black shale interval above the gray unit can be examined (Figs. 6, 7).

Within the gray shale unit in this locality are very thin, 0.2 – 6 cm-thick, black shale beds that often display sharp contacts and strong visual definition within the thicker gray succession. Buff gray concretions occur at two levels within the gray shale interval; these are concentrated closely below black shale bands and appear to be controlled by the presence of the bands. However, in a few places along the exposure, the thin, overlying black shale bands pinch out over the tops of the subjacent nodules. This suggests that concretion growth may have created differential paleorelief, perhaps due to early dewatering and differential settling of mud. The sharply defined thin, black bands pose an interesting question: Do they represent slow background deposition between turbiditic gray mud pulses, or do the thin black bands, themselves, represent some alternative type of rapid depositional event involving sedimentation, or resedimentation, of organic-rich sediment? Is it possible that the organic-rich sediment, instead, may have been originally pelletal, hence mobile and easily transported on the seafloor? This latter scenario, yet untested, could explain these sharp pinstripe bedforms as rapidly deposited, current-traction-generated features.

To the immediate northeast of the second waterworks outlet is a problematic structural displacement or offset at the level of the gray shale unit. At the lake edge, several fractures in the lower black shale division can be seen that are filled with gray shale that displays soft-sediment shearing and fracturing. Directly across from the area of shore fractures in the cliff face the gray shale unit thins to less than a third of its normal thickness across a distance of about

80 meters. However, debris on the beach conceals the intervening area and the full nature of this structure. The shore cliff and lake edge exposure displays excellent examples of joint networks, particularly for the black shale bands. These joints are believed by Gary Lash to have evolved during thermal-burial maturation of the black shale unit as the black shale units began to function as hydraulic top seals for moving fluids migrating up from below (see Lash, 2006.) The different orientations of the various joint sets are believed to correlate to a series of far-field stress phases associated with the Allegheny orogeny (Lash and Blood, 2006).

Between 40 and 45 cm above the gray shale interval, within black shale facies, is a styliolinid-rich, hashy layer that is associated with widely-spaced, spheroidal concretions (Figs. 6, 7). Close examination of the layer shows the presence of numerous, flattened goniatites (some partially pyritized), spotty concentrations of Styliolina, fish debris, large horizontal (arthropod?) trace fossils and scattered conodonts. The goniatites first identified during a survey of this section in 2006 belong to the genus Naplesites in the family Beloceratidae. The lineage is characterized by compressed (discoidal), evolute shells with increasingly numerous, distinctly pointed lobes (and saddles) forming chevron-like patterns. The ancestor of the family is Probeloceras which in New York occurs below the Rhinestreet in the Cashaqua Shale (Sonyea Group; MN Zone 5); the group culminates with the extremely multilobed Beloceras, a genus still unknown in North America (Fig. 3). The discovery of the Naplesites horizon at Sturgeon Point is important in that its presumed position in the lower Rhinestreet (House and Kirchgasser, 1993, 2008) is confirmed and the conodonts in the bed may prove to be datable. Naplesites is otherwise rare in New York and is known only from a few specimens (two species) described by Clarke (1898) far to the east from unspecified horizons and sections in the shales around Naples in Ontario County (Canandaigua Lake meridian). Probeloceras and Naplesites (as Mesobeloceras) are illustrated in Kirchgasser et al., 1994, fig. 7).The close stratigraphic coincidence of useful conodonts, Naplesites, and the K-bentonite bed is important geochronologically and is the subject of ongoing work.

Return to vehicles and proceed by car around to the southwestern most parking area near the Sturgeon Point pier.

Proceed on foot to beach below car park and follow beach southwestward for approximately 120 meters to a low outcrop bench of black Rhinestreet shale at the lake edge.

This exposure of black shale is believed to be the top of the lower Rhinestreet and phosphatic level below the “false Cashaqua” interval. The huge septarian concretions correspond to the conspicuous level at Seascape and the level studied by Lash and Blood at Eighteenmile Creek, but the precise match of beds can not yet be made owing to the long covered interval between the two sections. Notable in this outcrop are several bands of concretions including a line of massive septarial concretions below the bench of very resistant black shale. At the top of the black shale bench are two closely-spaced horizons of small spherical to ellipsoidal, 0.3 – 4 cm-diameter, phosphatic nodules. Phosphatic nodules, well known from the upper part of the New Albany Shale and the Cleveland Shale, have not been reported from the Rhinestreet. The occurrence of nodules of this type has been interpreted as evidence of nutrient upwelling and high productivity in surface waters (see Robl and Barron, 1989). What is striking here is that many, if not most, of the nodules are nucleated by fish spines and scales. Small, sand-size grains within some of the nodules may be radiolarian tests.

Return to vehicles and follow one-way road around to exit of Sturgeon Point Marina.

0.8	39.2	Proceed from the marina eastward on Sturgeon Point Road to Lake Shore Drive, turn southwest (right).
5.5	44.7	Proceed to Lake Erie Beach Park – Stop 3 – Point Breeze on Lake Erie shore.

Stop 3 – Lake Erie Beach Park. Lower Angola Formation at Point Breeze. From parking lot walk northeast up the beach to the cliffs on the point.

There is approximately 5 m of Angola Formation here. The lower Angola consists of light gray shale with interbeds of black shale and calcareous concretions. The Pt. Breeze Goniatite Bed is the first large concretionary bed at the water line, characterized by a diverse goniatite fauna – see text..

1.3	46.0	Proceed southwest on Lake Shore Drive, turn south (left) onto Evangola State Park Road.
1.1	47.1	Proceed southeast to NY 5, turn southwest (right).

7.0 54.1 Proceed toward Silver Creek on NY 5, merge with US 20 and continue on US 20 to Walnut Creek, cross bridge and park in Ehmke Drilling near the creek. Stop 4 – Walnut Creek

STOP 4. Section of Pipe Creek Formation ("lower Kellwasser Bed") and synjacent units at Walnut Creek, Silver Creek, NY Proceed from the parking area to Walnut Creek and exposure of the Hanover Formation and Pipe Creek Formation – base of the Java Group, and the underlying Angola Shale. The lowest strata at this site downstream from the US 20 bridge are the gray, silty, bioturbated Angola Formation of the West Falls Group. This is abruptly capped by the resistant, black, and well jointed Pipe Creek Formation of the Java Group (Fig. 8) that forms a bench in the stream. The 0.6 meter-thick Pipe Creek succession is followed upstream in the floor of the creek and bank by softer, nodule-rich, gray and black shale facies of the Hanover Formation (Fig. 8).

The black Pipe Creek shale consists of massive, organic-rich facies that contrasts markedly with both the underlying Angola and overlying Hanover. The base of the Pipe Creek is abrupt on the Angola with the development of abundant diagenetic pyrite in the uppermost Angola. No erosional, detrital pyrite has been found at the contact, but a profound change in microtexture is seen as one passes from the bioturbated, pyrite- suffused, uppermost Angola, into the laminated, black Pipe Creek (Fig. 9). As noted in the text, this unit has now been found to correlate to the "Lower Kellwasser Bed" which marks a major ecological reorganization and extinction event in global sections.

Fossils are common in the lower Hanover, but are usually very small. Diminutive gastropods, bivalves, and ostracodes make up most of the fauna found in concretions or as pyritized shells in the gray shale. Goniatites, important as chronostratigraphic markers, occur in the shales and concretions as well. There is a rich but still undescribed pyritic goniatite fauna at the Pipe Creek/Angola Shale contact beneath the US 20 bridge, over Walnut Creek, discovered years ago by G. Kloc; the pyrite lag is often covered in sediment and/or below water. Upstream of the bridge Crickites lindneri and Sphaeromanticoceras aff. S. rickardi occur in the first few meters of the Hanover Shale. Crickites lindneri is a species know also from Australia. In nodule bands in lowermost Hanover in nearby Silver Creek and in Beavermeadow Creek, Java Village, the goniatite Delphiceras cataphractum occurs. The lower Hanover goniatite levels are probably in the Crickites Goniatite Division UD I-L and probably in Conodont Zone MN 12 (House and Kirchgasser, 2008).

0.4	54.5	Head northeast on US 20 to intersection with NY 5, turn west (left)
10.5	64.9	Proceed west on NY 5 to Dunkirk and signal at Point Road, turn north (right).
0.4	65.3	Proceed north to sand road (unmarked) to Dunkirk Beach – Stop 5 – Point Gratiot on Lake Erie shore.

STOP 5. Upper Hanover and Dunkirk Shale type locality – Point Gratiot, Dunkirk, NY (see Figs. 9, 10).

Exit vehicles and proceed southwest along the lake shore to exposures. The interbedded gray and black shales of the upper Hanover are overlain by massive black shales of the Dunkirk (Fig. 10). The Point Gratiot Bed, a 15 cm thick black ledge, correlates to the "Upper Kellwasser Bed" of Late Devonian sections globally. The topmost part of this bed marks the Frasnian-Famennian extinction event of literature based on conodont work in western New York sections (see Over, 1997, 2002; Day and Over, 2002). Although the bed is composed of basinal black shale, fossils such as the probable anaptychus organ Spathiocaris, fish material, and wood debris can be found, particularly near the top of the bed. Moreover, elevated levels of Platinum Group elements occur at this level and other horizons in the boundary interval black shales (see Over et al., 1997). Above the Point Gratiot Bed is 10 cm of gray shale below the base of the thick black shale of the Dunkirk.. Eastward this interval expands to several meters of gray and black shale beds (Fig. 11). The upper Hanover interval closely resembles the lower Rhinestreet gray shale unit owing to several discrete, thin, black shale bands which contrast sharply with the thicker gray lithology. Reworked pyritic burrow clasts and exhumed geopetally pyritized Tasmanites half-spheres (sensu Schieber and Baird, 2001) have been found in thin lags at the base of the thin black beds and at the base of the Dunkirk Shale. Hanover deposits below the Point Gratiot Bed are markedly more calcareous, lighter colored, and more intensely bioturbated; upward changes across the Point Gratiot Bed probably reflect combined effects of transgressive deepening in the basin and adverse biological effects associated with the Frasnian-Famennian crisis.

End of Field Trip – return to Dunkirk and NY 98B south to SUNY Fredonia or NY 60 to I-90.