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).

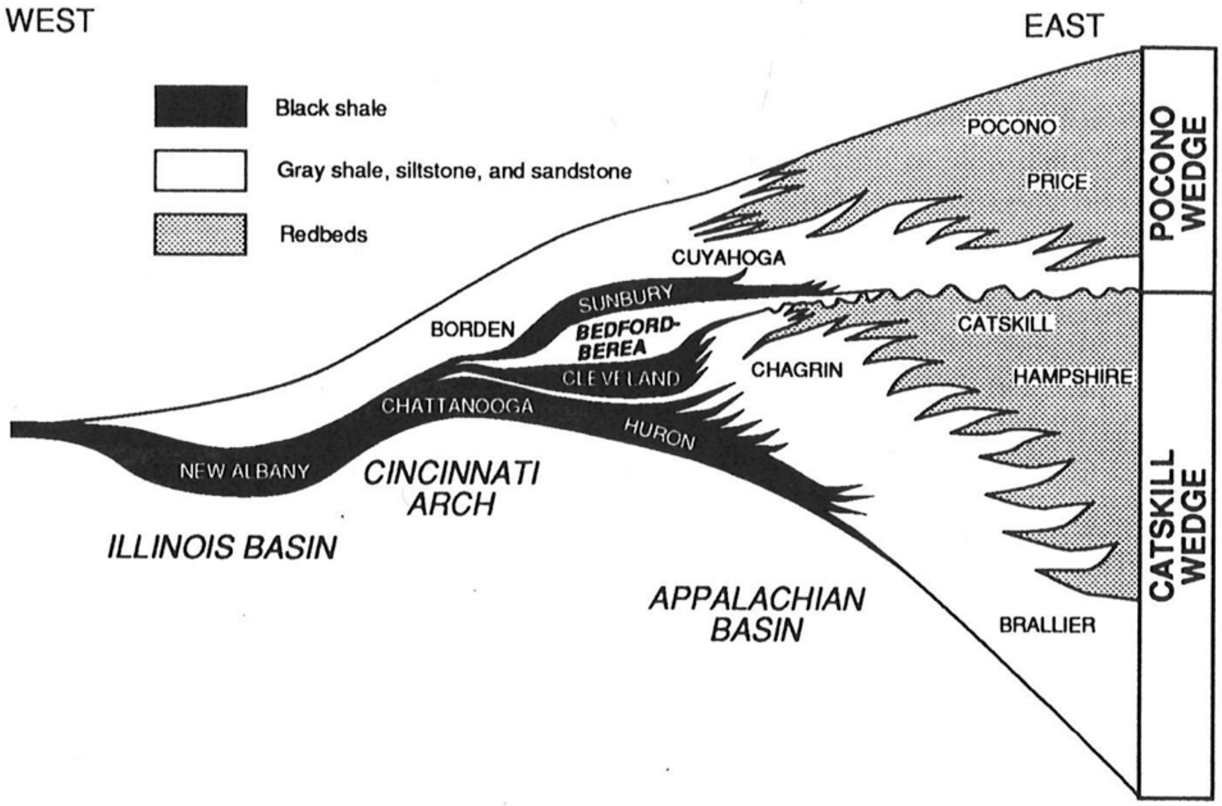

Figure 1: Regional schematic cross-section showing the generalized relationship of the end-Devonian succession in Pennsylvania and Ohio to the Catskill and Pocono clastic wedges in the northern Appalachian Basin (from Pashin and Ettensohn, 1992, 1995).

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).

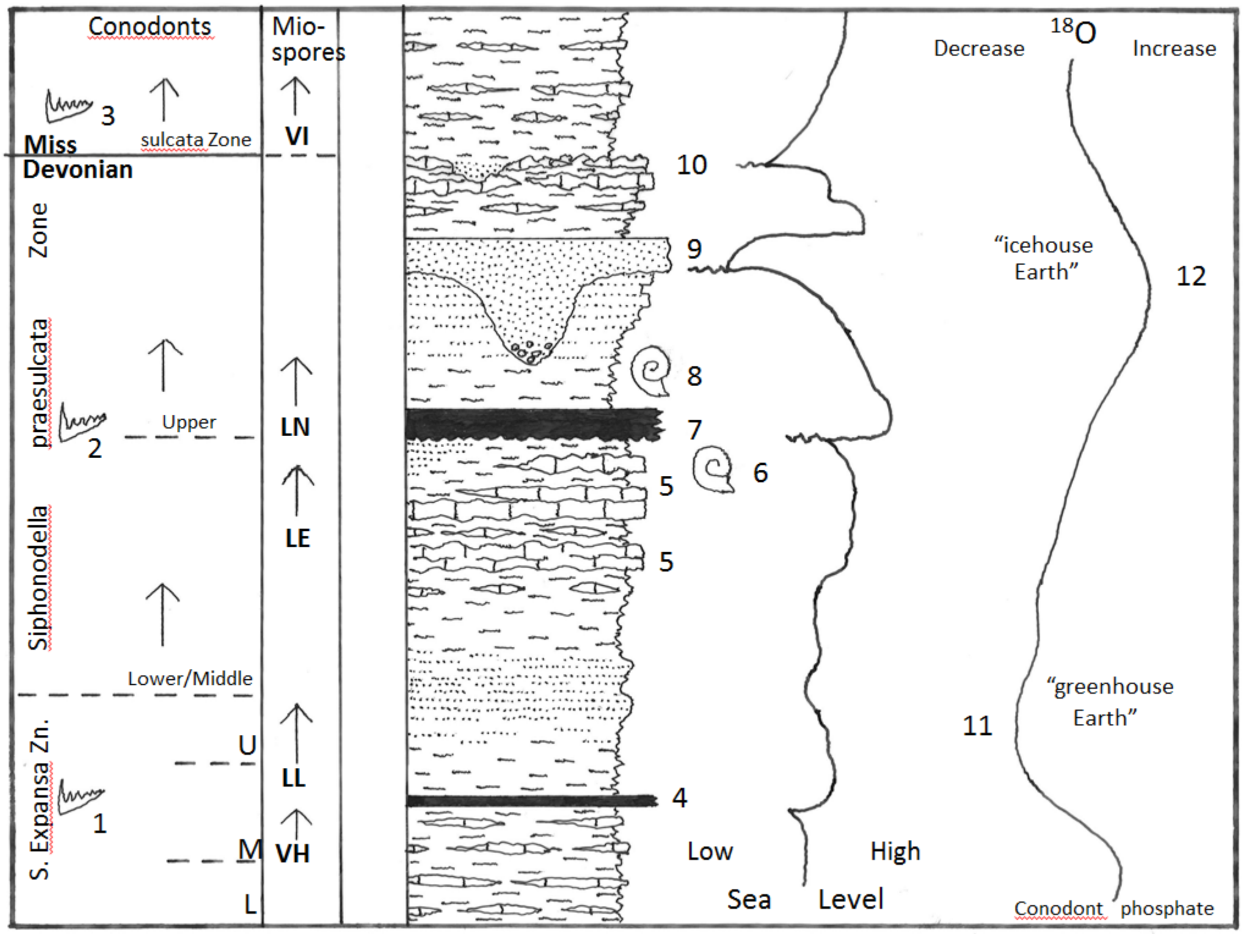

Figure 2: Generalized end-Devonian chronology in inferred eustatic and global bioevent context, based on conodont and palynomorph chronostratigraphy as well as carbon and oxygen isotopic studies (compiled from Cramer et al., 2008; Kaiser, 2008, 2011 and others). Note sea level oscillations calibrated 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).

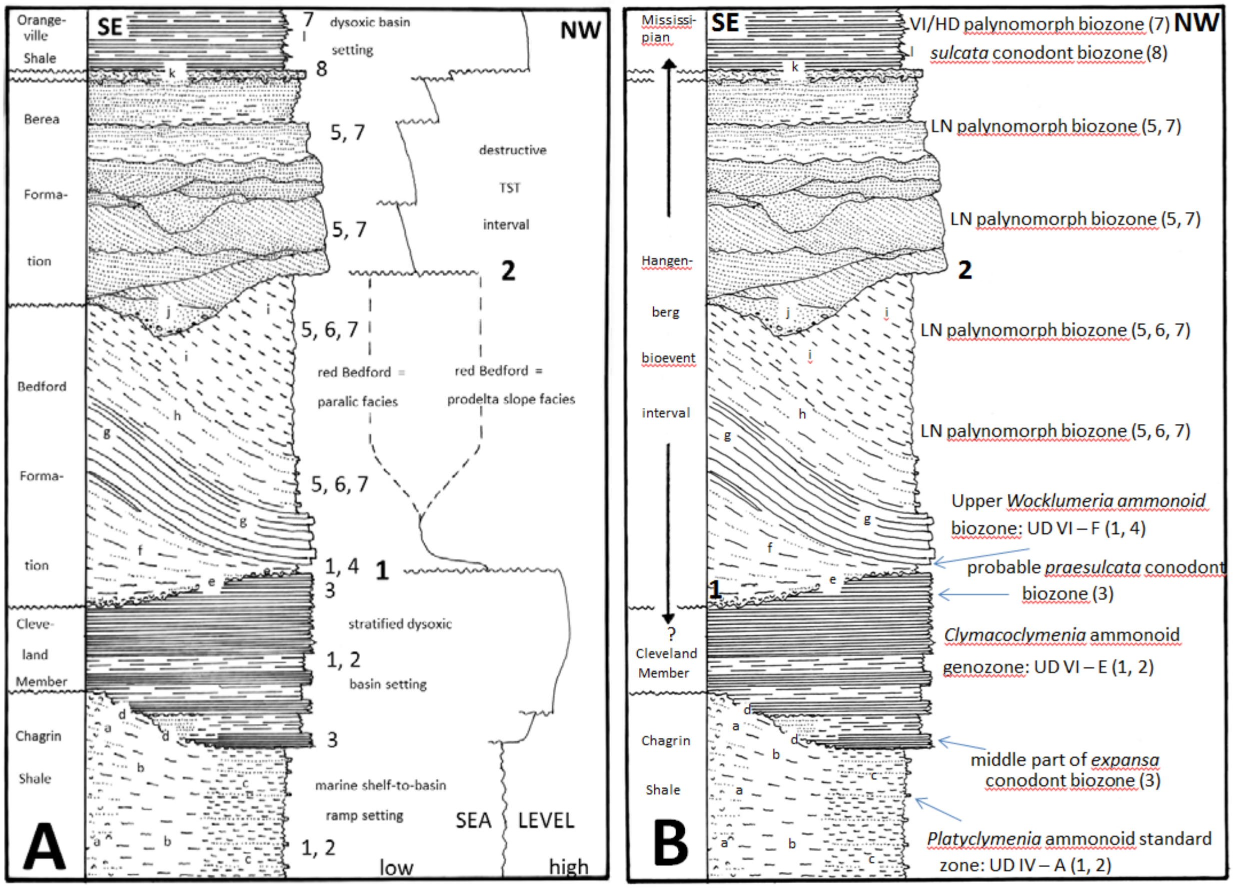

Figure 3: Temporal stratigraphic synthesis of the greater Cleveland area end-Devonian-basal Mississippian stratigraphic succession: A, Generalized stratigraphy showing inferred sea level changes. This schematic emphasizes the inferred Bedford constructional (progradational) phase preceding the base-Berea 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).

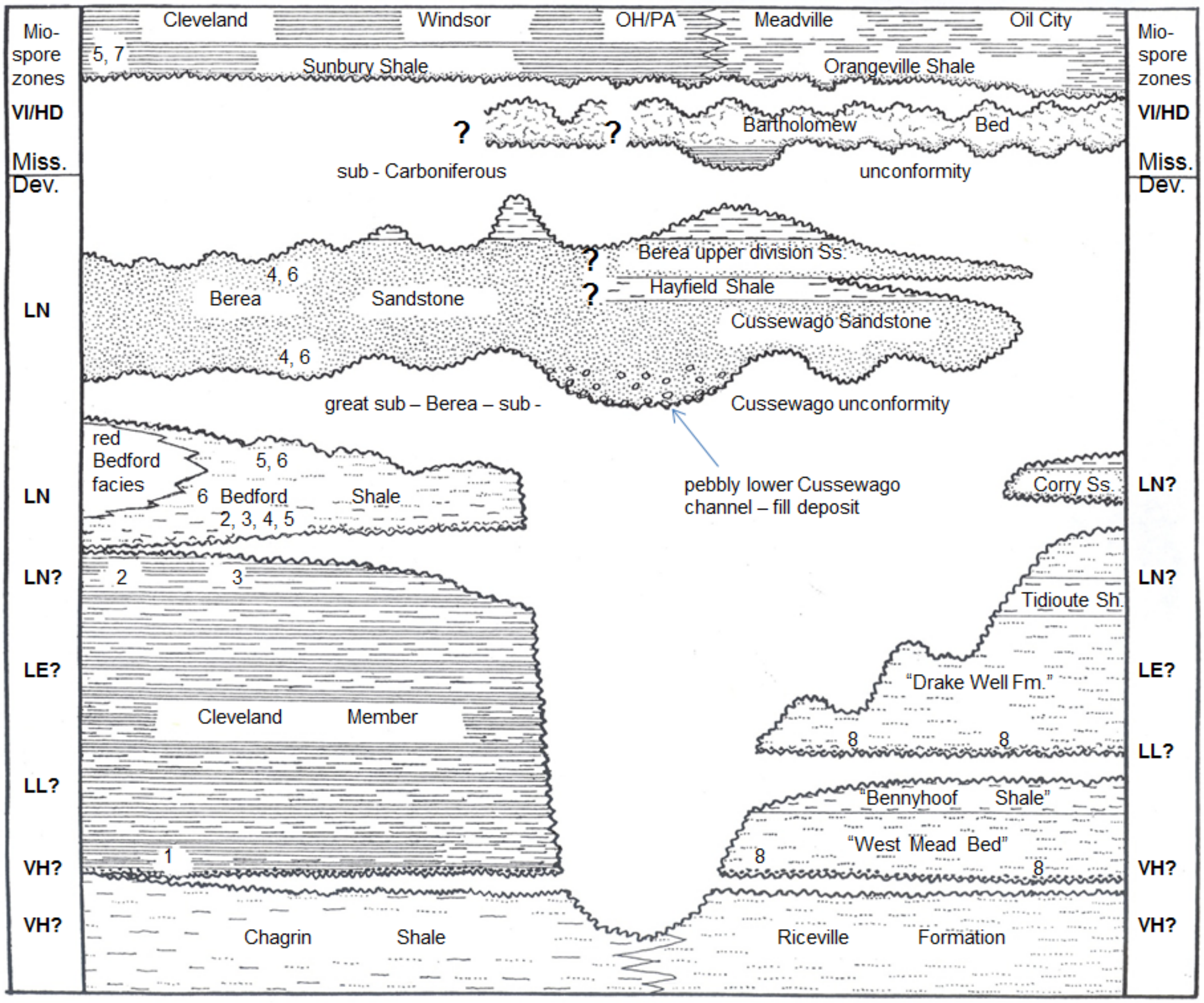

Figure 4: Proposed chronostratigraphic (time-rock) relationships of end-Devonian units across northwest Pennsylvania and northeast Ohio, based on existing reports and new, partly published work. Matches between the Ohio succession and that in northwest Pennsylvania are tentative owing to a need for biostratigraphic 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).

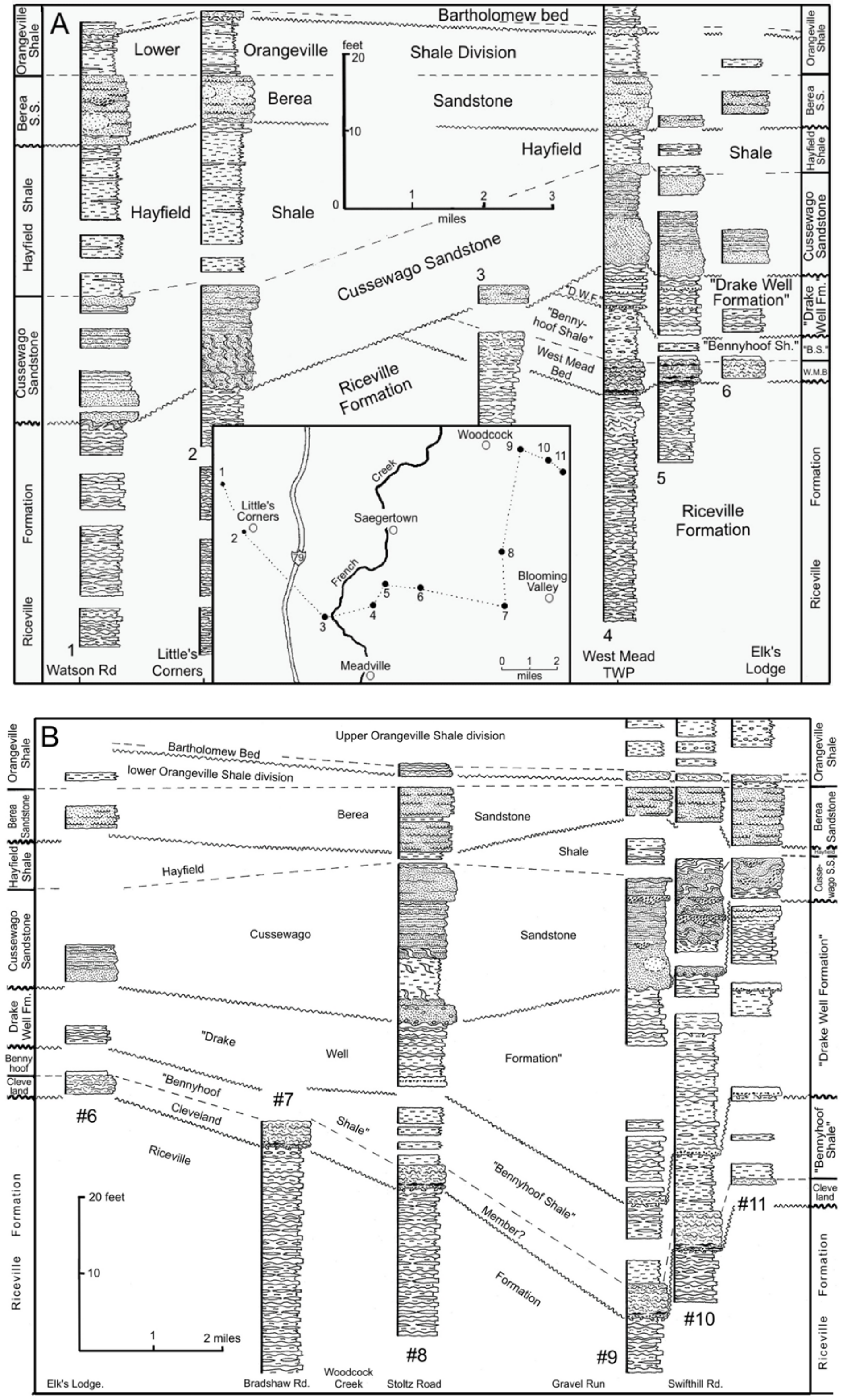

Figure 5: Stratigraphic transect of the end-Devonian-basal Mississippian succession across the French Creek Valley (Meadville area) and the Blooming Valley Quadrangle, to the northeast of Meadville (Baird et al., 2009 A). A, French Creek Valley transect. Note the progressive eastward

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).

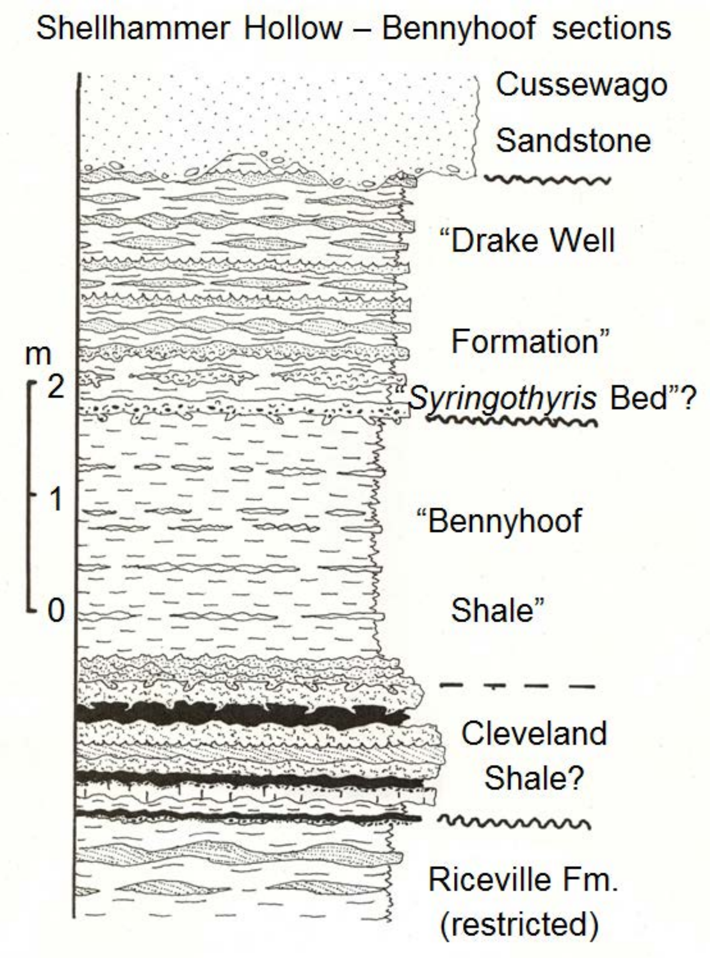

Figure 6: Top-Riceville-Formation-into-Cussewago Sandstone succession generalized from composite profiles of Bennyhoof Creek and nearby Shellhammer Hollow at the north edge of Meadville, Pennsylvania. Note presence of black shale partings and microbioturbated dark siltstone beds in the West Mead Bed (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

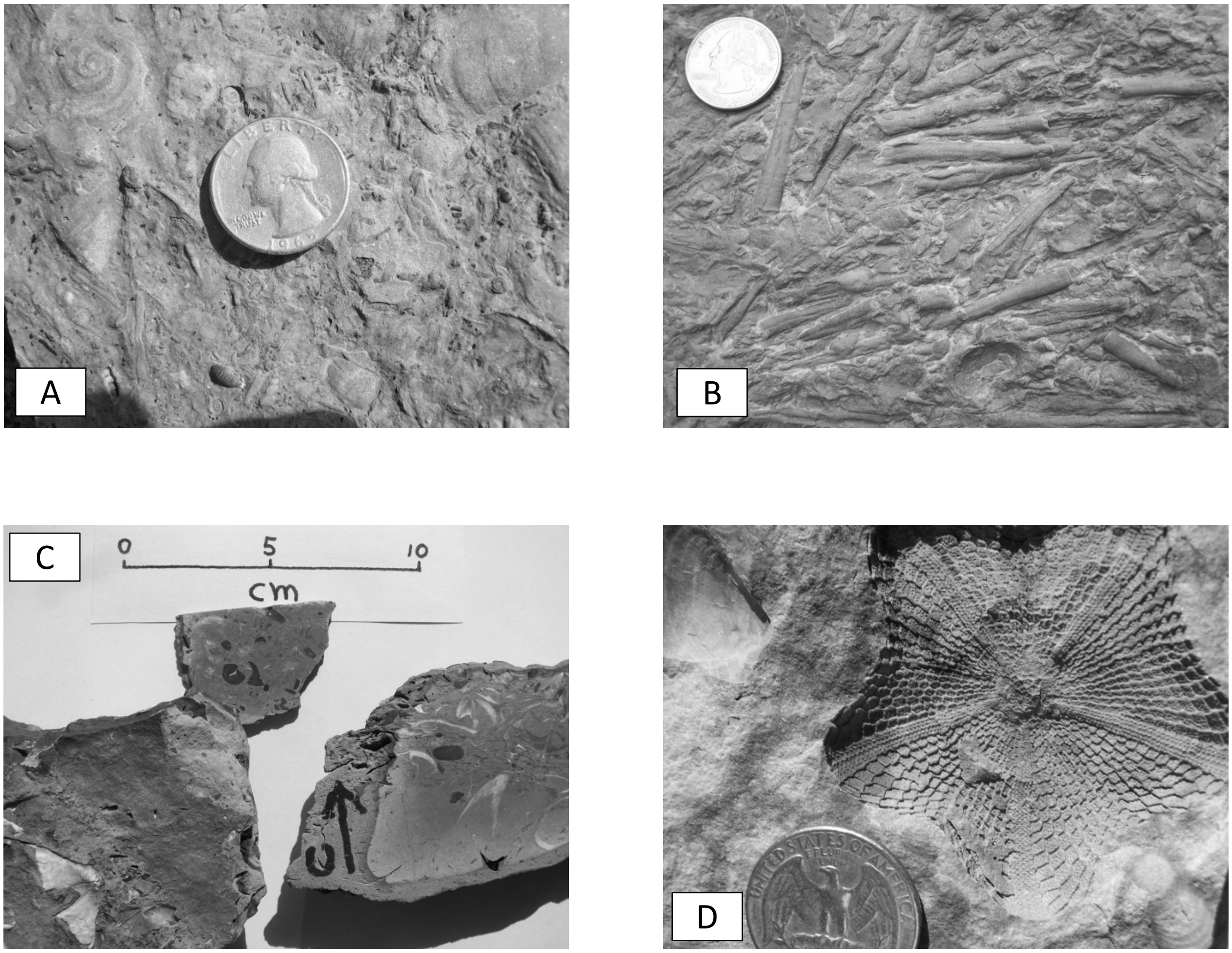

Figure 7: Distinctive features in the West Mead Bed and Drake Well Formation. A, Concentration of detrital (reworked) pyritic grains, gastropods, and fish bone debris which marks the base-West Mead Bed discontinuity. This lag deposit is believed to be correlative with the Skinner’s Run Bed of the Ohio 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.

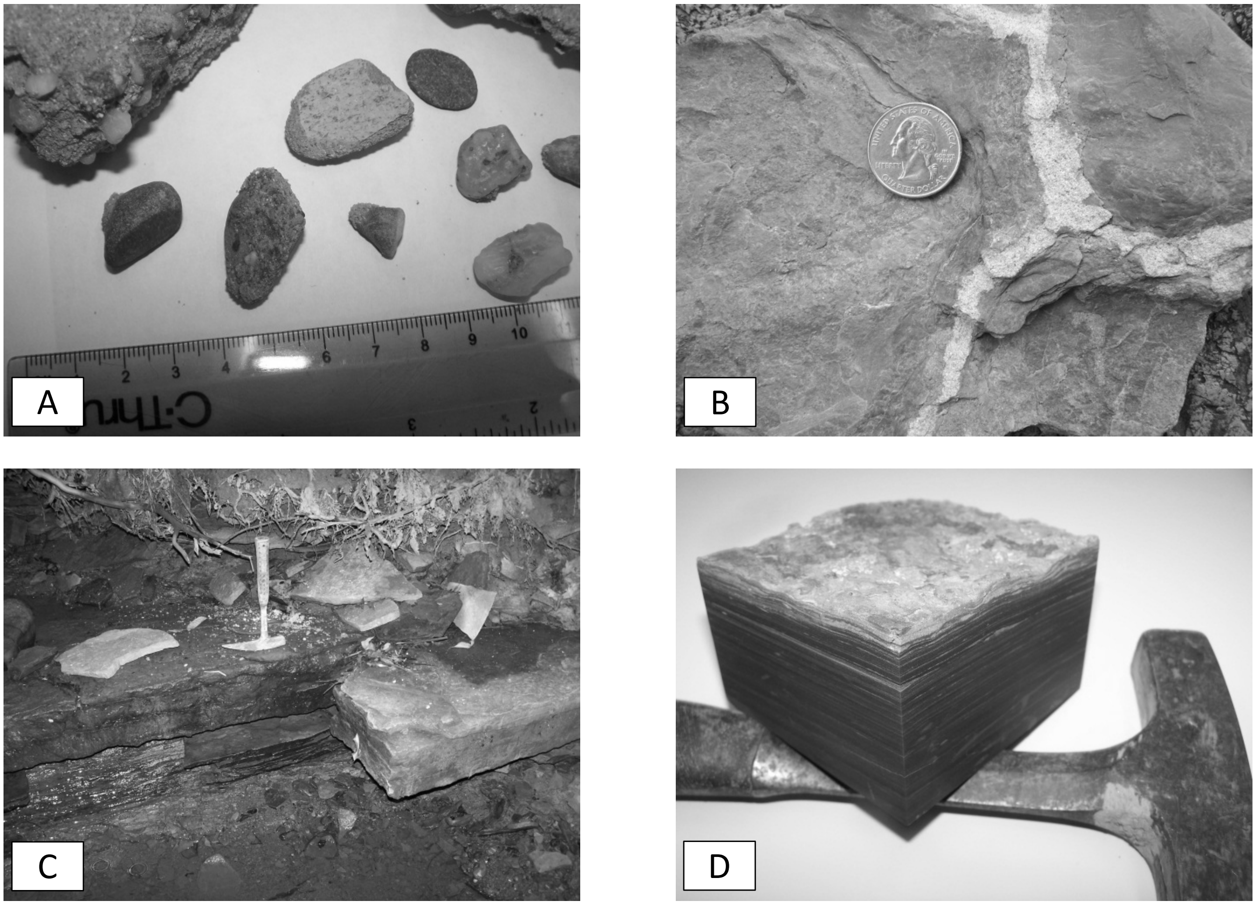

Figure 8: Key features of the end-Devonian-basal Mississippian succession. A, Dark colored, heterolithic pebbles from pebbly sandstone facies in thick, Cussewago paleovalley-fill deposits, collected along northwest-flowing Baughman Creek at North Bristol, Ohio. Note granitic and

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.

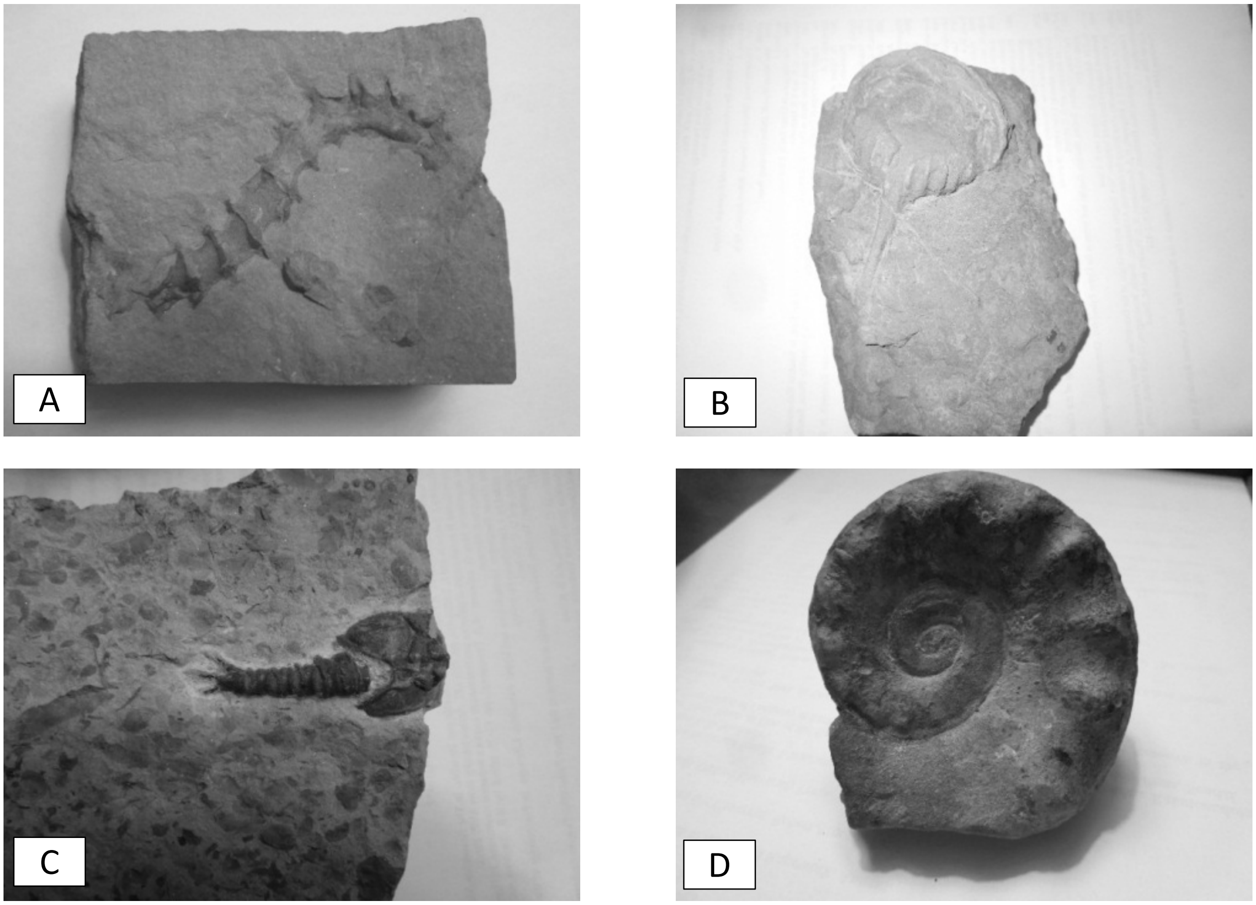

Figure 9: Important fossils from the Chadakoin and Drake Well formations. A, *Titusvillia* from the Drake Well railroad cut exposure (STOP 4), S. C. McKenzie collection. B, *Protolimulus eriensis*, a resting trace from a horseshoe crab found in the tri state area and at the Union City Dam spillway. Size 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 eastbound 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).

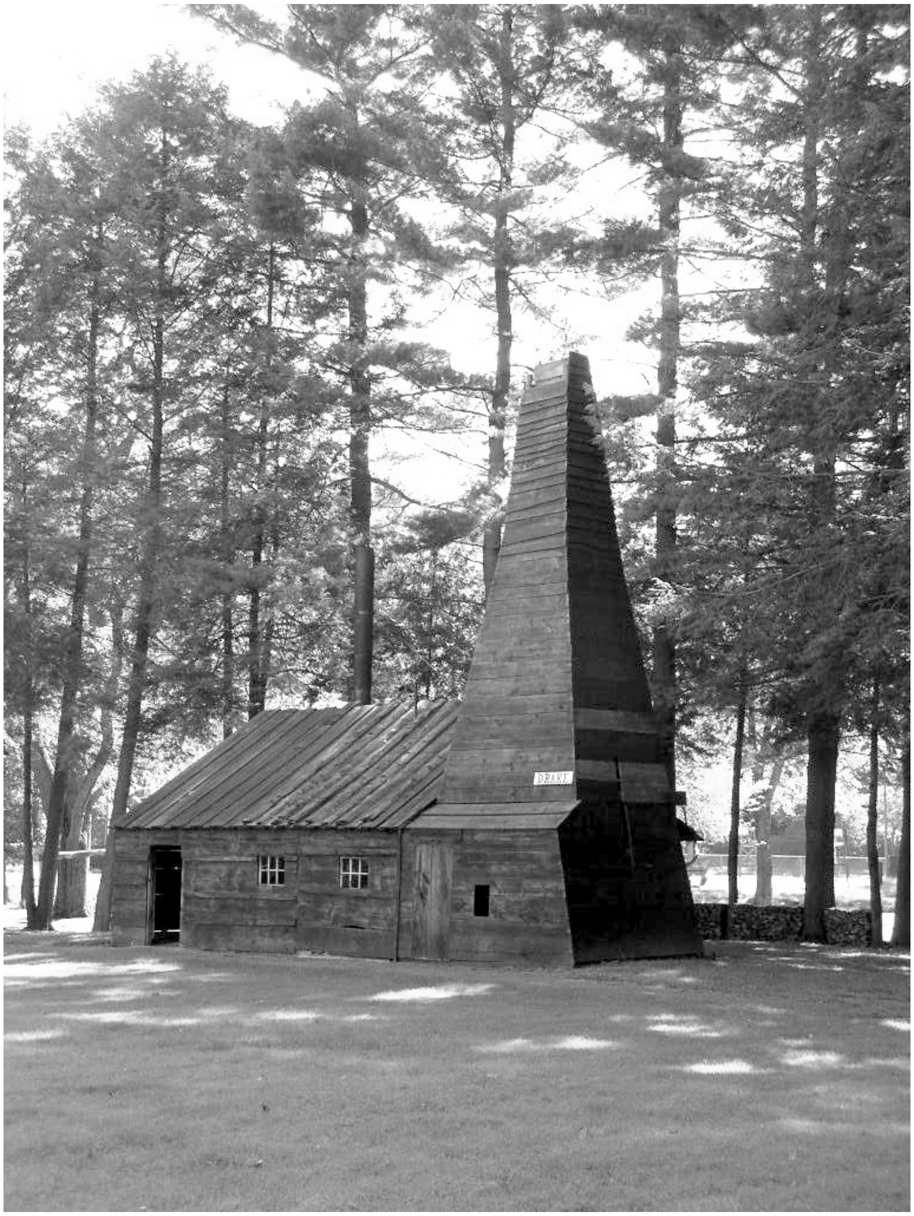

Figure 12. Recent photograph the Drake Well replica at the Drake Well Museum.

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).

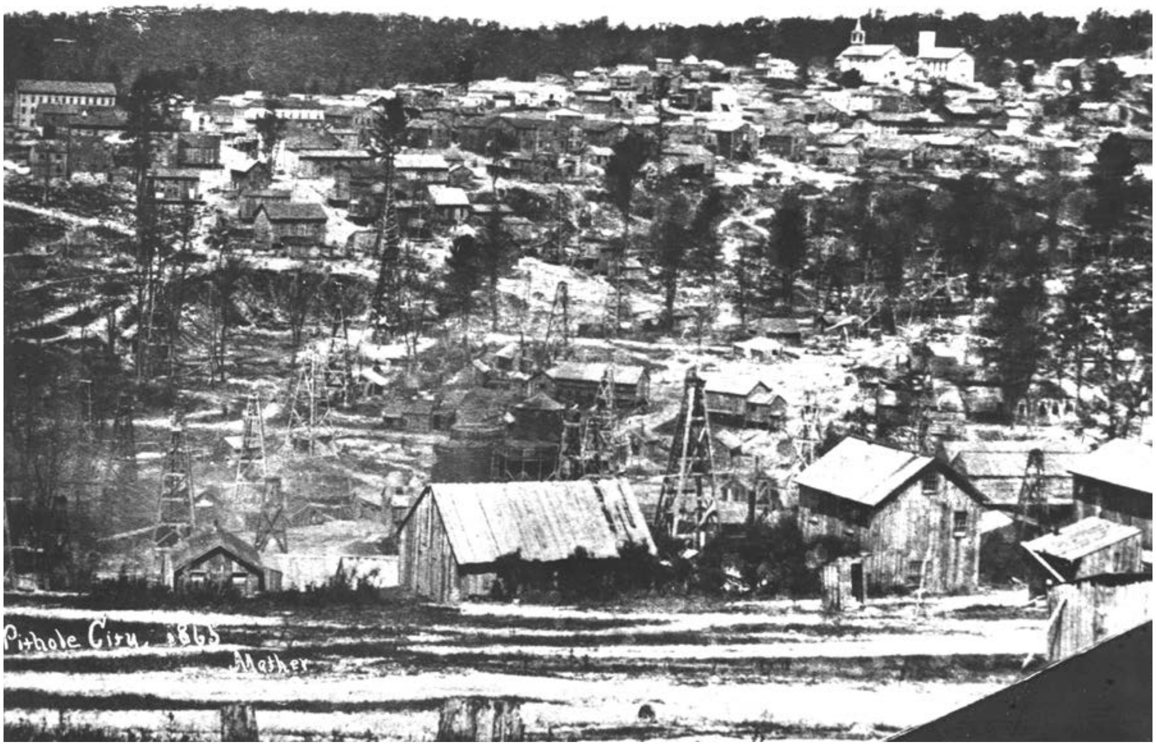

Figure 14. John Mather photograph of Pithole in 1865. The photo was taken from the flats of Pithole Creek looking northwestward across the oil producing flats to the town on the hill. Photo courtesy of the Drake Well Museum.

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.

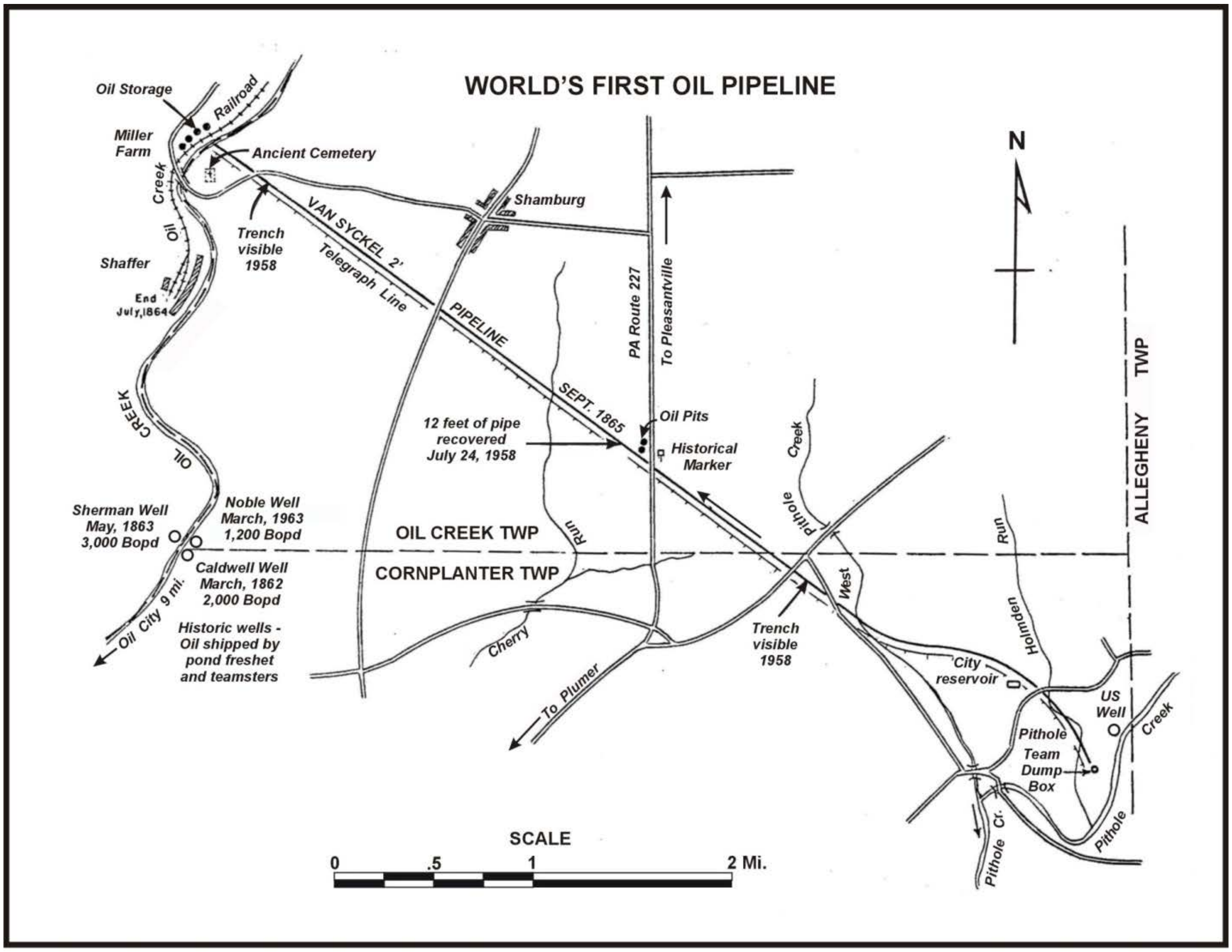

Figure 17. Map of Samuel Van Syckel's pipeline that carried crude oil from Pithole wells to the railroad terminal at Miller Farm (modified from Lytle, 1959).

		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 east-bound 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.