MARINE CRISIS EVENTS AND FOSSILS OF THE LATE DEVONIAN APPALACHIAN BASIN DELTAIC SEQUENCE OF WESTERN NEW YORK

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INTRODUCTION

The Devonian Period experienced many changes within the environmental and biological realms and terminated with one of the largest mass extinctions of the Phanerozoic. The Appalachian Basin of western New York contains several alternating successions of gray and black shale, many of which mark marine crises culmination in the end-Devonian mass extinction. The causes for the formation (e.g., anoxia, flooding, biological production changes) of the black shale sequences has long been debated within the basin. This period was characterized by major changes in both the terrestrial and marine biospheres and terminated with one of the largest mass extinctions of the Phanerozoic Era (Kaiser et al., 2016). Middle Devonian terrestrial environments saw tremendous increases in biomass and complexity with the evolution of vascular and seed-producing plants, trees, and the formation of deeply weathered and thicker soils (Beerbower et al., 1992). The Devonian marine realm has long been suspected to have been heavily affected by bottom water anoxia, enhanced organic carbon burial rates, dramatic shifts in primary production, and an extended biotic crisis. The biotic crises and related marine extinction events have been attributed to many factors including bolide impacts (McLaren, 1982), tectonism and climate change (Ettensohn et al., 1988), oceanic overturn and/or euxinic conditions (Kelly et al., 2019; Haddad et al., 2016; Boyer et al., 2021), cold water oceans and dysaerobic conditions (Copper, 1986), marine ecosystem collapse (McGhee, 2013), eustatic change (Johnson and Sandberg, 1988), and more recently linking the marine phenomena to coeval developments in the terrestrial realm (Algeo et al., 1995; Algeo and Scheckler, 1998; Algeo et al., 2000).

Algeo et al. (1995) presented the hypothesis that the Middle-to-Late Devonian marine biotic crisis and mass extinction of benthic communities were precipitated by the evolutionary development of vascular land plants; terrestrial floras appeared in the Middle Ordovician, and these land plants were small, either non-rooted or shallowly rooted, and ecologically limited to moist lowland habitats (Cascales-Miñana, 2016). Evolutionary innovations of these floras in the Devonian allowed them to interact with substrates and strongly influence weathering processes, hydrologic cycling that would have changed the amount of run-off and peak discharge (Schumm, 1977; Algeo and Scheckler, 1998), and has been suspected by some researchers to have resulted in geochemical fluxes and the formation of carbon-rich black shale beds within the Appalachian Basin. While flooding events in the Appalachian Basin have received much attention recently (Kelly et al., 2019; Haddad et al., 2016; Lash, 2019; Bartlett et al., 2021 (in press)), by no means is there a consensus on the causes of formation of black shale sequences and other major shifts in lithology during this global event (see Kaiser et al., 2016).

Over 100 years of research of the Devonian Appalachian Basin has led to the construction of one of the most detailed litho-stratigraphic frameworks of a Paleozoic foreland system that has allowed for detailed interpretations of sea level history and shifts in sedimentation rates (Dana, 1894; Wanless, 1947; Brett and Baird, 1986; House and Kirchgasser, 1993; Brett, 1995; Ver Straeten and Brett, 1995; Brett et al., 2011; Ver Straeten et al., 2011). As a result, a tremendous amount of geochemical proxy data from these gray and black shale sequences has shown that the perception that the Devonian black shales were deposited under anoxic conditions holds true, thus far, for only one black shale unit (Werne et al., 2002), the Oatka Creek Shale, and that intervals of terrestrial fresh water flux were not as prevalent as previously thought and that primary production plays a strong role in many, if not all black shale beds of the Appalachian Basin (Arthur and Sageman, 2005).

More recent research on intercalcated deposits described in ancient and modern marine settings (e.g., Cretaceous Western Interior Seaway and Eastern Atlantic Ocean, Pleistocene North Atlantic, Neogene Mediterranean, modern Black Sea) has focused on eutrophic conditions and the effects of organic input, climate variations, primary production changes and seasonal riverine input and has made clear that the formation of carbonaceous and organic-carbon-deficient layers is anything but straightforward. The same is true of investigations attempting to derive the mechanisms behind the gray and black sequences in the Devonian Appalachian Basin (Werne et al., 2002; Sageman et al., 2003; Arthur and Sageman, 2005; Ver Straeten et al., 2011; Wilson and Schieber, 2015; Kelly et al., 2019; Smith et al., 2019; Haddad et al., 2016; Lash, 2019; Boyer et al., 2021; Bartlett et al., 2021 (in press)).

GEOLOGIC BACKGROUND

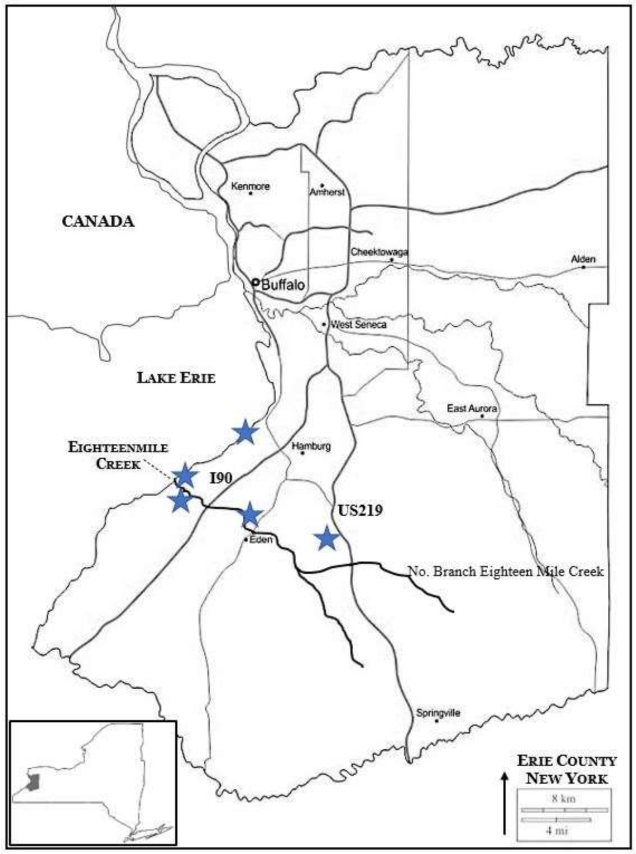

Figure 1: Inset map: Location of Erie Count, New York; Detail map: stars denote locations of field trip stops in and around Eighteenmile Creek, Erie County, NY.

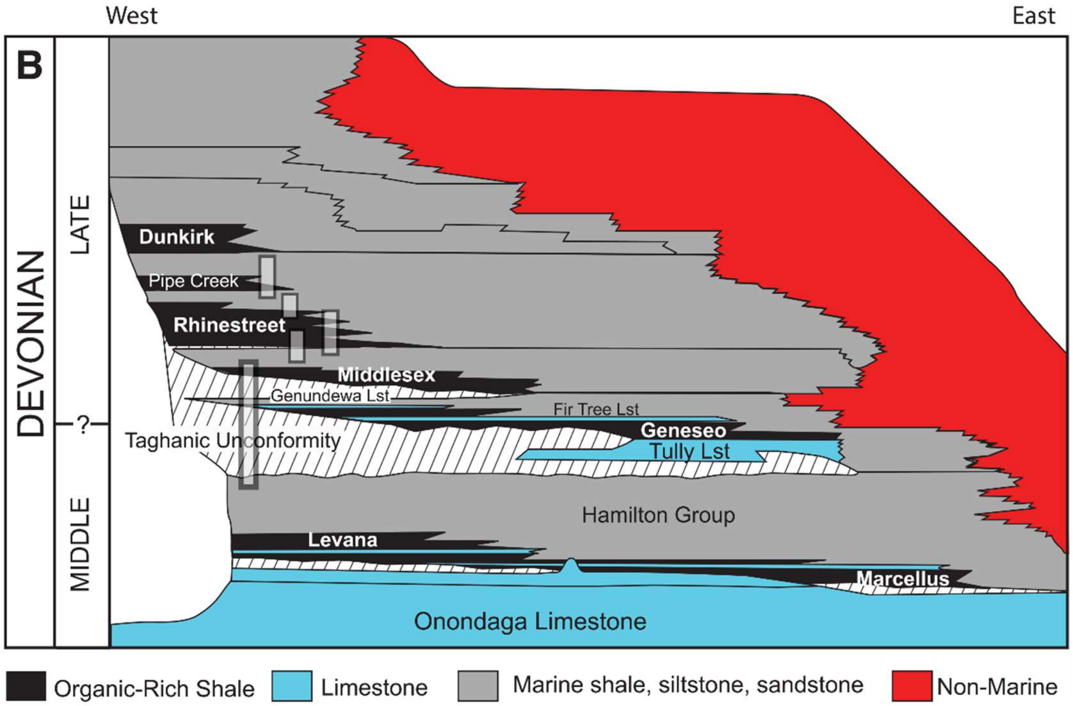

Figure 2: Hyper-generalized deltaic sequences of western New York from Smith et al., (2019). White highlights denote general portions covered along field trip stops.

The nearly one hundred years of research on the basic lithology of the deposits in Erie County, New York were summarized and compiled by Buehler and Tesmer (1963). More recently, work attempting to constrain the ecological conditions (e.g., freshwater inundation, primary production, and oxygen conditions) and relative sea level change have been published (Werne, 2002; Arthur and Sageman, 2005, Ver Straeten et al., 2011; Wilson and Schieber, 2015; Hupp and Weislogel, 2018; Lash 2016, 2019; Kelley et al., 2019; Fritz, 2019; Haddad et al., 2016; Smith et al., 2019; Bartlett et al., 2021 (in press); Li et al., 2021). These distal marine shales recorded relative sea level changes in alternating beds of deeper water, dark gray to black organic-rich shale, suspected to be deposited in dysoxic or anoxic bottom waters and light gray organic-poor shale, deposited in shallower, more oxygenated water (Ver Straeten et al., 2011; Fritz 2019).

Lithology

Givetian - Hamilton Group

Three units of the lower Moscow Formation, the Deep Run, Menteth, and Kashong members, present in the Finger Lakes region, are absent at Eighteenmile Creek due to non-deposition or erosion (Maletz, 2008). The Moscow Formation is fairly thin at the shores of Lake Erie, measuring about 11.5 feet, but increases in thickness to ca. 55 feet in the eastern part of Erie County (Buehler and Tesmer, 1963). At Eighteenmile Creek, the Moscow Formation starts with the Tichenor Limestone Member, overlain by the Windom Shale (Deep Run Shale, Menteth, and Kashong Shale are absent). A very thin upper Moscow Formation section is present comprising about 4.3 m of Windom Shale, despite its thinness, the Windom Shale is more stratigraphically complete (condensed), and is divided into a number of persistent faunal assemblage zones (Grabau, 1898; Brett, 1974; Brett and Baird, 1986). The top of the Moscow Formation is defined at the base of the Tully Limestone in the Seneca Lake region (south), but this unit is not represented in Erie County. Instead the Leicester Pyrite Bed and the North Evans Limestone represent the local base of the Genesee Group (Maletz, 2008).

The Tichenor Member, historically referred to as the 'encrinal limestone' (Grabau, 1898), is a reworked layer (~30- 60 cm) of medium gray, buff to rusty weathering calcarenite that forms a single massive unit at the shores of Lake Erie (Brett, 1974). It consists predominantly of echinoderm skeletal debris with a mixture of lime mud and sparry calcite cements and the lower surface of the unit hosts a distinct disconformity. Fossils from the upper part of the Wanakah Shale are often found incorporated into the base of the Tichenor Limestone. The top of the Tichenor Limestone is a discontinuity surface with a locally developed hardground. This surface shows a relief of up to 20 cm. Locally the upper surface of the Tichenor Limestone exhibits dark, possibly phosphatic staining, anchor-faceted fossils and directly cemented crinoid holdfasts, bryozoans, and auloporid corals (Brett, 1974).

The Windom Shale Member is only 4.3 m thick in the Eighteenmile Creek section along the shores of Lake Erie, but is fairly complete and a number of faunal associations can be differentiated. The Windom Shale generally thickens to the east and north but with increasing stratigraphic truncation of the upper portion of the unit to the north (Brett and Baird, 1986). The basal Windom Shale Member consists of about 50 cm of very soft, medium gray, richly fossiliferous shale that contains a brachiopod rich assemblage, similar to the middle Wanakah Shale (exposed only downstream of the crossing of Route 5 and Eighteenmile Creek). Abruptly overlying the brachiopod rich shale is a 10-15 cm thick band of soft, blocky crumbly weathering gray mudstone containing an exceedingly rich and unique fossil assemblage, termed the Bay View Coral Bed (Baird and Brett, 1983). A prominent and traceable carbonate concretion band a few centimeters below the contact with the Genesee Group is consistently found along Eighteenmile Creek. However, it alternates between being expressed as isolated concretions and a semi-continuous limestone band. The Windom Shale is sharply and disconformably overlain by the North Evans Limestone of the Genesee Group.

Frasnian – Genesee Group

The North Evans Limestone Member consists of lenses of <2-18 cm thick of bioclastic limestone, with sedimentary features like cross lamination, intraclasts, and abundant fossils. This limestone is a classic example of an erosional lag deposit or bone bed (Maletz, 2008).This unit was important in the development of conodont biostratigraphy and has been found to be composed of 50% conodonts by weight in some samples (Bryant, 1921)**.** It was deposited in a dysaerobic environment upslope of and coeval to the lower part of the Genundewa Formation and represent the erosional remnants of the Penn Yan Shale (largely absent in western New York, but see below) and the uppermost Windom Shale (Brett and Baird, 1986). This lag deposit thus covers six conodont chronozones and spans the Givetian-Frasnian boundary. The upper surface of the North Evans Limestone is most commonly expressed as an undulating unconformable contact with the Genundewa Limestone.

A thin (<5 cm) black shale unit is intermittently exposed between the North Evans Limestone and the overlying Genundewa Limestone along Eighteenmile Creek. This unit is probably a local remnant of the Penn Yan Shale Member that is more consistently present further east (Baird and Brett, 1986). However, given its spotty occurrence this correlation is tentative (Baird et al., 2006).

The Genundewa Limestone Member is a thin limestone unit (~10 – 20 cm) that marks a break in sedimentation associated with a regression (for detail see: Baird et al., 2006). The unit's base appears undulatory and erosional in western New York and is composed primarily of the problematic fossil *Styliolina* (Baird et al., 2006; Baird and Brett, 1986). This unit is relatively thin in Eighteeenmile Creek compared to exposures further east and south (Baird et al., 2006) as deposition in the local region started later. The lower Genundewa Limestone beds found further east are represented, in part, by the North Evans Limestone. Internally the Genundewa shows evidence of large burrows, hummocky cross-stratification, and soft sediment deformation structures. The unit becomes progressively more clastic and grades into the overlying West River Shale.

The West River Shale Member is ~2.5 m thick at the Lake Erie shore. It consists of dark gray shale with beds of argillaceous siltstone. These siltstone bands become more common to the east as the unit thickens (de Witt and Colton, 1978). The West River Shale has a conformable contact with the underlying Genundewa Limestone and an abrupt contact with the overlying Middlesex Shale of the Sonyea Group. The unit is finely laminated and darker at the base and grades upward into chippy grey calcareous shales.

Sonyea Group

The Sonyea Group is differentiated into the Middlesex and the Cashaqua Formations in the Lake Erie shore sections of Erie County. It consists mostly of dark gray to black shales and is about 12 m feet thick (David et al., 2004). The Middlesex Formation consists of black shales and is approximately 2.9 m thick in Erie County, New York (Sutton et al, 1970; Schieber, 1999; Prevatte, 2020). Freshly broken surfaces of this unit often smell of natural gas and an 'oil slick' is also often apparent (David et al., 2004). A few gray bands and concretionary layers are present in the unit.

The Cashaqua Formation is a gray shale, approximately ~9.1 m in thickness, with an abundance of often flattened ellipsoidal limestone nodule bands, and a few thin layers of black shale (Sutton et al., 1970; Prevatte, 2020). The nodule bands that are prevalent in this unit and in the overlying Rhinestreet are interpreted to represent times of exceptionally reduced rates of deposition and probably formed within a few meters of sediment-water interface (Lash and Blood, 2004a). The Cashaqua Formation grades eastward into a thickening sequence of siltstone and silty shale, and is part of a common turbidite facies of the Catskill Delta (Wilson and Schieber, 2015). This deposit is sharply overlain by the organic-rich Rhinestreet Formation

(Sageman et al., 2003) which marks the onset of the West Falls Group. The Sonyea Group is overlain by the West Falls Group comprised of the Rhinestreet, Angola, and Java Formations. The Java Formation itself contains the Pipe Creek and Hanover units.

West Fall Group

The West Falls Group is represented by two shale members in western Erie County: Rhinestreet and Angola Formations (Sutton, 1985). The Rhinestreet Formation, the basal shale unit of the West Falls Group, is a thick, mostly fissile, black shale that thickens rapidly from west to east (~30 m) and interfingers with, and grades into the overlying gray Angola shale (Wilson and Schieber, 2015) with a distinct oil content (Jaffe, 1950). The petroliferous Rhinestreet Formation, a heavily fractured black and gray shale, at its base along the Eighteenmile Creek section contains a total organic carbon content of 8.09% which diminishes upward in the column to 2.3 % at the Angola shale contact (Sageman et al., 2003). The Rhinestreet Formation contains a few thin gray siltstone beds and thin-bedded argillaceous limestones and when freshly broken smells distinctly of natural gas (Lash and Blood, 2004b). Carbonate concretions are common at many levels and often contain pyrite, but macrofossils are rare. The limestone concretions may be septarian limestones with veins filled with calcite, dolomite, albite and siderite. Distinct large (>2 m diameter) carbonate concretions, commonly referred to as the scraggy layer, marks the transitional zone between the upper-most black Rhinestreet Formation and the gray, fissile Angola Formation (Lash and Blood, 2004a; Wilson and Schieber, 2015).

Angola Formation is more than 67 m thick and alternates between intervals of gray and black shales with impure limestones and calcareous siltstone beds. It is characterized by about 50 distinct beds containing calcareous concretions and limestone nodules of up to 1 m in diameter (Lash, 2016). This unit is relatively barren of macrofossils.

Java Group

At the base of the overlying Java Group the thin, black Pipe Creek Formation (~1m), marks the onset of the Lower Kellwasser Event (Over, 1997, Bush et al., 2015; Kelley et al., 2019; Haddad et al., 2016; Boyer et al., 2021). The Pipe Creek Formation is a persistent, organic-rich black shale throughout its lateral extent (Lash, 2016; Wilson and Schieber, 2015) that intertongues its adjacent shale formations. This shale contains prolific thin and oblate carbonate tubules reminiscent of pipe systems from mud volcanoes and methane cold-seep structures, however, the true origins of the fluids' origination has yet to be determined as a vast majority of the formation lies below Lake Erie and is not well exposed in the area.

The Hanover Formation overlies the Pipe Creek Shale, and is a gray shale with some interbedded black shale beds. The Hanover also thickens to the east grading into silty shale, siltstone, and sandstone (Over et al., 1997; Over, 2002). The total organic carbon content rises from <1 wt.% in the Angola to an average of 4 wt.% in the Pipe Creek, and then falls back to <1 wt.% in the Hanover Formation (Sageman et al., 2003).

PALEONTOLOGY

Macrofossils

The macro-paleontological record within this deltaic complex is superb, thoroughly investigated (e.g., Sutton et al., 1970; Thayer, 1974; McGhee and Sutton, 1981; Sutton and McGhee, 1985; Over 1997), though considered mostly sparse in western New York, and reflects a series of marine crises associated with black-shale deposits throughout the mid to late Devonian (McGhee, 1996). In Erie County, some of the most prolific macrofossil beds are found within the Wanakah Shale, Tichenor Limestone, and through the majority of beds within the Windom Shale Member (e.g., Bayview Coral Bed, Smoke Creek Trilobite Bed. Penn Dixie Pyrite Beds, etc.). Beautifully summarized in the official Penn Dixie Field Guide by Stokes and Schrieber (2017) these beds contain abundant brachiopods (*Ambocoelia, Mediospirifer, Mucrospirifer*, etc.), bryozoans (A*tactotoechus, Fenestella*, etc.), corals (e.g., *Amplexiphyllum, Stereolasma, Favostires, Pleurodictyum*), crinoids, bivalves, gastropods, ammonites (e.g., *Spyroceras, Tornoceras*) and trilobites (e.g., *Eldredgeops, Greenops, Dipleura, Bellacartwrightia*, and *Pseudodechenella*). Large platy fish (placoderm) remains, such as *Eastmanosteus*, *Dinomylostoma*, smaller arthrodires and ptyctodonts, are found with many members of the Hamilton Group (e.g., Bryant, 1921; Buehler and Tesmer, 1963; Stokes and Schreiber, 2017).

Flora

Within the Genundewa, Middlesex, and Rhinestreet there are large fragments of plant remains. In the Middlesex and Rhinestreet shales these tend to be compresses carbon residues with either a frond or woody stem appearance. In the Genundewa these plant fossils retain some volume, though often the state of preservation otherwise is poor. These plant fossils were presumably washed in from terrestrial sources similar to the Gilboa forests deposit of similar age in eastern New York (Stein et al. 2012).

Microfossils

Conodonts

The North Evans Limestone contains a highly diverse conodont fauna of at least 41 species of conodonts (Bryant, 1921; Buehler and Tesmer, 1963). The mixed conodont zone faunas suggest that the unit might represent a multiply reworked deposit that accumulated over a long time period spanning the Givetian-Frasnian boundary (Maletz, 2008). Other units contain much less diverse assemblages of this group. Over (1997) produced one of the most detailed conodont biostratigraphic records of the area.

Tentaculites

The Genundewa Limestone contains abundant tentaculites and styliolina fossils; *Styliolina fisurella* being the most common fossil. Buehler and Tesmer (1963) provided a complete list of the rich conodont and fish fossils also found in relative abundance within this unit.

Foraminifera

Middle to Late Devonian (Givetian through Famennian) black and gray shale beds of Western New York contain hundreds of diminutive calcareous and agglutinated foraminifera (Wilson and Schieber, 2015; Li et al., 2021). The genera within these beds are reminiscent of shallow modern predominance facies. These foraminiferal assemblages and their associated predominance facies (Li et al., 2021) correlate well with prior lithologic and geochemical investigations that establish this portion of the Appalachian Basin as a deltaic setting but suggest are likely an inner neritic zone with depths most likely not exceeding 50m (Smith et al., 2019; Li et al., 2021). Dominant genera include several species of *Ammobaculites* and *Saccammina* which suggest that paleodepths did not exceed 50 m throughout the Frasnian. Opportunistic genera reflect a muted crisis associated with the *punctata* isotopic event (aka Rhinestreet Bioevent) and Lower Kellwasser (Pipe Creek) events. While there are definite shifts in the diversity of assemblages between gray and black shale, the foraminiferal type and feeding mode, indicative of depth and oxygen availability respectively, there is little variation between the distinct beds. No significance was found between total organic and foraminiferal type of feeding mode. Identification at the species level is problematic but suggest that the depositional environment was stressed. However, the effects of the end-Devonian mass extinction were not significant for these foraminifera in comparison to those frequently reported; the data suggests that there was no local extinction for benthic foraminifera at least through the lower-most Hanover Shale, just prior to the Upper Kellwasser and Hangenberg marine crisis events, within this portion of the deltaic complex of the Appalachian Basin of the western New York.

Algal Cysts – Tasmanites (?)

Over 50 years of palynological research of Late Paleozoic deposits have helped to determine that the lithologic sequences and paleoenvironments based on fossil dinoflagellates, acritarchs, foraminifera, silicoflagellates and radiolarians. The miospore biostratigraphy of the Late Devonian Appalachian Basin is well established (Streel, 1972; McGregor, 1979; Richardson and Ahmed, 1988; Loboziak and Melo, 2002). Within the Devonian Appalachian basin, varying palynological components have been reported (Over, 1997; Feist and Van Aller Hernick, 2014; Lash, 2016; Chamberlain et al., 2016; Kelley et al., 2019; Haddad et al., 2016; Boyer et al., 2021) but most commonly as secondary findings in these investigations.

In the past, *Tasmanites* have been commonly misinterpreted as terrestrial plant spores that were transported by the wind or currents into the black-shale seas and basins primarily due to their lack or limited external texture and internal structure. Although Dawson (1871) first described similar spore-like discs as Sporangites, Newton (1875) provided a more thorough description of the fossil and named it *Tasmanites* after the Tasmanian white coal, which is composed of these discs. Newton (1875) thought that *Tasmanites* were, "vegetable organs" or spore cases, but he was not certain from which plant they had come and suggested that they were related to lycopod macrospores. Subsequent investigations found that *Tasmanites* were of algal origin, bearing a resemblance to modern green alga (e.g., Schopf et al., 1944; Wall, 1962; Brooks, 1971). While debate remains as to the true marine algal assignment in this portion of the deltaic wedge, these structures have been identified as *Tasmanites* in the Tully Formation in Pennsylvania (Chamberlain et al., 2016) and several other coeval basins across Laurentia (e.g., Iowa Basin, Michigan Basin, Ohio Basin, etc.).

On a world-wide basis, marine algal cysts are found in deposits ranging in age from the Silurian to the Cretaceous (Brooks, 1971) and their remains occur in relative higher abundance throughout black shales ranging in age from Middle Devonian to Early Mississippian in both Gondwana and Laurentia (Revill et al., 1994; Vigran et al., 2008; Wicander and Playford, 2008; Haddad et al., 2016; Mouro et al., 2016; Lelono, 2019). Many such enrichments have been interpreted as reflecting algal blooms in areas supplied with meltwater from surrounding glaciers or other terrestrial run-off sources (López-Gamundí, 2010; Lelono, 2019). The localities investigated in this study are known to have been located within the southern tropics (Fig. 1a) and mostly likely did not have direct meltwater influence. There is strong sedimentological evidence that this deltaic wedge may have been inundated with fresh water run-off due to increased seasonal riverine input shifting the hydrochemistry and productivity levels (Arthur and Sageman, 2005; Lash, 2016; Kelly et al., 2019; Haddad et al., 2016; Boyer et al., 2021; Bartlett et al., 2021 (in press)) leading to a series of black shale formation.

Charophytes

Charophyta fossil materials include oogonia (female reproductive organs; most common), antheridia (male reproductive organs, less common), and portions of the Characeae plant itself (e.g. branches, thalli, stipules, leaves, etc.). Well-preserved oogonia and thalli have been reported in the Givetian-aged Ludlowville Formation in eastern New York (Feist and Van Aller Hernick, 2014) and more recently in Bartlett et al. (2021, in press) within several deposits in western New York. Outside of this single publication, charophyte fossils are yet to be reported from any other portion of the Upper Devonian Appalachian Basin.

Charophyta are a group of extant aquatic alga found most commonly in freshwater but have been found to be occasionally abundant in brackish areas (Shepherd et al., 1999; Soulié-Märsche, 1999, 2008). Generally occurring in quiet or gently flowing waters, charophytes have specific light and specific oxygen level requirements (de Winton et al., 2004; Küster et al., 2004) and so they are usually found in very shallow depths (several cm) but have been found in deeper waters, where nutrient input is reduced (<30m; Middelboe and Markager, 1997) as long as light sources are adequate. Some have been found in swiftly flowing rivers (McCourt et al, 2016), but such occurrences have been rarely noted in the literature.

A clear and distinct inverse relationship has been identified between the presence of marine algal cysts and charophyte fossils within Frasnian beds (Bartlett et al., 2021 (in press)). Two of beds have discrete contacts and mark the onset of a marine crisis and known transgressive events (Johnson et al., 1985; Veevers and Powell, 1987; Algeo et al., 1995; Algeo and Scheckler, 1998; Ver Straeten et al., 2011); the Cashaqua-Rhinestreet contact of the *punctata* event, the Angola-Pipe Creek contact for the onset of the Lower Kellwasser event. The Upper Kellwasser event occurs within the Hanover Formation.

Trace Fossils

Burrows are by far the most obvious trace fossils in this succession and are mostly clearly present at the base of the Genundewa. Burrows can sometimes be several centimeters across and cross-cut the underlying North Evans Limestone in some locations. The surface of the Tichenor limestone may also show burrows of substantial size and smaller, mostly horizontal, burrows can be found in the grey shale units such the Windom. These small burrows weather to a rusty brown color that is easy to spot against the gray background shale.

DEVONIAN MARINE CRISES EVENTS

The Devonian Period contains evidence of a series of marine crises that are recorded globally, a few which, in western New York in particular, correlate to the deposition of black and gray shale sequences or limestones, and accentuated pelagic faunal turnovers (e.g., House, 1996; DeSantis et al. 2007; Haddad et al., 2016; Kelly et al., 2019, Lash, 2019). The events which straddle the beds of this investigation are the punctata event (Rhinestreet event), the Lower Kellwasser Event (Frasnian-Famennian, with the Lower Kellwasser Event at the Pipe Creek, ~372 Ma and second and more severe Upper Kellwasser Event in the uppermost Hanover Shale). The latter event impacted up to 80% of marine species (Hallam and Wignall, 1997). The subsequent and terminal Devonian Hangenberg event (359 Ma; not covered in this field trip), saw losses of an additional ~50% of invertebrate diversity (upper Hanover Shale, correlated beds not included in this investigation; Streel et al., 2000).

Taghanic Event

A major global eustatic transgression is recognized in the Late Devonian. Pre-Taghanic Event Givetian marine areas of eastern and western North America were not connected across the southern United States and were connected only briefly between western Canada and the north-central United States (Indiana and Michigan). upper Tully Formation, a major transgression accompanied upward change from clean carbonate to increasingly muddy limestones, and culminated in the overspread of anoxia and resulting black mud deposition within the foreland basin; this deepening partly reflects eustatic highstand conditions (Johnson et al. 1985), but it also was greatly enhanced by flexural loading of the craton by thrust slices during a collisional pulse (Third Tectophase) of the ongoing Acadian Orogeny (Ettensohn et al., 1998). Pre-Taghanic Middle Devonian brachiopod faunas of eastern and western North America belong to different faunal provinces, that is, to the Appalachian and Old World provinces respectively. The Taghanic onlap of the continental backbone in the southwestern United States provided shallow-water marine areas for dispersal of bethonic animals and the resulting intermigration brought an end to brachiopod provinciality that had prevailed since the Early Devonian. By analogy, provincial shifts in established faunal successions should provide dates for other sedimentary-tectonic events.

Because Appalachian Province fossils are known to range as far as Colombia and Venezuela in Emsian-Eifelian time, but not at the same time to the American west, a large land barrier is postulated for times of provinciality, that is, during the intervals Ludlow-early Siegenian, and Emsian-mid-Givetian. Other intervals during the Silurian and Devonian were times of breaching of the land barrier by marine seas.

During deposition of the Additionally, Tully strata record major faunal fluctuations associated with the regional demise and/or geographic restriction of the long lasting, diverse, and endemic Hamilton Fauna (Brett 1995; Sessa et al., 2002; Baird and Brett, 2003; Baird et al., 2003); this pattern of faunal overturn and global extinctions, known as the "Taghanic Event" (Johnson, 1970; House, 1981), is increasingly recognized as actually representing two or more temporally closely-spaced global bioevents which may have been as severe, or more so, than the widely-known Frasnian-Famennian extinction (Aboussalam and Becker, 2001; House, 2002).

punctata Event

At the contact of the Middlesex-Cashaqua a muted expression of the well documented global *punctata* carbon excursion event in North America begins and terminates just below the Cashaqua-Rhinestreet contact (Lash 2019). Magnetic susceptibility readings published by Lash (2019) shows that the final peak of the ^{13}C excursion in this locality begins at 40 cm below the contact Cashaqua-Rhinstreet, following this final peak at 10cm below the contact. Recent foraminiferal investigations has shown that the number of species sampled drops from 22, at 10 cm below, to 11 (50%), at the contact (Li et al., 2021). The lowest number of genera within the Rhinestreet Formation, a notable second plummet, occurs at 60 cm above the contact (Li et al., 2021). The reduction of genera occurs where the lithology shifts to a well lithified black shale. While several species 'disappear' within these formations, their genera do persists throughout the Frasnian deposits of western New York. Marine algal cysts (possibly *Tasmanites*) have recently been identified and found to be highly concentrated at 40 and 21 cm below the Cashaqua-Rhinestreet contact (Bartlett et al., 2021 (in press)). These concentrations also coincide with carbonate concretion layers, well preserved freshwater algal reproductive organs (e.g., oogonia, antheridia) and associated branchlets and stipules, and microtektites (Lash, 2019; Bartlett et al., 2021 (in press); Meehan and Lash, 2021).

Lower Kellwasser Event

The Pipe Creek Shale marks the onset of the Lower Kellwasser Event and contains the highest peak of foraminiferal species counts for Frasnian beds in western New York (Li et al, 2021). Being flanked by gray shales, the Angola and Hanover Shale Members, with periodic increases in epifaunal and mixed populations suggests that within the time just prior to, during, and immediately after the Lower Kellwasser Event, this portion of the deltaic wedge was either well oxygenated or the organic influx remained high. There is essentially no biotic turnover within foraminiferal populations; genera/species remain the same, abundance, diversity, and richness are statistically unchanged within the Pipe Creek Shale.

Up-section, the Hanover Shale contains a continuously diminishing number of foraminiferal genera (Li et al., 2021). While the authors suggested that this decrease in population may be reflective of the biotic crisis, the sampling did not extend high enough within the member to determine whether this is the case absolutely. Within the reaches of the investigation conducted by Li et al. (2021) the expression in benthic foraminiferal may not be as distinct as in the macrofaunal due to the opportunistic nature of the populations in these deltaic environments and the lack of taxonomic literature with which to identify species, thus, potentially muting any changes in diversity at the species level.

Upper Kellwasser Event

The Upper Kellwasser event is represented in western New York by a thin black shale deposit within the Hanover Formation, less than a meter below the contact with the overlying Dunkirk Formation (Lash, 2016). While the Kellwasser events have traditionally been associated with consistent widespread anoxia, and even euxinic conditions this does not appear to be the case in western New York based on geochemical (Lash, 2016; Kelly et al.2019; Haddad et al., 2016) and trace fossil (Boyer et al., 2021) evidence. Instead, findings suggests rapidly fluctuating oxygenation between dysoxic to anoxic and perhaps occasionally euxinic conditions The Upper Kellwasser bed is associated with a negative $\delta^{13}C$ excursion and high TOC followed immediately by a positive excursion and drop in TOC for the remainder of the Hanover Formation (Lash, 2016). It is worth noting though that the overlying grey shales of the Dunkirk Formation continue to have elevated TOC levels while carbon isotopes return to background levels prior to the Upper Kellwasser event. This recovery interval corresponds to an increase in siliceous microfossils (i.e. radiolarians). Several additional papers have recently been published adding much data to support these hypotheses. Recent data include marine agal cyst abundance, lipid geochemical proxies, trace metals, and ichnofossil assemblages; suggesting that this environment was highly stressed and not likely to be continuously anoxic, but periodically euxinic (Kelly et al., 2019; Haddad et al., 2016; Boyer et al., 2021).

FIELD GUIDE AND ROAD LOG

Meeting Point: Buffalo State Campus; Burchfield Penny Art Center Parking lot Rockwell Road and off Elmwood Avenue Entrance (across from the Albright-Knox Art Museum).

Meeting Point Coordinates: 42°52’53.11”N 78°52’42.10”W

Distance (miles)

Cumu-lative	Point to point	Route Description

Stop A: Eighteenmile Creek Access Site at the end of Basswood Drive, Lake View, New York. 42°42'27.0"N 78°57'22.1"W

20.1	0.3	From Rockwell Road Entrance at Elmwood Avenue, turn left, head north on Elmwood Avenue toward Iroquois Drive.
	0.1	Turn left onto NY-198 (Scajaquada Pkwy).
	1.2	Merge onto NY-198 W.
	3.6	Use the left lane to merge onto I-190 S toward Downtown Buffalo.
	7.6	Take exit 7 to merge onto NY-5 W/Buffalo Skway toward Outer Harbor/ Lackawanna. (Bad merge – take caution of right lane oncoming traffic from Downtown).
	7.1	At fork (after Woodlawn State Park Overpass/Ford Stamping Plant) keep right to stay on NY-5 W.
	0.2	Continue to North Creek Road on NY-5 W (BEFORE the bridge; turn around available off South Creek Road).
	0.1	Turn Left onto North Creek Drive.
	0.1	Turn Right onto Basswood Drive. Destination at end of the street
	0.2	Walk down dirt path to Eighteenmile Creek.
	0.3	Walk downstream. Outcrop on north side of the creek.

Regardless of creek level reaching this outcrop will require at least a brief dip into shallow water (usually less than a foot deep), so dress appropriately. This large amphitheater-style exposure stretches ~0.3 miles along the north side of the creek with the Tichenor limestone member of the Moscow Formation at the base providing a resistant platform to walk along. At this site members of the Hamilton (Tichenor, Windom), Genessee (North Evans, Genundewa, West River), and Soneya (Middlesex, Cashaqua) Groups can be observed. Large blocks of the more resistant North Evans, Genundewa, and Middlesex formations are common along the surface and can be readily examined. The underside of the North Evans is most accessible in situ at the upstream end of this outcrop where its unusual character is clearly visible.

There is a second exposure just upstream of where we will enter the creek but it is more difficult to view without crossing deeper water. However, for those interested this secondary location shows the full exposure of the

Genundewa, West River, and Cashaqua units and even shows the lowest few meters of the Rhinestreet Formation at its top. The ubiquity of carbonate nodule bands in the Cashaqua is on full display at this exposure as well.

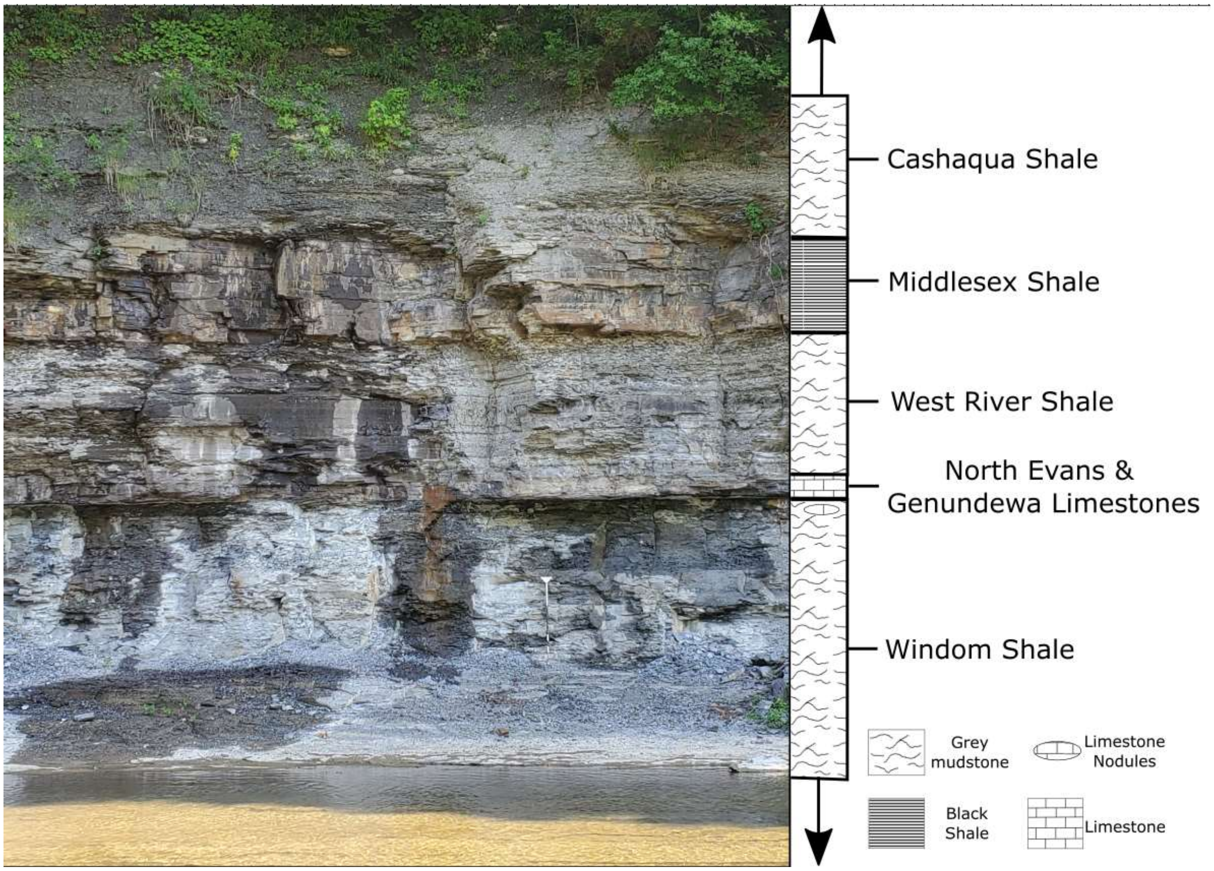

Figure 3. Photograph of stop A along Eighteenmile Creek with lithological units labeled. Arrows on the stratigraphic column indicate units that are truncated at this location.

Stop B: Eighteenmile Creek Hobuck Flats at the end of Versailles Road, Derby, New York. 42°42’28.07” N 78°57’22.30”W

2.6	0.2	Head north on Basswood Drive toward North Creek Road.
	0.1	Turn left onto North Creek Road.
	0.5	Turn left onto NY-5 W.
	1.6	Cross the Eighteenmile Creek Bridge and make left at South Creek Road.
	0.2	Turn left onto Versailles Road. Destination at the end of the road.
	0.2	Walk downstream. Outcrop along north side of creek.

A short walk upstream there is an exceptional exposure of most of the Cashaqua and Rhinestreet Formations. There are numerous carbonate concretion layers accessible on foot from the Cashaqua and nodules originating from the Rhinestreet can often be found as talus along the base of the outcrop. Some of these nodules contain ammonite fossils and more rarely other macrofossils, such as placoderm fishes. There are also several soft pockets of organic matter within the upper Cashaqua that can often be spotted by their rusty weathering pattern. While the Rhinestreet is dominantly a black laminated shale there are also silty layers of grey shale within it that are visible at this locality.

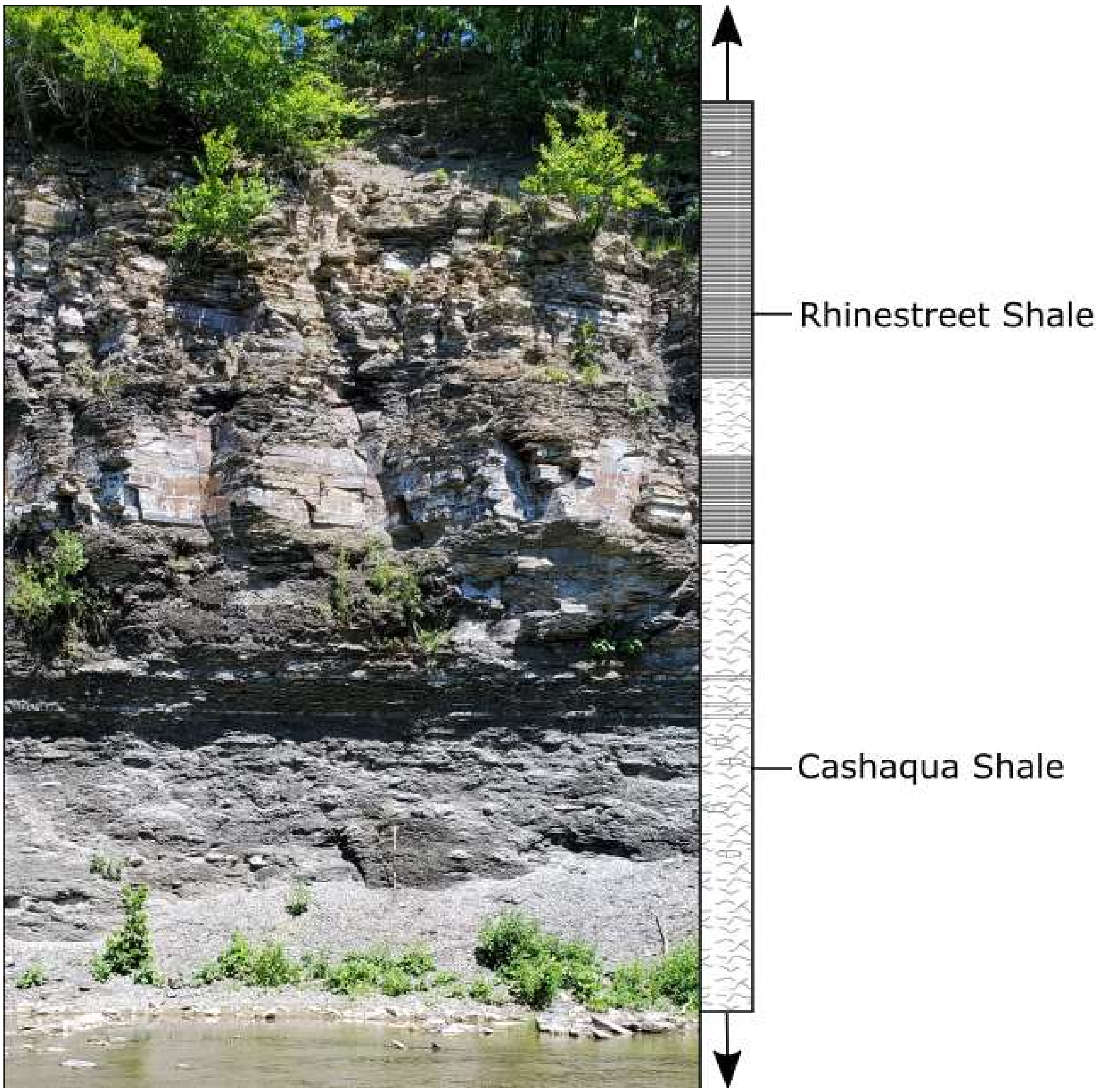

Figure 4. Photograph of stop B along Eighteenmile Creek with lithological units labeled. Lithological key as in figure 3.

Stop C: Eighteenmile Creek at NY-20 (Southwestern Blvd), fisherman's trail across from North Evans Cemetery. Gravel path descent, may be washed out in places. Take caution on this foot path). 42°41'42.20"N 78°56'10.34"W

0.5	0.2	Head southeast on Versailles Road toward South Creek Road.
	0.2	Turn left onto South Creek Road (becomes Shadagee Road)

0.2 Continue on Shadagee Road (also So. Creek Road). Park on right at North Evans, St. Vincent De Paul Cemetery.

Uppermost Cashaqua Formation and beginning of the Rhinestreet Formation (Frasnian). This is the location where Lash found the ^{13}C/TOC excursion for the *punctata* event and also at 20 and 40 cm below Cashaqua-Rhinestreet contact, at concretion layers, microtektites presumed to be from the Alamo event were found in macerated shale. Flooding event; hyperpycnal/monsoonal suspected.

Some ammonoids and their casts have been found here, however, this location is mostly barren of macrofossils. Though there are abundant microfossils – not visible with naked eye.

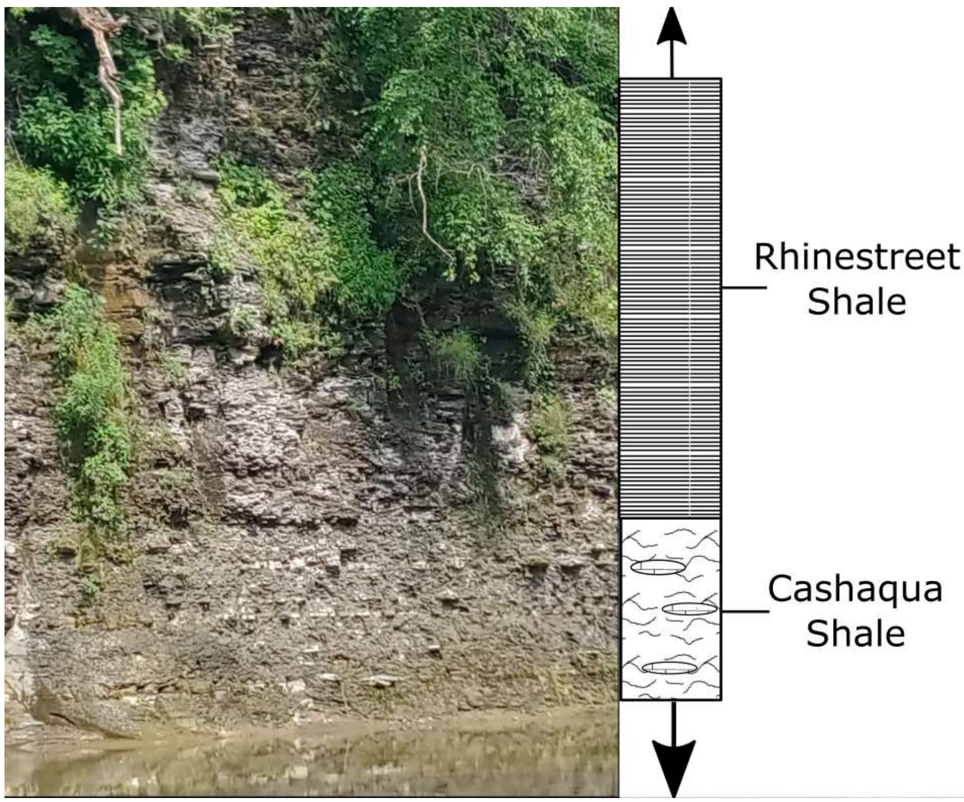

Figure 5. Photograph of stop C along Eighteenmile Creek with lithological units labeled. Lithological key as in figure 3.

Stop D: Preischel's Farm. 2993 Belknap Road, Eden, New York. 42°41'1.06"N 78°52'47.30"W

3.3	0.9	Head southeast on Shadagee Road toward Bauer Road.
	0.9	Turn left on Bauer Road.
	1.5	Continue Straight on Belknap Road. Meet in lot on left at Preischel's Farm.

Optional drive/walk

*** All wheel or 4x4 drive <u>strongly</u> suggested. By foot this is a 0.5 mile walk:

Take dirt road next to tractor garage and milk silos on eastside of street. Last I was there the road was pretty washed out and steep, strongly recommend parking before the final drop off (you WILL see it), field with household appliances there for parking.

Rhinestreet and Angola Formation transitional zone, scraggy layer. Amazingly large concretions (average 1 m but can be as wide as >3m). This location contains geochemical signals and microfossils (charophytes, oogonia, antheridia), suggest seasonal to intermittent but regular flooding. Some macrofossils can be found but are rare. The Rhinestreet Formation is rich in methane/oil and contains a very distinct and strong odor.

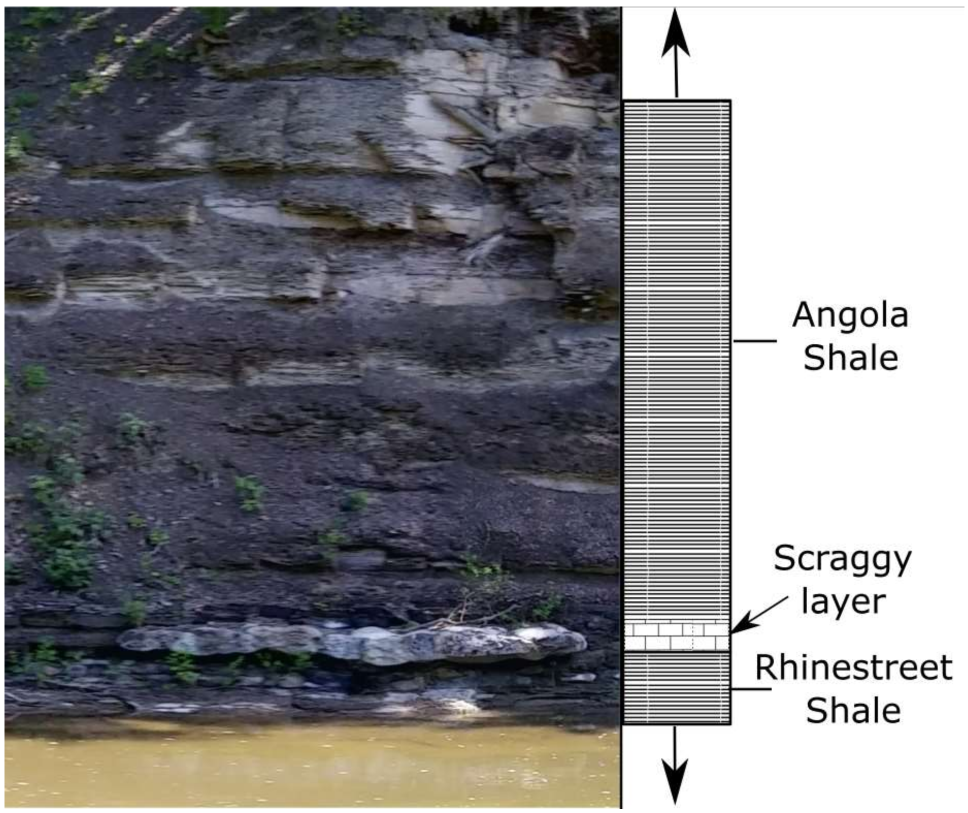

Figure 6. Photograph of stop D at Preischel Farm with lithological units labeled. Lithological key as in figure 3.

Stop E: US- 219 and Zimmerman Road overpass (broad shoulder for parking). 42° 40' 40.35"N 78° 47' 01.63"W

7.3	0.8	Head south on Belknap Road toward Bley Road.
	0.4	Turn left on Bley Road.
	443 ft	Continue onto Eden Valley Road to the right (NY-62)
	4.3	Make immediate left onto North Boston Road.
	0.3	Turn left onto Heinrich Road
	0.4	Continue to the right onto Eckhardt Road
	0.1	Turn right onto NY-391 S/Boston State Rd/Hamburg-Springville Rd.
	1.2	Use the right lane to merge onto US-219 S via the ramp to Springville.

Park on wide shoulder near Zimmerman overpass.

*** be mindful of oncoming traffic. Speed limit is 65 mph, use due diligence should you cross the highway. It is strongly recommended that you use proper exit/entrance ramps to view the east side of the outcrops.

Angola, Pipe Creek (1m thick), and Hanover Formations on the west, middle, and east side shoulders. Oldest to youngest trending north to south along the highway. Pipe Creek marks the Lower Kellwasser Event. Uppermost Hanover marks the Upper Kellwasser Event.

Pipe Creek finger concretions 13C bear evidence of short-lived flow – disputed as to whether microbial, hydrates, or mud volcano … nonetheless, methane was discharged either due to common weather related mechanical dissociation.

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