PENN DIXIE FOSSIL PARK & NATURE RESERVE: A WINDOW INTO THE DEVONIAN PERIOD OF WESTERN NEW YORK

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AN IMAGE CAUGHT IN TIME

Earth was very different four hundred million years ago (Figure 1). Eons before the first dinosaurs scuttled through prehistoric forests, North America and Europe together formed a large landmass along the Tropic of Capricorn (Figure 2B). Western New York was submerged beneath tropical seas, which were teeming with both old and new forms of life.

The Devonian Period (419 to 359 million years ago) marked an important chapter in Earth history. Life on land was just starting to take root — literally, as Earth's first forests produced the oxygen needed by the earliest amphibians who hunted giant insects at the water's edge. Along the Eastern half of North America, mountains rose as the Acadian Orogeny (i.e., mountain building event) -- was underway. Like a highway pileup, the Proto-African Plate crashed into and onto the North American plate, causing earthquakes, intense volcanic activity, and crustal deformation (Figure 2C).

Beginning in the middle of the Devonian Period and lasting for 60 million years, The Acadian Orogeny set the stage for our unique assemblage of fossils. To the West of the coastal collision zone, the Earth's crust flexed and bent to accommodate the incoming mass of another continent. Like a compressed accordion, land was forced downwards. Over centuries, the ocean meandered its way along the widening and deepening depression towards New York. As the Eastern mountains grew, the Western basin was inundated with saltwater (Figure 2).

Like a beach slowly submerging, the flooded slopes of this ancient basin transformed dry land into the ideal environment for marine life. Shallow water reefs

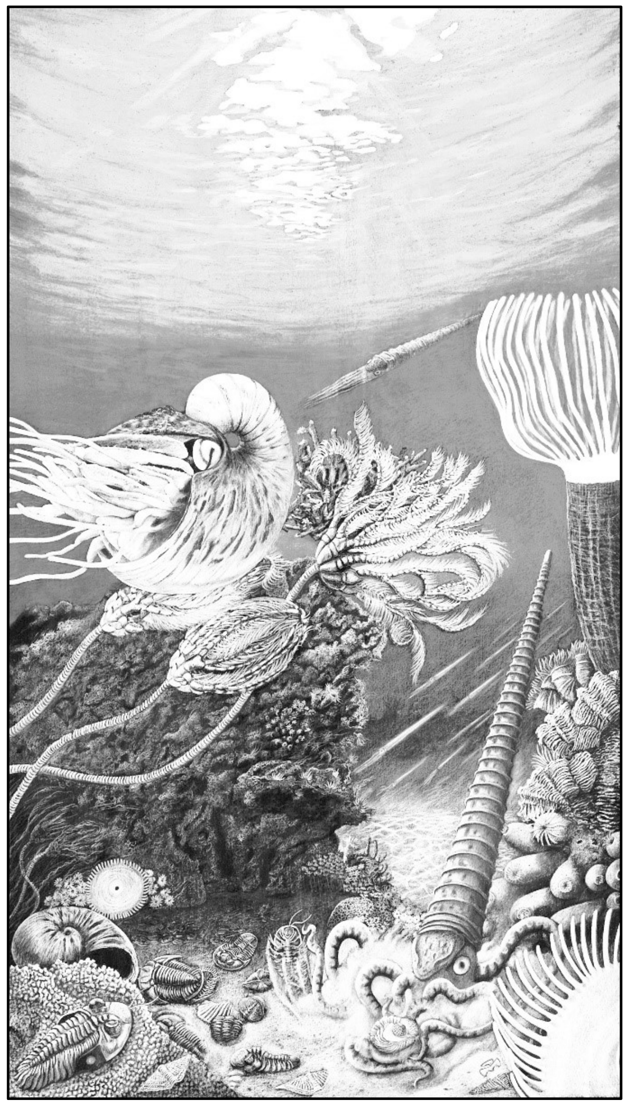

Figure 1 – *Into the Depths of the Devonian* © Mike Menasco. Reconstruction of a Devonian reef based on the fossils found along Eighteen Mile Creek near Penn Dixie.

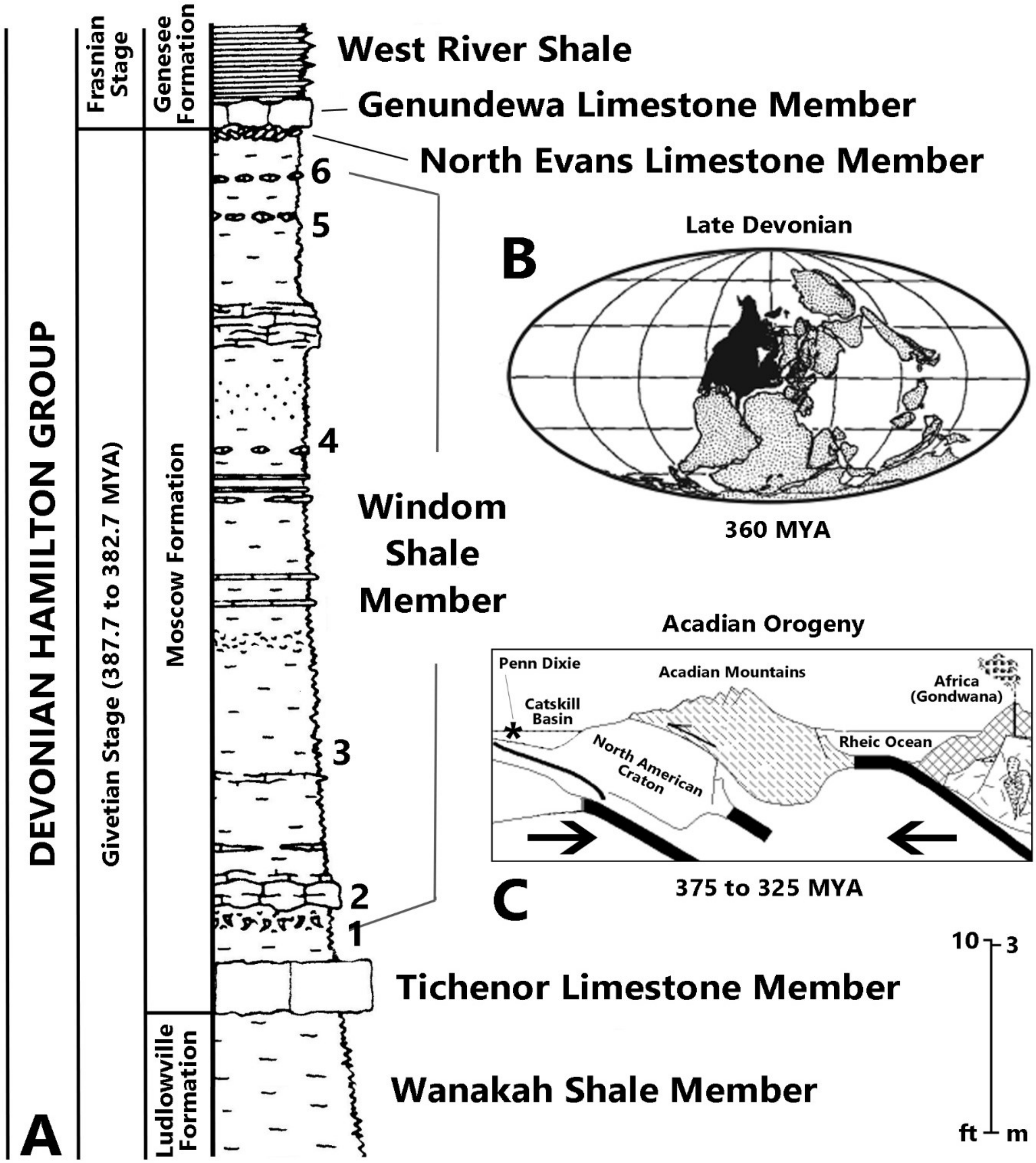

Figure 2 – A) Stratigraphic section of rocks present at Penn Dixie. Numbers 1-6 correspond to units of geological importance. See text for description of members. Modified from Brett and Baird, 1982. B) Paleomap showing locations of the continents during the Devonian Period. North American is in black. Modified from New York State Earth Science Reference Table. C) Cross-section of North America – Africa collision during the Devonian Acadian Orogeny. Location of Penn Dixie is denoted by asterisk. During the Devonian, Penn Dixie was located in the Catskill Basin. Modified from Fichter, 2014.

were dominated by brachiopods and corals. Trilobites — the potato bugs of the ocean — skittered and rolled along the murky bottom as they evaded predators and scavenged what they could. In open water, armored fish, sharks, and the first ammonites — predatory cephalopods in round, chambered shells — feasted on a diverse buffet of newly evolved fish. It was a snapshot of life on Earth -- a geological instant spanning roughly 1% of our planet's long history.

FOUNDATIONS OF STONE

Visitors often ask us why -- if the Earth is covered mostly in water -- do we only find fossils in particular places? Shouldn't fossils be more common? The short answer is that fossils are common, but only in certain places. The long answer is…more complicated.

In *Principles of Geology* (1830-1833), Scottish Geologist Charles Lyell discussed the idea of uniformitarianism -- that "The present is the key to the past." Lyell referenced the modern world as an analogue to the ancient world as he reasoned the stories of rocks and fossils.

Today, life is found globally. However, the conditions for fossilization to occur limit the types of places where the remains of life may fossilize. Four are needed: rapid burial, presence of body parts that will preserve, delayed/prevented decay by microbes, and a geologically stable environment. Penn Dixie met all of these conditions.

Our rocks -- which are geologically consistent across Western New York -- were created from sediments transported westward by ocean currents and waves. Layers of sand became sandstone; silt became siltstone; and clay particles became shale. Limestone, another sedimentary rock, formed from the secretions of skeletal fragments of tiny reef organisms such as corals, snails, crinoids, and plankton. Theses formed the local sequence of geological layers, referred to as stratigraphy, and preserved many types of fossils.

The layers represent varying sea levels in time. In general, sandstone formed in beaches; limestone in warm, shallow water; gray shale in deeper water; and black shale in the deepest, coldest water. Some environments had a much higher biodiversity than others. For example, warm, shallow water supports reef ecosystems with many species. Oppositely, cold, deep water -- with limited oxygen, very few food sources -- cannot support a diverse ecosystem and the rocks that form here are often devoid of fossils.

Fortunately, our local inhabitants possessed many body parts that fossilized, including exoskeletons, shells, and teeth. Though the soft body parts rarely become fossils, we can reconstruct many extinct creatures based on living relatives or internal physiology. For instance, we recognize that extinct horn corals had tentacles just like modern corals.

Preventing decay is pretty straightforward. An animal has to be buried, and thus sealed from outside contaminants, very quickly. The seal must be able to prevent the transfer of oxygen so that bacteria cannot do their work to break down the creature's cells. Charles Lyell might have asked: where do we find these conditions today? Beaches, lagoons, and shallow reef environments are often prime locations for the rapid influx of sediment caused by natural disasters. Storms (e.g., hurricanes) generating underwater avalanches are likely to blame for many of the fossil-rich rocks at Penn Dixie. These rocks -- where animals were brought together in mass mortality and buried -- are called death assemblages.

Finally, a geologically stable environment is needed to ensure that the deceased become fossils. What happens after a fossil is buried? First, in a process called diagenesis, transported sediments are heated and compacted into sedimentary rocks. Fluids flow through microscopic pores in the rock during diagenesis. Inorganic minerals replace organic molecules as water is ultimately driven out of solid rock. Too much heat and pressure results in metamorphism, which destroys fossils. The conditions must be just right during diagenesis.

There are many ways to destroy rocks after they form. Rocks can be uplifted and eroded, subducted beneath tectonic plates, fractured and faulted by earthquakes, deformed by metamorphism, or melted and recrystallized by magmatic fluids. With few geological threats, Devonian rocks survived to became the foundation of our region.

UNDER THE SEA

The sea that covered Erie County and Western New York during the Devonian was relatively shallow and probably had normal marine salinity as evidenced by the diverse and abundant fauna of stenotypic organisms (i.e., tolerant of a narrow range of environmental factors) (Brett & Baird, 1982).

One of the most common and diverse groups of animals during the Devonian period was brachiopods. Brachiopods are bivalved, benthic marine invertebrates. Most live attached to the ground by a fleshy stalk called a pedicle. They are still alive today, but are generally found in deeper, cold waters. Brachiopods eat by filtering organic particles from the water. Brachiopods are often confused with bivalves (members of the Phylum Mollusca) because they both have shells that are comprised of two valves. However, they are very different animals and not closely related at all. The easiest way to tell a brachiopod from a bivalve is the symmetry of their valves. Brachiopods (Figure 3) are bilaterally symmetrical through the two valves, while the two

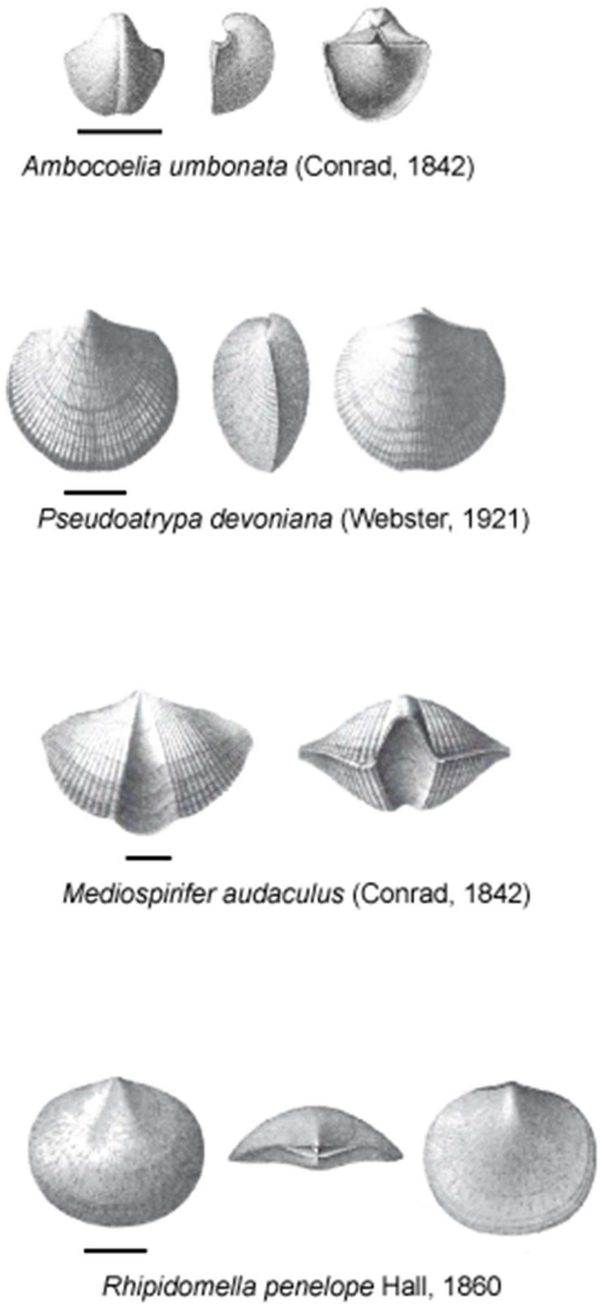

Figure 3 – Most common brachiopods found at Penn Dixie. All scale bars are 1 centimeter. Modified from Wilson, 2014.

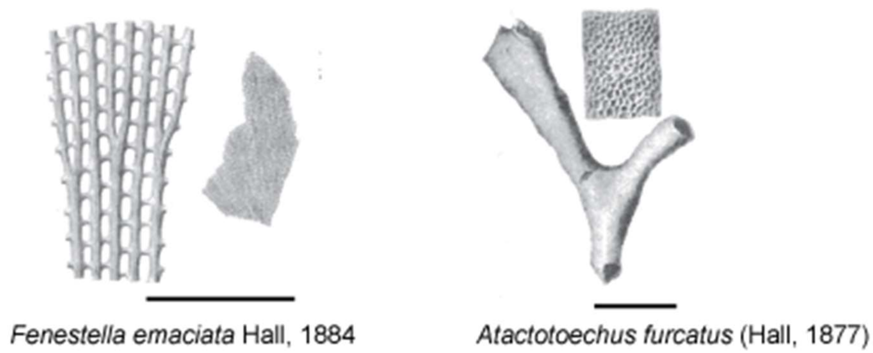

Figure 4 – Bryozoans found at Penn Dixie. Scale bars are 1 centimeter. Modified from Wilson, 2014.

valves of a bivalve are mirror images of each other (Figure 8).

Bryozoans were less common than corals during the Devonian, but can still be found at Penn Dixie (Figure 4). Bryozoans are commonly called moss animals and superficially resemble coral, but are more closely related to the brachiopods. Bryozoans and brachiopods both have lophophores, a fleshy organ used to feed and respire. They are colonial and often grow on rocks or other organisms. Bryozoans are still alive today and can be found in both fresh and salt water.

Many types of corals were found in Devonian seas, just like in the oceans today. These corals are the most common fossils found at Penn Dixie (Figure 5). Most fall into one of two categories: rugose (i.e., horn) corals and tabulate corals. Horn corals are named for their horn-shaped skeletons. Tabulate corals are named for the table-like horizontal structures of their skeletons called tabulae. Both rugose and tabulate corals were very prevalent during the Devonian, forming large, diverse reefs similar to the Great Barrier Reef of today. These two groups of corals are

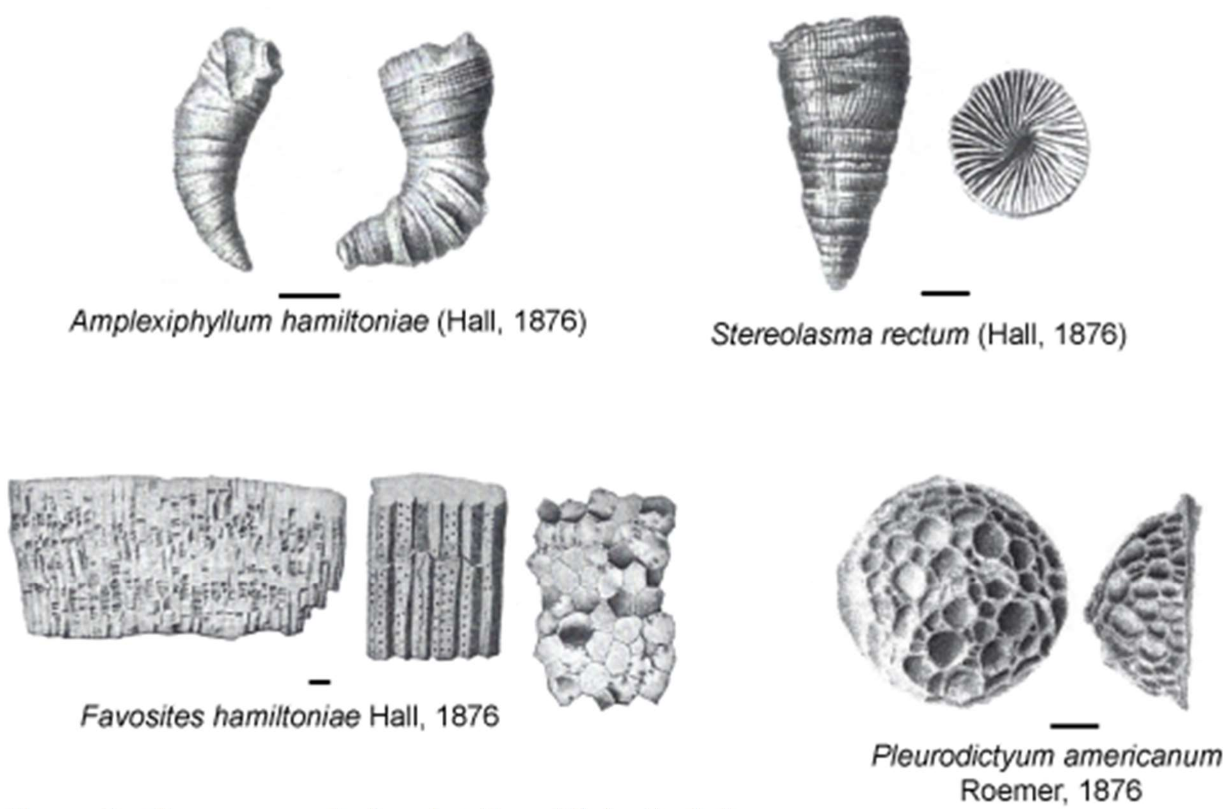

Figure 5 – Common corals found at Penn Dixie. Scale bars are 1 centimeter. Modified from Wilson, 2014.

distant cousins to the living members of Cnidaria. Corals are suspension feeders, grabbing food from the water as it floats past their tentacles. Both rugose and tabulate corals became extinct at the end of the Permian period about 250 million years ago.

Trilobites were also a major component of Devonian oceans (Figure 6). Trilobites are extinct, marine arthropods. They are called trilobites because of their three-lobed body and are sometimes called the potato bugs of the ocean. Trilobites were known for their excellent vision. They were the first animals to evolve true eyes. Earlier "eyes" consisted of photoreceptor cells that sensed light and dark, but could not distinguish shapes. Trilobites had compound eyes (made of many lenses – 17 columns of them!) like insects have today. Their lenses are calcite, and fossilized very well, so we know a lot of information about how trilobites saw their environment. Trilobites went extinct at the end of the Paleozoic Era, but their closest living relative is the horseshoe crab.

Crinoids are arguably one of the most beautiful components of the Devonian seas (Figure 7). Crinoids are members of the Phylum Echinodermata. Think of them as cousins to the starfish, sea urchins, and sand dollars, however they look very different from these other echinoderms. Crinoids are commonly called sea lilies due to their resemblance to flowers (Figure 1). Though they look like flowers, crinoids are animals and grab their food from the water with their feather-

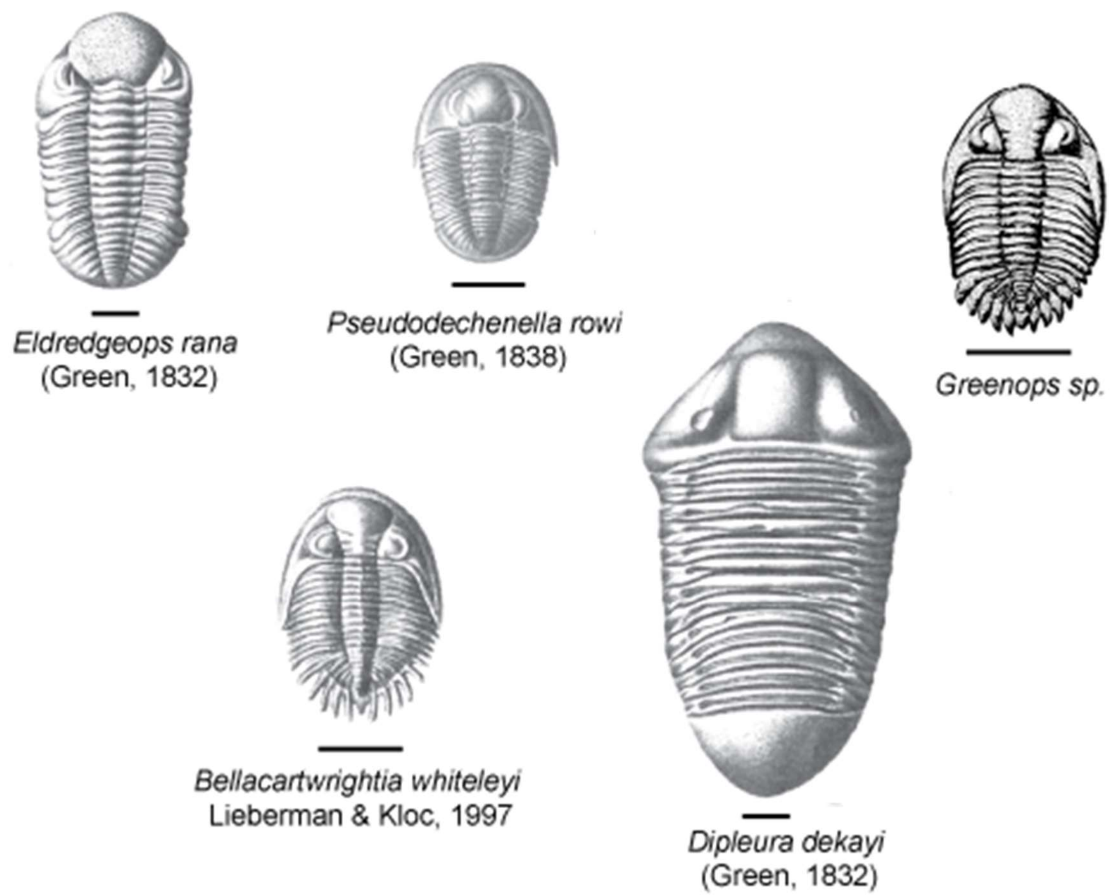

Figure 6 – Trilobites at Penn Dixie. *Eldredgeops* is the most abundant trilobite at Penn Dixie. *Greenops* and *Bellacartwrightia* are uncommon; *Dipleura* and *Pseudodechenella* are rare. Scale bars are 1 centimeter. Modified from Wilson, 2014 and http://www.isgs.illinois.edu/outreach/geology-resources/trilobites.

like fronds. Crinoids are still found in today's oceans, but usually at great depth.

The Devonian oceans was also home to a variety of molluscs, including cephalopods, bivalves (i.e., clams), and gastropods (i.e., snails; Figure 8). Bivalves (sometimes referred to by their former name, pelecypods) are relatively uncommon at Penn Dixie. Most fossils that have two valves found at Penn Dixie are brachiopods (see the discussion above). Bivalvia during the Devonian was far less diverse and abundant than brachiopods. It wasn't until after the late Devonian extinction that bivalves began to overtake brachiopods in diversity and abundance. Cephalopods were some of the top predators during the Devonian. Straight-shelled and coiled-shelled varieties of cephalopods were both common during this time and both can be found as fossils at Penn Dixie. Gastropods are also one of the rarer fossils at Penn Dixie. During the Devonian, marine gastropods tended to be small with variably coiled shells.

Occasionally Devonian plant fragments are found among the rocks of Penn Dixie. These are extremely rare, but should be mentioned because of the unique nature of plants during the Devonian. Plants as we know them today did not exist. Land was first colonized by plants during the preceding period, the Silurian. At the start of the Devonian, small plants (no more than a meter tall) with shallow root systems, dominated the land. By the end of the Devonian, ferns, horsetails and seed plants evolved (Figure 9). Most of these plants had true roots and leaves, forming the first trees and forests. Because large land herbivores had yet to evolve, plants expanded to new forms and colonized the land unchecked.

In Devonian seas, fish were also some of the top predators (along with cephalopods). But, the fish of the Devonian looked very different from the of fish today. Armored jawless fish (i.e., ostracoderms) were common. These fish generally lived along the ocean floor and had elaborate, armored exteriors, but lacked jaws.

By the middle Devonian, fish had evolved jaws. These first jawed fish were called placoderms, for their armored plates. The most famous placoderm was the ten meters long *Dunkleosteus terrelli* (Newberry, 1873; Figure 10). In Western New York, the Devonian oceans were ruled by its cousins, *Eastmanosteus magnificus* (Hussakof and Bryant, 1918) and *Dinichthys hertzeri* Newberry, 1873.

At Penn Dixie, isolated pieces of the armored plates and bone fragments of these fish can be found, most often in the limestone layers above the Windom Shale. It is nearly impossible to identify the specific species to which these pieces belong. Bony fish also evolved during the Devonian, one lineage of which evolved into land-living tetrapods from which humans descended.

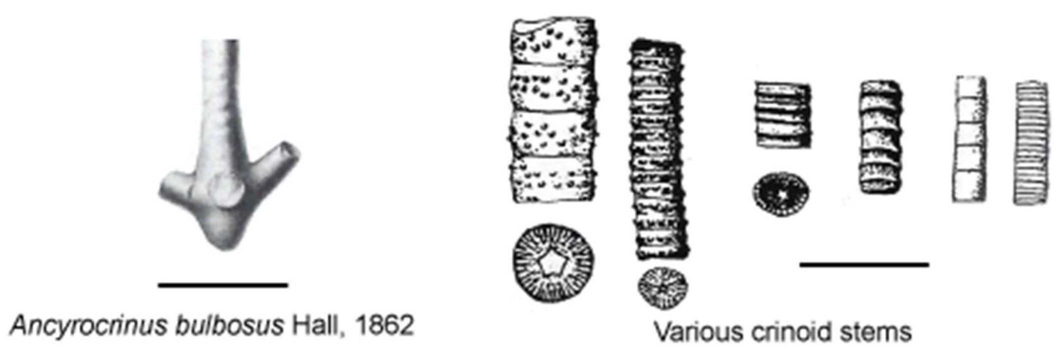

Figure 7 – Crinoids found at Penn Dixie. Scale bars are 1 centimeter. Modified from Wilson, 2014 and Grabau, 1898.

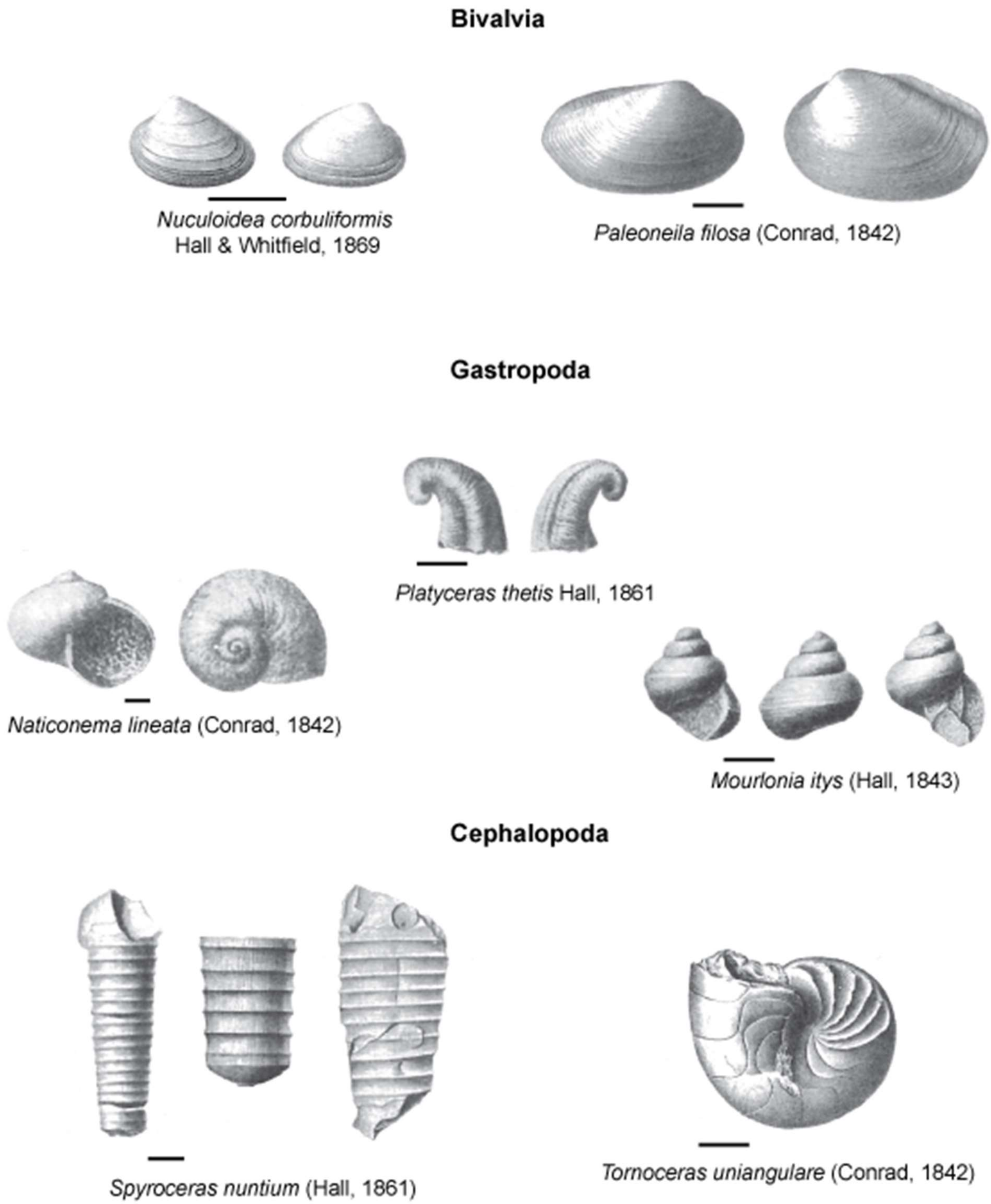

Figure 8 – Common molluscs at Penn Dixie. Scale bars are 1 centimeter. Modified from Wilson, 2014.

Figure 9 – *Vegetation of the Devonian period, restored* from Dawson (1888).

TURN TO STONE

Wanakah Shale – This is the uppermost unit of the Ludlowville Formation (Figure 2A) and is exposed in the northeast corner of Penn Dixie in the creek bed. The unnamed creek bed in the northeast section of the site is a tributary of Rush Creek. The uppermost meter of the Wanakah Shale is exposed at Penn Dixie. This thinly-bedded unit is gray in color and is often highly fractured where it is exposed in the tributary. Large concretions of muddy limestone within the unit are noticeable where erosion has removed the softer shale. These concretions often contain fossils and are thought to be formed by the rapid decay of organisms. The Wanakah Shale was deposited in moderately deep water.

The exposed portions of the unit are fossil rich. Bryozoans, trilobites, gastropods, bivalves, echinoderms, corals, sponges, and ostracods can be found. Brachiopods are especially abundant and the primary component of the fossils in the Wanakah. Common species include *Mediospirifer audaculus* Conrad 1842, *Mucrospirifer mucronatus* Conrad 1841, *Athyris spiriferoides* Eaton 1831, and *Ambocoelia umbonata* (Conrad, 1842). Water collects in this creek bed throughout the year, so fossils found here can be quite delicate and break apart easily. Flowing water and wet leaves can also make collecting in this area difficult.

Tichenor Limestone -- The Tichenor Limestone, the base of the Moscow Formation, overlies the Wanakah Shale and is approximately a meter thick at Penn Dixie (Figure 2A). The Tichenor is a prominent layer due to its off-white color and its resistance to weathering. Large blocks of the Tichenor are present where excavation has taken place. Erosion at the site has exposed bedded Tichenor Limestone along drainage channels. Exposed areas of the Tichenor darken in color over time due to chemical weathering. Portions of this unit are almost entirely fossiliferous and consist of microfossils and fragments of crinoids and other invertebrates.

The Tichenor represents a near-shore, shallow water environment with well-circulating waters. These currents allowed for rapid burial, but also mixed previously deposited remains. Oxidation of the upper surface of the Tichenor suggests that the unit was exposed to air prior to diagenesis. This exposure was likely the result of falling sea level and created an unconformity between the Tichenor and the overlying Windom Shale. The Tichenor Limestone, which rises and plunges within Penn Dixie, illustrates the folding of rocks by some yet unknown process.

The Tichenor Limestone contains diverse and abundant fossils, though they are difficult to remove from the hard limestone. Numerous horn corals (*Sterolasma rectum* Hall 1876; *Amplexiphyllum hamiltoniae* Hall 1876) and tabulate corals (*Favosites hamiltoniae* Hall 1876; *Pleurodictyum americanum* Roemer 1876) can be found throughout. Brachiopods, bivalves, and trilobites can also be found. Bryozoans (*Fenestella emaciata* Hall, 1884) are also plentiful in the Tichenor, one of the easiest places to find them at Penn Dixie. Pyrite nodules, often weathered to a reddish-brown color, can also be found throughout the unit.

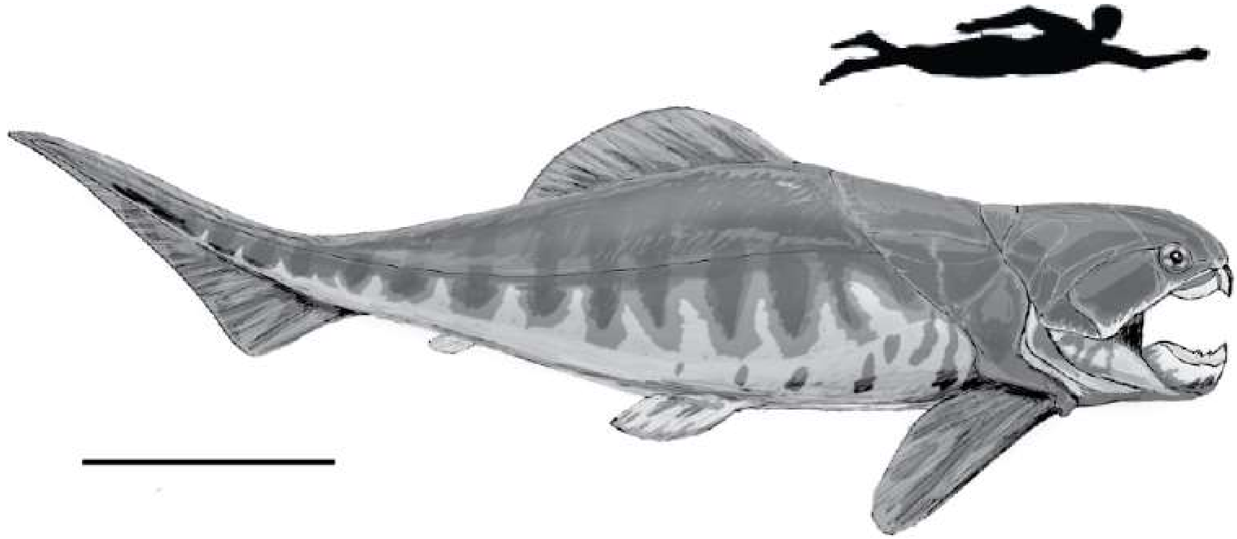

Figure 10 – Reconstruction of *Dunkleosteus terrelli* (Newberry, 1873) with human for scale. Scale bar is 1 meter.

Windom Shale -- The literature (e.g., Brett and Baird, 1982) describes many distinct beds within the Windom Shale; here, we discuss the most relevant beds to fossil collectors and educators (Figure 2A).

1) Bayview Coral Bed -- The Bayview Coral Bed is near the bottom of the Windom Shale. This layer is a soft, gray shale that is easily weathered. Excavation is required to reach this unit since surface exposures rapidly break down. Most likely a death assemblage, this unit lacks cohesive strength from smaller sediment grains (e.g., clay and silt). Our interpretation is that the smaller grains were washed away by currents -- disrupting the burial process, leaving behind only large and incomplete fossils.

The fauna of this bed is incredibly diverse with at least 50 species represented. Brachiopods are the most common and diverse fossils in this bed including *Rhipidomella penelope* Hall, 1860, *Mediospirifer audaculus* Conrad 1842, *Mucrospirifer mucronatus* Conrad 1841, *Athyris spiriferoides* Eaton 1831, *Spinatrypa spinosa* Hall 1843, *Pseudoatrypa devoniana* Webster 1921, and *Ambocoelia umbonata* (Conrad, 1842). Large (e.g., *Heliophyllum halli* (Edwards & Haime, 1850)) and small rugose corals are also very common throughout this bed. The exposure of this bed at Penn Dixie is one of the few places where the Bayview Coral bed can be easily accessed in Western New York.

2) Smoke Creek Trilobite Bed -- The Smoke Creek Trilobite Bed sits atop the Bayview Coral Bed. It is a distinctive marker bed within the Windom Shale. This layer is a dark gray, calcareous (i.e., rich in calcite) shale unit that is resistant to weathering. Large blocks of the Smoke Creek Trilobite Bed are challenging to split as the bedding is thick and massive. The unit has a distinctive oily odor due to the presence of hydrocarbons.

The Smoke Creek Trilobite is widespread in Erie and Genesee Counties and has a uniform thickness of 20-75 centimeters (Brett and Braid, 1982). This suggests a relatively stable geologic environment when compared to thinner beds within the Windom Shale.

As the name implies, it is rich in trilobites with at least five species represented, including *Eldredgeops rana* Green 1832 (often mistakenly called *Phacops rana*), *Greenops sp., Bellacartwrightia whiteleyi* Lieberman & Kloc 1997, *Pseudodechenella rowi* Green 1838, and *Dipleura dekayi* Green 1832. *Eldredgeops* is the most common trilobite found at Penn Dixie. It is commonly found either prone or enrolled. *Eldredgeops* individuals are also often found in clusters. In addition to trilobites, rugose corals, brachiopods, bivalves, and cephalopods can be found in the Smoke Creek Bed.

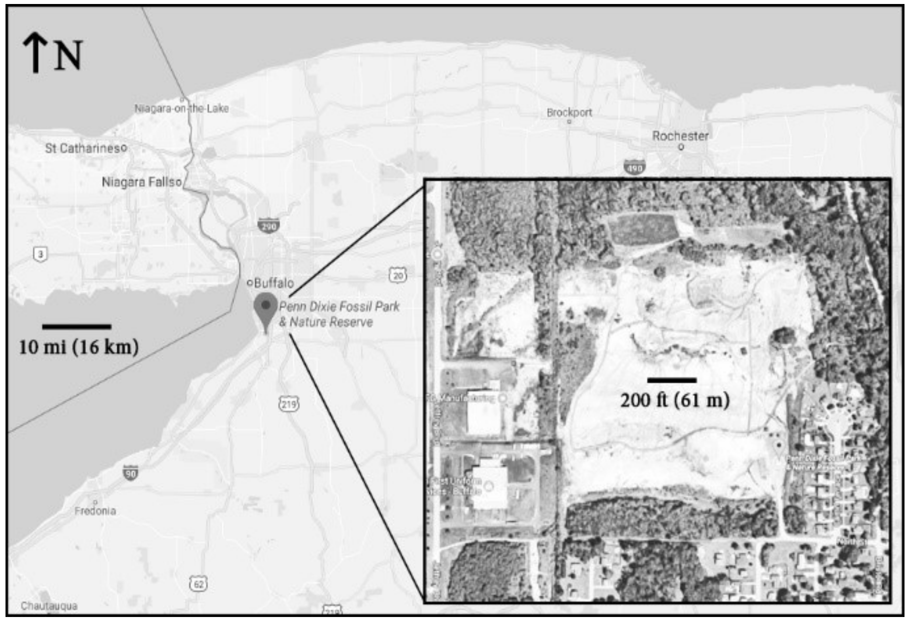

Figure 10 – Location of Penn Dixie, south of Buffalo, New York. Modified from Google Maps.

3) Barren Zone -- Shales that overlie the Smoke Creek Bed are lighter in color and are sparsely fossiliferous or completely devoid of fossils. This unit has been interpreted as a low oxygen environment, most likely deeper water.

4) Mid to Upper Windom Shale -- The Mid to Upper Windom Shale is sparsely fossiliferous, just like the earlier Barren Zone. This portion of the Windom Shale was exposed by original quarrying operations and is relatively unchanged from that time. This interval -- which contains many thin, interbedded layers of shale -- is known for a series of three regularly-spaced white limestone bands. Some portions are fossiliferous, but not to the degree of other beds in the Windom Shale. In the Upper portion, small brachiopods such as *Ambocoelia umbonata* (Conrad, 1842) can be found. As a whole, the mid to upper Windom Shale represents varying sea level within the local basin. Limestone bands likely represent shallow water; shales are deeper water deposits.

5) Penn Dixie Pyrite Beds -- Near the upper portion of the Windom Shale, a pronounced pyrite-rich gray shale layer is exposed. At Penn Dixie, fossils are commonly found in this interval pyritized and therefore are golden in color. Pyrite weathers to a brownish-red color when exposed at the surface, so many fossils have this weathered color as well. A variety of fossils can be found in this pyritized layer, including nuculoid bivalves, gastropods, ammonoids and enrolled trilobites (the golden trilobite!) Most fossils from this layer are diminutive in size, but well preserved. Pyritization of fossils usually occurs in deep, anoxic conditions.

6) *Ambocoelia* Bed -- The *Ambocoelia* bed is named for the abundance of the brachiopod *Ambocoelia umbonata* (Conrad, 1842). *Ambocoelia* is the most common fossil found in this gray shale layer. Other fossils include rugose corals and the occasional bivalve. Trace fossils that have been interpreted as worm coprolites are also common in this layer. The *Ambocoelia* bed tends to be much more fossiliferous that the Barren Zone or the Mid to Upper portion of the Windom, but the fauna is dominated by *Ambocoelia*.

North Evans Limestone -- This unit is a mottled beige to dark gray color with a granular texture despite the calcite composition (Figure 2A). The rock contains clasts of inorganic materials (e.g., inclusions of Windom Shale) and organic materials (e.g., microfossils) mixed together during deposition in shallow waters. The limestone is not well exposed at Penn Dixie due to ample vegetation, but the weathered surface can be accessed in the southern portion of the site. Wood, fish plates, teeth, bone, and mandibles can be found in the North Evans Limestone, but are extremely rare.

Figure 11 – Penn Dixie Cement Plant along Lake Erie, south of Buffalo, New York in 1959. Photo courtesy of the Hamburg Historical Society.

Genundewa Limestone -- This unit is thinly bedded muddy limestone and is dark gray in color due to clay impurities (Figure 2A). It is poorly exposed along the densely vegetated, southern ridge of Penn Dixie, but weathered blocks wash down slope and mix with North Evans pieces. The Genundewa fossils are similar to those found in the North Evans Limestone. The units are separated by an unconformity, indicating a pause in shallow water deposition.

West River Shale -- This unit is dark gray in color, weathers easily, and has essentially turned into the soil supporting the forested ridge along the southern boundary of the site (Figure 2A). No natural exposures exist at the surface but can found elsewhere in Western New York.

DIGGING IN THE DIRT

Though glaciers scoured the Western New York surface long after dinosaurs became extinct, human activities had the most noticeable effect on our geology. Beginning in the early 1950s, the rocks at Penn Dixie (Figure 10) were quarried for the making of Portland cement, which is the main ingredient in the concrete commonly used in construction (Streamer, 1988). Heavy machinery ripped off the surface layers -- which are rich in calcite and clay particles -- and crushed the rocks into smaller pieces. The rocks were transported approximately one mile away to a facility along the shore of Lake Erie for processing into cement. The proximity to railroads and water made our location ideal for this activity (Figure 11).

The Penn Dixie Cement Corporation was the third entity to operate a quarry at our location; Federal Cement and Bessemer Cement were the two prior. At one time, the combined plant and quarry were the third largest industrial employer in the Town of Hamburg! From the 1950s to the 1970s, Penn Dixie Cement, whose name was shortened from Pennsylvania-Dixie Cement, owned numerous plants and offices in the Eastern U.S. However, a number of factors led to the shutdown of active quarrying in our location by the early 1970s. The end came for the entire Penn Dixie Cement Corporation in 1980 when the company filed for bankruptcy (Streamer, 1988; NYT, 1981).

For 20 some years, the quarry changed hands several times through private ownership while remaining undeveloped. During this time, trespassers used the open land for the illegal dumping of household appliances and vehicles, hunting and shooting, and revelry. The former quarry also became known in the fossil collecting and educational communities due to its profusion of well-preserved fossils. When development threatened to turn the quarry into a waste transfer station, a group of local activists coalesced around the goal of preserving the land for science education (Bastedo, 1999).

Formed in 1993, The Hamburg Natural History Society, a 501(c)3 nonprofit, successfully lobbied the Town of Hamburg to purchase the land and donate it to the society. In turn, The Society agreed to remove accumulated waste and to develop the property so that it could become a unique destination for science education and tourism. Since its formation, The Society has grown from an all-volunteer organization to a cultural institution embedded in the community fabric of Western New York. Annual attendance averages 18,000 with one in eight visitors traveling from out-of-state -- or outside the U.S. -- to collect fossils (Figure 12). The Society delivers on its mission of hands-on science education by offering engaging, inquiry-based field trips for K-16 students and summer programming for youth and families.

CLOSER TO THE HEART

Fossil collecting -- once a wealthy gentleman's hobby in Georgian England -- is now enjoyed by many.

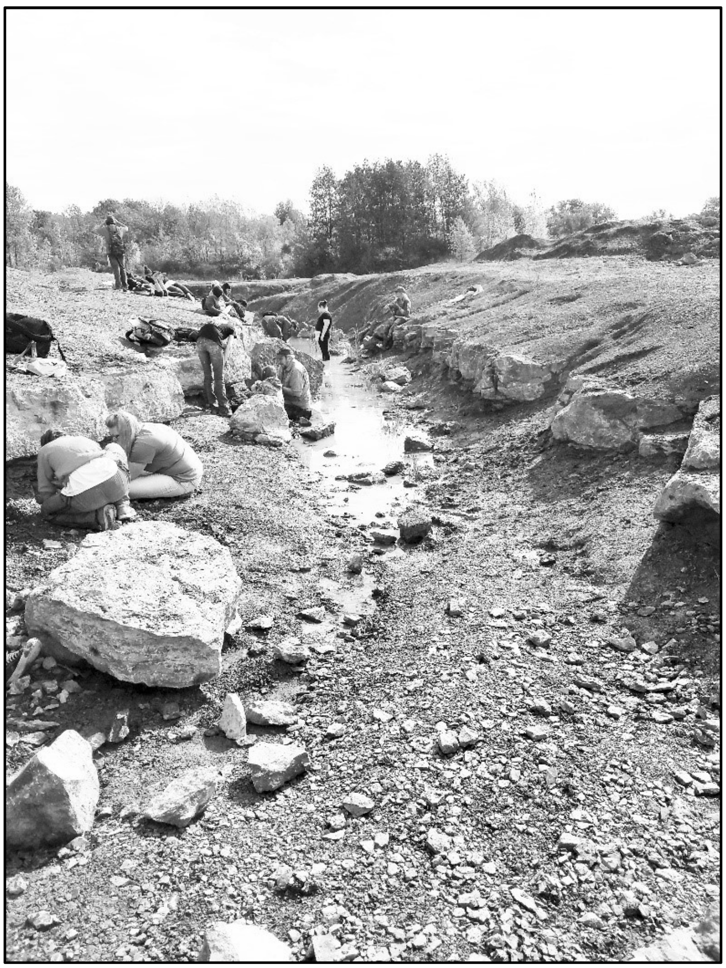

Figure 12 – Visitors digging at Penn Dixie during the 2017 season.

Happily, our mission extends beyond this one activity; it serves to educate the public about the past, to engage the imagination while looking back in time, to improve understanding of scientific and environmental issues affecting society, to promote tourism, and to inspire youth to science, technology, engineering, and math (STEM) careers.

Informal science education, which includes trips to science and nature centers, is an important complement to formal science education in a K-12 setting. These sorts of experiences educate and motivate youth to pursue more STEM knowledge and build confidence and self-efficacy. For example, outdoor experiences -- and particularly those shared with family members -- are frequently cited by geoscience majors as critical factors in their choice of major (Stokes et al., 2015). Can you imagine what problems society might solve if students had more opportunities for hands-on learning?

We are very proud of the positive impact that we have on our young visitors. Penn Dixie is a unique treasure. In 2011, we were honored to be recognized as the top fossil park in the U.S. in a scientific study (Clary and Wandersee, 2011). Of the parks studied over seven years, the authors wrote that Penn Dixie "provided the best visitor experience and the greatest opportunities to learn geobiological concepts in an informal fossil park environment (p. 131)." We are honored by this recognition and continue to develop and refine our goals to maintain this ranking.

In their concluding remarks, Clary and Wandersee wrote that "there is no equivalent virtual substitute for direct interaction with Earth, and fossil ownership sparks thought about deep time, evolution of life forms, and environmental change over geologic time (2011, p. 132)." We wholeheartedly agree. Albert Einstein, perhaps the most influential scientist of the past 100 years, propelled innovation and discovery across many fields. His observations led to a radical new awareness of our universe, yet the simplicity of his theoretical writings is often overlooked. “Look deep into nature,” Einstein wrote, “and then you will understand everything better.” We hope you’ll look with us.

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APPENDIX 1 – Abbreviated and in-progress list of species found at Penn Dixie. Modified from Brett (1974).

SUMMARY CHART
OF THE DISTRIBUTION
OF FOSSILS IN ROCK
LAYERS PRESENT AT
PENN DIXIE

C = Common
R = Rare
L = Locally abundant,
but rare elsewhere

	Wanakah Shale (A)	Tichenor Limestone (B)	Windom Shale: (1) Bayview Coral bed (C)	Windom Shale: (2) Smoke Creek Trilbite bed (D)	Windom Shale: (4) Mid to Upper Windom (E)	Windom Shale: (5) Pyrite bed (F)	Windom Shale: (6) *Ambocoelia* bed (G)	North Evans Limestone (H)
Cnidaria:								
Amplexiphylloides hamiltonae (Hall, 1874)	C			C				
Aulocystis dichotoma (Grabau, 1899)			C					
Aulocystis jacksoni (Grabau, 1899)			C	C	C			
Cystiphylloides americanum (Edwards & Haime, 1851)			L					
Cystiphylloides conifollis (Hall, 1876)			L					
Hadrophyllum woodi Grabau, 1899			C					
Heliophyllum halli (Edwards & Haime, 1850)			L					
Heterophrentis simplex (Hall, 1843)			L					
Pleurodictyum americanum Roemer, 1876		L	L	C		R		
Stereolasma rectum (Hall, 1876)	C		C	C		R		
Streptalasma ungula Hall, 1876	C			C				
Favosites hamiltonae Hall, 1876		L						
Bryozoa:								
Fenestella emaciata Hall, 1884		L						
Leptotrypella ssp.			C					
Reptaria stolonifera Rolle, 1851						R		
Sulcoretipora incisurata (Hall, 1881)								
Atactoechus furcatus (Hall, 1877)								
Echinodermata:								
Arthrocantha sp.				R				
Deltacrinus clarus (Hall, 1862)		C	R	R				
Dolatocrinus liratus Hall, 1862			R					

	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
Brachiopoda:								
Amocoelia umbonata (Conrad, 1842)	C		C	L		C	C	
Athyris spiriferoides (Eaton, 1831)	C		C					
Atrypa reticularis (Linneaeus, 1758)	C		C					
Emanuella praeumbonata (Hall, 1857)						R	C	
Longispina mucronatus (Hall, 1843)			R					
Mediospirifer audaculus (Conrad, 1842)	C		C					
Megastrophia concava (Hall, 1857)			R					
Mucrospirifer consobrinus (D'Orbrigny, 1850)			C					
Mucrospirifer mucronatus (Conrad, 1841)	C		C					
Protoleptostrophia perplana (Conrad, 1842)			R					
Pseudoatrypa devoniana (Webster, 1921)	C		C					
Rhipidomella penelope Hall, 1860			C	C				
Rhipidomella vanuxemi (Hall, 1857)			C	C				
Spinatrypa spinosa (Hall, 1843)	C		C					
Spinocyrtia granulosa (Conrad, 1839)			C					
Tropidoleptus carinatus (Conrad, 1839)			R					
Mollusca:								
Gastropoda:	R		R					
Mourlonia itys (Hall, 1843)			R	R				
Naticonema lineata (Conrad, 1842)			R	R				
Platyceras thetis Hall, 1861								
Bivalvia:								
Cypricardinia indenta Conrad, 1842				R				
Nuculoidea corbuliformis Hall & Whitfield, 1869	R			R				
Nuculites triqueter Conrad, 1841				R				
Palaeoneilo filosa (Conrad, 1842)			R					
Palaeoneilo sp.			R					
Pterinopecten sp.				R				
Cephalopoda:								
Michelenoceras ssp.	R		R	R				
Spyroceras nuntium (Hall, 1861)		R				R	R	
Tornoceras uniangulare (Conrad, 1842)						R	R	
Trilobita:								
Bellacartwrightia whiteleyi Lieberman & Kloc, 1997				R				
Dipleura dekayi (Green, 1832)		R		R				
Greenops sp.	R		R	C				
Eldredgeops rana (Green, 1832)	C		R	C				
Pseudodechenella rowi (Green, 1838)		R		R				