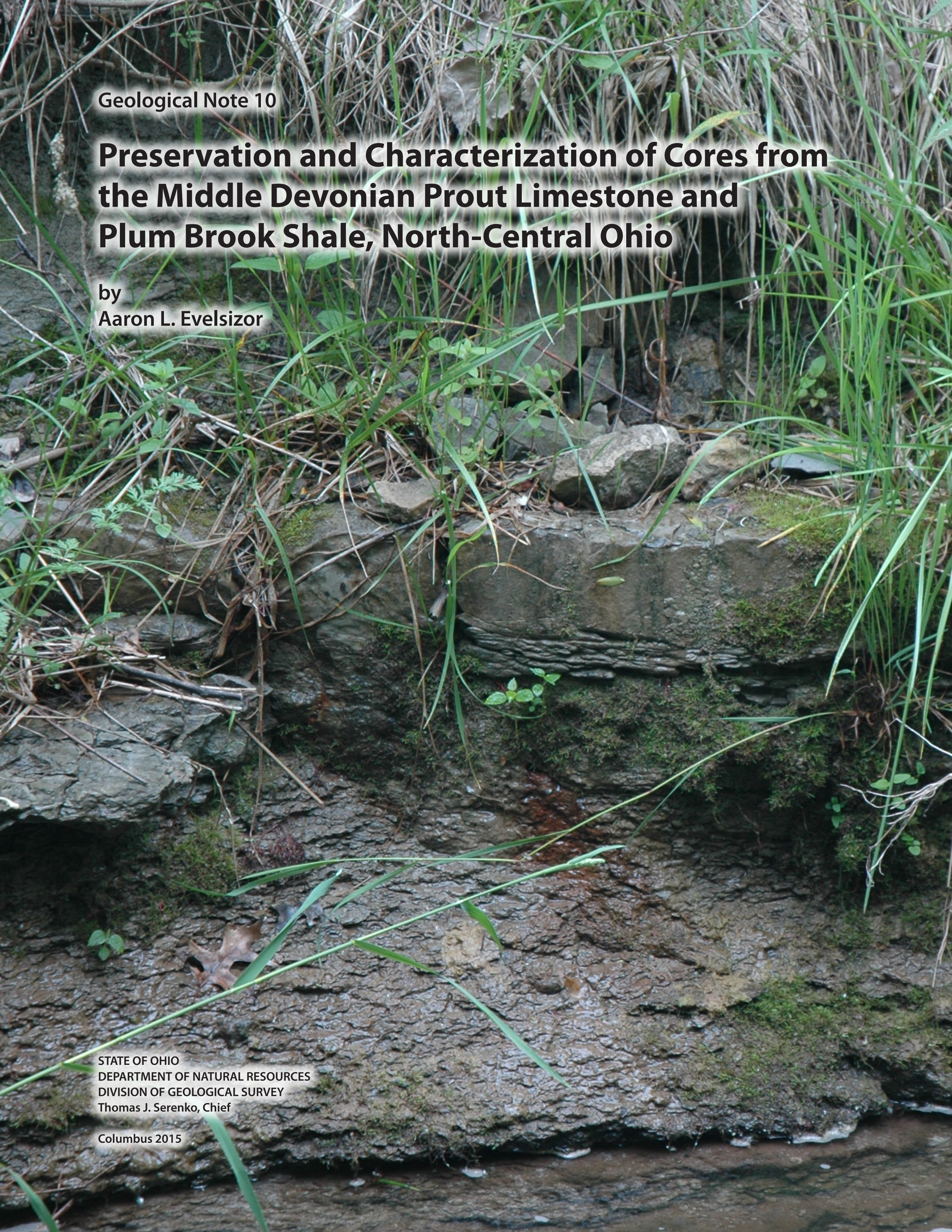

Geological Note 10

Preservation and Characterization of Cores from the Middle Devonian Prout Limestone and Plum Brook Shale, North-Central Ohio

by
Aaron L. Evelsizor

STATE OF OHIO
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY
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Front cover: A weathered outcrop of Plum Brook Shale overlain by the Prout Limestone. The contact of the units is marked by a sharp unconformity (middle of photo). This exposure is seen along Plum Brook, which flows through NASA Plum Brook Station in Erie County, Ohio.

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ABBREVIATIONS USED IN THIS REPORT

Units of Measure

Foot/feet	ft
Inch(es)	in
Kilometer(s)	km
Mega-annum	Ma
Meter(s)	m
Mile(s)	mi
Parts per million	ppm

Lithologic & Stratigraphic Units*

Formation	Fm/fm
Group	Gp/gp
Limestone	Ls/ls
Member	Mbr/mbr
Shale	Sh/sh

*Lowercase lithologic and stratigraphic names and abbreviations indicate informal status of a unit.

Preservation and Characterization of Cores from the Middle Devonian Prout Limestone and Plum Brook Shale, North-Central Ohio

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ABSTRACT

The Prout Limestone and underlying Plum Brook Shale are two of Ohio's lesser-known bedrock units which occur along a narrow band across north-central Ohio and have limited outcrop exposure. Recently acquired cores from Erie County, Ohio, containing the Prout-Plum Brook interval and adjacent units provided the opportunity for research. Newly collected spectral gamma data in conjunction with existing geophysical well logs were used to construct several geologic cross sections. From their outcrop locations in western Erie and Huron Counties, these units have lateral extents to the south and east through the subsurface of Lorain, Medina, and northern Wayne Counties. The deposition of these units appears to have been influenced by eustatic fluctuations and tectonic controls, specifically lithospheric responses that occurred during the ongoing Acadian Orogeny and formation of the Appalachian Basin during the Middle Devonian. The reactivation of a basement structure, the Middleburg Fault, may have also impacted sedimentation.

INTRODUCTION

The Ohio Department of Natural Resources, Division of Geological Survey (Ohio Geological Survey) received a donation of core from the NASA Plum Brook Station that provided a wealth of research potential and contributed to a more stratigraphically complete representative subsurface section of the Devonian succession. The organic-rich mud rocks of the Middle and Upper Devonian have attracted the attention of modern-day researchers interested in unconventional oil-and-gas reserves. Although not necessarily a producer of hydrocarbons, the lesser known Prout Limestone and Plum Brook Shale units deserve investigation given their relative scarcity in outcrop and in the subsurface.

Ohio Geological Survey staff members had been trying to acquire the NASA Plum Brook Station core for several decades, according to internal notes and memos on file (Garry Yates, written commun., 1989; Greg Schumacher, written commun., 2010). Access to the Plum Brook Station was eventually granted by NASA, and over 2,000 ft (600 m) of assorted core was removed from storage and donated, along with geotechnical drawings, to the Ohio Geological Survey in late 2013. The acquisition of these cores made an important addition to the core collection; although it holds a substantial number of cores, the Ohio Geological Survey lacks a complete stratigraphic section of the interval representing the lower Huron Member, Ohio Shale, through Columbus Limestone in the area of Perkins and Oxford Townships, Erie County. Also, the deeper Silurian through Ordovician strata contained in core no. 3709 was poorly known in the subsurface of this area. Further, this acquisition enabled the Ohio Geological Survey to conduct the first known stratigraphic (as opposed to geotechnical) examination of much of the core.

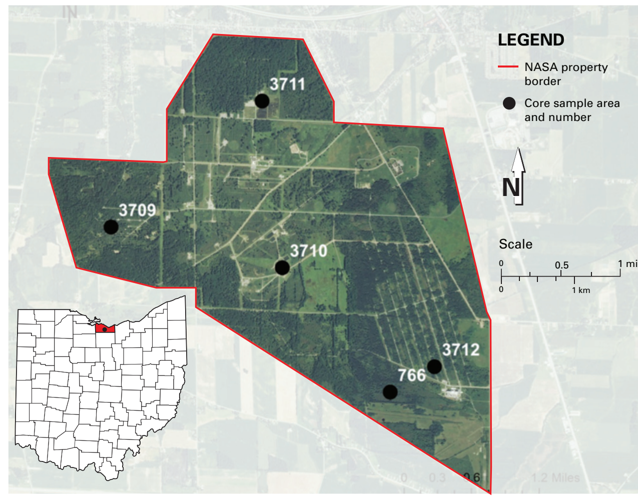

FIGURE 1. NASA Plum Brook Station core locations, Erie County, Ohio. Location has been approximated for core nos. 3711 and 3712.

PROJECT AREA AND PURPOSE

The NASA Plum Brook Station is a remote testing facility that occupies 6,400 acres of land approximately 5 mi south of Sandusky, Ohio, on property originally purchased in 1941 by the United States government. Then named the Plum Brook Ordnance Works, the site was designed to aid growing munitions demands and produced nearly a billion pounds of explosives before its closure at the end of World War II in 1945. The site was repurposed in the early 1950s and once housed a nuclear reactor, now decommissioned, that was functional for 18 years (Bowles and Arrighi, 2004). Samples drilled and cored for geotechnical research were collected to assist in the design of foundations for many of the various structures at Plum Brook Station (fig. 1). These cores extend over 1,800 ft (550 m) below the surface and represent nearly 100 million years of geologic history.

This report characterizes the Prout Limestone and Plum Brook Shale, both in core and geophysical logs, and traces their extents from outcrop through the subsurface. Geophysical wireline logs and physical cores were used in the construction of geological cross sections of the sequence of units. Core descriptions and representative stratigraphic photographs accompany the material. Depositional history, including a review of previous research and newly acquired data, is discussed herein.

PREVIOUS WORK

First recognized by Newberry (1873), the Prout-Plum Brook interval has long been a topic of study, and modern nomenclature was later adopted for the Prout Limestone (Prosser, 1903) and Plum Brook Shale (Cooper, 1941). Orton (1893) and Stauffer (1909, 1916) considered the Plum Brook Shale to be equivalent to the locally named Olentangy Shale of central Ohio. Grabau (1917) believed the Olentangy Shale to be a facies of the Upper Devonian Huron Member, Ohio Shale, and the Prout Limestone and Plum Brook Shale to be "early Hamilton" (Middle Devonian) in age; he recommended they be called the Prout series. Subsequent faunal studies concluded the Olentangy Shale to be Upper Devonian in age (Baker, 1942; Stewart and Hendrix, 1945).

Stauffer (1938) concluded the Olentangy to be "Hamilton" (Middle Devonian) in age based on faunal assemblages. Louden (1965) divided the Olentangy Shale into two parts, separated by an unconformity, suggesting that the lower is continuous with the Plum Brook Shale. Tillman (1969, 1970) divided the Olentangy Shale into formal upper (Upper Devonian) and lower (Middle Devonian) units, correlating the latter with the Plum Brook Shale. Schwietering's work (1979) reinforced this conclusion.

These units have been correlated to lateral equivalents across the Great Lakes region by means of gamma and biostratigraphic correlation: the Prout Limestone with the Hungry Hollow Formation of Western Ontario, the Tenmile Creek Dolomite of northwestern Ohio, and the Tully Limestone and Moscow and Ludlowville Formations of New York; the Plum Brook with the Arkona Shale of Western Ontario, the Silica formation of northwestern Ohio, and the Skaneateles Formation of New York (Stumm, 1942, 1968; Gable, 1973; Schwietering, 1979; Rickard, 1984; Sparling, 1988, 1995; Brett and others, 2011).

Recent research has examined possible structural effects on deposition. Bartholomew and Brett (2007) argued that the Findlay Arch was not an active structure at the time of deposition during the Middle Devonian and that the Appalachian and Michigan Basins were once connected. Uplift and erosion of these units could have been related to a forebulge that developed in response to renewed thrust loading during the Acadian Orogeny (Ettensohn, 1987).

METHODOLOGY

Prior to donating it, NASA had stored the core for decades at the Plum Brook Station in large, non-climate controlled concrete structures referred to as igloos, which were originally designed to store TNT explosives. Following retrieval, the Ohio Geological Survey assessed each core for its condition, completeness, location, and accompanying documentation. Cores deemed the best candidates were kept for permanent archive at the Horace R. Collins Core Repository in Delaware, Ohio.

Excess dirt and debris was removed from the surfaces of the candidate cores with a mild detergent solution, followed by a rinse with distilled water. The cores were then transferred to new cardboard boxes, 10 ft (3 m) per box, and depth and orientation lines were marked directly on the core surfaces with a permanent marker. High-resolution photographs of both wet and dry core were taken for archival purposes.

The cores were described and were then assigned core numbers. Pertinent information, such as depth, surface location, and identifiable formations, were added to a searchable core database. In all, four lengths of core received such treatment and were entered into the permanent archive as Ohio Geological Survey core nos. 3709, 3710, 3711, and 3712. For core no. 3709, several descriptions were already on file. Due to incomplete geotechnical drawings, the locations of core nos. 3710 and 3711 were approximated to the centers of the facilities for which they were originally drilled. A surface location for core no. 3712 was determined by georeferencing the associated engineering drawings in ESRI ArcGIS®; roads and other landmarks recognizable on the original drawings were used as control points (fig. 1).

First used in 1927, wireline logs have become a part of routine procedure on nearly all modern day wells. A rock formation's natural radioactivity can be observed on a gamma ray log, which can distinguish nonradioactive sandstone or carbonate from naturally occurring potassium isotopes in clays and adsorbed uranium and thorium contained in shale (Ellis and Singer, 2008). Stratigraphic units can be traced from well to well by comparing geophysical log curves.

The core was scanned with a Core Lab Instruments® Spectral Gamma Logger model SGL-300, which is capable of collecting gamma measurements, in order to

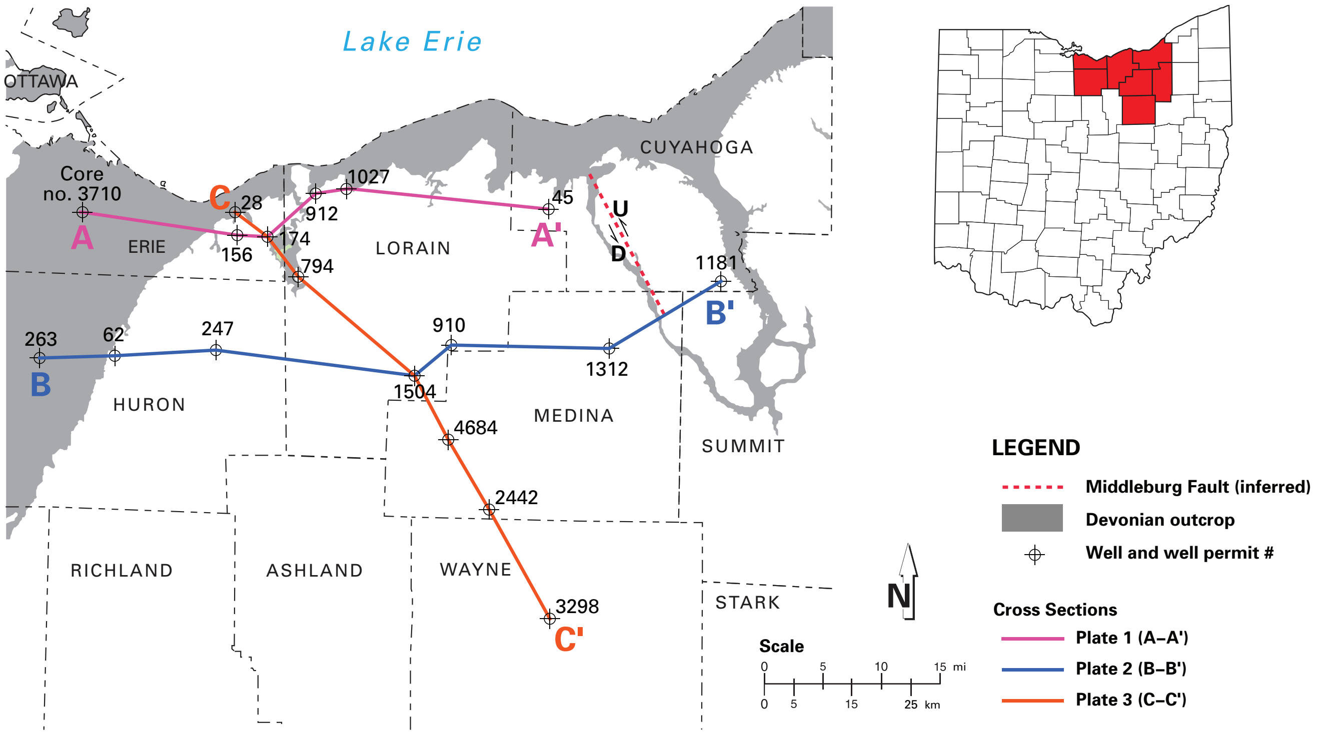

FIGURE 2. Map of cross sections from geophysical log locations across the study area, including core 3710 (permit #2), the Middleburg Fault (Baranoski, 2012) and Devonian outcrop (Slucher and others, 2006).

correlate to existing wireline logs. The conveyor belt-driven, sodium iodide-detecting system measures natural radioactivity of 2-in diameter core at an optimum speed of 0.55 ft (0.17 m) per minute; the system records gamma counts in approximately 1 in intervals. This offers a higher resolution compared to typical 6 in or 12 in intervals for traditional downhole well logs. Total gamma and elemental contributions of potassium (%), uranium (ppm), and thorium (ppm) were obtained for core nos. 3210, 3211, and 3212. Spectral gamma measurements were also collected for core no. 766, which previous to the NASA donation, was one of the only Erie County cores held by the Ohio Geological Survey containing the Prout Limestone and Plum Brook Shale. Raw data from the SGL-300 was then converted to a LOG ASCII Standard (LAS) format. Geophysical wireline logs from wells across the area were converted from raster images (Tagged Image File Format) to LAS files using Neuralog®, an auto-vectoring software application. This process of conversion provides significant assistance in the correlation and creation of geologic cross-sections (Crangle, 2007). Files were then imported into Geographix Discovery® software to create several cross sections across the study area (fig. 2), referencing formation tops with deWitt and others (1993). Cross sections and a raster image of the gamma curve and representative photos from Ohio Geological Survey core no. 3710 can be found in plates 1–4.

DISCUSSION

Geologic Setting

The Middle–Upper Devonian interval of the study area was deposited in broad intercontinental seas on the northwestern edge of the Appalachian Basin, along the western edge of the Catskill Delta. Clastic sediments that formed the delta were eroded from the Acadian mountains. Generally speaking, this orogeny was produced by the collision of North America with Europe (fig. 3; see Schwietering, 1979, Coogan, 1996). More specifically, oblique convergence between terranes from Avalonia (a microcontinent and source of many rocks from Western Europe) and the southeastern margin of Laurussia (North America) is thought to have produced this Orogeny (Ettensohn, 1987).

The foreland basin and lithologic units that formed at the base of the rising Acadian Mountains were a result of the flexural effects of sediment loading and subsequent isostatic responses of the orogeny (fig. 4; Beaumont, 1981). Deformational responses in the lithosphere allowed deposition in the trough of wave-like forms that migrated over time and with changing sediment loads. A peripheral bulge, or forebulge, formed parallel to the deepening basin and moved cratonward.

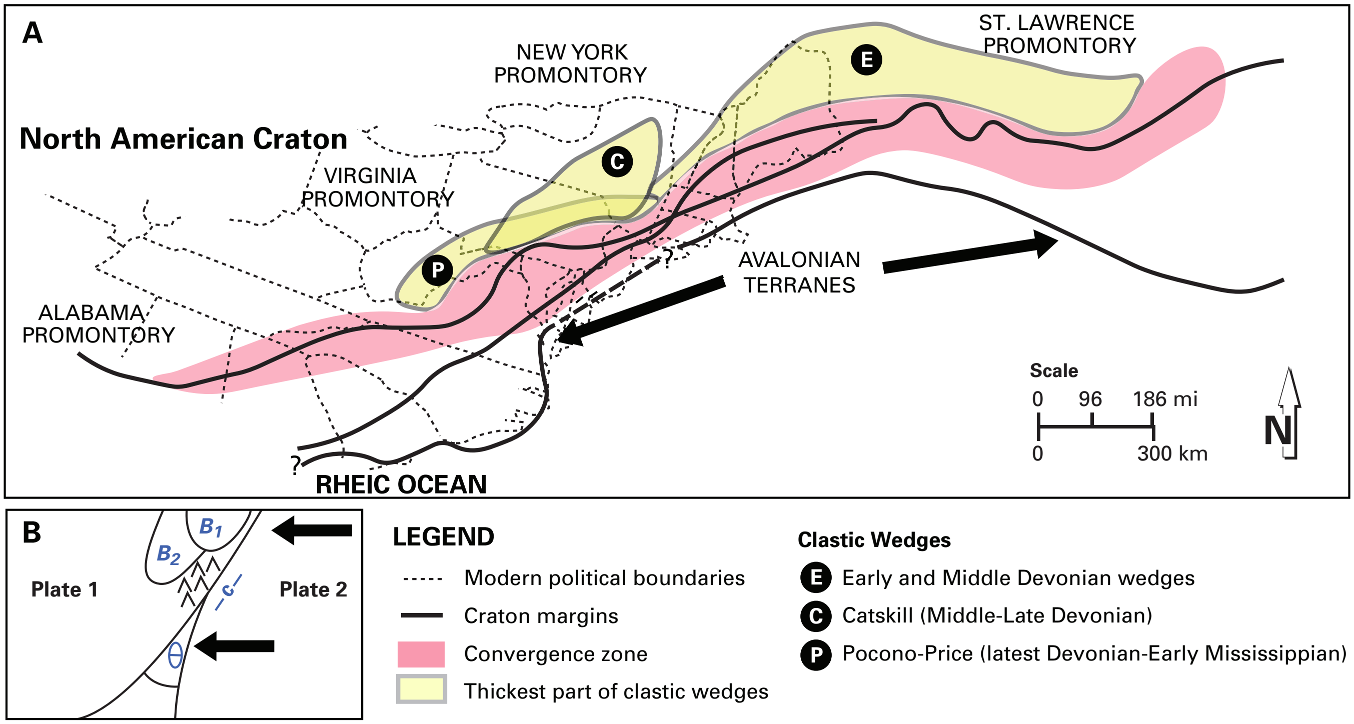

FIGURE 3. Schematic diagram showing: (A) possible nature of oblique convergence between Avalonian terranes and southeastern margin of Laurussia (North America); major clastic wedges appear to emanate successively from each promontory and fill parts of adjacent reentrants as deformation migrated southwestward; and (B) the geometry of such a collision; – c – represents the longitudinal offset of basins or the distance along which the most recent convergence or closure has occurred, as reflected by the distance between the end of foreland basin B_1 and the end of basin B_2; θ is the angle of obliquity of convergence (modified from Ettensohn, 1987).

Comprised of smaller deformational events called tectophases, these processes generate unconformity-bounded cycles, and many foreland basins typically exhibit a cyclic array of dark shale and intervening clastic units. An ideal tectophase cycle exhibits seven tectophases, the first three being unconformity formation, transgressive shallow-water deposition, and rapid subsidence and dark-mud sedimentation (Ettensohn and Lierman, 2012). The units discussed in this study are recognized as being deposited by second- and third-order tectophases. Shallow-water deposition occurs on top of an unconformity produced by a migrating bulge following initial subduction. Relatively short-lived carbonate or clastic units are drowned by rapid basin subsidence induced by deformational loading. Sediment high in organic matter accumulates below a pycnocline in an anoxic environment where living organisms are unable to consume the settling debris (fig. 5). Dark shale deposition is common in the subsiding central part of the basin, grading into carbonates and lighter colored shales in the more distal regions (Ettensohn and Lierman, 2012). As subsidence increases these dark shale basins migrate cratonward (fig. 6).

Oscillations in sea level also have been recognized as a driving mechanism behind the cyclical display of black and gray shale and carbonates. Using sequence stratigraphy, Brett and others (2011) concluded that while the Acadian Orogeny provided accommodation space for stratigraphic successions through subsidence, oscillations in sea level during the Middle Devonian may have been equally important. By examining coeval units, they found that multiple transgressive-regressive depositional sequences exist within major unconformity-bounded sequences and are synchronous across large areas with respect to conodont biostratigraphy. These sequences are thought to be the product of widespread allocyclic controls, as opposed to autocyclic controls such as sediment supply (Brett and others, 2011).

Climatic shifts may have worked in tandem with eustatic sea-level change to produce distinct depositional sequences. Brett and others (2011) cite similarities between Pleistocene sea-level fluctuations (Miller and others, 2005) and transgressive-regressive oscillations during the Middle Devonian (Elrick and others, 2009); they suggest that glacioeustacy may have accounted for sea-level variations of 165–393 ft (50–119 m). Recent research of a granitic boulder in eastern Kentucky, located in situ in Upper Devonian strata, implies it is a glacial dropstone of Appalachian origin delivered to the adjacent foreland basin from a higher structural level which is no longer preserved (Ettensohn and others, 2009). Alpine glaciation during the Middle Devonian cannot be ruled out, despite a present lack of supporting evidence.

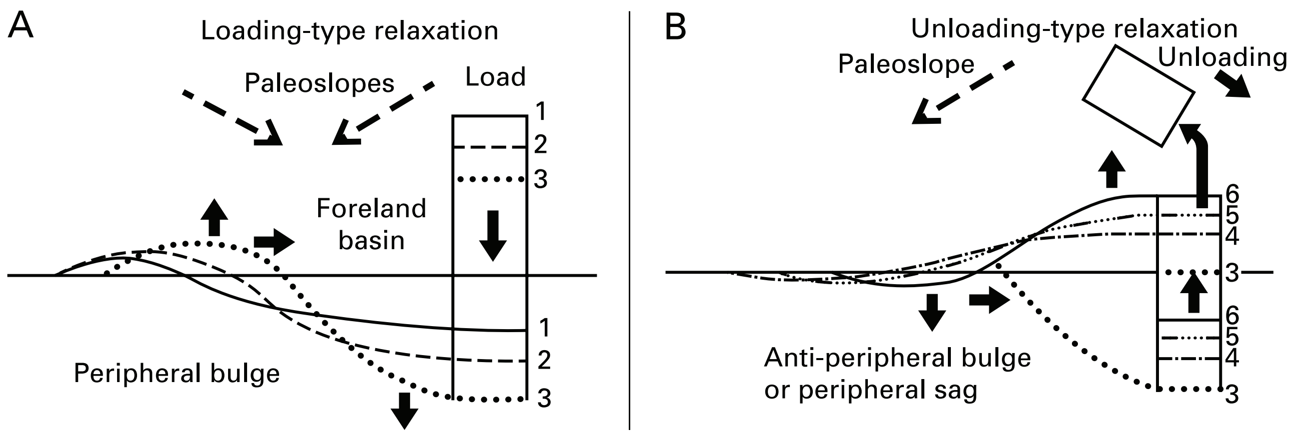

FIGURE 4. Diagram showing the flexural response to lithospheric stress, adapted from Beaumont and others (1988). (A) Loading-type relaxation, wherein the now static load causes subsidence of a foreland basin, and (B) unloading-type relaxation which causes rebound and erosion of old uplands and proximal parts of the foreland basin.

Geologic Units

The stratigraphic units found in the cores taken from Plum Brook Station on the western side of the study area range in age from Eifelian (394 ma) to Famennian (359 ma; Cohen and others, 2013). They are listed in stratigraphic order from the oldest (deepest) to youngest (shallowest).

Columbus Limestone

The Columbus Limestone is a gray to tan, thick- to massive-bedded fossiliferous limestone and typically has an unconformable surface, although it appears to be more transitional in core no. 3710. The unit is underlain by a brown, finely crystalline unit called the Lucas Dolomite (Schumacher and others, 2013). There are various petroliferous zones present in core no. 3710, as well as macrofossils and cherty zones.

Delaware Limestone

The Delaware Limestone is argillaceous and characterized by its brown to bluish-gray color and zones of chert nodules. The unit has a petroliferous odor when broken, indicating hydrocarbons have migrated through the unit, particularly through the underlying Columbus Limestone (Schumacher and others, 2013). The Delaware Limestone has an unconformable surface, which is evident in core.

The top of the Delaware Limestone is easily discernable in well logs due to its characteristically low gamma signature, which can be traced across the study area. The Delaware-Columbus interval has a thickness of 146 ft (45 m) in central Erie County (core no. 3719), increasing to ≈190 ft (58 m) in Wayne County (permit no. 3298). The interval increases in depth towards the southeast into the deepening basin as clastics onlap the unit, including the organic-rich Marcellus Shale, which is present in the far eastern side of the study area. The Delaware-Columbus interval transitions to the Onondaga Limestone on the eastern side of the state. For simplicity in cross sections, the term Onondaga Limestone is used to group these carbonates.

Plum Brook Shale

The Plum Brook Shale overlies the Delaware Limestone and previously has been correlated to the Olentangy Shale of central Ohio, the Silica Formation of northwestern Ohio, and the Hamilton Group of northwestern Pennsylvania (Schwietering, 1979). Characterized as blue-gray fossiliferous shale, the unit is rich in brachiopods and other fauna (Schumacher and others, 2013). Distinctive pyrite marker beds are present in

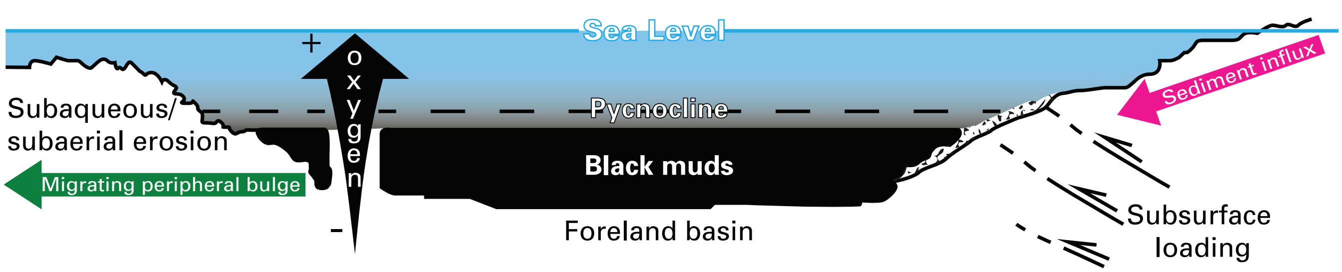

FIGURE 5. Tectonic model for early stages of foreland basin subsidence and depositional controls conducive to formation of organic-rich black shale, such as the lower Huron Member, modified from Ettensohn and Lierman (2012).

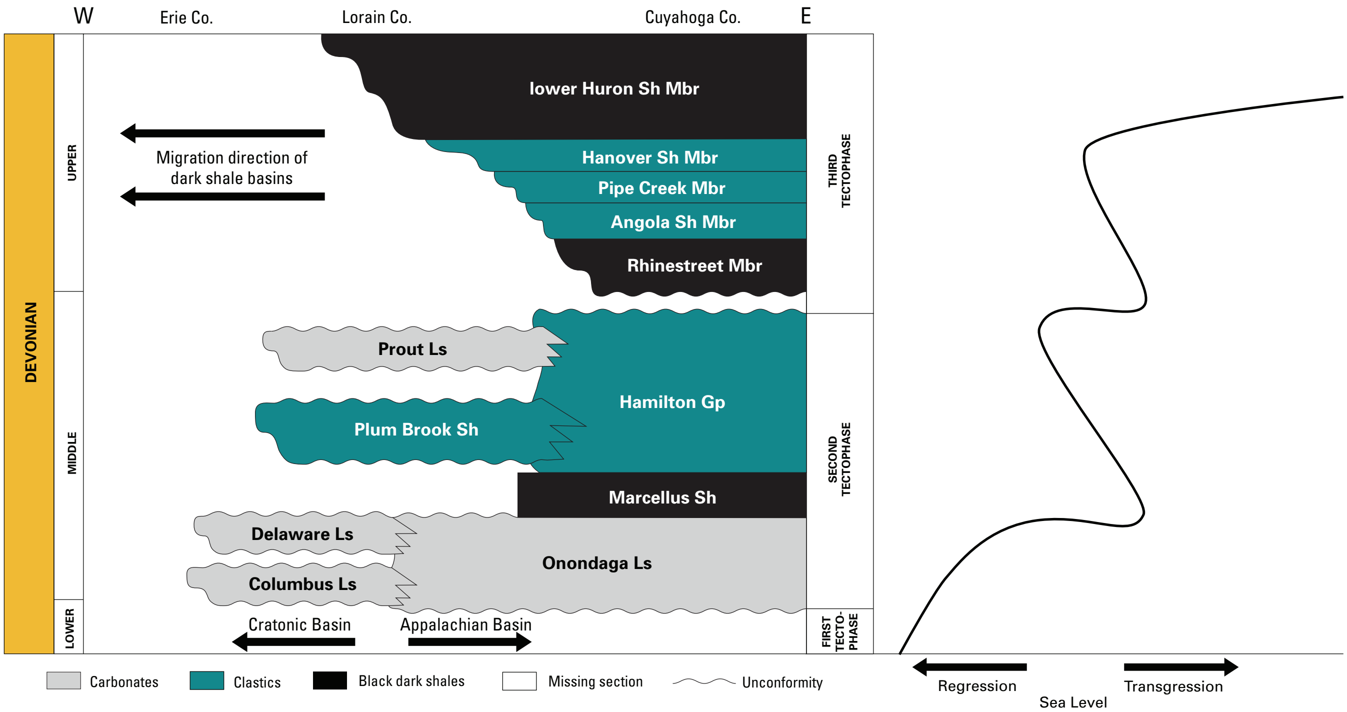

FIGURE 6. Generalized west–east section through the study area showing the relative timing and distribution of strata formed during the first three tectophases of the Acadian orogeny, and relative sea level during time of deposition.

substantial quantity at the basal portion. Macrofossils are present in core, including large fragments of brachiopods, bryozoans, and crinoids in the upper 12–15 ft (3.6–4.6 m), while the remainder of the unit through the basal portion is sparsely fossiliferous. Thin limestone interbeds are found throughout, marked by occasional depressions in an otherwise moderately strong gamma signature (plate 4). The top of the Plum Brook is marked by an unconformable surface containing a calcareous mudshale, which is present in cores taken from Plum Brook Station. Core no. 766 was previously found to contain various faunal fragments in the upper portion of this marl (Louden, 1965).

The Plum Brook is ≈60 ft (20 m) thick in core no. 3710 and thickens gradually to ≈80 ft (24 m) just 15 mi (24 km) to the east (permit no. 0174, plate 1). The unit gradually dips towards the southeast and interfingers with the Hamilton Group where it undergoes a facies change; the calcareous gray shale typical of the Plum Brook core from Erie County shifts to a siliciclastic-rich, dark-gray shale towards the east (Bartholomew and Brett, 2007). This change appears to occur across northern Medina and eastern Lorain Counties (plates 1–3).

Prout Limestone

The Prout Limestone rests unconformably on the Plum Brook Shale and is characterized by locally dolomitic, microcrystalline to fine-crystalline limestone containing brachiopods, corals, and crinoids. Cores from the Plum Brook Station share similar characteristics, including large vugs containing secondary crystallization, and a distinctive fossil bed containing abundant crinoid fragments midway through the interval. A sharply defined, corroded, and stained top exists in places. The unconformable surface is clearly visible in core no. 3710 (plate 4).

Thickness is variable, ranging from 0 to 9 ft (0–3 m; Schumacher and others, 2013). Total thickness in core from the Plum Brook Station is 5.0–5.9 ft (1.5–1.7 m). Like other carbonates, the characteristically low gamma signature of the Prout Limestone is recognizable in well logs (plate 4). The unit dips towards the east and south, truncating slightly as the gamma curve becomes less pronounced, then ends abruptly in cross section midway through northern Lorain County and in the northeastern corner of Medina County (plates 1 and 2), and it appears to extend southerly through the northern half of Wayne County (plate 3).

Lower Huron Member, Ohio Shale

The lower Huron Member, Ohio Shale is a dark-gray to black, carbonaceous, fissile shale, with alternating olive-gray to pale-yellow to brownish bands. The bedding is often inclined and deformed due to compaction around concretions, which are carbonate masses produced by decaying organics in an oxygen-deficient environment. The unit is recognizable in geophysical logs and cross sections due to its characteristically high gamma signature, with uranium counts exceeding 50 ppm. The lower

Huron Member sits disconformably on the Prout Limestone, exhibiting an abrupt contact with the underlying unit. The lower Huron Member dips and thickens towards the southeast.

Other Units

The Hanover Shale and Pipe Creek Members of the Java Formation and the Angola Shale and Rhinestreet Members of the West Falls Formation are clastic wedges that onlap the Prout Limestone/Hamilton Group unconformity to the eastern side of the study area (fig. 6). These formations are identified in cross sections (plates 1–3) but are not discussed in detail due to their absence in the Plum Brook Station cores.

CONCLUSIONS

Findings from this investigation are consistent with recent research, specifically that of Bartholomew and Brett (2007) and Ettensohn and Lierman (2012). The basin-wide unconformity at the base of the Onondaga (Ohio Division of Geological Survey, 1990) resulted from lithospheric upwarping caused by a peripheral bulge that followed initial subduction; this event marked the first tectophase and beginning of the Acadian Orogeny. Although typically short lived, this event appears to have been gradual, given the substantial thickness of the carbonate unit. The Delaware and Columbus Limestones formed towards the distal portion, onlapping onto a structural high to the west. Sedimentation appears to be continuous moving to the center of the basin where rapid subsidence created water depth sufficient to produce a pycnocline, resulting in the formation of the organic-rich Marcellus Shale, which onlaps the Onondaga to the southeast (plates 1–3).

A minor regression occurred following deposition of the Marcellus Shale and prior to deposition of the Plum Brook Shale. Given the facies change from the Hamilton Group to the east, the Plum Brook represents westward shallowing, with source muds coming from the Acadian Orogeny, as no other sources appear to be available midcontinent. These calcareous muds are thought to represent enormous mud plumes dispersed after storm floods, which extend far west of the foreland basin into equivalent units west of the Findlay Arch (Bartholomew and Brett, 2007).

Thought to represent shallow marine reefoid structures (Krywany, 1982), the Prout Limestone is one of several lateral equivalents across the Great Lakes region. More recently it is believed to have been comprised of a stacking of thin lenses of condensed limestones of varying ages, separated by cryptic unconformities (Brett and others, 2011). Bartholomew and Brett (2007) suggest the topography over the entire region was relatively flat given subtle gradients recorded in the limestone. Sedimentation and subsidence rates likely reached a near equilibrium, allowing for the formation of a widespread carbonate shelf. Sea level remained moderately shallow and probably within the photic zone given the diversity and abundance of fauna and corals.

The reactivation of a basement structure during the Acadian Orogeny may have contributed to the erosion and separation of the Prout Limestone from equivalent units to the east (Ettensohn and Lierman, 2012). The Middleburg Fault (Gray, 1982; Baranoski, 2012), which is

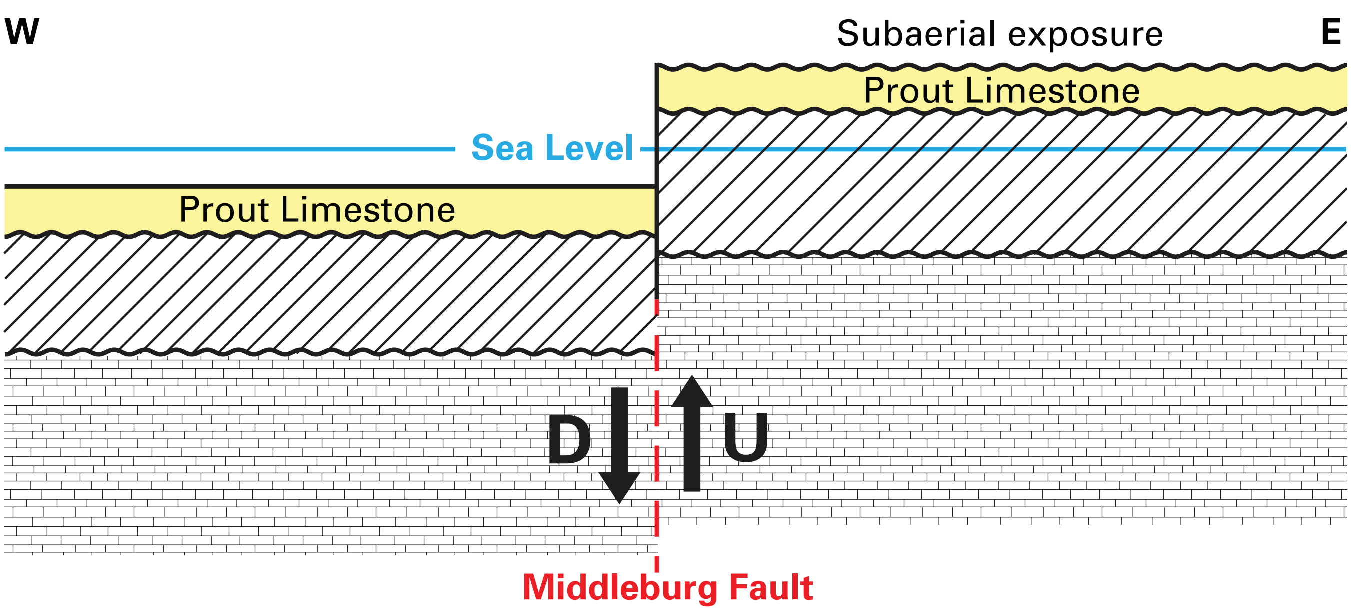

FIGURE 7. Generalized diagram showing possible effects of tectonic uplift near Medina and Cuyahoga Counties, Ohio, due to reactivation of the Middleburg Fault during the Upper Devonian. Assuming post-depositional uplift, the fault was reactivated at the beginning of the third tectophase, raising the Prout Limestone and exposing it subaerially on the upward (U) throw of the fault, where it was eroded.

inferred primarily across Cuyahoga County, supports this interpretation, considering the location of the fault relative to the disappearance of the Prout Limestone gamma signature in cross section, specifically cross section B–B' (plate 2, location shown in fig. 2.) The Prout Limestone is absent on the northeastern side of the inferred fault, on the upward throw of displacement. Reactivation of this fault at the beginning of the third tectophase may have contributed to exposing the unit, perhaps subaerially, where it was completely eroded before downward flexure and subsequent burial beneath the lower Huron Member and younger overlying strata (fig. 7).

While the original lateral extent of the Prout Limestone is uncertain, the eastern portion appears to have been partially eroded prior to its burial into a deepening basin. Upward lithospheric flexure in the form of a migrating forebulge may have had some influence on exposure and erosion. Likewise, reactivation of a basement fault also may have contributed to its removal.

The drowning and downward flexure of the Prout Limestone marked the beginning of the third tectophase. The sharp unconformity at the top of the unit represents a flooding surface during a time of sediment starvation (Brett and Baird, 1996). Transgression continued and younger units were deposited as the basin deepened and migrated toward the craton. Subsidence was apparently rapid enough that the sea bottom never aggraded above the pycnocline into oxygenated waters, and clastic influx is thought to have overfilled the basin, pushing westward during deposition of the lower Huron Member (Ettensohn and Lierhman, 2012).

The Prout Limestone and Plum Brook Shale represent two components in a larger sedimentary cycle. Deposited as distal facies in a developing basin, they were partially eroded prior to burial under successive units. While tectonic and eustatic controls appear to be driving mechanisms behind sedimentation, faulting also may have regional implications.

ACKNOWLEDGMENTS

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REFERENCES CITED

Baker, R.C., 1942, The Age and Fossils of the Olentangy Shale of central Ohio: American Journal of Science, v. 240, p. 137–143.

Baranoski, M.T., 2012, Structure Contour Map on the Precambrian Unconformity Surface in Ohio and Related Basement Features: Ohio Department of Natural Resources, Division of Geological Survey Map PG-23.

Bartholomew, A.J., and Brett, C.E., 2007, Correlation of Middle Devonian Hamilton Group-equivalent strata in east-central North America—Implications for eustasy, tectonics and faunal provinciality: London, Geological Society Special Publication 278, p. 105–131.

Beaumont, Christopher, 1981, Foreland basins: Geophysical Journal of the Royal Astronomical Society, v. 65, no. 2, p. 291–329.

Beaumont, Christopher, Quinlan, G.M., and Hamilton, Juliet, 1988, Orogeny and stratigraphy—Numerical models of the Paleozoic in the Eastern Interior of North America: Tectonics, v. 7, no. 3, p. 389–416.

Bowles, M.D., and Arrighi, R.S., 2004, NASA's Nuclear Frontier, The Plum Brook Reactor Facility, 1941–2002: Monographs in Aerospace History No. 33, SP-2004-4533, 187 p.

Brett, C.E., and Baird, G.C., 1996, Middle Devonian sedimentary cycles and sequences in the northern Appalachian Basin, in Witzke, B.J., Ludvigson, G.A., and Day, Jed, eds., Paleozoic Sequence Stratigraphy—Views from the North American Craton: Boulder, Colorado, Geological Society of America Special Paper 306, p. 213–241.

Brett, C.E., Baird, G.C., Bartholomew, A.J., DeSantis, M.K., and Ver Straeten, C.A., 2011, Sequence stratigraphy and a revised sea-level curve for the Middle Devonian of Eastern North America: Paleogeography, Paleoclimatology, Paleoecology v. 304, nos. 1–4 p. 21–53.

Coogan, A.H., 1996, Ohio's surface rocks and sediments, in Feldman, R.M., and Hackathorn, Merrianne, eds., Fossils of Ohio: Columbus, Ohio Department of Natural Resources, Division of Geological Survey Bulletin 70, p. 31–50.

Cooper, G.A., 1941, New Middle Devonian Units: Washington Academy Science Journal, v. 31, no. 5, p. 179–181.

Crangle, R.D., Jr., 2007, Log ASCII Standard (LAS) files for geophysical wire line well logs and their application to geologic cross sections through the central Appalachian Basin: United States Geological Survey Open-File Report 2007-1142, 14 p.

deWitt, Wallace, Jr., Roen, J.B., and Wallace, L.G., 1993, Stratigraphy of Devonian black shales and associated rocks in the Appalachian Basin, chap. B of Roen, J.B, and Kepferle, R.C., eds., Petroleum geology of the Devonian and Mississippian black shale of eastern North America: U.S. Geological Survey Bulletin 1909, 57 p., 40 figs., 11 plates.

Ellis, D.V., and Singer, J.M., 2008, Well logging for Earth scientists (2d ed.): Springer Science Business Media B.V., 692 p.

Elrick, Maya, Berkyova, Stana, Klapper, Gilbert, Sharp, Zachary, Joachimski, Michael, and Fryda, Jiri, 2009, Stratigraphic and oxygen isotope evidence for My-scale glaciation driving eustacy in the Early-Middle Devonian greenhouse world: Paleogeography, Paleoclimatology, Paleoecology, v. 276, nos. 1–4, p. 170–181.

Ettensohn, F.R., 1987, Rates of relative plate motion during Acadian Orogeny based on spatial distribution of black shales: Journal of Geology, v. 95, no. 4, p. 572–582.

Ettensohn, F.R, and Lierman, R.T., 2012, Large-scale Tectonic Controls on the Origin of Paleozoic Dark-shale Source-rock Basins—Examples from the Appalachian Foreland Basin, Eastern United States, in Gao, Dengliang, ed., Tectonics and sedimentation—Implications for petroleum systems: American Association of Petroleum Geologists Memoir 100, p. 95–124.

Ettensohn, F.R., Lierman, R.T., Mason, C.E., Dennis, A.J., and Anderson, E.D., 2009, Kentucky dropstone "ices" the case for Late Devonian alpine glaciation in the central Appalachians—Implications for Appalachian tectonics and black-shale sedimentation, in Ettensohn, F.R., Lierman, R.T., Mason, C.E., and Clayton, Geoff, eds., Changing physical and biotic conditions on eastern Laurussia, Field Trip 2:, North American Paleontological Convention, Cincinnati, Ohio, June 21–26, 2009, p. 44–51.

Gable, K.M., 1973, Conodonts and Stratigraphy of the Olentangy Shale (Middle and Upper Devonian), central and southern Ohio: Columbus, The Ohio State University, M.S. thesis, 90 p.

Grabau, A.W., 1917, Age and stratigraphic relations of the Olentangy Shale of central Ohio, with remarks on the Prout Limestone and so-called Olentangy Shales of northern Ohio: Journal of Geology, v. 25, no. 4, p. 337–343.

Gray, J.D., 1982, Subsurface structure mapping of eastern Ohio, chap. 3 of Gray, J.D., Struble, R.A., Carlton, R.W., Hodges, D.A., Honeycutt, F.M., Kingsbury, R.H., Knapp, N.F., Majchszak, F.L., and Stith, D.A., eds., An Integrated Study of the Devonian-Age Black Shales in eastern Ohio: U.S. Department of Energy, Technical Information Center, DOE/ET/12131-1399 (DE83011204), 13 p., 3 figs., 5 maps.

Krywany, J.M., 1982, Biostratigraphical study of the Prout Limestone in north central Ohio: Toledo, Ohio, The University of Toledo, M.S. thesis, 150 p.

Louden, R.O., 1965, The Prout Limestone and Plum Brook Shale; description of lithofacies and discussion of lithostratigraphic relationships with the Olentangy Shale: Bowling Green, Ohio, Bowling Green State University, M.S. thesis, 112 p.

Miller, K.G., Kominz, M.A., Browning, J.V., Wright, J.D., Mountain, G.S., Katz, M.E., Sugarman, P.J., Cramer, B.S., Christie-Blick, Nicholas, and Pekar, S.F., 2005, The Phanerozoic record of global sea-level change: Science, v. 310, no. 5752, p. 1293–1298.

Newberry, J.S., 1873, The Geological structure of Ohio—Devonian system, chap. 5 of Report of the Geological Survey of Ohio, v. 1, pt. 1, sec. 1—General geology: Columbus, [State of Ohio Legislature], p. 150.

Ohio Division of Geological Survey, 1990 (rev. 2000, 2004), Generalized column of bedrock units in Ohio: Ohio Department of Natural Resources, Division of Geological Survey, 1 sheet.

Orton, Edward, 1893, Geological scale and geological structure of Ohio, chap. 1 of Report of the Geological Survey of Ohio, v. 7, pt. 1—Economic geology: Columbus, [State of Ohio Legislature], p. 1–44.

Prosser, C.S., 1903, The nomenclature of Ohio geological formations: Journal of Geology, v. 11, no. 6, p. 519–546.

Rickard, L.V., 1984, Correlation of the subsurface Lower and Middle Devonian of the Lake Erie region: Geological Society of America Bulletin, v. 95, no. 7, p. 814–828.

Schumacher, G.A., Mott, B.E., and Angle, M.P., 2013, Ohio's Geology in Core and Outcrop—A field guide for citizens and environmental and geotechnical investigators: Columbus, Ohio Department of Natural Resources, Division of Geological Survey Informational Circular 63, p. 83–108.

Schwietering, J.S., 1979, Devonian shales of Ohio and their eastern and southern equivalents: U.S. Department of Energy, Technical Information Center, METC/CR-79/2, 68 p.

Slucher, E.R., Swinford, E.M., Larsen, G.E., Schumacher, G.A., Shrake, D.L., Rice, C.L., Caudill, M.R., and Rea, R.G., 2006, Bedrock geologic map of Ohio: Columbus, Ohio Department of Natural Resources, Division of Geological Survey Map BG-1, scale 1:500,000.

Sparling, D.R., 1988, Middle Devonian Stratigraphy and Conodont Biostratigraphy, North-Central Ohio: The Ohio Journal of Science, v. 88, no. 1, p. 2–18.

Sparling, D.R., 1995, Conodonts from the Middle Devonian Plum Brook Shale of north-central Ohio: Journal of Paleontology, v. 69, no. 6, p. 1123–1139.

Stauffer, C.R., 1909, The Middle Devonian of Ohio: Columbus, Ohio Geological Survey, Fourth Series, Bulletin 10, 204 p.

Stauffer, C.R., 1916, The relationships of the Olentangy Shale and Associated Devonian deposits of northern Ohio: Journal of Geology, v. 24, no. 5, p. 476–487.

Stauffer, C.R., 1938, Conodonts of the Olentangy Shale: Journal of Paleontology, v. 12, no. 5, p. 411–443.

Stewart, G.A., and Hendrix, W.E., 1945, Ostracoda of the Plum Brook Shale, Erie County, Ohio: Journal of Paleontology, v. 19, no. 2, p. 87–95.

Stumm, E.C., 1942, Fauna and stratigraphic relations of the Prout Limestone and Plum Brook Shale of northern Ohio: Journal of Paleontology, v. 16, no. 5, p. 549–563.

Stumm, E.C., 1968, The corals of the Middle Devonian Ten Mile Creek Dolomite of northwestern Ohio: Ann Arbor, The University of Michigan, Contributions from the Museum of Paleontology, v. 22, no. 3, p. 37–44.

Tillman, J.R., 1969, On the age of the Olentangy Shale of central Ohio [abs.]: Geological Society of America North-Central Section Meeting, Columbus, Ohio, Abstracts with Programs, v. 7, p. 49.

Tillman, J.R., 1970, The age, stratigraphic relationships, and correlation of the lower part of the Olentangy Shale of central Ohio: Ohio journal of Science, v. 70, no. 4, p. 202–217.

APPENDIX

Core Record

Core No. 3710

County: Erie
Township: Perkins
Latitude: 41.352986°
Longitude: -82.679866°
Location Remarks: Location approximated; see remarks.
Property Owner: National Aeronautics and Space Administration (NASA)

Core Hole Designation (project): Boring DH250 for NASA Plum Brook Station

Purpose: Stratigraphic test
Driller: Unknown
Drilling Co.: Unknown
Surface Elev.: 669.2 ft.
Datum for Elev.: DEM/Engineering Drawings
Logged by: Aaron L. Evelsizor
Date Logged: 8/15/2014
Core Diameter: 2.125 in.
No. of Core Boxes: 24
Total Depth: 250 ft.
Direction of Hole: Vertical

Remarks: Core acquired by ODGS September 2013. Core was drilled for Spacecraft Propulsion Research Facilty in 1964. Despite concentrated efforts, referenced drawing #PF21014 (engineering schematics) was unobtainable and exact location is unknown. Core location estimated by georeferencing current location of present day facility. Many intervals were removed by original owner for testing-please see descriptions for details. Measurements were taken in tenths of feet. Rock color determined with wet samples and Munsell® color chips.

TOP FT.	BOTTOM FT.	THICKNESS FT.	DESCRIPTION
0.0	8.3	8.3	Core Not Recovered
8.3	20.0	11.7	Shale: alternating dark-medium gray (N3 - N4) and lighter gray (N6 - 7) to light bluish gray (5B 7/1), occasionally moderate yellow (5Y 7/6). Carbonaceous, siliceous in part, nonparallel and discontinuous thin-bedded laminae, thin parallel bedded clay-rich mudstones 2–3'' in thickness. Occasional sulfide rich layers. Lower Huron Shale.
20.0	23.5	3.5	Shale: alternating dark-medium gray (N3 - N4) and lighter gray, occasionally moderate yellow (5Y 7/6). Carbonaceous, slightly calcareous mass between 20.5'–22.5', possible concretion with deformed and inclined bedding, assorted intraclasts. 1'' thick sulfide layer at base of mass. Various calcite filled fractures.
23.5	33.6	10.1	Shale: light gray (N7 - N6), olive black (5Y 2/1) in part, even to non-parallel bedding, carbonaceous, non-calcareous, traces of bitumen @ 28.8'. Missing intervals: 25.6'–26.1', 30.2'–30.7', 32.2'–32.7'.
33.6	37.1	3.5	Shale: dark medium gray (N4 - N3). Carbonaceous, siliceous. Predominantly evenly bedded with thin-medium thick laminae. 12–14 calcareous laminations, 1–5 mm thick. Contact with underlying Limestone is abrupt at base, discontinuous surface at 37.1'. Total thickness of Lower Huron in core = 18.8'. Prout Limestone at 37.1'.

TOP FT.	BOTTOM FT.	THICKNESS FT.	DESCRIPTION
37.1	43.0	5.9	Limestone: Medium Gray to Light Gray (N6 - N7) to Light Olive Gray (5Y 6/1). Dolomitic, fossiliferous. Lenticular and irregular bedding towards lower portion (42.3'). Secondary porosity and calcite filled vugs; calcite, dolomite, and pyrite filled voids. Calcite filled vertical fracturing at 42.5'. Silicified brachiopod fragments at 39.7'. Fossil has and crinoid fragments at base. Increasing Pyrite with depth. Abrupt, discontinuous contact at 43'. Missing intervals: 40.3'–40.7', 40.9'–41.3'. Total thickness of Prout Limestone in core = 5.9'. Plum Brook Shale at 43.0'.
43.0	47.1	4.1	Marl: Medium to medium light gray (N6 - N7). Calcareous mud shale, very siliceous. Transitional at top contact with Prout Limestone. Very poor core recovery. Missing intervals: 43.7'–44.2', 46.5'–46.9'.
47.1	102.7	55.6	Shale: medium gray to light gray (N5 - N7), olive gray (5Y 4/1) to Light Bluish (5B 7/1) in part. Calcareous mud and clay shale. Irregular, discontinuous, and non-parallel thin to thick bedded. Fossiliferous zone in upper portion (49.8'–51.2') (54.5'–56') with macrofossils, including abundant brachiopods. Interbedded limestone stringers. Increased fissility in lower portion. 1/2'' thick sulfide deposit @ 88'. Increasing pyrite towards base. Abrupt change to bluish gray limestone @ 102.7', disconformable surface. Total thickness of Plum Brook Shale = 59.7'. Missing intervals: 47.9'–48.4', 53.6'–54.0', 56.1'–57.1', 67.0'–68.0', 70.8'–71.3', 76.5'–77.0', 83.4'–83.9', 89.0'–89.5', 93.6'–94.1', 95.6'–96.0', 101.5'–102'. Top Delaware Limestone at 102.7'.
102.7	106.5	3.8	Limestone: medium light gray (N6) to brownish gray (5YR 4/1) to light bluish gray (5B 7/1). Argillaceous. Fossil fragments in upper 20''. Blebs of pyrite in upper portion below contact with overlying Plum Brook Shale. Missing intervals: 105.5'–106.5'.
106.5	114.0	7.5	Limestone: medium dark gray (N4) to brownish gray (5YR 4/1). Nodular white to light brown chert at 109.5'. Fossiliferous.
114.0	126.9	12.9	Limestone: medium to medium light gray (N5 / N6) to yellowish gray (5Y 7/2) to buff. Argillaceous. Black shale partings, light brown chert nodules, styolitic in part. Missing intervals: 116.7'–117.1', 126.9'–127.6'.
126.9	130.0	3.1	Limestone: medium light gray (N6). Argillaceous. Concentrated cluster of chert nodules at 128.0'. Missing intervals: 129.5'–130.0'.
130.0	138.5	8.5	Limestone: medium to medium light gray (N5 / N6) to yellowish gray (5Y 7/2) to buff. Argillacous. Shale partings at 133.5', 136.0' w/fossiliferous limestone, 137.5'. Missing intervals: 136.1'–137.6'.
138.5	146.5	8.0	Limestone: light olive gray (5Y 6/1) to light olive brown (5Y 5/6) to Medium light gray (N6). Finely crystalline, dolomitic, chert nodules, petroliferous odor near basal contact. Missing intervals: 145.5'–146.5'. Total thickness of Delaware Limestone in core = 35.8'. Top Columbus Limestone at 138.50'.
146.5	176.5	30.1	Limestone: light to medium gray (N6 / N7). Fossiliferous. Chert nodules at top, fossiliferous zone with scattered crinoid stems and brachiopod fragments 162.5'–173.5'. Dolomitized zone with macrofossils present at 167.7'. Missing intervals: 175.1'–176.6'.
176.5	190.6	14	Limestone: fossiliferous, light to medium gray (N6 - N7). Fossiliferous, becoming dolomitic towards base, occasional shale partings, styolitic in part, trace oil stains, strong petroliferous odor. Missing intervals: 186.6'–187.0', 189.5'–190.0'.
190.6	229.9	39.3	Limestone: medium to light gray (N5 - N8) to olive gray (5Y 4/1) to Yellowish Gray (5Y 7/2 to 5Y 8/1). Highly Fossiliferous, large well preserved macrofosils including rugose and tabulate corals. Styolitic in part, large chert nodules in part. Becoming finely crystalline and argillaceous towards base. Lower portion of described interval becoming increasingly dolomitic. Missing intervals: 199.1'–199.6', 205.0'–205.5', 205.9'–206.4', 213.6'–214.9', 224.7'–225.7'.
229.9	248.5	18.6	Limestone: light gray to medium light gray (N6 / N7), light olive gray (5Y 6/1). Fine crystalline dolomite, sparsely fossiliferous, few chert nodules, parallel/wavy shale laminae increasing in frequency at bottom of described interval (243.8'–245.6'). Clear change in deposition/material within missing interval. Missing intervals: 234.9'–236.3', 247.5'–248.5'. Total thickness of Columbus Limestone in core = 109.5'. Top Lucas Dolomite estimated at 248'.
248.5	250.0	1.5	Dolostone: pale brown (5YR 5/2) to light gray (N7) to light brown (5YR 6/1). Medium bedded, finely crystalline, few shale partings and laminations, pin point porosity and dolomite crystals in upper portion of described interval. Missing intervals: 247.5'–248.5'. Total thickness of Lucas Dolomite in core = 1.5'.

END OF CORE @ 250' DEPTH

Core Record

Core No. 3711

County:	Erie
Township:	Perkins
Latitude:	41.386715°
Longitude:	-82.683858°
Location Remarks:	Location approximated; see remarks.
Property Owner:	National Aeronautics and Space Administration (NASA)

Core Hole Designation (project): Boring Space Tank 15 for NASA Plum Brook Station

Purpose:	Stratigraphic test
Driller:	Unknown
Drilling Co.:	Unknown
Surface Elev.:	629 ft.
Datum for Elev.:	DEM
Logged by:	Aaron L. Evelsizor
Date Logged:	8/18/2014
Core Diameter:	2.125 in.
No. of Core Boxes:	24
Total Depth:	60 ft.
Direction of Hole:	Vertical

Remarks: Core acquired by ODGS September 2013. Core believed to have been drilled for now-decommissioned Nuclear Reactor Facilty. Depth of core, depth to Prout Limestone, and releative age of core boxes are in agreement with information from *NASA's Nuclear Frontier:The Plum Brook Reactor Facility*, Monographs in Aerospace History No. 33, SP-200f04522, August 2004. Coordinates georeferenced to location of reactor assembly within the pressure tank. Description is in tenths of a foot. Rock color determined with wet sample.

TOP FT.	BOTTOM FT.	THICKNESS FT.	DESCRIPTION
0.0	7.0	7.0	Core Not Recovered
7.0	49.1	42.1	Lower Huron Shale. Shale: dark–medium gray (N3 - N4) to lighter gray (N6 - N7) to light bluish gray (5B 7/1) to pale olive (10Y 6/2) to moderate yellow (5Y 7/6). Carbonaceous, siliceous. Even to discontinuous, thin-bedded laminae to thin, parallel-bedded, clay-rich mud shales, 2–3' in thickness. Medium bedding at 20–30° dip between 22.5' and 24.5'. Slightly calcareous, massive mud shale at 22.0'. Sulfide-rich layers in upper 18' of described interval. Pyrite nodules at 34.0' and 42.0'. Calcareous laminations at 43.0'. Bioturbated zone at 26.5'. Abrupt change at 49.1' to dolomitic limestone, disconformable surface, scour zone. Total depth of Lower Huron Shale in core = 42.1'. Top of Prout Limestone at 49.1'.
49.1	54.1	5.0	Limestone: medium gray to light gray (N6 - N7) to light olive gray (5Y 6/1). Dolomitic, fossiliferous. Irregular bedding towards lower portion. Pinpoint porosity and larger vugs at 50.2'–52.0'. Large calcite- and dolomite-filled vug at 51.0'. Pyrite present in lowermost interval. Scattered pyrite and macrofossils. Abrupt change in material/core loss at bottom of unit. Total thickness of Prout Limestone in core = 5.0'. Top of Plum Brook Shale at 54.1'.
54.1	60.0	5.9	Shale: medium gray to light gray (N5 - N7) to light bluish (5B 7/1) to olive gray (5Y 4/1) in part. Calcareous mud shale and marl in uppermost described interval. Discontinuous upper contact. Micropyrite at upper contact. Poor core recovery, missing intervals every several inches. Total thickness of Plum Brook Shale in core = 5.9'.

END OF CORE @ 60' DEPTH

Core Record

Core No. 3712

County: Erie
Township: Oxford
Latitude: 41.352986°
Longitude: -82.653629°
Location Remarks: Location approximated; see remarks.
Property Owner: National Aeronautics and Space Administration (NASA)

Core Hole Designation (project): B-2 Site 468 Boring #B9 for NASA Plum Brook Station

Purpose: Stratigraphic test
Driller: Unknown
Drilling Co.: Unknown
Surface Elev.: 659 ft.
Datum for Elev.: DEM/Engineering Drawings
Logged by: Aaron L. Evelsizor
Date Logged: 8/18/2014
Core Diameter: 2.125 in.
No. of Core Boxes: 3
Total Depth: 40 ft.
Direction of Hole: Vertical

Remarks: Core acquired by ODGS September 2013. Engineering drawings provided by NASA staff. Boring B9 located at southeast corner of property, 500' north of Magazine Rd. on Line 14 Rd. Location of core georeferenced with drawing. Description is in tenths of a foot. Rock color determined with wet sample.

TOP FT.	BOTTOM FT.	THICKNESS FT.	DESCRIPTION
0.0	10	10	Core Not Recovered
10	32.7	22.7	Lower Huron Shale. Shale: Olive black (5Y 2/1) to dark to medium gray (N3 - N4) to light bluish gray (5B 7/1) to moderate yellow (5Y 7/6) in part. Carbonaceous, siliceous. Thin to medium thickness, predominantly parallel and some irregular bedding. Bioturbated strata in part. Scattered pyrite increasing in intensity toward basal contact with underlying unit. Abrupt change in lithology, unconformity at 32.7'. Total thickness of Lower Huron in core = 22.7'. Top of Prout Limestone at 32.7'.
32.7	38.3	5.60	Limestone: medium gray to light gray (N5 - N6) to olive gray (5Y 6/1) to medium dark gray (N3 - N4) in part. Dolomitic, fossiliferous. Pinpoint and vuggy porosity, large porous zone at 34.5'–37.5'. Large calcite- and dolomite-filled vug at 36.3'. Pyrite present at lowermost interval. Scattered pyrite and macrofossils. Abrupt change in material/core loss at bottom of described interval. Total thickness of Prout Limestone = 5.6'. Top of Plum Brook Shale at 54.1'.
23.5	33.6	10.1	Shale: medium gray to light gray (N5 - N7) to light bluish gray (5B 7/1) to medium dark gray (N3 - N4) in part. Calcareous. Thin bedded. Some scattered pyrite at top; fragmented material at base of overlying unit through end of core. Very poor core recovery. Total thickness of Plum Brook Shale in core = 1.7'.

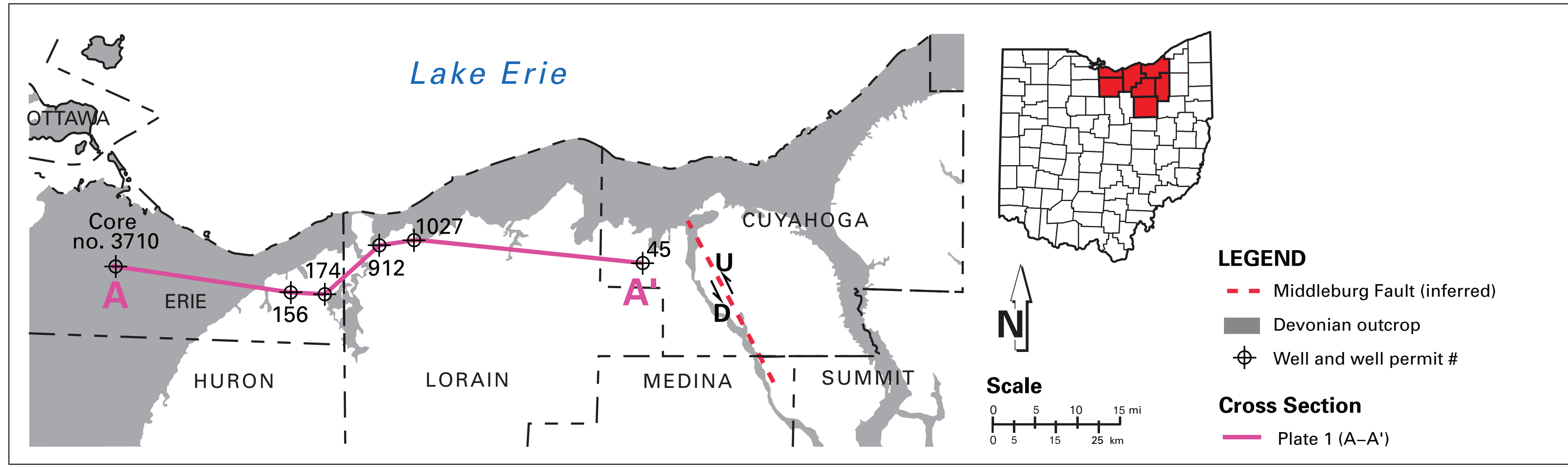
END OF CORE @ 40' DEPTH

PLATE 1

Cross section A–A' illustrating the Onondaga Limestone to lower Huron stratigraphy from Erie County to Cuyahoga County, Ohio.

WELL TYPES

- Stratigraphic test
- Dry hole
- Oil-and-gas well



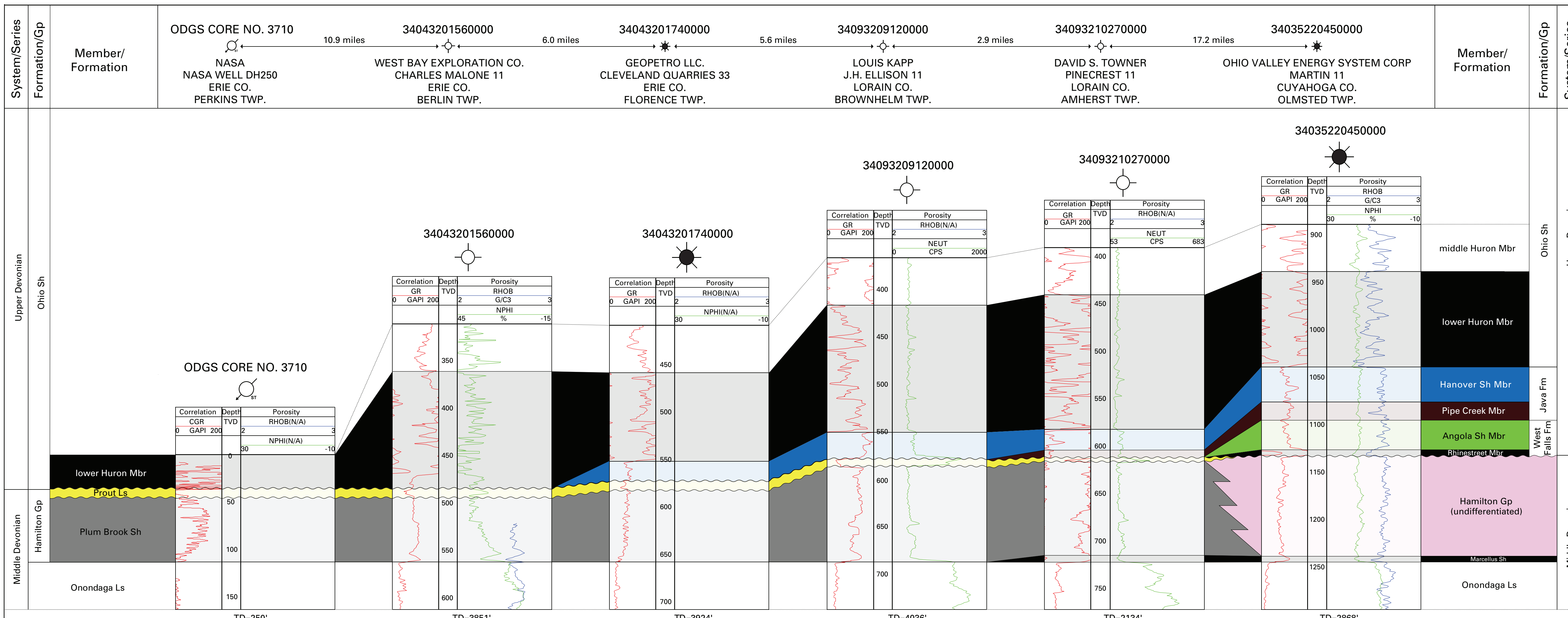
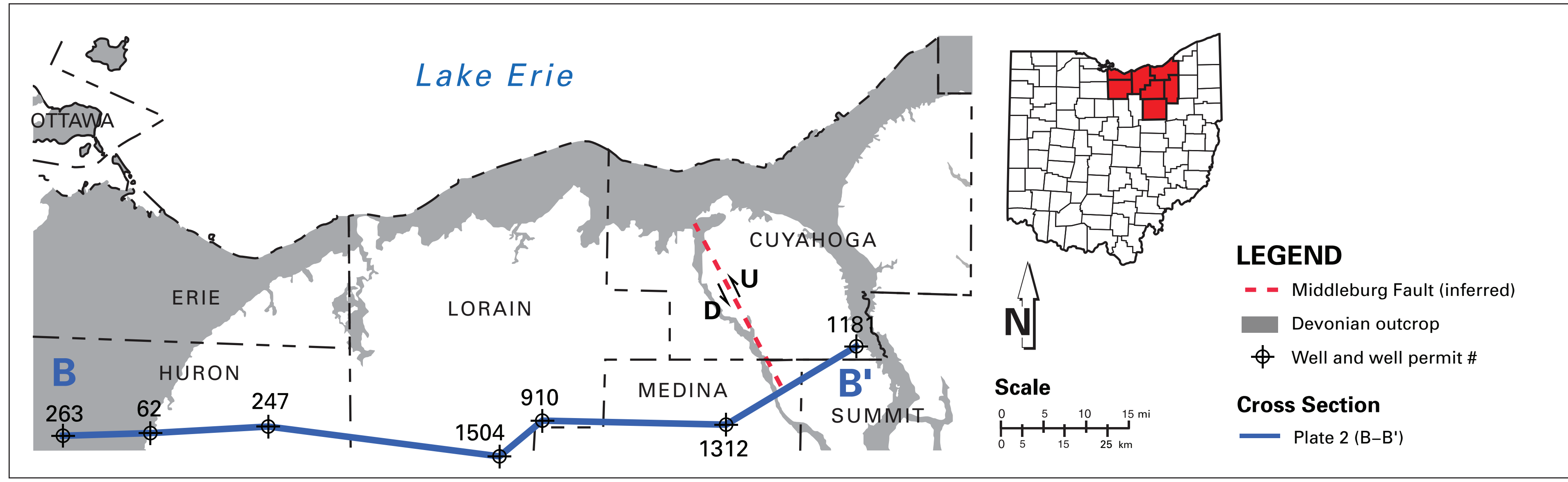


PLATE 2

Cross section B–B' illustrating the Onondaga Limestone to lower Huron stratigraphy from Huron County to Cuyahoga County, Ohio.

WELL TYPES

- Dry hole
- Plugged oil-and-gas well
- Dry hole with oil and gas showing



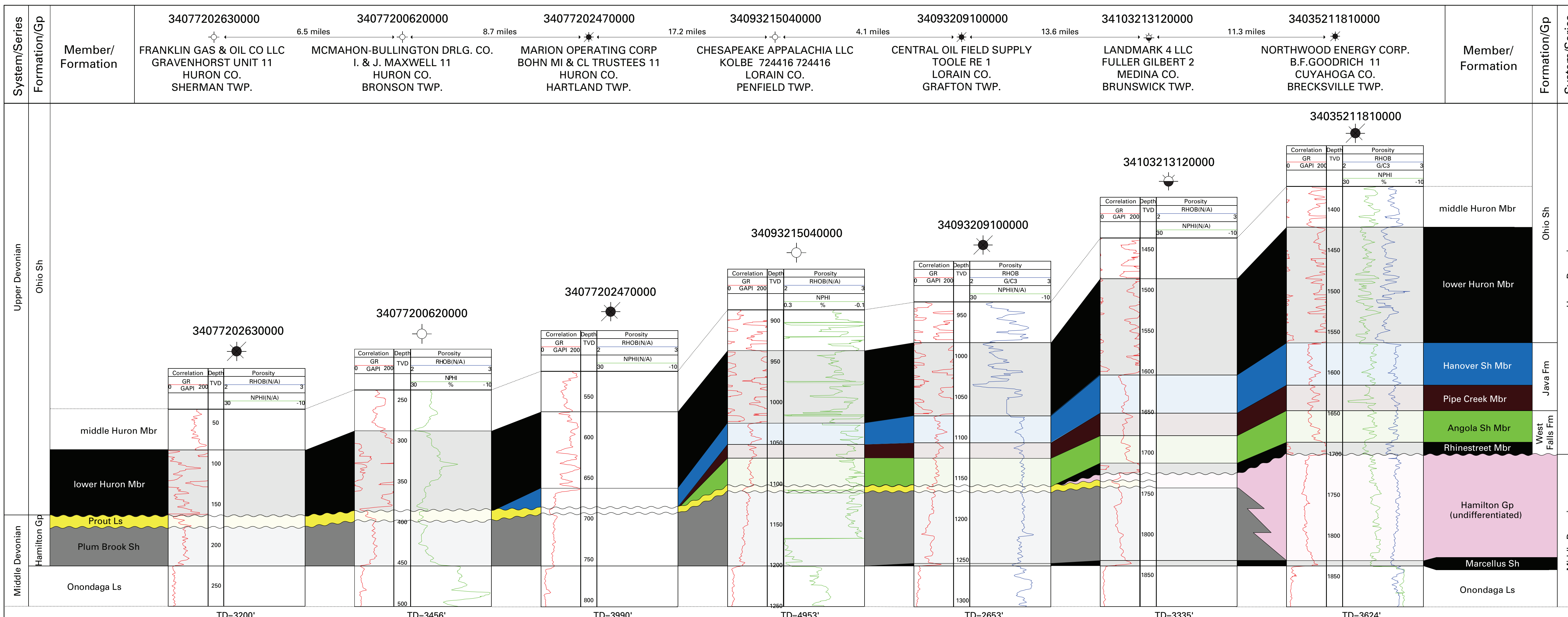


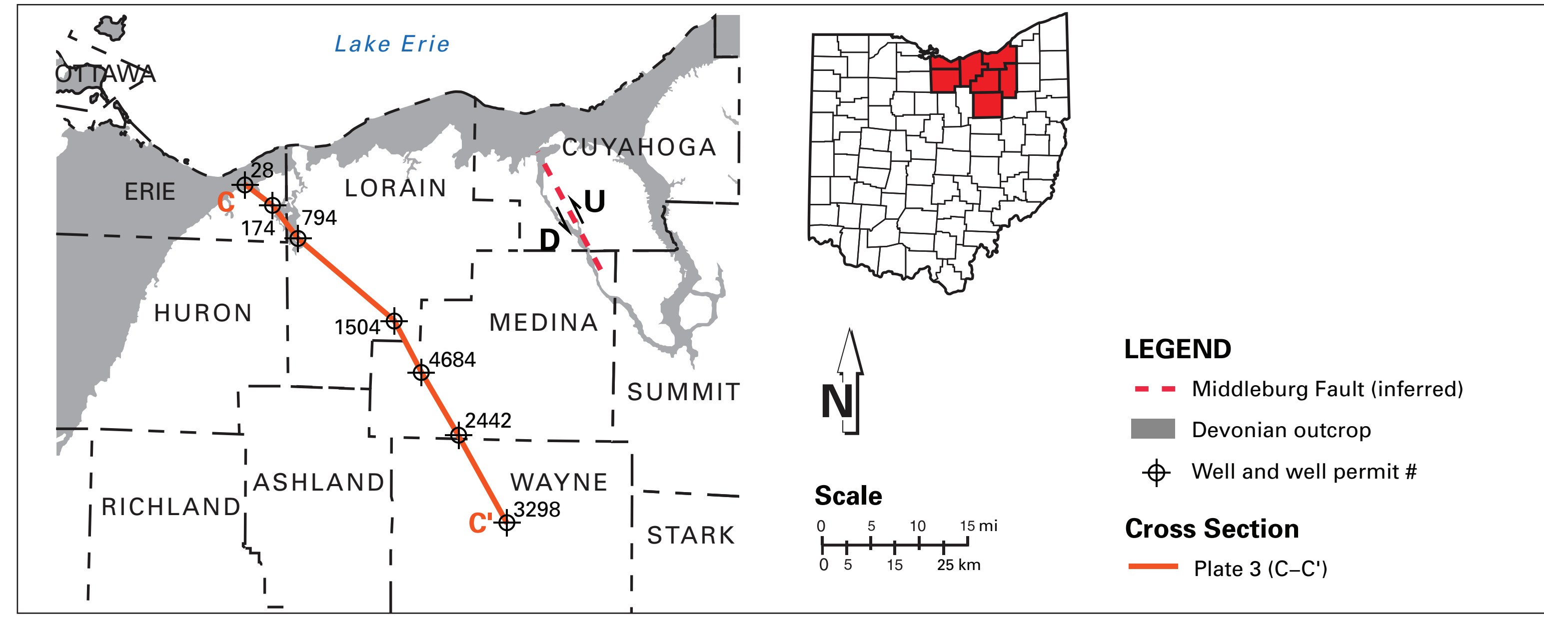
PLATE 3

Cross section C–C' illustrating the Onondaga Limestone to lower Huron stratigraphy from Erie County to Wayne County, Ohio.

WELL TYPES

Dry hole

Oil-and-gas well



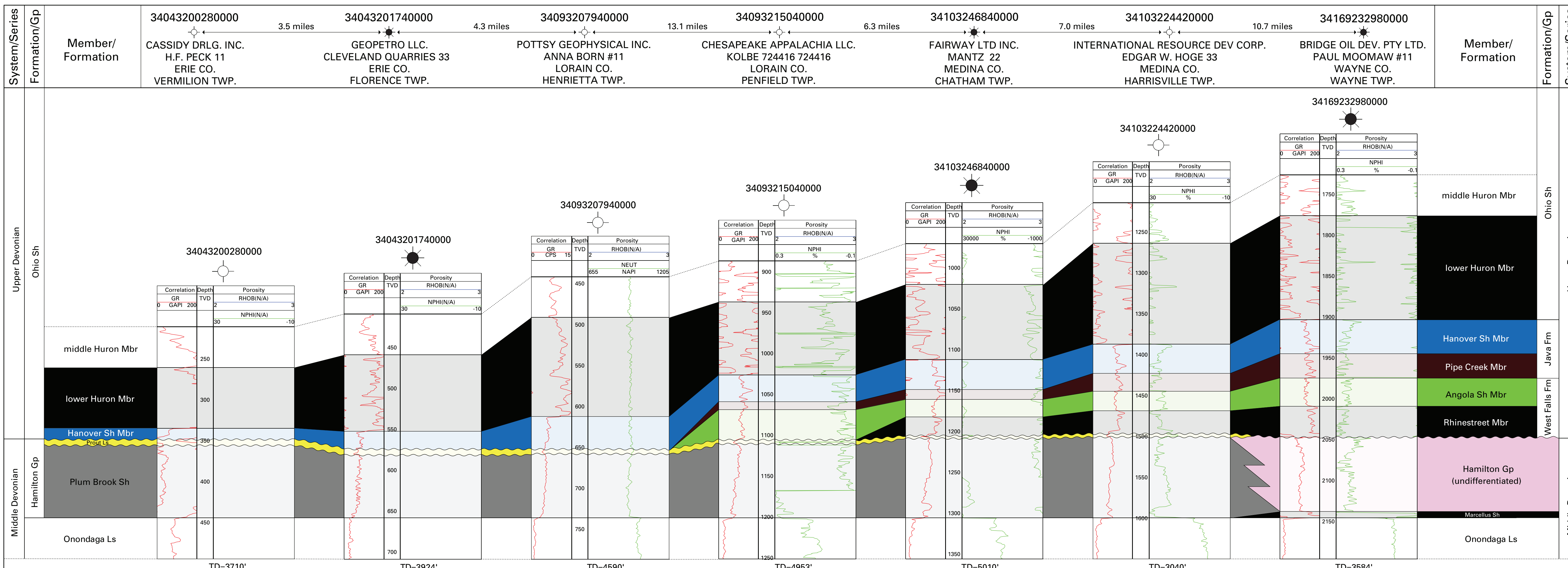
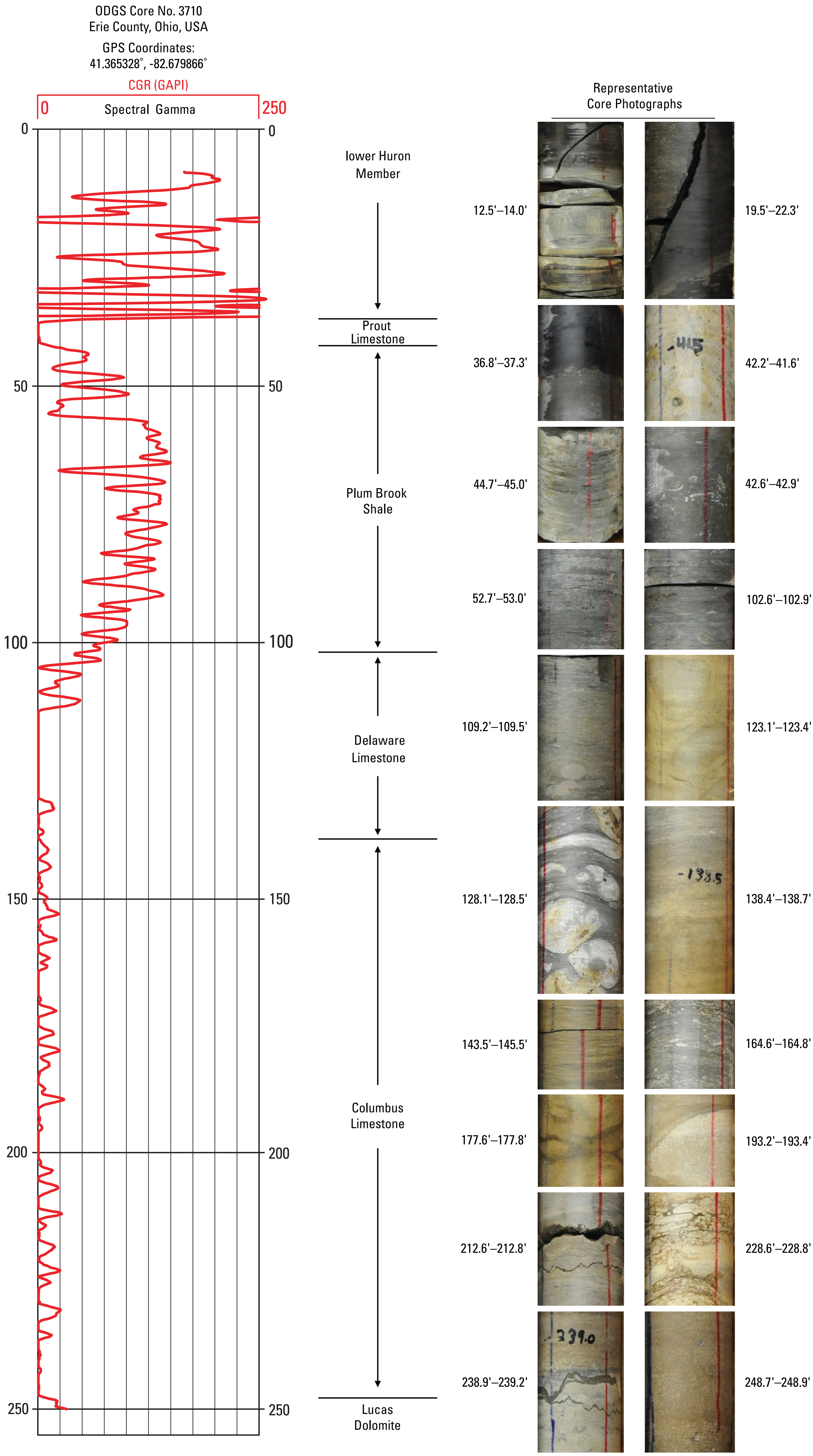


PLATE 4

Raster image of SGL gamma curve and representative wet core photographs (not to scale) of Ohio Division of Geological Survey core no. 3710.



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