Independent Statistics & Analysis
U.S. Energy Information Administration

Utica Shale Play

Geology review

April 2017

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Introduction

The U.S. Energy Information Administration (EIA) is adding and updating geologic information and maps of the major tight formations and shale plays for the continental United States. This document outlines updated information and maps for the Utica shale play of the Appalachian basin. The geologic features characterized include a contoured elevation of the formation top (structure), contoured thickness (isopach), paleogeography elements, and tectonic structures (regional faults and folds, etc.), as well as play boundaries, well location, and initial GOR (gas-to-oil ratio) of wells producing from January 2004 through December 2016.

EIA integrates these geologic elements into a series of maps. The Utica play map consists of layers of geologic and production information that users can view either as separate thematic maps (such as Figure 1) or as interactive layers of the U.S. Energy Mapping System. Additional map layers may be added if additional geologic data (such as petrophysical and thermodynamic formation properties) become available. Data sources include DrillingInfo Inc. (DI, a commercial oil and gas well database), the United States Geological Survey (USGS), New York State Geological Survey, Ohio State Geological Survey, Pennsylvania Bureau of Topographic & Geologic Survey, West Virginia Geological & Economic Survey, Appalachian Oil & Natural Gas Research Consortium, EIA reports, peer-reviewed research papers, and academic theses.

The Utica and Point Pleasant formation extent in the Appalachian basin and play boundaries

The Utica is a stacked play that includes both the Utica formation and the underlying Point Pleasant formation of Late Ordovician age as shown on the geologic cross section (Figure 3). Utica and Point Pleasant are organic-rich formations that extend in the subsurface across the Appalachian basin from New York state in the north to northeastern Kentucky and Tennessee in the south. The play has seen substantial growth in natural gas production in the past four years. Currently, the deeper Point Pleasant formation is more often targeted for drilling because of its higher productivity. The most prolific areas of the Point Peasant formation are located in eastern Ohio and western Pennsylvania.

Utica and Point Pleasant formations cover about 115,000 and 108,000 square miles respectively with a prospective area about 85,000 square miles. Formation structure and thickness are controlled by basement tectonics. EIA estimates proven reserves of 6.4 trillion cubic feet (Tcf) for the Utica Play in Ohio at the end of 2015. The Utica play footprint extends across four states: New York, Pennsylvania, Ohio, and West Virginia. Like other low-permeability plays, key geologic criteria that control play boundaries and high productivity areas include thermal maturity, total organic carbon (TOC) content, formation thickness, porosity, depth, pressure, and the ability of the formation to be hydraulically fractured.

The extent of the Utica and Point Pleasant formations (Figure 1) is defined to the north, south, and east by the outcrop of the formations (Ordovician outcrops) and to the west by the pinching out of the Utica and Point Pleasant formations by the Middle Devonian Unconformity buried in the subsurface.

The northwest boundary of the Utica Play is roughly defined by where the oil window ends and the immature area begins, and the southeast boundary is defined by where the gas window ends and the over-mature area begins, according to a study that used thermal maturity modeling calibrated to published vitrinite reflectance (%R_o) data (Hohn, Pool, and Moore, 2015). The limits of the oil window correlate to the subsea depth range of -4,000 to -8,000 feet, and the limits of the gas window correspond to the subsea depth range of -7,000 to -12,000 feet. The change in depth in relation to maturity reflects the amount of differential subsidence within the Appalachian basin and subsequent uplift and erosion with certain basement blocks.

Structure maps of the Utica and Point Pleasant formations

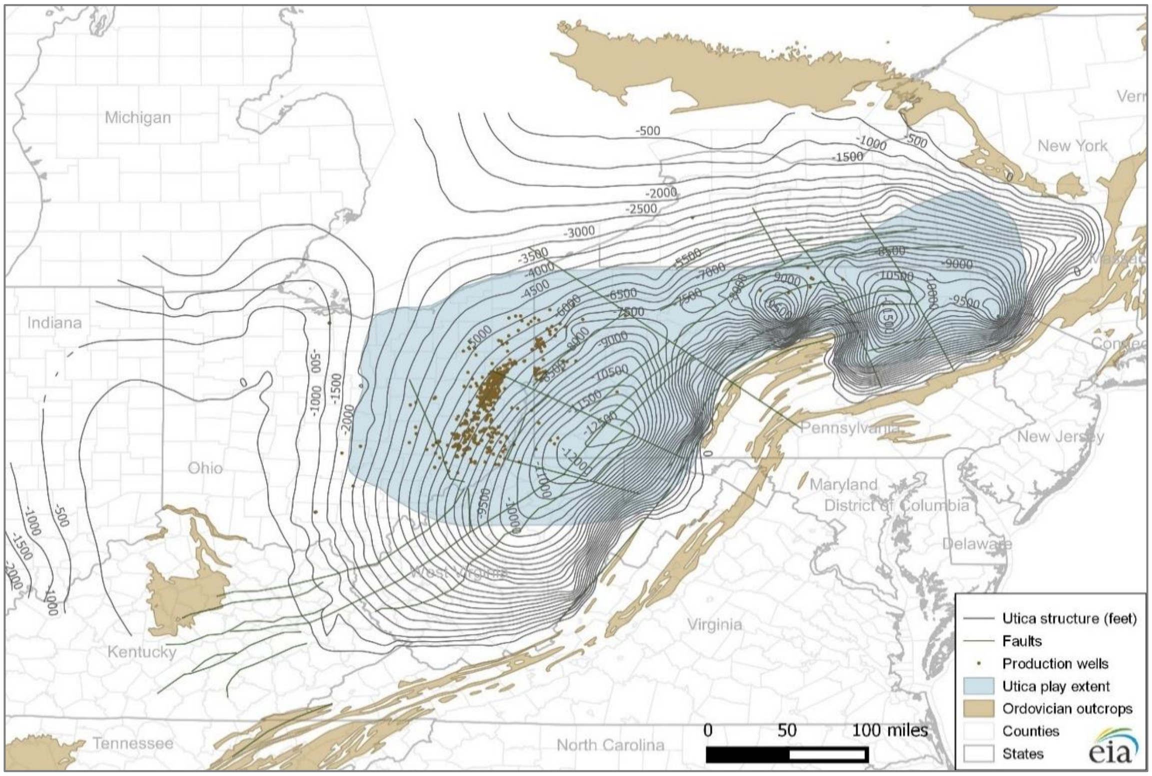
Contoured structure maps (subsea depth to the top of a geologic formation) are constructed from two types of data: (1) point-measurement depth data from oil and natural gas wells referenced to sea level, and (2) formation outcrops. These data are used to show the elevation of a reservoir on a two-dimensional map. Structure maps not only provide valuable geologic information, but they also lend insight into the distribution of oil and gas throughout the play. (A surface elevation is also required to determine the drilling depth to the formation.) To generate the structure maps of the Utica and Point Pleasant formations (Figures 1A and 1B), EIA used stratigraphic correlations provided by the Appalachian Oil & Natural Gas Research Consortium based on interpretations from 1,182 well logs.

In the southwest corner of Pennsylvania, the Point Pleasant formation reaches subsea depths of up to -14,000 feet and is shallowest at the junction of Ohio, Indiana, and Kentucky and along the outcrops. The Utica formation reaches subsea depths of up to -13,000 feet in a northeast trending arc through Pennsylvania and is shallowest at the junction of Ohio, Indiana, and Kentucky and along the outcrops. The area where most producing wells are found has a subsea depth ranging from -5,000 to -11,000 feet. The Utica and Point Pleasant formations currently produce in four states: Pennsylvania, West Virginia, Ohio, and New York. Because of the recent ban on hydraulic fracturing in New York, natural gas production in New York state is from wells drilled prior to the ban in 2010.

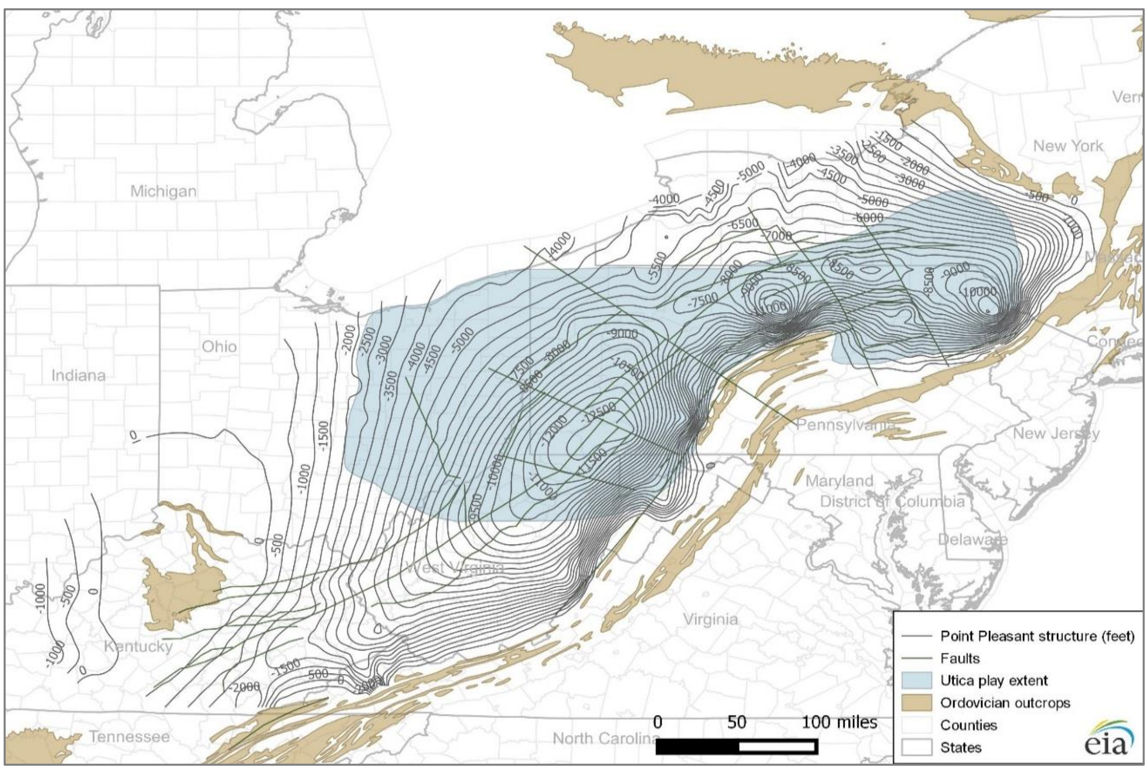
As the structure map shows, the Appalachian basin is an asymmetric depression. The depths of the Utica and Point Pleasant formations increase gradually from northwest to southeast, with an abrupt uplift along the Appalachian Mountains’ structural front, where formations are exposed along the outcrop belt. The deepest portions of both formations are related to the synclines adjacent to the structural front.

Figure 1. A) Structure map of the Utica formation and B) Structure map of the Point Pleasant formation

A)



B)



Source: U.S. Energy Information Administration based on DrillingInfo Inc., New York State Geological Survey, Ohio State Geological Survey, Pennsylvania Bureau of Topographic & Geologic Survey, West Virginia Geological & Economic Survey, Appalachian Oil & Natural Gas Research Consortium, and U.S. Geological Survey.

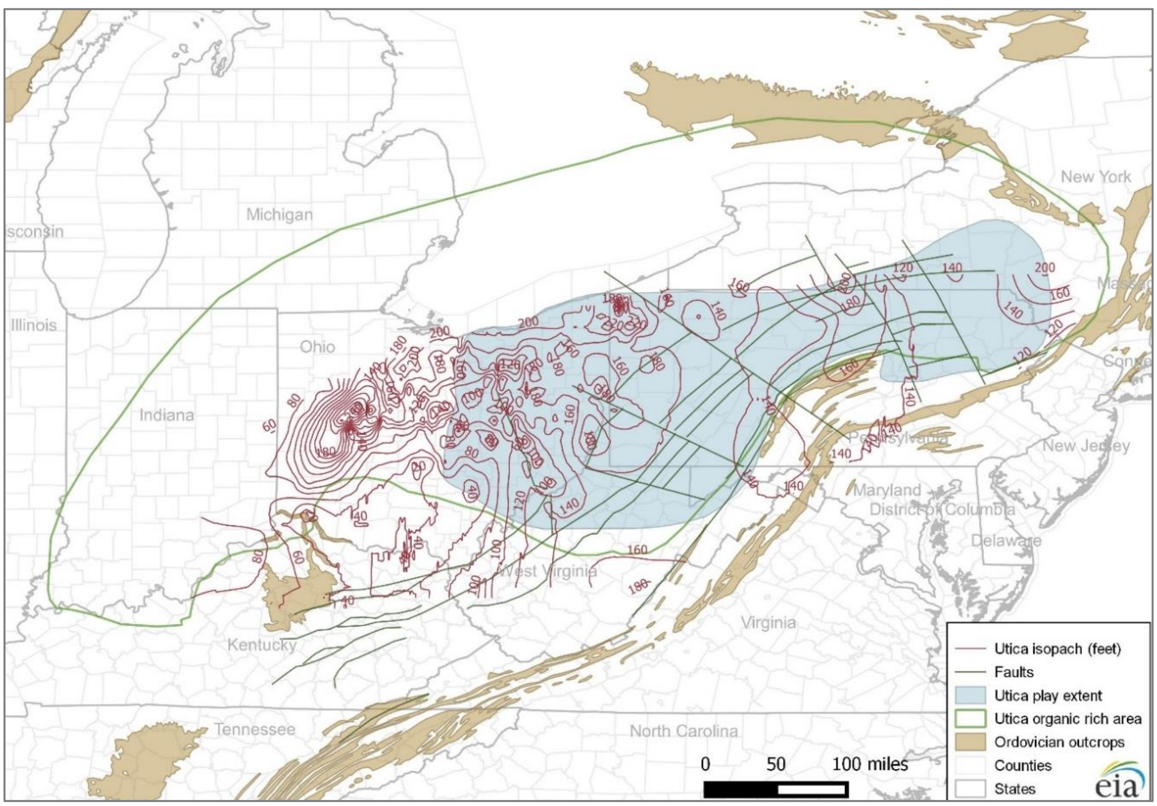
Thickness maps (isopach) of the Utica and Point Pleasant formations

Thickness maps (isopachs) show spatial distribution of formation thickness across the formation. Thickness values, combined with reservoir petrophysical properties such as porosity and thermodynamic parameters (reservoir temperature and pressure), are used to calculate resource volume estimates such as oil-in-place and gas-in-place.

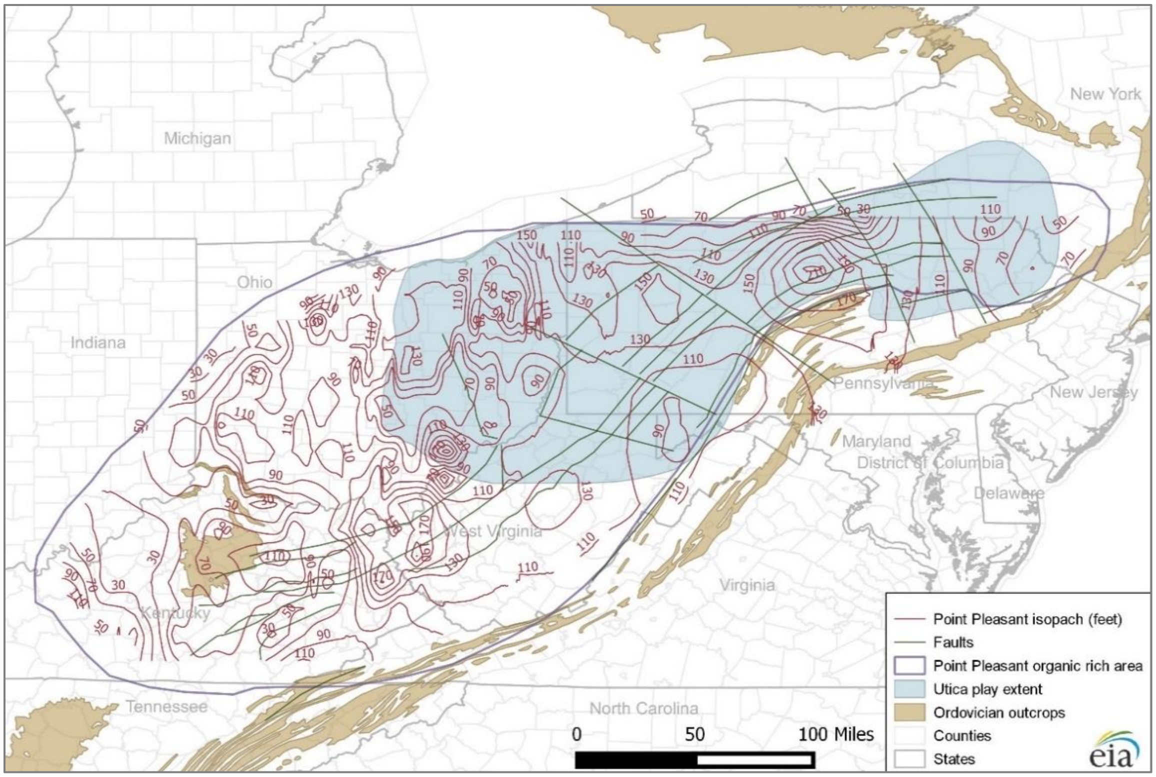
The isopach maps for the Utica and the Point Pleasant formations (Figures 2A-2C) are constructed from subsurface point measurements from individual wells that include both depth to the top and to the base of the formations. These stratigraphic picks are provided by the Appalachian Oil & Natural Gas Research Consortium based on well log interpretation from 1,182 wells. For the Utica formation map, the difference between the top of the Utica formation and the top of the Point Pleasant formation was used as a proxy for the Utica thickness. For the Point Pleasant thickness map, the top of the Point Pleasant formation and the top of the underlying Trenton formation were used to define the thickness of the Point Pleasant. The top of the Utica and the top of the Trenton were used to determine the combined thickness. Formation thickness is a factor in calculating the amount of oil and gas held in the formation.

Figure 2. A) Isopach map of the Utica formation; B) Isopach map of the Point Pleasant formation; C) Isopach map of the Utica–Point Pleasant interval

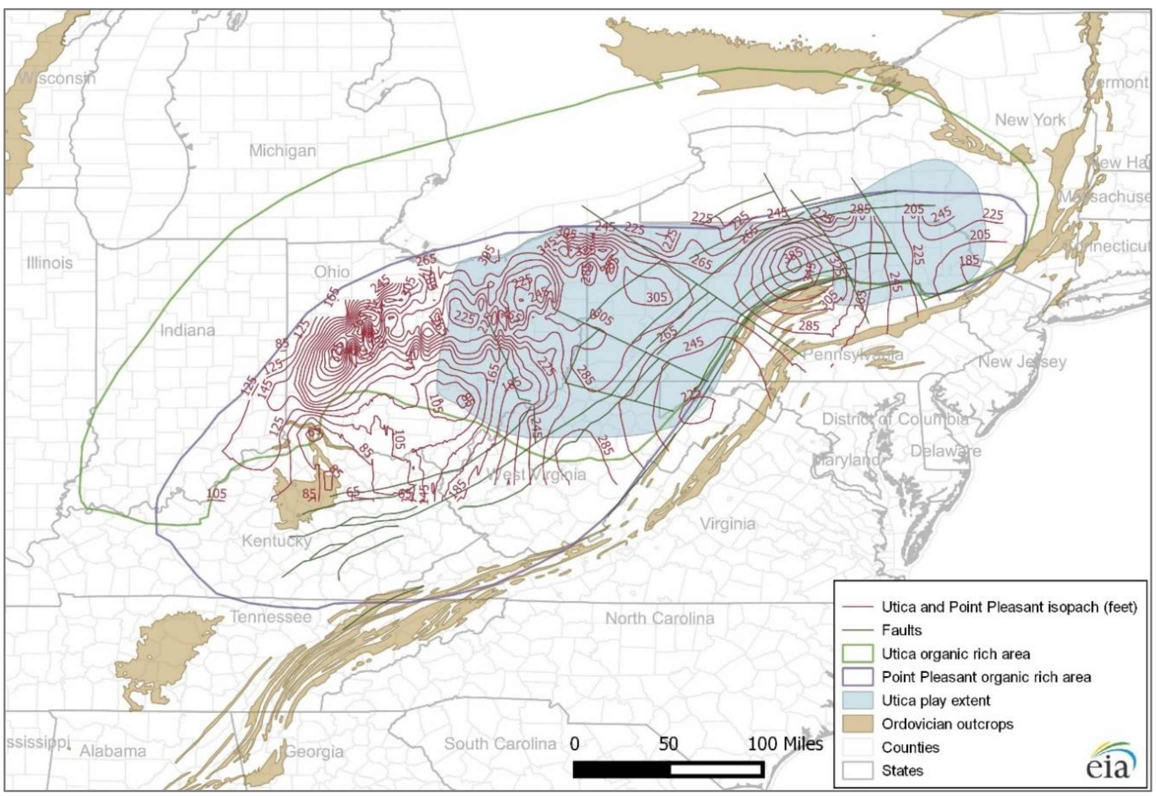
A)



B)



C)



Source: U.S. Energy Information Administration based on DrillingInfo Inc., New York State Geological Survey, Ohio State Geological Survey, Pennsylvania Bureau of Topographic & Geologic Survey, West Virginia Geological & Economic Survey, Appalachian Oil & Natural Gas Research Consortium and U.S. Geological Survey.

The Utica formation is thickest in western Ohio and the northwest corner of Pennsylvania at 200–300 feet and thins out to 50 feet or less in southern Ohio and northern Kentucky. The Point Pleasant formation reaches a thickness of more than 200 feet in central Pennsylvania and thins out to less than 20 feet in the eastern part of Kentucky. The combined thickness of Utica and Point Pleasant is as thin as 100 feet or less where Ohio, West Virginia, and Kentucky meet. The combined thickness exceeds 300 feet in northwest and central Pennsylvania, and in northeast and central Ohio.

On the maps above, the outlined area of the Utica's highest organic content shows the continuous reservoir where productive wells would likely be drilled. This area has relatively high levels of total organic carbon (TOC, an indication of the amount of hydrocarbon in the rock), which is important for successful wells. Like structure maps, isopach maps provide valuable drilling information because thickness of the reservoir is one component of the decision to drill a well and its subsequent success. Most of the current production is located in areas where combined thickness of the Utica–Point Pleasant interval is more than 150 feet.

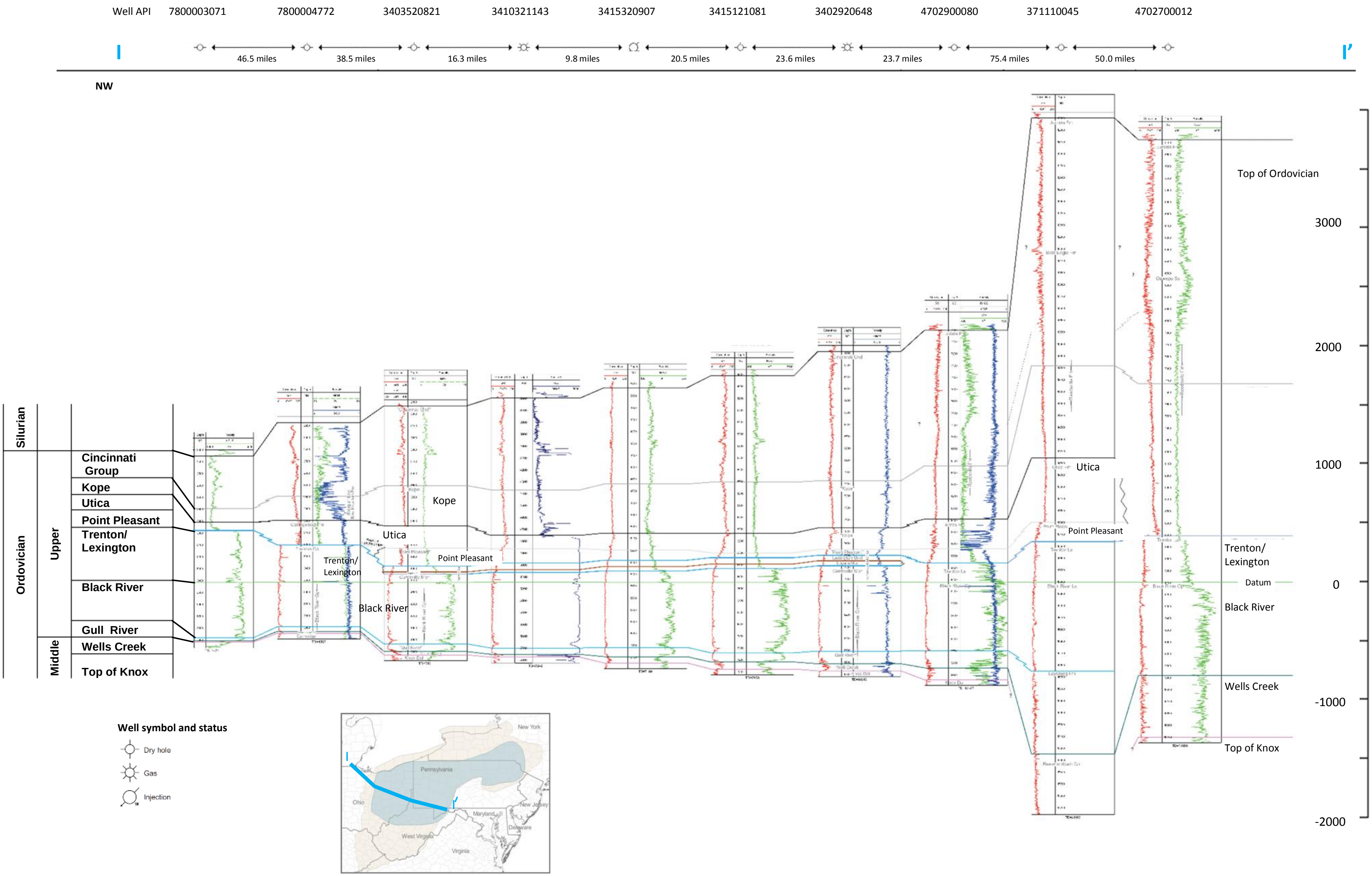
Summary of the Utica Play geology

Regional stratigraphy and lithology

The Utica and Point Pleasant formations are parts of the ancient sedimentary system known as the Appalachian basin. The Utica and Point Pleasant formations were deposited in a foreland basin roughly paralleling the structural front of the present-day Appalachian Mountains during the Late Ordovician time about 445 million years ago (Harper, 1999; Anderson et al., 1984, Patchen et al., 1985). The Utica-Point Pleasant interval is described as carbonaceous grey to black shale that encloses scattered carbonate concretions and locally abundant fossils. The Utica-Point Pleasant lithology varies significantly across the Appalachian basin. This lithological heterogeneity is controlled by depositional and diagenetic processes (Roen and Walker, 1996).

Typically, the Utica consists of interbedded gray to black and brown calcareous shale (10% to 60% calcite), locally fossiliferous. This shale in often laminated, tends to be bioturbated, and generally has TOC content of approximately 3.5%, which is lower than the underlying organic-rich carbonate facies of the Point Pleasant and Lexington-Trenton (Smith, 2013). The Point Pleasant Formation is an organic-rich calcareous shale with some limestone beds. It extends beneath the Utica Shale and is composed of interbedded, fossiliferous limestone, shale, and minor siltstone. The Upper interval of the Point Pleasant Formation is an organic-poor gray shale with abundant thin carbonate beds. TOC is generally low (in the most samples it is less than 1%). This interval is considered to be primarily non-reservoir. The Lower interval of the Point Pleasant Formation is organic-rich calcareous shale (roughly 40%–60% carbonate content) with average TOC content 4%–5%.The Point Pleasant has abundant storm beds, is a clearly storm-influenced formation, and has common burrows, even in the organic-rich facies (Luft, 1972; McDowell, 1986; Harper, 2015).

Figure 3. Geological cross-section through the Appalachian basin with the regional stratigraphic schema of the Ordovician interval



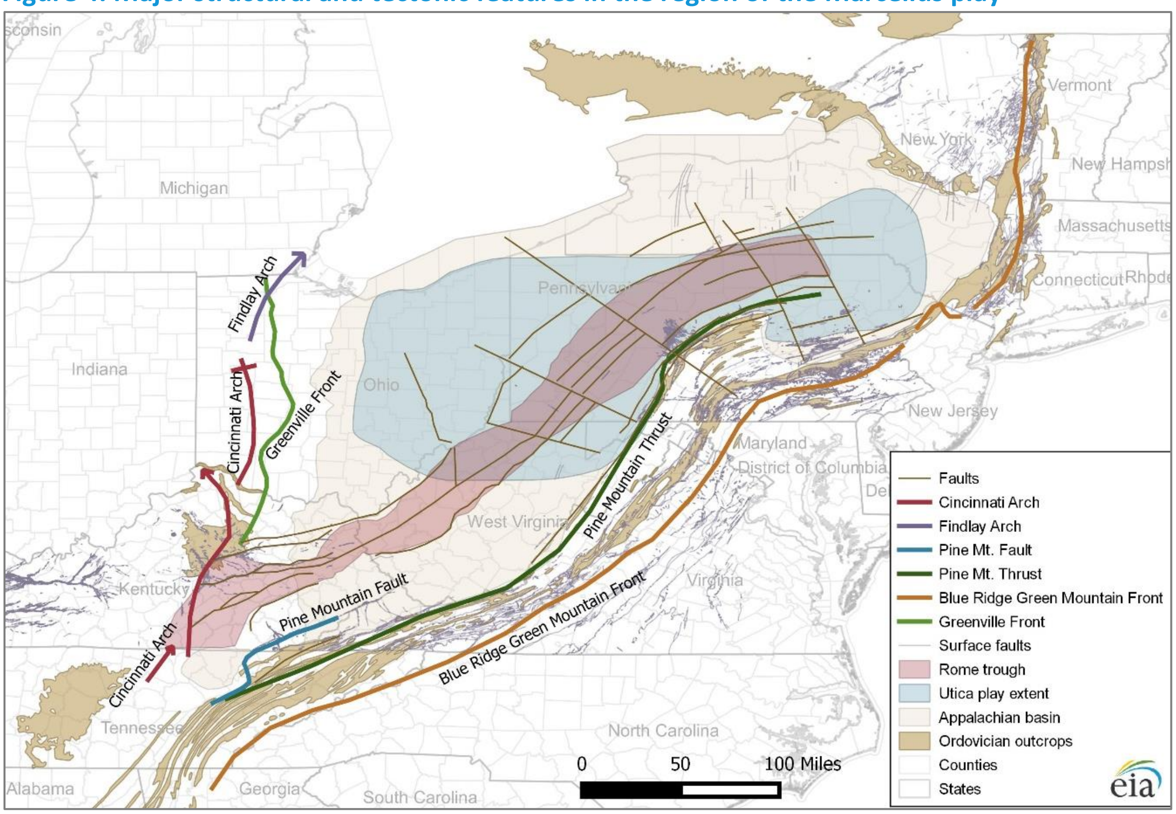
Source: U.S. Energy Information Administration based on the Trenton-Black River Appalachian Research Consortium final report, Stratigraphic Cross-section, Line I-I’

Figure 3 shows the regional stratigraphy of the Ordovician system, including the Utica and Point Pleasant Formations. The Utica-Point Pleasant overlies the Trenton formation and sits beneath the Cincinnati Group (Bergsorm and Mitchell, 1992; Hickman et al., 1985).

Structural and tectonic features

The Appalachian foreland basin encloses a platform-margin sedimentary succession that is dominated by siliciclastic and carbonate sequences of the Early Cambrian age through the Early Permian age. The Appalachian basin is an asymmetrical, northeast-trending trough bounded by the Blue Ridge Green-Mountains front to the southeast and the Cincinnati arch to the northwest (Figure 4) and was formed in response to the Alleghanian orogenic event (Quinlan and Beaumont, 1984; Gao et. al., 2000). Major causes of subsidence during the Paleozoic era were related to tectonic flexure of the lithosphere and sediment loading associated with the rejuvenation of the Appalachian foreland basin (Castle, 2001). The basin dips from a zero-edge in the northeast to the southwest, reaching a depth of more than 5 kilometers at the thrust-and-fold belt of the Appalachian Mountains (Filer, 2003; Harper, 1999).

Figure 4. Major structural and tectonic features in the region of the Marcellus play



Source: U.S. Energy Information Administration based on DrillingInfo Inc., New York State Geological Survey, Ohio State Geological Survey, Pennsylvania Bureau of Topographic & Geologic Survey, West Virginia Geological & Economic Survey, U.S. Geological Survey.

The major structural features in Figure 4 influenced the depositional history, depth, and thickness of productive areas in the Utica play. The Cincinnati Arch, Findlay Arch, and Greenville Front run in a north-south direction along the western boundary of the play. The Pine Mountain Fault, Pine Mountain Thrust, and the Blue Ridge-Green Mountain Front run along the eastern edge of the formation in a northeast-southwest direction. Ordovician outcrops run in the northeast-southwest direction along the southern and eastern borders and in an east-west direction along the northern boundary of the formation. To the west of the Pine Mountains thrust is the Rome trough, a Cambrian extensional feature that controlled sedimentation of organic shale, deposition of reservoir sands, and facilitated natural fracturing through reactivation of basement faults.

The basement structure of the Appalachian basin, along with major interpreted faults and the projected position of the Rome trough, serves as tectonic features controlling depositional and burial history of the sedimentary formations in the region, including the Utica-Point Pleasant interval. The mapped basement faults fall into two categories: (1) faults that strike parallel to the basin and are associated to the Rome trough and (2) transform faults that have been developed perpendicular to the strike of the basin and are interpreted as cross-strike structural discontinuities (Harper and Laughrey, 1987). These basement faults represent zones of weakness assumed to have been reactivated several times during the Paleozoic period and have continued well into the Quaternary (Negus-De Wyss, 1979; Shumaker, 1993). Ordovician age faults and surface faults extend in both the northeast-southwest and perpendicular northwest-southeast directions. A number of these faults coincide with other subsurface features like the Greenville Front. These major features represent points of weakness that often allow for enhanced movement and accumulation of oil and natural gas (Roen and Walker, 1996).

Paleogeography and depositional environment

A paleogeographic reconstruction of the Late Ordovician (445 Ma[1]) shows present-day West Virginia; Pennsylvania; and parts of New York, Virginia, Maryland, Kentucky, and Ohio as a semi-enclosed epicontinental sea (Woodrow, 1985; Blakey, 2011). Groups of associated fossils that likely were not transported, fine layer sequences reflecting moving currents, and erosional surfaces indicative of recurrent storms point to a depositional environment that was a shallow marine area that experienced frequent storms and algal blooms. This environment led to a deposition of interbedded shale and limestone with unconformities representing periods of erosion or non-deposition between the main layers (McClain, 2013, Wickstrom and Shumway, 2014; Carter and Soeder, 2015; Hickman et al., 2015).

The depositional environment of the Point Pleasant Formation and upper Trenton Formation was a fairly shallow, most likely less than 100 feet deep, storm-dominated, carbonate shelf that experienced frequent algal blooms. Cross-sections demonstrate that water depth was did not vary much across the organic-rich and organic-poor areas of deposition. The fossils present in the limestone indicate well-oxygenated water that was exposed to sunlight. The storm-bedding throughout suggests deposition of the Point Pleasant above the storm wave base (Hickman et al., 2015).

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[1] Ma is abbreviated from Latin mega-annum, a million years

Figure 5. Late Ordovician paleogeographic reconstruction (445 Ma) exhibiting North America. Modified after Blakey (2011)

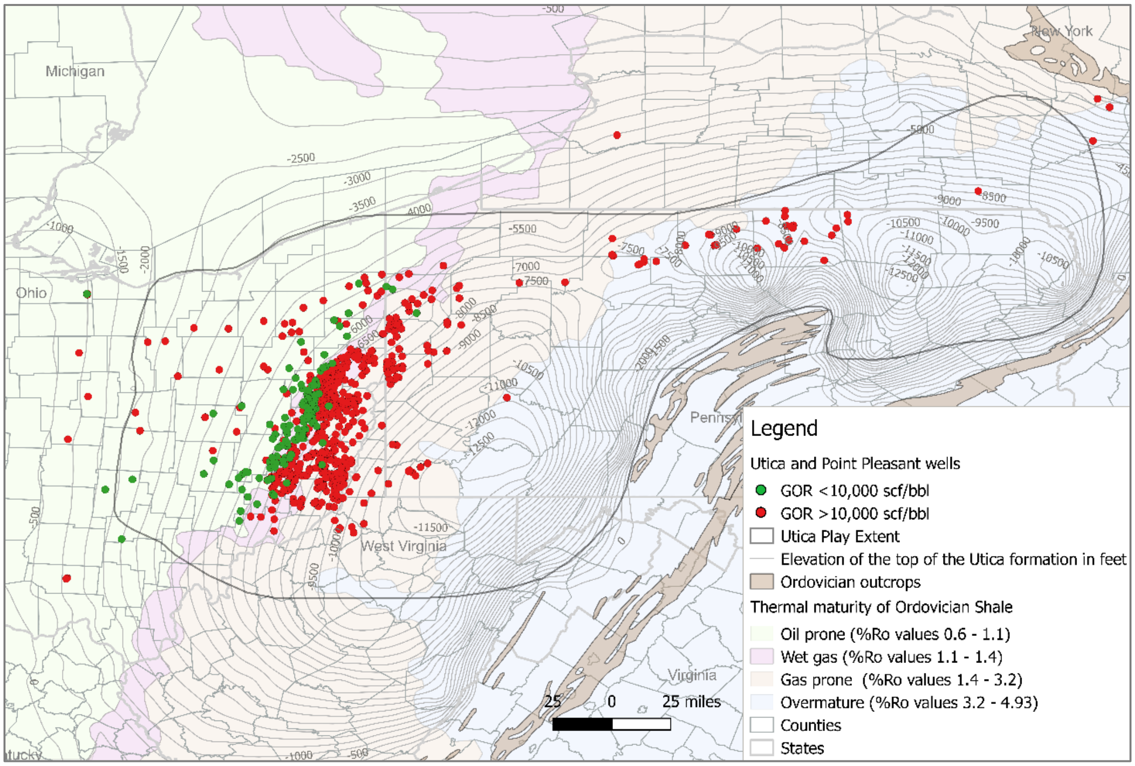
The Utica-Point Pleasant interval was deposited during a major transgression across the eastern United States. The shale composition indicates a large influx of organic material, restricted circulation, and low energy conditions. The Utica and Point Pleasant formations represent a deeper basin, relative to the Trenton Platform milieu, with inter-platform, restricted circulation and anoxic depositional environment. Deposition of this unit began contemporaneously with the Trenton carbonate buildup in response to compression from the Taconic orogeny, which altered the basin shape and water bathymetry. Deposition of these units ceased with complete inundation of the region by deeper water and open–marine condition represented by the Cincinnati Group, which sits above the Utica formation (Patchen et al., 2015).

Thermal maturity and initial GOR (gas-to-oil ratios of wells producing from the Utica-Point Pleasant)

Crude oil and natural gas are produced by heating the organic materials (i.e., kerogen) found in some rocks. When organic-rich rocks, usually shales, are buried over long periods of time, they are exposed to increasing temperatures and pressures. Heat causes the organic matter to change into the waxy material known as kerogen, then into oil, and finally into natural gas as the temperature further increases. Thermal maturity is a measure of the extent organic material has been converted (e.g., conversion of sedimentary organic matter to petroleum or cracking of oil to natural gas).

Vitrinite (a type of kerogen) reflectance (R_o) is a proxy to thermal maturity: the higher the R_o percentage value, the higher the maturity. In the case of Utica, the rocks are Ordovician in age, so vitrinite reflectance is calculated from conodont and bitumenen reflectance data (Jacob, 1989; Patchen et al., 2015). The temperature ranges conducive to converting organic material to oil and natural gas are referred to as the oil window and the gas window, respectively. The oil window has average R_0 values of 0.6–1.1% vitrinite reflectance. The wet gas window ranges from 1.1–1.4% vitrinite reflectance, the dry gas window ranges from 1.4–3.2% vitrinite reflectance. East of the production area, the Utica play becomes over mature with R_0 values up to 4.93%. Figure 6 shows consistency between production trends and thermal maturity (Patchen et al., 2015).

Figure 6. Initial Gas-to-Oil Ratios of Utica Play Wells



Sources: U.S. Energy Information Administration, DrillingInfo, Inc., Appalachian Oil & Natural Gas Research Consortium, U.S. Geological Survey.
Note: EIA calculated the initial gas-to-oil ratio for each well using the first six months of liquid and/or gas production. Vitrinite reflectance (R_o) is calculated from conodont and bitumenen reflectance data.

The oil window typically occurs at temperatures between 60 degrees and 120 degrees Celsius, while the natural gas window occurs between 100 degrees and 200 degrees Celsius. Although this temperature range is found at different depths below the surface throughout the world, a typical subsea depth for the oil window in the Utica play is -4,000 feet to -8,000 feet, and the corresponding gas window is -7,000 feet to -12,000 feet.

Thermal maturity values (based on calculated vitrinite reflectance and measurements of core samples) in the Utica-Point Pleasant interval generally increase in a southeastern direction, as shown in Figure 6, ranging from 0.6% R_o to more than 4.5% R_o across the Appalachian basin.

Figure 6 also shows the distribution of production across the play in terms of initial GOR. GORs represent the ratio of natural gas produced to oil produced from a well, expressed in standard cubic feet per barrel (scf/bbl). The distribution of oil and natural gas in a formation is mainly controlled by the thermal maturity of the rock. In the map above, natural gas-rich wells in the Utica play are mostly located in the eastern portion of the play, and oil-rich wells are typically located in the western portion. This distribution of initial GORs matches a depth pattern as the oil-rich wells with lower initial GORs (less than 10,000 scf/b) fall in the area of the formation where the subsea elevation to the top of Utica ranges from -4,500 feet to -7,000 feet. As expected, the wells producing mostly natural gas with higher initial GORs (greater than 10,000 scf/b) are in deeper areas where subsea elevation to the top of Utica ranges from -7,000 feet to -9,500 feet. The established natural gas-productive areas in the northeastern part of the play have a higher thermal maturity profile, with the most natural gas production occurring between R_o values of 3.2% to more than 3.5%. The limits of the gas window in this area correspond to subsea depth between -8,000 feet and -10,500 feet.

Recent Utica-Point Pleasant drilling activity suggests that the most substantial hydrocarbon production takes place roughly in the southeastward of the 1.1% R_o maturity contour in eastern Ohio, in the western parts of West Virginia, in the western and northern parts of Pennsylvania, and in southern New York.

Total organic carbon (TOC)

Amorphinite[2] is the major organic matter component of the Utica-Point Pleasant, which suggests an algal source for most of the organic material in the rocks. Analytical results from multiple well core samples indicate that TOC content in the Utica formation ranges from less than 1%–3.5%. It typically has average carbonate content of 25%. The Upper interval of the Point Pleasant Formation is an organic-poor gray shale with generally low TOC content (most samples are less than 1%). This interval is considered to be primarily non-reservoir. The Lower interval of the Point Pleasant Formation is an organic-rich calcareous shale with some limestone beds. The organic-rich facies have roughly 40%–60% carbonate content, with TOC ranging from 3% to 8% (average 4%–5%). This interval is apparently the target for drilling in most of the wells that have been drilled to date (Patchen et al., 2015).

During shale deposition, several factors play important roles in the preservation of radioactive elements and the organic matter. The presence of potassium, uranium, and thorium in shales is indicative of the depositional environment characteristics, as well as the way organic matter is deposited. Unlike the Devonian Marcellus Shale, where the best proxy measurement of TOC content is its gamma-ray log values[3], the Ordovician shales in the Appalachian basin do not exhibit a correlation between gamma-ray count and TOC content (Cluff and Holmes, 2013). The GR intensity for Utica and Point Pleasant is

[2] Amorphinite is organic detritus related to algal remains.

[3] Gamma ray logging is a method of measuring naturally occurring gamma radiation to characterize the rock or sediment in a borehole or drill hole. It is a wireline logging method used in oil and gas well drilling and for formation evaluation. Different types of rock emit different amounts and different spectra of natural gamma radiation. In particular, shales usually emit more gamma rays than other sedimentary rocks, such as sandstone, coal, or limestone, because radioactive potassium is a common component in their clay content, and because the cation exchange capacity of clay causes them to absorb uranium and thorium.

controlled by the presence of potassium, but there is no correlation between potassium and the amount of organic matter deposited. Previous studies demonstrate that TOC does not directly relate to any radioactive substance in the Utica-Point Pleasant interval. Other methods may be used for evaluating TOC in the Ordovician shales, such as bulk density and electrical resistivity log method (Meyer and Nederlof, 1984; Passey at al., 1990; Herron, 1991). When carbonate-content results and TOC measurements were plotted with geophysical logs, graphs demonstrate that the GR log is mainly influenced by carbonate and clay content, rather than by TOC content. These findings are different from the Marcellus Shale play, where GR and TOC are correlated strongly with TOC. In the Utica and Point Pleasant formations, the TOC and GR do not track each other, whereas the carbonate content trails the GR closely (Erenpreiss, 2015).

Typically, the organic-rich portion is more carbonate-rich in the basal interval of the Utica and more clay-rich upward. Most or all wells drilled in the Utica Play are targeting the Point Pleasant, which is the organic- and carbonate-rich portion at the base of the organic-rich interval. In general, the organic-rich interval in the Utica formation has an average carbonate content of about 25%. This means that the clay content is in the 70% range, which is very high (which might prevent rock from being fracked effectively). The Point Pleasant has an average clay content of about 50% (Patchen et al., 2015).

Acknowledgments

This document benefited from thoughtful suggestions by members of West Virginia Geological & Economic Survey, Pennsylvania Bureau of Topographic & Geologic Survey, Ohio State Geological Survey, and New York State Geological Survey.

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