

A Geologic Play Book for Utica Shale Appalachian Basin Exploration

Abstracts

The following pages contain the compiled individual abstracts for each section of the Play Book. Please visit www.wvgs.wvnet.edu/utica or <http://karl.nrcce.wvu.edu> to access project content.

Citation

Please use the following text for citation of the overall Play Book:

Patchen, D.G. and Carter, K.M., eds., 2015, A geologic play book for Utica Shale Appalachian basin exploration, Final report of the Utica Shale Appalachian basin exploration consortium, 187 p. Available from: <http://www.wvgs.wvnet.edu/utica>.

A Geologic Play Book for Utica Shale Appalachian Basin Exploration

Abstract

Introduction and Purpose Utica Shale Play Book Study Website

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The Appalachian Oil and Natural Gas Research Consortium (AONGRC) and the West Virginia University Shale Research, Education, Policy and Economic Development Center are pleased to present the Utica Shale Appalachian Basin Exploration Consortium website. This website contains research results and data collected as part of a two-year, industry-sponsored consortium facilitated by West Virginia University's National Research Center for Coal and Energy (NRCCE). Research team members include geoscientists from the Kentucky, Ohio, Pennsylvania and West Virginia geological surveys, Washington University, Smith Stratigraphic LLC and the U.S. Department of Energy National Energy Technology Laboratory.

The Utica Shale Consortium website contains three main sources of data: the project play book, well file document search and interactive mapping application. The project play book, a final technical report of project results, contains chapters on drilling activity and production, lithostratigraphy, subsurface mapping and log analysis, core studies, inorganic and source rock geochemistry, reservoir porosity and permeability and resource assessments. Datasets utilized for each of these research topics are available for download via a well file document search. The well document database includes a comprehensive repository of more than 2500 digitized or scanned well logs as well as source rock analyses, scanning electron microscope (SEM) images, X-ray computed axial tomography (commonly known as "CT") scans and analyses, rock mechanics tests, isotope data and X-ray diffraction (XRD) reports. These data are searchable by any combination of analysis type, API number, state and/or county. Finally, data are also accessible via an interactive mapping application created in Esri ArcGIS for Server. The interactive map enables users to search and retrieve information based on geographic location and links to the project data repository. In addition, map layers are published as ArcGIS services to ensure ease of access. Please visit www.wvgs.wvnet.edu/utica or <http://karl.nrcce.wvu.edu> to access project content.

Citation

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A Geologic Play Book for Utica Shale Appalachian Basin Exploration

Abstract

Regional Drilling Activity and Production

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Through the end of May 2015, approximately 2,425 permits have been issued to drill horizontal wells to the Upper Ordovician Utica/Point Pleasant Shale, mainly in eastern Ohio, but with approximately 253 in Pennsylvania and 29 in the northern panhandle counties of West Virginia. Chesapeake is by far the biggest player in the trend (860 wells permitted) with Hilcorp and Gulfport following next (222 and 214, respectively). Drilling has been concentrated in the liquids-rich core area of eastern Ohio that includes Carroll, Harrison, Belmont, Monroe, Noble, Guernsey and Columbiana counties. Activity extends to Tioga County, Pennsylvania (east); Wood County, West Virginia (south); Licking County, Ohio (west); and Ashtabula County, Ohio (north). At this point in time, there have been no horizontal Utica/Point Pleasant horizontal wells drilled in Kentucky or New York. Increased drilling and production in southern Ohio may eventually extend the play into northern Kentucky. Currently there is a horizontal drilling moratorium in New York. Oil, condensate and natural gas liquids (NGLs) are driving production growth. As midstream operations (pipelines, fractionation and gas processing plants) continue to expand, additional drilled wells are being placed into production mode.

Annual and quarterly production data reported in Ohio have shown a marked increase over the past 4 years. In 2011 the cumulative annual production was approximately 46,000 barrels of oil (bbl) and 2.5 billion cubic feet of gas (Bcf) from nine producing wells. This represented only 1% of the total oil production and 3.5% of the total gas produced in Ohio. By 2014, 786 Utica/Point Pleasant wells had yielded approximately 15.3 million bbl oil and 518 Bcf gas, which represented 70% of the total oil and 85% of the total gas produced in Ohio. The total reported cumulative production in Ohio for the Utica/Point Pleasant from 2011 through the first quarter of 2015 was approximately 19.5 million bbl oil and 744 Bcf gas. Production numbers are expected to continue increasing in the upcoming years as mid-stream operations expand out and additional drilling continues.

A map of cumulative production per well was constructed for data through the end of the first quarter 2015. Gas production was converted to barrels of oil equivalent (boe) and added to the barrels of oil produced to determine cumulative production per well in boe. Approximately 143.5 million boe were produced from 2011 to the end of the first quarter 2015. A northeast-southwest trend of higher production is seen extending through Columbiana, Carroll, Harrison, Belmont, Noble and Monroe counties in Ohio. The best ten wells produced over 600,000 boe during this time and are located in Belmont, Monroe and Harrison counties. Higher pressures in this region are thought to be a factor in these higher rates. The highest cumulative producing well through the end of the first quarter 2015 was the Chesapeake Buell well (API#340672I 0570100) in Harrison County, which produced approximately 829,945 boe. Range Resources recently completed the Claysville Sportsmen Club well in Washington County, Pennsylvania (API#3712527333), reporting an initial production rate of 59 million cubic feet (MMct) of gas per day. This is the highest producing well in the dry gas region of the play to date.

Results have been less encouraging to the north and west of these better producing areas. The northern portion of the trend in Ashtabula and Trumbull counties has shown lower producing rates and is reflected by the decline in permitting and drilling. Thus far, drilling further west in the updip portion of the oil window also have had less encouraging results as seen by the nonproductive Devon wells drilled in Coshocton, Knox, Medina, Wayne and Ashland counties. Clearly, the economic producing extents of this play are still being developed.

A gas-to-oil (GOR) map was constructed using the reported production data in Ohio. A northeast-southwest trend separating the oil from the dry gas window is evident using a GOR of 10,000 standard cubic feet of gas/barrel of oil (scfg/bo). A GOR map used in conjunction with bitumen reflectance and RockEval mapping from this project has helped to better refine the oil and gas window in this unconventional shale play.

Citation

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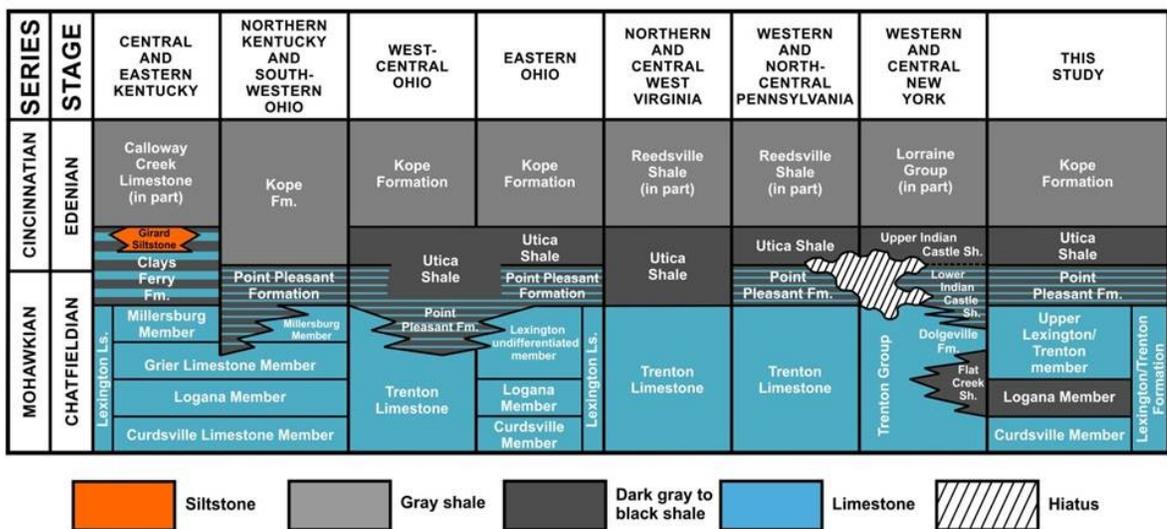
A Geologic Play Book for Utica Shale Appalachian Basin Exploration

Abstract

Lithostratigraphy

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The geologic section analyzed in this Study includes Upper Ordovician strata from the Mohawkian and Cincinnati Series across parts of Kentucky, Ohio, West Virginia, Pennsylvania and New York. While the local names for these units differ across the Study area, the stratigraphic nomenclature used herein corresponds to those used in southwestern Ohio, as well as adjacent parts of Kentucky where these units have been mapped at the surface. These units, in descending order, are the siltstone-rich Kope Formation, the more organic-rich Utica Shale, the Point Pleasant Formation of alternating limestone and shale beds and the Lexington Limestone/Trenton Formation. The Lexington Limestone/Trenton Formation interval is further subdivided into the informal "upper Trenton," the Logana Member and the Curdsville Member.



Correlation chart for early Late Ordovician strata evaluated by the Utica Shale Play Book Study

Citation

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A Geologic Play Book for Utica Shale Appalachian Basin Exploration

Abstract

Subsurface Mapping and Correlation through Geophysical Log Analysis

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A large, regionally extensive IHS Petra® software database was constructed using information from 10,416 wells within the Appalachian basin and surrounding crustal arch provinces. To aid in regional correlation, geophysical well logs were obtained for 1,978 of the wells (the vast majority of which were in digital LAS format) and loaded into the Petra project. This enabled project researchers to extend well-log-based stratigraphic interpretations for the Kope Formation, Utica Shale, Point Pleasant Formation, upper Lexington/Trenton Formation and Logana and Curdsville members of the Lexington/Trenton Formation from their mapped exposure areas into the subsurface. In addition, researchers studied the Upper Ordovician stratigraphy on outcrops in the Maysville, Kentucky area and interpreted Upper Ordovician stratigraphy for three continuous cores from Kentucky. The Upper Ordovician intervals of two of these (C-209 in Montgomery County and C-316 in Pulaski County) were photographed in 10-foot intervals for visual analysis. These detailed analyses facilitated the research team's understanding of depositional and facies characteristics of the Utica and Point Pleasant formations, and how those characteristics might be expressed within typical log suites. Following the log correlations for individual wells, regional structure and isopach maps were prepared for each of the six relevant stratigraphic units.

Citation

Please use the following text for citation of this section:

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A Geologic Play Book for Utica Shale Appalachian Basin Exploration

Abstract

Core Studies

High-Resolution Core Photography and Spectral Gamma-Ray Logging

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A key element for successful exploration of the Upper Ordovician shales in the Appalachian basin, as with any shale play, is the amount of Total Organic Carbon (TOC) present in the shale. The percentage of TOC is a vital factor in determining the potential for hydrocarbon generation, as well as understanding its areal distribution, both of which allow exploration efforts to focus on higher potential areas in a given basin.

TOC data are usually acquired by collecting and analyzing core or drill cuttings. Due to the limited volume of rock samples typically available, however, understanding the regional distribution of TOC can be challenging. This challenge has been managed in other stratigraphic units and shale basins (e.g., Marcellus Shale and Alberta basin) by identifying a proxy for predicting TOC using downhole wireline logs. In these cases, the Uranium-to-TOC or Density-to-TOC relationship could be used to accurately predict the percentage of organic carbon present in the rocks.

For this study, high resolution photography, spectral gamma-ray (SGR) and TOC data were collected from 11 Appalachian basin cores. A detailed examination of the relationships between gamma-ray (GR), uranium (U), thorium (Th) and potassium (K) to TOC was studied to identify a proxy for predicting TOC in the Upper Ordovician Utica and Point Pleasant shales using more abundant downhole wireline logs.

Study results indicate that Upper Ordovician shales in the Appalachian basin do not exhibit a direct correlation of TOC to the SGR signature. The GR intensity for Utica and equivalent rocks is dominated by the presence of potassium, and there is no correlation with the amount of organic matter. Factors that may prevent such a relationship include, but are not limited to, the volume of carbonate material, the lack of available uranium in seawater, or the amount of oxygen in the system. This investigation clearly demonstrates that TOC does not directly correlate to any radioactive material in the Utica/Point Pleasant interval. Other methods, including the density to TOC relationship, appear to be better gauges for predicting TOC in these Ordovician shales.

Sedimentology, Stratigraphy, Carbonate Content, Organic Content and Depositional Environment Characteristics of Utica/Point Pleasant in Ohio and New York

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The Utica/Point Pleasant interval in Ohio is equivalent to the Flat Creek-Dolgeville Indian Castle interval in New York. These can be correlated using carbon isotopes and logs. The Point Pleasant in Ohio is

equivalent to the Flat Creek and Dolgeville formations in New York, which also are carbonate- and organic-rich and significantly thicker. Carbonate content is in the 40-80% range and TOC ranges from 1-3% in New York and up to 5% in Ohio. The organic-rich Utica in Ohio is equivalent to the Lower Indian Castle Formation in New York which has carbonate content around 25%. TOC ranges from 1-3% in both Ohio and New York.

Five long cores of the Utica-Point Pleasant-Trenton interval in Ohio were studied in detail. Thin sections were described semi-quantitatively and used to aid in centimeter-scale core description. TOC and carbonate content were analyzed down to one-foot scale in organic-rich intervals.

The basal Kope and uppermost Utica Shale consist of interbedded gray and black shale. The black shale beds have TOC up to 3%. Carbonate content is generally <10% in this interval. The middle portion of the Utica Shale is composed of black shale with TOC up to 3.5% and carbonate content generally around 25%. At the base of the Utica is an interval consisting of gray shale and coarse limestone storm beds with abundant bryozoans and crinoids. This interval is organic-poor with TOC generally <1 % and carbonate content of 25-50%. There is an apparent unconformity at the top of this interval.

The organic-rich limestone interval that is the main target for drilling incorporates three stratigraphic units: the Point Pleasant Formation and the upper Lexington and Logana members of the Lexington/Trenton Formation. The organic-rich Point Pleasant has abundant carbonate storm beds. TOC values are up to 5% and carbonate content is generally in the 40-60% range. The upper Lexington member has higher carbonate content and some well-developed limestone beds at the top where there is evidence for an erosional unconformity. Higher TOC was measured immediately above and below this apparent unconformity with values up to 4.5%. The upper Lexington generally has carbonate content around 70%. The underlying Logana member has TOC up to 5% and contains abundant ostracods. The upper Logana has few limestone beds, but the lower part has some laterally-extensive brachiopod rudstone beds interbedded with high-TOC strata.

There is good evidence for storms and currents throughout the main organic-rich reservoir interval, with burrows and benthic fossils interpreted to be in situ within the organic-rich facies. This suggests that the organic-rich strata were deposited in a relatively shallow water environment that was affected by frequent storms. Water conditions were not permanently anoxic but may have been seasonally anoxic.

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Smith, Langhorne B., Jr., 2015, Core description, petrography, sedimentology, stratigraphy, TOC and depositional environment, *in* Patchen, D.G. and Carter, K.M., eds., *A geologic play book for Utica Shale Appalachian basin exploration, Final report of the Utica Shale Appalachian basin exploration consortium*, p. 49-73, Available from: <http://www.wvgs.wvnet.edu/utica>.

A Geologic Play Book for Utica Shale Appalachian Basin Exploration

Abstract

Inorganic Geochemistry

Bulk Mineralogy

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The research team used X-ray diffraction (XRD) and scanning electron microscopy (SEM) to evaluate the bulk mineralogy composition of Utica, Point Pleasant and Trenton samples from the Study area. X-ray powder diffraction aided in determining mineral compositions of these lithologies in drill cutting samples from five wells in New York, six wells in Ohio and 17 wells in Pennsylvania, as well as of Utica-equivalent rocks from 18 outcrops in central Pennsylvania, for a total of 930 samples. Semi-quantitative results made using the Rietveld method, a sophisticated technique that can take into account such factors as preferred orientation and peak shape, provided a level of precision sufficient for dividing the minerals into major categories for classifying the lithologies that were encountered. Data from interpreted XRD analyses fell into three broad categories: (1) quartz plus feldspar; (2) carbonates; and (3) clay minerals. Plots of these data for all wells in which more than three intervals were sampled (none of the outcrops had sufficient samples) reflect changes in mineralogy with depth. Displaying the mineralogy results in this manner facilitates the interpretation (or in many cases, confirmation of past interpretation) of Utica, Point Pleasant, Trenton and other formation and member boundaries. While XRD plots are based on drill cuttings obtained from specific intervals within each well, interpretations based on them without reference to geophysical logs of the same intervals may result in inconsistent or inaccurate correlations. A complete set of the data spreadsheets and plots is available in the final report.

SEM imaging was used in conjunction with energy-dispersive spectroscopy (EDS) techniques of nine samples of Utica and Point Pleasant drill cuttings from three wells in Pennsylvania. Analytical data for each sample included: (1) a high-resolution image; (2) an EDS spectrum, which includes a graph and a text file listing the percentages of the elements in the entire area shown in the high-resolution image; and (3) a set of element maps showing where the particular element was detected. A map for sulfur, for example, shows where pyrite grains exist, whereas a map for calcium probably indicates the distribution of carbonates. For each sample, separate maps for aluminum, calcium, iron, potassium, magnesium, sodium, sulfur, silicon and titanium were constructed. In addition, the research team prepared element maps that illustrate multiple elements in contrasting colors that can be used not only to show the distribution of elements, but also to verify the identity of grains in the SEM photomicrographs. For example, a map of silicon and calcium that has a high percentage of calcium but basically no silicon most likely indicates grains of carbonates rather than of plagioclase feldspars. Likewise, a three-color map of aluminum, silicon, and potassium showing an abundance of each element scattered across the map would suggest that the sample is composed mainly of potassium aluminum silicate, indicating probable clay minerals, k-feldspar or other silicate minerals. When used in conjunction with XRD analysis, this becomes a powerful tool to determine the most likely mineralogy.

Carbonate Content

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The research team measured rock cuttings and core samples from approximately sixty wells in New York and Ohio in order to determine carbon content using an insoluble-residue analytical procedure. For each given sample, carbonate-content results and Total Carbon Content (TOC) were then plotted with geophysical logs. The results indicate that within the Utica/Point Pleasant interval, TOC does not directly correlate to any radioactive material, and that the gamma-ray (GR) log is primarily driven by carbonate and clay content instead of TOC. In fact, the carbonate content tracks the GR almost exactly.

Data collected and analyzed from four wells in Ohio indicate that reservoirs, in the absence of matrix porosity, containing high TOC and carbonate content may be the most successful. Higher carbonate content will consist of more brittle and "fracable" rock, whereas high TOC will provide the amount of organic matter needed for a productive reservoir. Some additional porosity can also be found between clay particles, suggesting that slightly higher clay content is indeed beneficial.

The organic-rich interval of the Utica is more carbonate-rich in the basal sections of the formation. The Ohio wells that were studied indicate that the organic-rich shale in the Utica had an average carbonate content of approximately 25% and a clay content of about 70%. The clay content in the Utica is incredibly high, likely too high for the rock to be fraced effectively. The Point Pleasant Formation contains an average clay content of about 50% within the organic-rich facies, and an even greater percentage in the limestone beds. The upper Lexington/Trenton and Logana members have carbonate content values that average approximately 70% in their organic-rich facies.

Carbon Isotopes

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Carbon isotopes can be used as a chronostratigraphic tool because the isotopic composition of the marine inorganic carbon reservoir ($\delta^{13}\text{C}_{\text{DIC}}$) changes synchronously across the ocean over time. There is little isotopic fractionation during carbonate precipitation so that $\delta^{13}\text{C}_{\text{carb}} \approx \delta^{13}\text{C}_{\text{DIC}}$. This allows researchers to use $\delta^{13}\text{C}_{\text{carb}}$ to temporally correlate spatially disparate strata. This Study used $\delta^{13}\text{C}_{\text{carb}}$ to set up a chemostratigraphic framework for the greater Appalachian basin. Similar to a previous study on coeval strata in New York, numerous $\delta^{13}\text{C}_{\text{carb}}$ trends were identified in the current Study region, and these $\delta^{13}\text{C}_{\text{carb}}$ trends were used to correlate strata across various lithologies. Organic-rich strata appear to be most

abundant in a specific $\delta^{13}\text{C}_{\text{carb}}$ interval named TR-1, which occurs just after another $\delta^{13}\text{C}_{\text{carb}}$ interval, the Guttenberg isotopic carbon excursion (GICE), a global positive $\delta^{13}\text{C}_{\text{carb}}$ excursion. The GICE represents a major perturbation of the global biogeochemical carbon cycle, but its cause is unknown. Strata containing $\delta^{13}\text{C}_{\text{carb}}$ interval TR-1 are currently interpreted to have been deposited during a sea level rise, perhaps during post-GICE deglaciation; however, evidence for glacially-forced sea level change is indirect. Here the research team presents a sediment accumulation model where sea level is the only free variable controlling sedimentation locus. The driver of sea level change may be shifts in glacial ice abundance due to the short nature of a transgressive-regressive cycle (<500,000 years). Alternatively, the change in sedimentation locus could be tectonic in origin, or at least tectonically influenced as the study units were deposited during the end of the Taconic Orogeny, a period of heightened tectonism and explosive volcanism in the region.

While the true mechanism that drove changes in lithology and $\delta^{13}\text{C}_{\text{carb}}$ is still uncertain, it is apparent the carbon cycle was perturbed during the transition in depositional environment. Further, deposition of the most organic-rich strata appear to fall in the transitional argillaceous carbonates of the Trenton Group, deposited between the clean carbonates of the Black River Group and the calcareous shales of the Utica Shale. This suggests that organic matter production and/or preservation was enhanced during environmental transition rather than during periods of environmental stability. Numerical box models of the biogeochemical carbon cycle were used to explore the general magnitude and duration of the perturbations the global carbon cycle that drove the $\delta^{13}\text{C}_{\text{carb}}$ signal. Model results supply a broad, but important set of constraints changes on global organic carbon burial and weathering patterns.

Citation

Please use the following text for citations of this section:

Harper, John A., 2015, Bulk mineralogy, *in* Patchen, D.G. and Carter, K.M., eds., *A geologic play book for Utica Shale Appalachian basin exploration, Final report of the Utica Shale Appalachian basin exploration consortium*, p. 74-81, Available from: <http://www.wvgs.wvnet.edu/utica>.

Smith, Langhorne B, Jr., 2015, Carbonate content, *in* Patchen, D.G. and Carter, K.M., eds., *A geologic play book for Utica Shale Appalachian basin exploration, Final report of the Utica Shale Appalachian basin exploration consortium*, p. 82-90, Available from <http://www.wvgs.wvnet.edu/utica>.

Metzger, J. Garrecht, Fike, David A., and Smith, Langhorne, Jr., 2015, Carbon Isotopes, *in* Patchen, D.G. and Carter, K.M., eds., *A geologic play book for Utica Shale Appalachian basin exploration, Final report of the Utica Shale Appalachian basin exploration consortium*, p. 90-102, Available from: <http://www.wvgs.wvnet.edu/utica>.

A Geologic Play Book for Utica Shale Appalachian Basin Exploration

Abstract

Source Rock Geochemistry

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Reported source rock geochemistry incorporates both legacy and newly-generated data, and includes evaluations of organic matter content, quality and thermal maturity. The research team performed total organic carbon (TOC) analyses, reviewed legacy RockEval data and performed bitumen reflectance analyses to assess the thermal maturity of these reservoir rocks. Well cuttings and core samples were analyzed to assess their TOC content. TOC values greater than 1% are interpreted to have the potential for hydrocarbon production, presuming that adequate thermal maturation has occurred. A total of 1,094 samples, from 29 wells, were analyzed for TOC content during the course of the Study. Additional TOC data were incorporated using values from existing TOC datasets that were collected for other projects. These legacy data include 3,054 Upper Ordovician TOC data points from Ohio and 4,652 TOC data points from New York wells (including some shallower data). Collectively, a total of 368 well locations with TOC data were used to determine vertical and spatial variability of TOC in the Utica Shale. Using these data, regional maps were generated for (in stratigraphically descending order), the Kope, Utica and Point Pleasant formations, and the upper Lexington/Trenton, Logana and Curdsville members.

Once the regional TOC data had been compiled for the studied units, numerous data comparisons and crossplots were made. The one commonly recorded parameter that appears to correlate with TOC abundance is the bulk density log. This correlation appears to be the strongest within the upper Lexington/Trenton and Logana members, and with diminished correlation within the more shale-rich Point Pleasant Formation and Utica Shale. The Kope Formation and Curdsville Member displayed little to no correlation between density and TOC.

Historical results for 1,900 RockEval analyses of Upper Ordovician strata were examined for the Study. Thorough inspection of these data revealed a high degree of variability in the RockEval results. This variability was noted both between adjacent wells and even within the same unit of individual wells. The variation appears to be the result of weak, or poorly defined, S2 peaks on the pyrolysis curves for these units. Whether this is due to the oxidation of older cuttings samples, or it is just the nature of the specific organic material within these units, is unclear.

More than 500 samples of the Utica Shale from Kentucky, Ohio and Pennsylvania were taken from exploration wells and examined petrographically in reflected light to obtain bitumen reflectance measurement data (Ro). Of these, roughly half had sufficient amounts of bitumen to analyze. In Ohio, the level of thermal maturity in the Utica shows a progression in increasing bitumen reflectance from west to east, with a very steep increase occurring in eastern Ohio. Ro random values from central Ohio ranged from 0.66 to 0.84%, where sample depths were between 100 and 4,800 ft. In eastern Ohio, sample depths ranged from 8,700 ft to more than 15,000 ft, and corresponding Ro values ranged from 0.94 to 1.43%. Thermal maturity analyses of bitumen reflectance broadly matched expected maturities based upon the fluid content (oil, wet gas, dry gas, etc.) from initial production reports in the eastern Ohio Utica Play area.

In northwestern Pennsylvania, reflectance samples ranged from 1.1 to 1.4%. In a south to southeasterly direction, reflectance values increased from 1.7%, in areas that border Ohio and West Virginia, to more than 2.0% in the central portion of the state.

Conodont Alteration Index (CAI) is a well-known technique used to evaluate the level of thermal maturation in source rocks. Their color alteration is both time- and temperature-dependent, and is a progressive, irreversible condition, making them ideal for correlating to maximum reservoir temperatures (Tmax). The Study's CAI dataset incorporates measurements collected specifically for this project (ten Ohio wells) as well as those compiled from a previously published USGS report. These data report values between 1.0 and 1.5 for samples from the western-most portion of the Study area, and values between 1.5 and 2.0 for central and east-central Ohio. Values of 2.0 or greater were observed only in eastern-most Ohio, near the borders of Pennsylvania and West Virginia. These data illustrate an increased maturity from west to east, very similar to the bitumen reflectance pattern observed for Ohio.

Collectively, the bitumen reflectance, RockEval, and CAI data indicate that petroleum liquids and wet gas are predicted to be the principle recoverable resource in central and east-central Ohio, as well as northwestern Pennsylvania. In eastern-most Ohio, and the majority of Pennsylvania, elevated levels of thermomaturity indicate wet and dry gas to be the dominant hydrocarbon resource.

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A Geologic Play Book for Utica Shale Appalachian Basin Exploration

Abstract

Reservoir Porosity and Permeability

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The Study used a multi-disciplinary approach to assess Utica reservoir porosity and permeability characteristics. The research team employed scanning electron microscopy (SEM) and X-ray Computed Axial Tomography (CT X-ray) techniques to visualize and describe pore space characteristics at different scales of resolution. Due to a lack of access to relatively new (i.e., "fresh") core samples, we augmented our data set using laboratory-derived porosity and permeability data obtained from other earlier research activities in the Study area. The resulting data set represents a compilation of both legacy and newly generated analyses from publicly available Utica/Point Pleasant core and rock cuttings samples collected in the Appalachian basin.

Petrographic studies indicate there is little to no matrix porosity in Utica/Point Pleasant rocks, and standard SEM imaging confirmed the tight nature of the shale matrix in these rocks. SEM analyses of ion-milled samples, however, illustrated various pore types and sizes. Pore types include phyllosilicate framework pores (due to presence of clay mineral platelets in various orientations or state of compaction), dissolution pores (from the dissolution of carbonate minerals) and organic matter pores (resulting from out-migration of hydrocarbons). Pores vary in size, and from location to location, but generally range from tens or hundreds of nanometers (nm) to as much as 1 micron (μm) or more. Based on these observations, we have interpreted the organic matter pores, formed during maturation of hydrocarbons, to be the dominant contributor to hydrocarbon production in the Utica/Point Pleasant play.

Two cores were selected for CT X-ray analysis as part of the Study: (1) the Lost River core, collected as geotechnical samples from a dam site in the eastern panhandle of West Virginia in 1978; and (2) the Fred Barth No. 3 (API#3403122838), collected in Coshocton County, Ohio, in 1976. The Lost River core was taken from an interval of shelf carbonate in the limestone facies associated with the lower portion of the Martinsburg Formation, approximately equivalent in age to the Utica Shale, while the Fred Barth No. 3 core comprises organic-rich, calcareous black shales more commonly associated with the Utica/Point Pleasant interval.

Intact segments of the Lost River core were run through a Geotek© Multi-Sensor Core Logger. Measurements included magnetic susceptibility, acoustic impedance via P-wave velocity, gamma density using a Caesium-137 source and elemental composition via X-ray fluorescence spectrometry. The Barth No. 3 core had been too extensively sampled, plugged and slabbed to provide usable material for the Geotek© scanner. Selected samples of both cores were imaged using CT X-ray techniques. This method

produces a three-dimensional, digital reconstruction of the scanned object by measuring the contrast as X-rays are attenuated by areas of different density within a sample.

Porosity and permeability analyses were not performed on either the Barth No. 3 or Lost River cores as part of the Study because both were too old to provide reliable results. Nonetheless, a considerable amount of legacy core data was available for the Barth core. The measured porosity to gas in this core ranged from 2 to 8%, with an average porosity of 5.6% across the entire interval tested. The permeabilities of most of the Barth samples were below the minimum reporting limit of 0.1 millidarcy. Oil saturations varied from about 20 to 60% of pore volume, with an average oil saturation of 40.6%. The average water saturation in the core interval tested was 35.2%.

Citation

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A Geologic Play Book for Utica Shale Appalachian Basin Exploration

Abstract

Utica Play Resource Assessment

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A Utica Play resource assessment was conducted to estimate: (1) remaining recoverable hydrocarbon resources and (2) original hydrocarbon resources in-place. Remaining technically recoverable resources were determined using a probabilistic approach following an outline developed by the USGS. Original hydrocarbon in-place resources were determined using a volumetric approach.

Remaining Recoverable Hydrocarbon Resources, Probabilistic (USGS-Style) Approach

Assessment units were defined on the basis of structural geology, maturation and distribution of producing wells. Conodont alteration index (CAI) values were converted to equivalent vitrinite reflectance (%Ro), and results were combined with published values to draw a new map of thermal maturity trends in the Study area. Vitrinite reflectance equivalents were also converted to a new set of indicator variables according to whether raw Ro equivalents exceeded published thresholds for immature, oil-prone, gas-prone and overmature hydrocarbon generation windows. Each indicator variable, when contoured, gave a measure of the likelihood of exceeding each threshold. Maps of producing gas wells, liquids-rich gas wells, and oil wells superimposed on the contoured indicator variables gave specific contours from which to outline the oil, wet gas and dry gas sweet spots. Assessment unit boundaries and sweet spot outlines were compared with structure contour maps for refinement in areas of sparse or no wells.

Annual cumulative production data collected from public records in each state were graphed and fitted with a harmonic model of decline. A maximum of four years of data were available. Models were fit to median values of annual production and estimated ultimate recoveries (EURs) after forty years calculated. The fifth percentile of annual production for 2014 was used to calculate the minimum recovery within sweet spots. Maximum EUR was calculated from a model fitted visually to scatter plots of individual well production values.

This Study followed the probabilistic approach developed by the USGS and used in their 2012 assessment of undiscovered oil and gas resources of the Utica Shale. Under this approach, the geologist defines the geographic limits of an assessment unit, which is an area with expected oil or gas resources with generally the same or similar thermal maturity, organic content, lithology, source rock and trapping mechanism. The largest source of production data was a public database from the state of Ohio, which for the years available has natural gas liquids (NGLs) and gas reported as a single number. Therefore, calculation of the gas resource in the wet gas assessment unit includes a significant percentage of natural gas liquids.

The following tables present results for the three assessment units.

Oil Assessment Unit	Remaining Technically Recoverable Resources							
	Oil (MMbo)				Gas (Bcf)			
	F95	F50	F5	Mean	F95	F50	F5	Mean
Sweet Spot	733	1,677	3,744	1,908	2,231	6,636	17,722	7,949
NonSweet Spot	23	49	91	52	69	191	446	216
Total	791	1,728	3,788	1,960	2,370	6,858	17,960	8,165

Wet Gas Assessment Unit	Remaining Technically Recoverable Resources							
	Oil (MMbo)				Gas (Bcf)			
	F95	F50	F5	Mean	F95	F50	F5	Mean
Sweet Spot					23,840	49,601	106,550	55,980
NonSweet Spot					99	379	1,023	447
Total					24,484	50,037	106,852	56,427

Gas Assessment Unit	Remaining Technically Recoverable Resources							
	Oil (MMbo)				Gas (Bcf)			
	F95	F50	F5	Mean	F95	F50	F5	Mean
Sweet Spot					220,473	590,680	1,542,873	710,341
NonSweet Spot					2,862	6,584	13,835	7,238
Total					228,478	598,026	1,549,586	717,579

Original In-Place Hydrocarbon Resources, Volumetric Approach

The second resource assessment method used a volumetric approach to determine original hydrocarbon-in-place. The volumetric approach provides a means to assess resource potential from fundamental data in a manner that is independent of development practice, well performance, economics and the limited geographic extent of exploratory activity that often characterize the early development of a hydrocarbon play. Basic geologic and reservoir data are used to define characteristics of a stratigraphic unit and calculate hydrocarbon volumes.

The Utica Shale, Point Pleasant Formation and Logana Member of the Trenton Limestone were each evaluated separately applying the volumetric assessment method. The overall evaluation area was separated into two regions - one to address original in-place oil resources in the western portion of the Utica Shale Play and another to address original in-place gas resources to the north and east. For each region, a single phase of either oil or gas was presumed to exist in the reservoir.

The calculation for total original hydrocarbon-in-place includes separate determination of free and adsorbed hydrocarbon volumes and was applied to individual wells for every half-foot of thickness. To derive all required parameters, a substantial amount of data was necessary. Digital petrophysical data, primarily

supplied by Utica Consortium partners, provided the foundation. Wells with gamma-ray, density/porosity, and resistivity well log data (at minimum) were selected preferentially for the Study. Additional well selection factors considered included well orientation, structural complexity, stratigraphic unit depth, geographic location and proximity to other wells. Depending on the particular stratigraphic unit, up to approximately 60 wells were selected for analysis. To augment digital log data, reservoir-specific input included or encompassed: thermal maturity, total organic carbon (TOC), gas content, pressure and temperature. Thermal maturity was determined from a map developed using equivalent %Ro values for the probabilistic resource assessment approach, while TOC was available for individual wells or extracted from stratigraphic-specific TOC maps constructed for the volumetric assessment task. Gas content, pressure and temperature were taken largely from publicly-available data, although some data were available for individual wells. After well-level calculations, summary data were gridded to interpolate between and extrapolate beyond wells. Petra®, ArcGIS and internally-developed software were used to manage, manipulate and analyze data.

The following table shows *preliminary* summary results for each stratigraphic unit evaluated using the volumetric approach.

Stratigraphic Unit	Original In-Place Resources, Average Volume Per Unit Area	
	Oil (MMbo/mi ²)*	Gas (Bcf/mi ²)*
Utica Shale	20.8	53.5
Point Pleasant Formation	15.8	85.1
Logana Member of Trenton Limestone	3.0	17.0

*~ average volume per square mile in the sweet spot area; sweet spot area is as defined to estimate remaining technically recoverable resources using a probabilistic (USGS-style) approach

Based on these studies, it is estimated that the current oil recovery factor is approximately 3% and the gas recovery factor is approximately 28% in the sweet spot areas.

Citation

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