PSMapping Storage and Enhanced Gas Recovery for Organic Shale in the Midwest Regional Carbon Sequestration Partnership*

Brandon C. Nuttall[1], Thomas N. Sparks[1], and Stephen F. Greb[1]

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Abstract

Midwest Regional Carbon Sequestration Partnership teams are investigating the potential for CO_2 storage and enhanced gas recovery in organic shales such as the Middle Devonian Marcellus Shale and Upper Ordovician Utica Shale in the Appalachian Basin. This work builds on past research on the Upper Devonian Ohio Shale in eastern Kentucky. For the Ohio Shale, Schmoker's density model was found to accurately estimate total organic carbon (TOC) from density in downhole geophysical logs. Because there are always more logs than sample analyses, determining if TOC can be reasonably estimated from logs is beneficial for regional mapping. For the Ohio Shale, density logs could then be used to map regional TOC distribution and thereby calculate potential CO_2 storage volume when used to enhance gas production. When Schmoker's density model was tested on Marcellus and Utica Shale data, however, results were more variable. Different models were developed to estimate TOC from downhole log data for each shale.

The Marcellus structure was mapped from 8900 well-log tops from southern New York southeast into Ohio and West Virginia. A net thickness map of the Marcellus Shale with net gamma ray greater than 180 API was constructed from 1,559 wells with gamma logs. A subset of 575 wells with density logs was used to model organic distribution. Mean (P50) TOC was contoured from an average of multiple wireline-based models. A gridded net thickness of shale with calculated TOC > 4% was mapped using the same data. General trends in the calculated TOC > 4% map compare well with the 180 API cutoff map, although a broader area of net organic-rich shale in northeastern Pennsylvania and southern New York is estimated from the TOC > 4% map. A potential Marcellus Shale volume of 2 billion acre-ft with a storage capacity of 1.1 to 3.7 billion tons of CO2is estimated from the TOC > 4% map. CO_2 storage capacity in the shale is based on the potential to use CO_2 for enhanced gas recovery and retention of CO_2 by adsorption on the organic-rich matrix.

A similar set of maps is being generated for the Upper Ordovician Utica–Point Pleasant play and potential CO_2 storage capacities will be estimated from the maps developed. Results to date show that different models are needed for estimating TOC in different organic-rich shales. Regional mapping of net organic thickness of the various shales will provide insight into the potential for CO_2 storage with enhanced gas recovery across the region.

References Cited

deWitt Jr., W., Roen, J.B., and Wallace, L.G., 1993, Stratigraphy of Devonian black shales and associated rocks in the Appalachian basin, in Roen, J.B., and Kepferle, R.C., eds., Petroleum geology of the Devonian and Mississippian black shale of eastern North America, USGS Bulletin 1909, p. B1–B57.

EIA, 2017, Utica Shale Play, Geology Review, April 2017, U.S. Energy Information Administration, https://www.eia.gov/maps/pdf/UticaShalePlayReport_April2017.pdf

Hickman, J., Eble, C., and Harris, D., 2015a, Lithostratigraphy, 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. 19-21, http://www.wvgs.wvnet.edu/utica.

Hickman, J., Eble, C., and Harris, D., 2015b, Subsurface mapping and correlation through geophysical log analysis: 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. 22–35, http://www.wvgs.wvnet.edu/utica.

Milici, R.C., 1996, Play Dbg: Upper Devonian fractured black shales and siltstones: in Roen, J.B., and Walker, B.J., 1996, The Atlas of Major Appalachian Gas Plays: West Virginia Geological and Economic Survey Publication V-25, p. 86–92.

Nuttall, B.C., 2010, Reassessment of CO_2 Sequestration Capacity and Enhanced Gas Recovery Potential of Middle and Upper Devonian Black Shales in the Appalachian Basin, MRCSP Phase II Topical Report, October 2005–October 2010, DOE Cooperative Agreement DE-FC26-05NT42589, OCDO Grant Agreement No. DC-05-13.

Patchen, D.G., Avary, K.L., and Erwin, R.B., 1985, Correlation of Stratigraphic Units of North America (COSUNA) project-Northern Appalachian Region, and Southern Appalachian Region: American Assoc. of Petroleum Geologists, 2 sheets.

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Schmoker, J.W., 1993, Use of formation-density logs to determine organic-carbon content in Devonian shales of the western Appalachian basin and an additional example based on the Bakken Formation of the Williston basin: in Roen, J.B., and R.C. Kepferle, eds., Petroleum geology of the Devonian and Mississippian black shale of eastern North America: U.S. Geological Survey Bulletin 1909, p. J1–J14.

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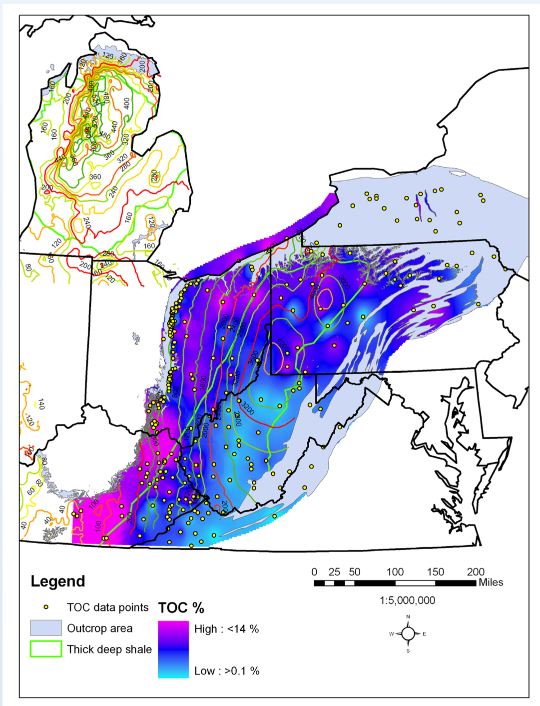
The Marcellus structure was mapped from 8900 well-log tops from southern New York southeast into Ohio and West Virginia. A net thickness map of the Marcellus Shale with net gamma ray greater than 180 API was constructed from 1,559 wells with gamma logs. A subset of 575 wells with density logs was used to model organic distribution. Mean (P50) TOC was contoured from an average of multiple wireline-based models. A gridded net thickness of shale with calculated TOC > 4% was mapped using the same data. General trends in the calculated TOC > 4% map compare well with the 180 API cutoff map, although a broader area of net organic-rich shale in northeastern Pennsylvania and southern New York is estimated from the TOC > 4% map. A potential Marcellus Shale volume of 2 billion acre-ft with a storage capacity of 1.1 to 3.7 billion tons of CO_2 is estimated from the TOC > 4% map. CO_2 storage capacity in the shale is based on the potential to use CO_2 for enhanced gas recovery and retention of CO_2 by adsorption on the organic-rich matrix.

A similar set of maps is being generated for the Upper Ordovician Utica–Point Pleasant play and potential CO_2 storage capacities will be estimated from the maps developed. Results to date show that different models are needed for estimating TOC in different organic-rich shales. Regional mapping of net organic thickness of the various shales will provide insight into the potential for CO_2 storage with enhanced gas recovery across the region.

Original storage estimate

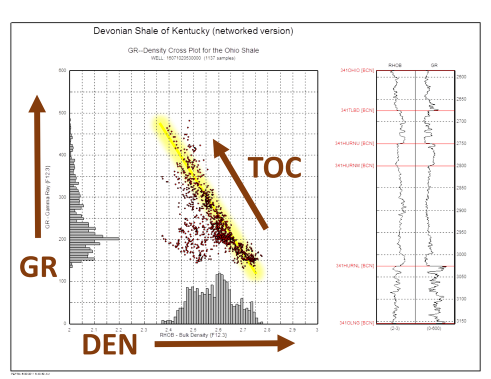


Spatial distribution of TOC percent including isopach of total Devonian Shale thickness (Nuttall, 2010).

- "One size fit all" – 3D distribution of TOC not considered
- Digital well log data not incorporated
- Total Devonian Shale (including Marcellus)

The Original Model:

- TOC from well logs
  - Density (Schmoker, 1979 & 1993)
  - Gamma ray (Schmoker, 1981)
- Based on shale mineral model



$$TOC = 55.822\left(\frac{\rho_B}{\rho} - 1\right)$$

Density is a function of:
- Matrix
- Pores
- Pyrite
- Organic matter

Caveats and Disadvantages

- Bulk density, ρ_B = maximum density of gray shale intervals
- Does not account for relationship between porosity and maturity

MRCSP Phase III Project
Task 1.0 – Regional Characterization
Subtask 1.3 – Assessment of Storage and Enhanced Gas Recovery for Organic Shale

The Plan
The Geoteams from each state compiled TOC and density data from downhole logs for the Marcellus Shale from which a 3-D geospatial model of **the distribution of organic matter, gas-in-place estimates, and CO2 storage capacity was built**.

As team leader, KGS is **compiling existing gas content (adsorption isotherms), geophysical logs, and organic content data (TOC and Rock-Eval) into the model**. The current model for estimating TOC using observed density data from geophysical logs and relating those data to gas storage capacity was developed for quartz-, clay-, and organic-rich black shales. Data for the Middle Devonian Marcellus Shale is being used to refine previous estimates of gas storage volumes specifically for that shale.

Similar data for the Utica Shale is being compiled. In the Upper Ordovician **Utica Shale**, the mode of organic matter preservation and **carbonate-dominated mineralogy** differ from classic black shales like the Marcellus. Hence a new model for gas storage content was required.

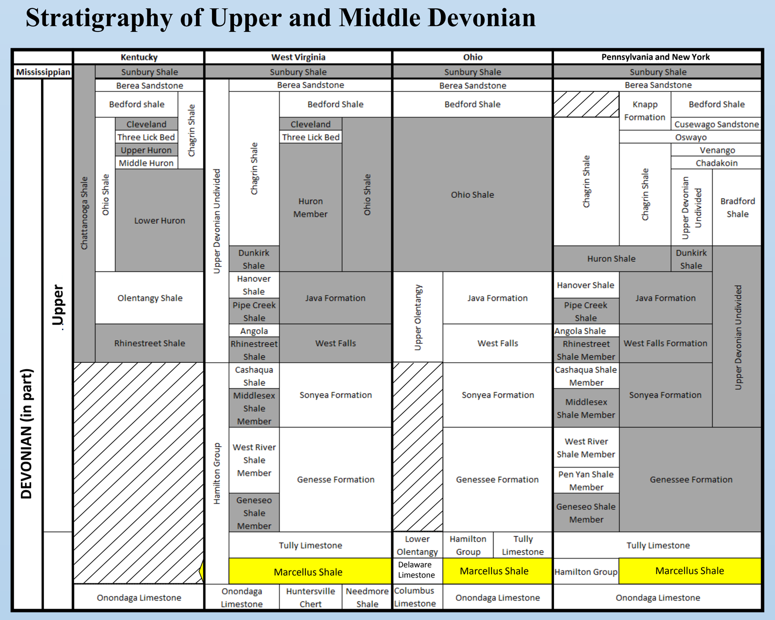
The results of the project will provide insight into the potential for storage and EGR resulting from the continuous injection of CO2 into shale gas formations. It is expected that improved methane production would be achieved (similar to that observed in enhanced coalbed methane operations).

Kentucky Geological Survey

MRCSP MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP

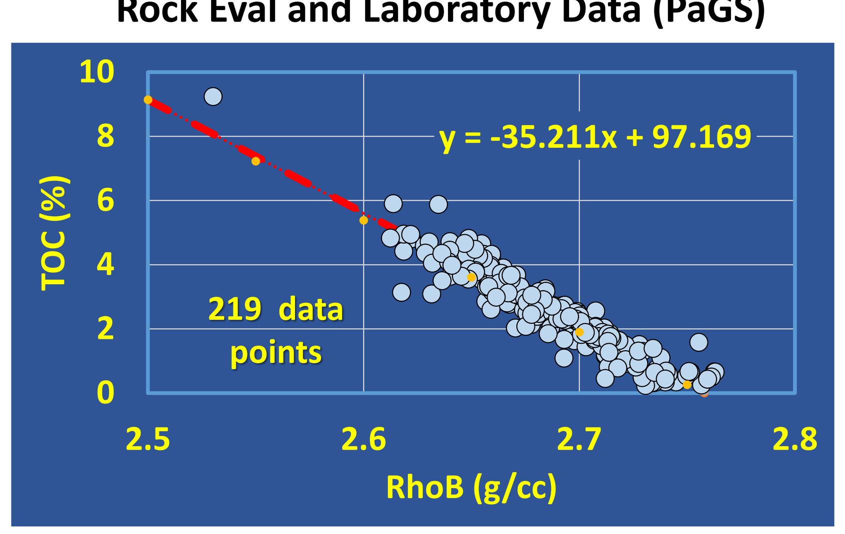
2018 Joint Eastern Section AAPG/SPE Meeting
October 7-11, 2018
Pittsburgh, Pennsylvania

Stratigraphy of Upper and Middle Devonian



Correlation chart of the Middle-Upper Devonian. Black organic-rich shales are shaded gray. The Marcellus Shale is highlighted in yellow (adapted from Patchen and others, 1985, deWitt and others, 1993, and Milici, 1996).

Rock Eval and Laboratory Data (PaGS)



Data for Analysis – Dev. Sh (including Marcellus)
- 129 wells & 1,995 depth records provided

MARCELLUS SHALE PLAY
2013 – 2016 Study

Mapping & 3D Modeling

Method summary
- TOC=f(GR) or f(RhoB)
- $Scf_{CO2}=f(TOC)$
- $Tons_{shale}$=A*h*RhoB
- Storage=$Tons_{shale}$*Scf_{CO2}*efficiency

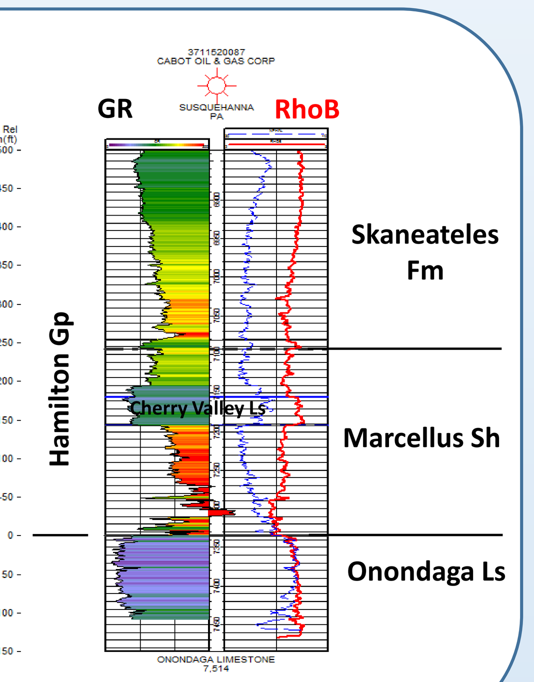
TOC Models employed

$$TOC_{Schmoker} = 55.822 * \left(\frac{Rho_{max}}{RhoB} - 1\right)$$

$$TOC_{mod} = 88.55 * \left(\frac{Rho_{max}}{RhoB} - 1\right)$$

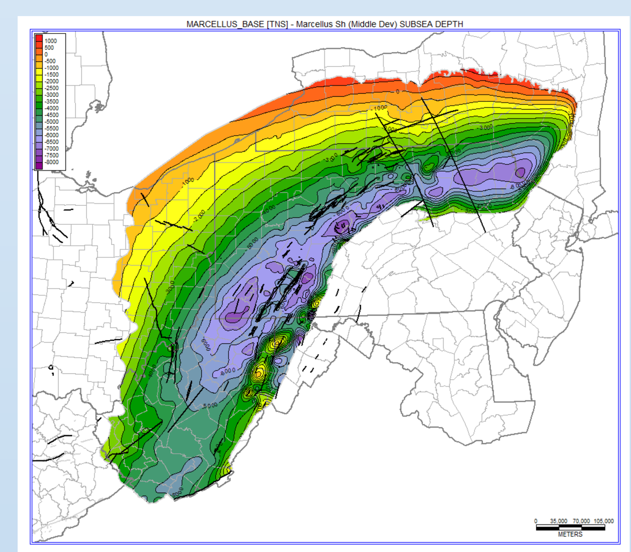
$$TOC_{Linreg} = -35.21 * RhoB + 97.17$$

$$TOC_{GR} = \frac{(GR_{min} - GR)}{1.378 * A}$$

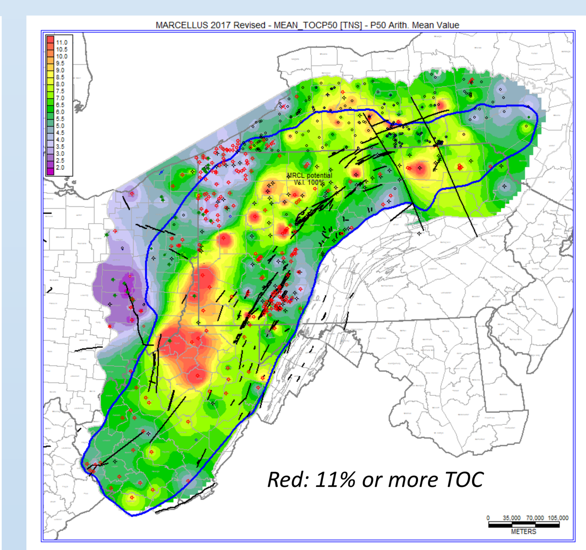


TOC models developed for the Marcellus Shale employing multiple analyses.

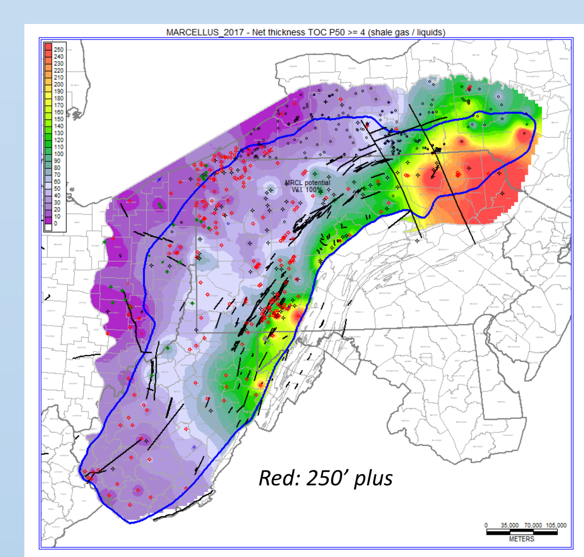
Regional Mapping – Marcellus Shale study area



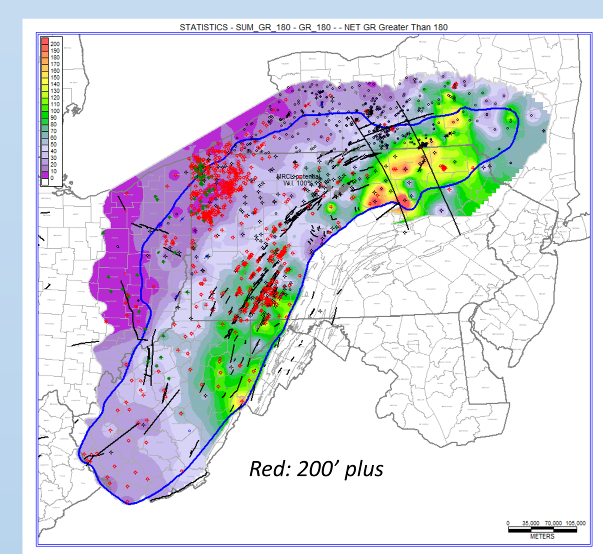
Structure contour map on the Base of the Marcellus Shale, mapped on 8,924 wells (not shown).



Marcellus Shale mean TOC from density (RhoB) and gamma ray (GR) log data. Contoured on mean (P50) of calculated TOC content in 575 wells.



Gridded net thickness of organic-rich Marcellus Shale with TOC >= 4 % (shale gas/liquids potential) utilizing 575 wells.



Updated net thickness of organic-rich Marcellus Shale. Computed on net gamma ray (GR) greater than 180 API calculated in 1559 wells.

***Note:** Marcellus Potential area outlined in blue in net maps above.*

Current Estimated Marcellus CO_2 Storage

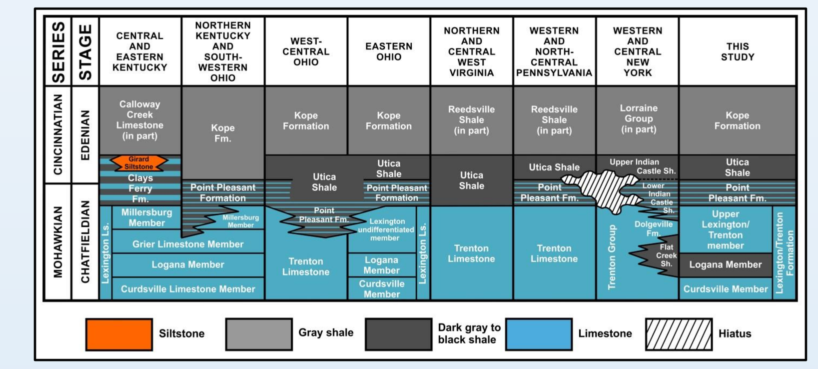
Factor	Current
Volume	≈2 billion acre-ft
Shale density	2.4 g/cc
CO_2 (scf/ton of shale)	100
Displacement efficiency	3% to 10%

Storage ≈ 1.1 to 3.7 billion tons CO_2

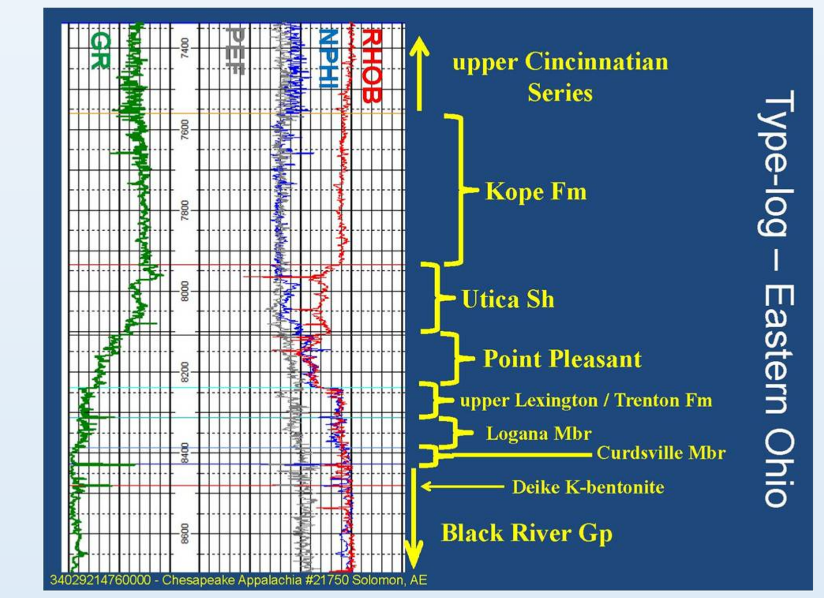
Grid-based methods for estimating the distribution of organic matter will yield a probabilistic result.

UTICA-POINT PLEASANT SHALE PLAY
2016 – 2018 Study (ongoing)

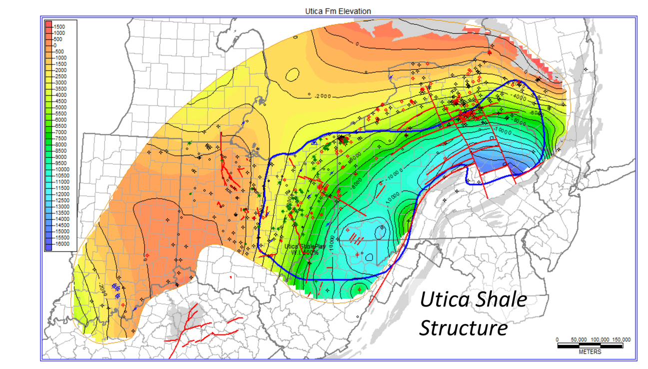
Stratigraphy of Upper Ordovician

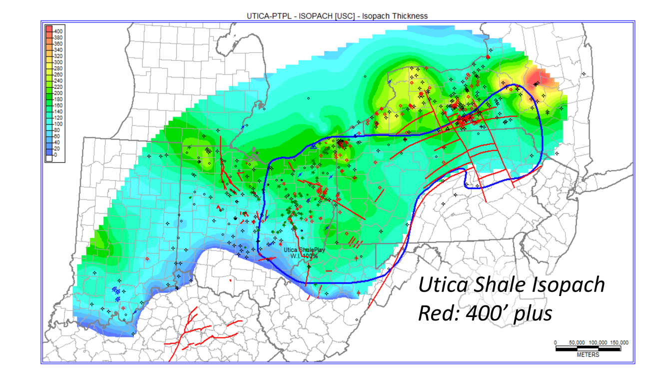


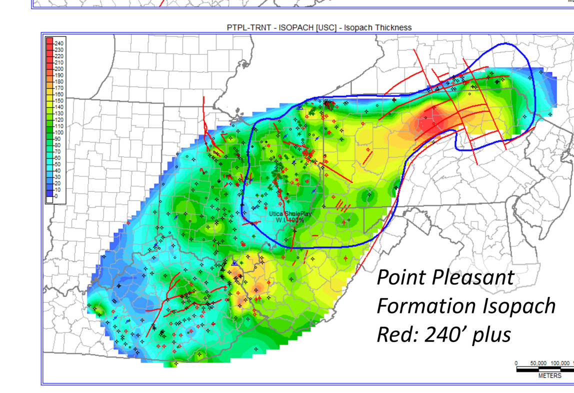
Correlation chart of Upper Ordovician strata showing the position of the organic-rich Utica Shale (dark gray) and Point Pleasant Formation (dark gray with interbedded blue) (Hickman and others, 2015a).



Type log Upper Ordovician section (Hickman and others, 2015b).



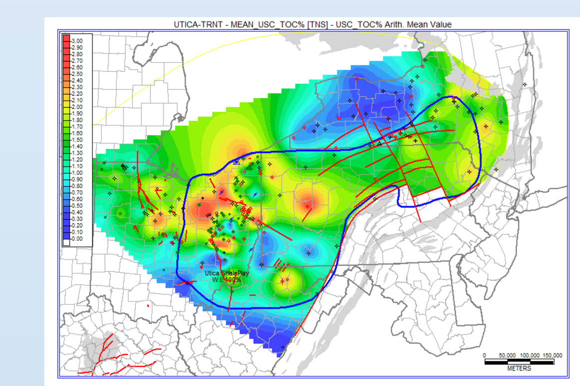




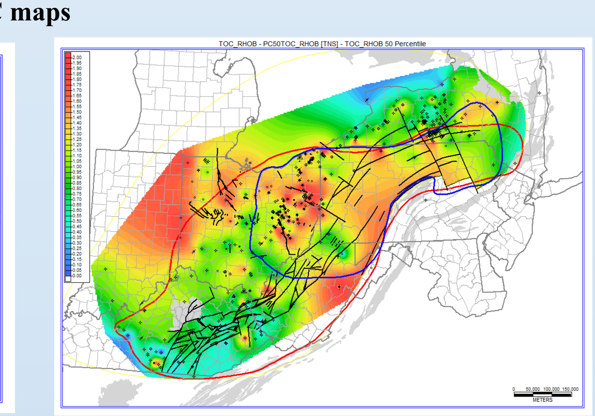
Original Utica structure map and selected isopachs provided by the Utica Shale Play Book (Hickman and others, 2015b).

Note: Utica Play Area of Investigation outlined in blue

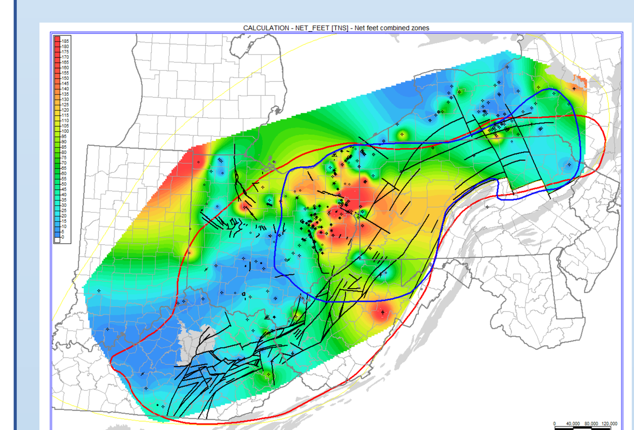
Regional Mapping – Utica Shale study area
TOC maps



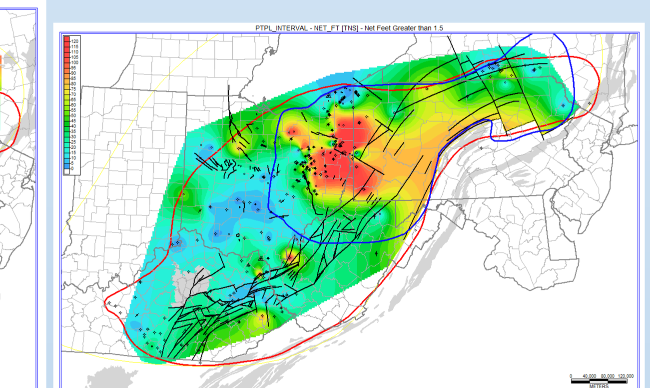
Utica Shale and Point Pleasant Fm. mean TOC (P50), gridded from the Utica Shale Play Book laboratory dataset (Patchen and Carter, 2015).



Utica Shale and Point Pleasant Fm. mean TOC (P50) gridded from calculated TOC_RhoB (368 wells).



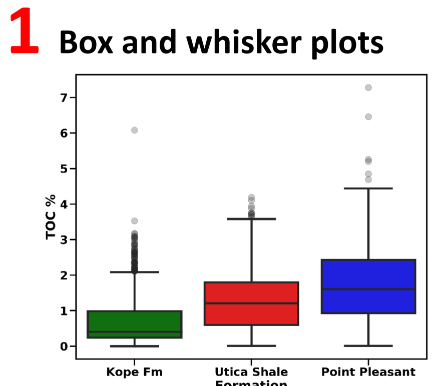
Utica Sh. and Point Pleasant Fm. intervals (combined) net feet with TOC greater than or equal to 1.5 % (250 wells).



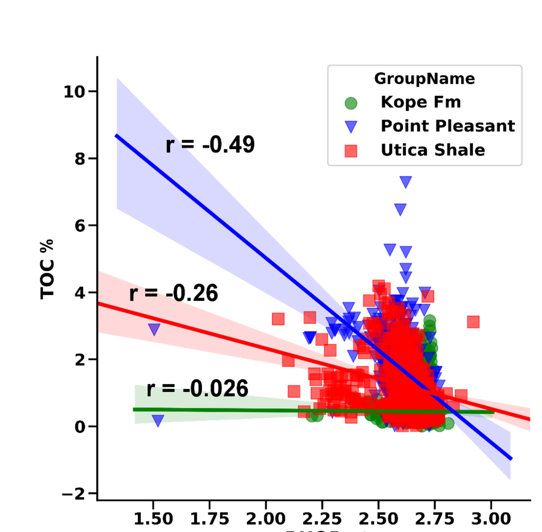
Point Pleasant Fm. interval with net feet TOC greater than or equal to 1.5 % (254 wells).

Note: Point Pleasant Play Area of Investigation outlined in red

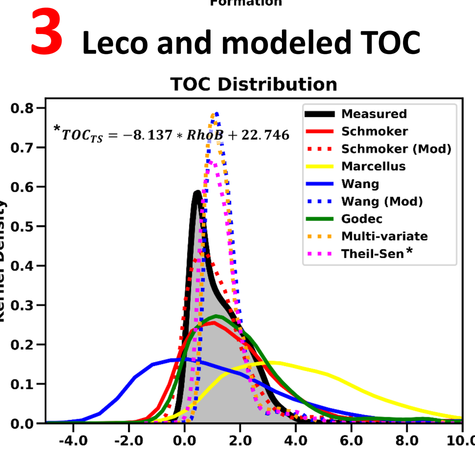
1 Box and whisker plots



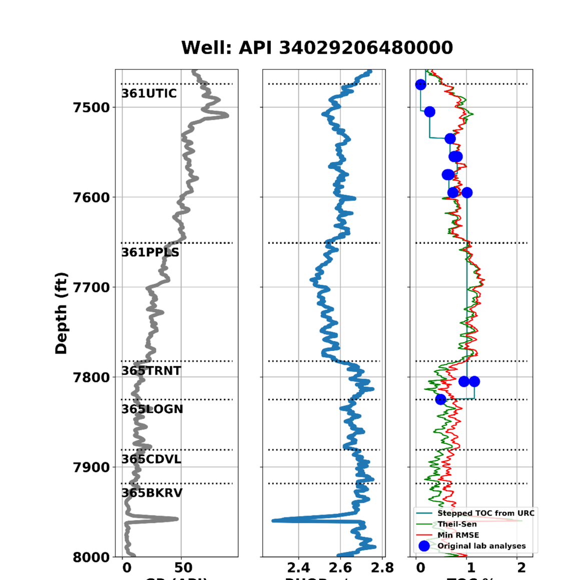
2 Multiple regressions



3 Leco and modeled TOC



4 Utica log-plot model



Current Utica Shale TOC analysis (2018)

1) Box and whisker plots of the grouped Upper Ordovician units in the Utica Consortium TOC data set.
2) Linear least squares plots of Leco TOC values and depth-paired bulk density data from digital logs. The Kope Formation (green) shows no correlation. The data scatter for the Utica Shale suggests correlation is weak (r = -0.26), while for the Point Pleasant Formation it is moderate (r = -0.49).
3) Observed Leco TOC ("Measured," black) and other modeled distributions of TOC for the Upper Ordovician Utica Shale and Point Pleasant Formations. A linear model ("Theil-Sen," magenta dash) has the lowest root mean square deviation between actual and predicted TOC values.
4) Gamma ray and density log showing Leco TOC values (blue dots), the "stepped" TOC curve from the Utica Shale Consortium Petra® project, and TOC curves calculated using a "Theil-Sen" and a multi-variate "Min RMSE" model.

References cited
deWitt Jr., W., Roen, J.B., and Wallace, L.G., 1993, Stratigraphy of Devonian black shales and associated rocks in the Appalachian basin, *in* Roen, J.B., and Kepferle, R.C., eds., Petroleum geology of the Devonian and Mississippian black shale of eastern North America, USGS Bulletin 1909, p.B1–B57.
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