Explorations in TOC Assessment of CO_2 Storage and Enhanced Gas Recovery for the Middle Devonian Marcellus and Upper Ordovician Utica Shales*

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Abstract

The potential for carbon storage and enhanced gas recovery in the Middle Devonian Marcellus and Upper Ordovician Utica organic-rich shales in the Appalachian Basin is being investigated using methods developed during investigation of the Upper Devonian Ohio Shale. Laboratory analysis of core and well cuttings provides baseline data for modeling TOC content in shale. In general, continuous resource plays exhibit relationships between measured TOC and wireline log data. TOC is in turn related to gas content and storage capacity. Wireline-based petrophysical models for estimating TOC have been proposed by many authors, but choice and application of a model depends on data availability. Only those based on total gamma-ray and bulk-density log data were used in this study, because they are most regionally available.

For the Marcellus, multiple models were analyzed to estimate TOC from log data. The simplest model for estimating TOC is a linear regression of a density and TOC cross plot based on laboratory data because TOC is generally regarded as the main control on density changes in an organic-rich shale. Gamma-ray- and density-based models use the slope of the gamma ray–density cross plot. A median TOC curve (P50) was calculated using multiple models to provide a probabilistic summary of TOC by well, which was used as input to geospatial modeling.

The Utica Shale was deposited in a carbonate-dominated open-marine shelf setting, suggesting that organic matter types and their mode of preservation differ significantly from those of the Marcellus. Classic models to estimate TOC for organic-rich shale may not provide acceptable results. Laboratory TOC and digital well-log data were compiled by the Utica Shale Consortium. Leco TOC data were depth-matched with gamma-ray and bulk-density data from logs. Neutron-porosity and photoelectric effect data were collected, but limited digital data precluded their use. Gamma-ray and density data were used to assess existing TOC models and formulate new ones. Two new models for calculating TOC from well-log data are proposed based on best-fit correlations to the distribution of laboratory TOC data.

Selected References

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MRCSP
MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP

Brandon C. Nuttall, Thomas N. Sparks, & Stephen F. Greb (speaker)

Kentucky Geological Survey

Eastern Section AAPG, Pittsburgh, PA

October 9, 2018

TOC from Wireline Logs

- Gamma Ray
- Spectral GR
- Density
- Neutron
- PE
- Sonic
- Resistivity

- Methods
  - Godec (2013a)
  - Herron (1991)
  - Meyer and Nederlof (1984)
  - Passey and others (1990)
  - Schmoker (1979, 1981, 1993)
  - Others

Availability in Digital Format (LAS)

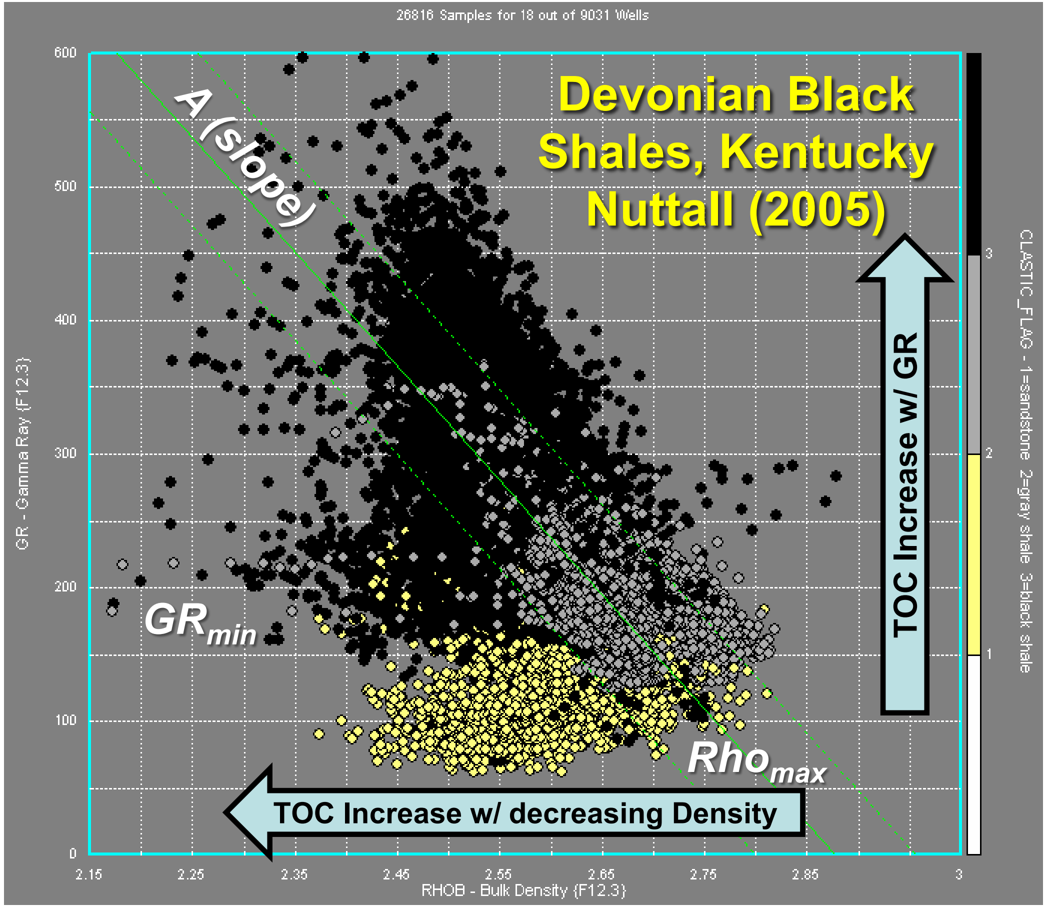
- Gamma Ray
- Spectral GR
- Density
- Neutron
- PE
- Sonic
- Resistivity

- Not in historic wells
- Dependent on drilling fluids
- Not across zone of interest
- Not digitized
- Scale errors

Basic Petrophysical Observations

- Given relatively constant
  - Lithology (mineralogy)
  - Porosity
  - Pore fluids & saturations

1. OM tends to concentrate U, K, Th
2. Density is a function of TOC

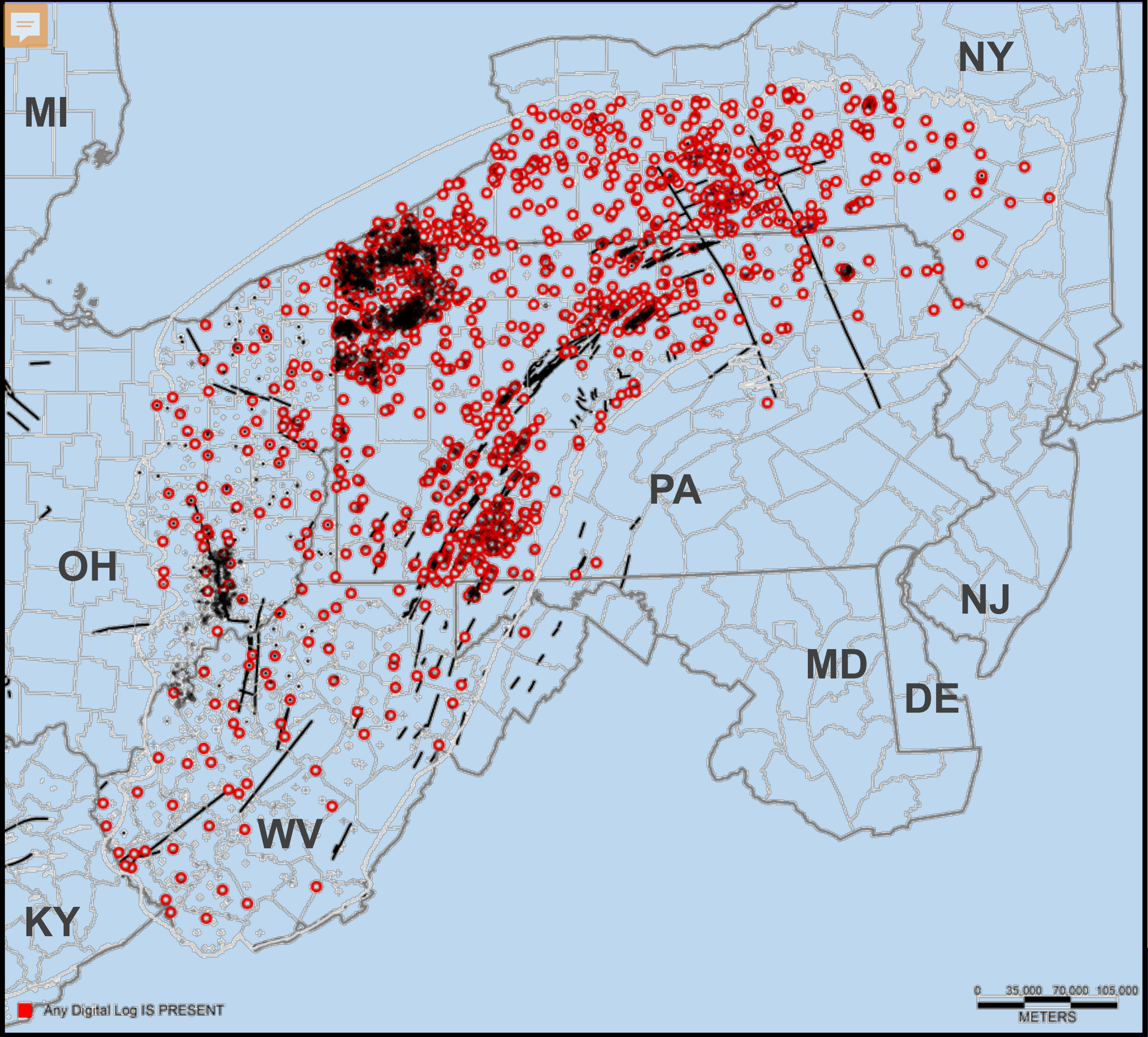


Organic matter

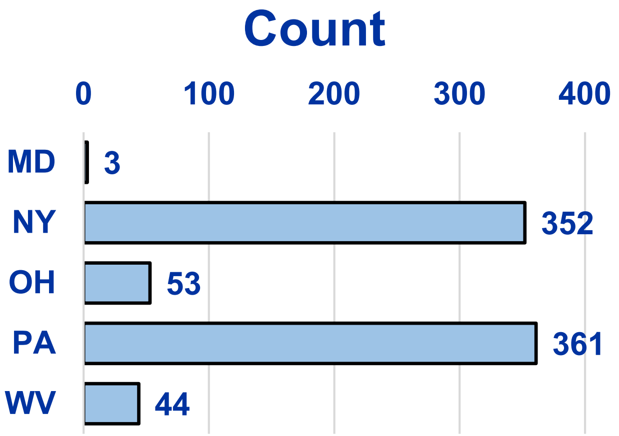
- TOC from well logs
  - Density (Schmoker, 1979 & 1993)
  - Gamma ray (Schmoker, 1981)
- Shale density is a function of:
  - Matrix mineralogy
  - Pores
  - Pyrite
  - Organic matter

Middle Devonian Marcellus

- Fissile
- Gray to black
- Fractured
- Organic-rich
- Clastic
  - Quartz
  - Clay



Data Distribution for Marcellus: 813 LAS files



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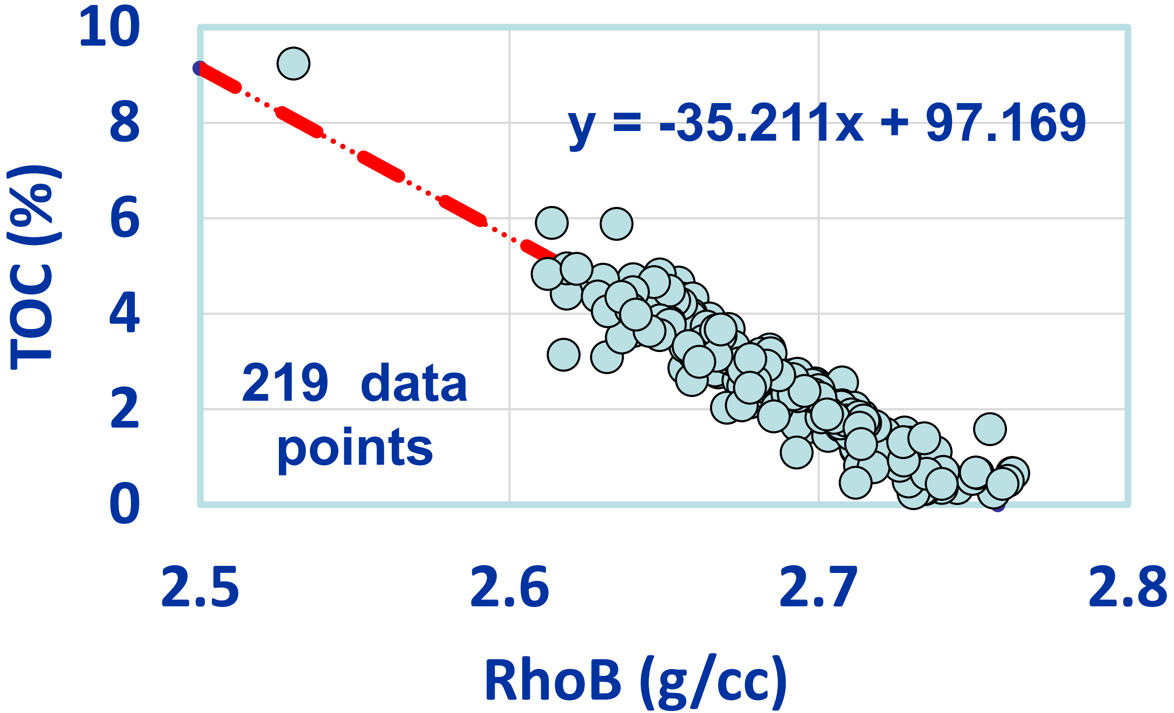
Rock-Eval and Laboratory Data

- Marcellus PA Databook
  - Devonian shales
  - 129 wells
  - 1,995 depth records
- Basis of linear model



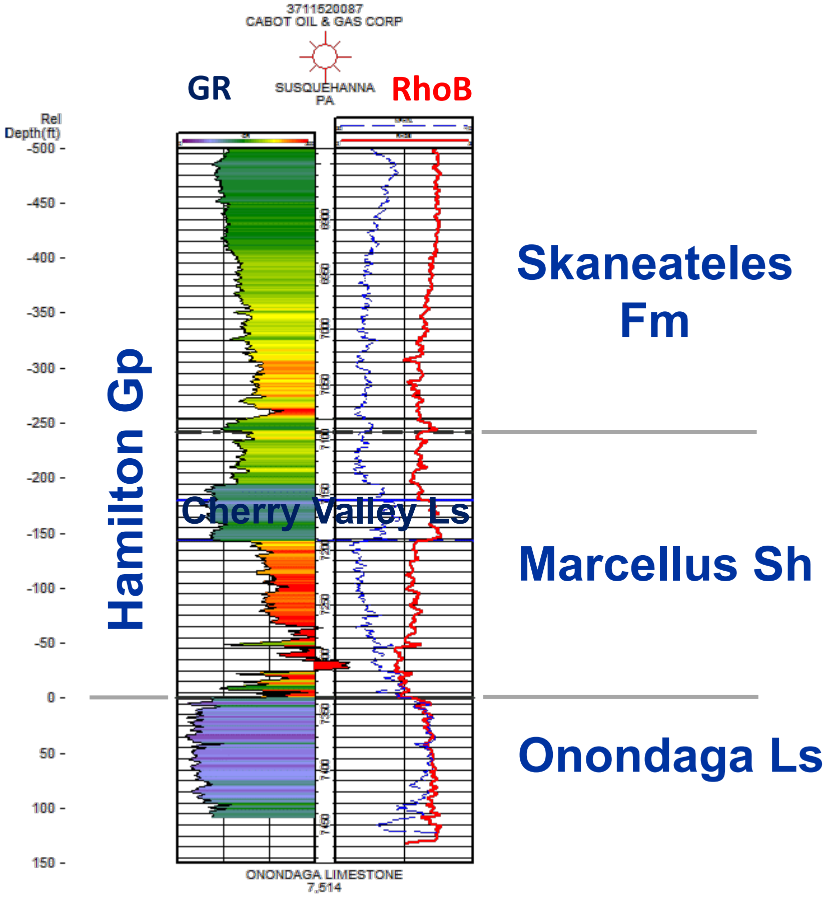
TOC Models

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

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

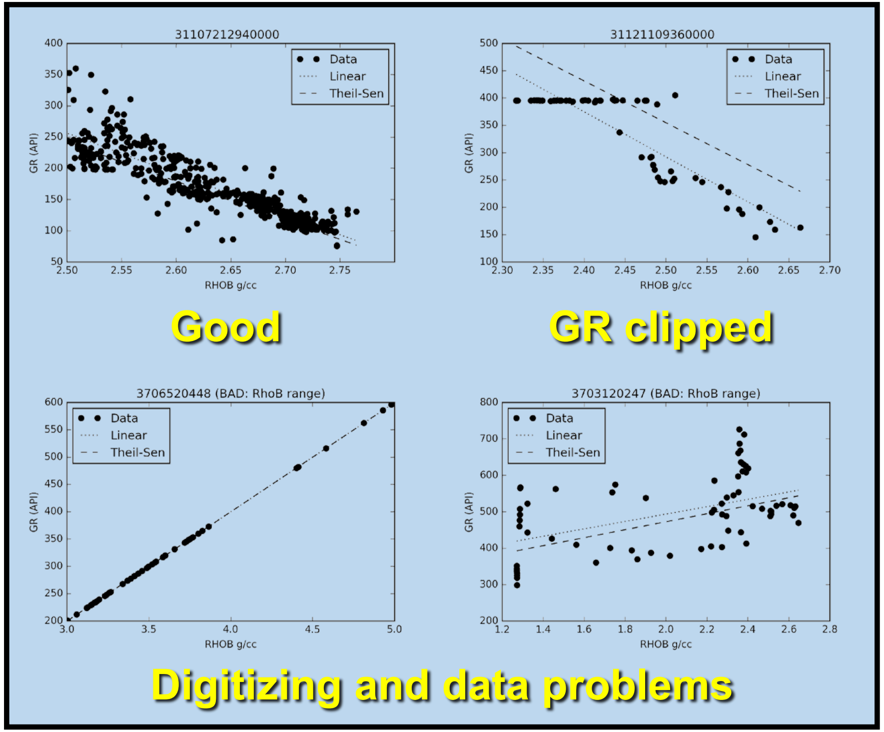
$$TOC_{Linreg} = -35.21 * RhoB + 97.17$$

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

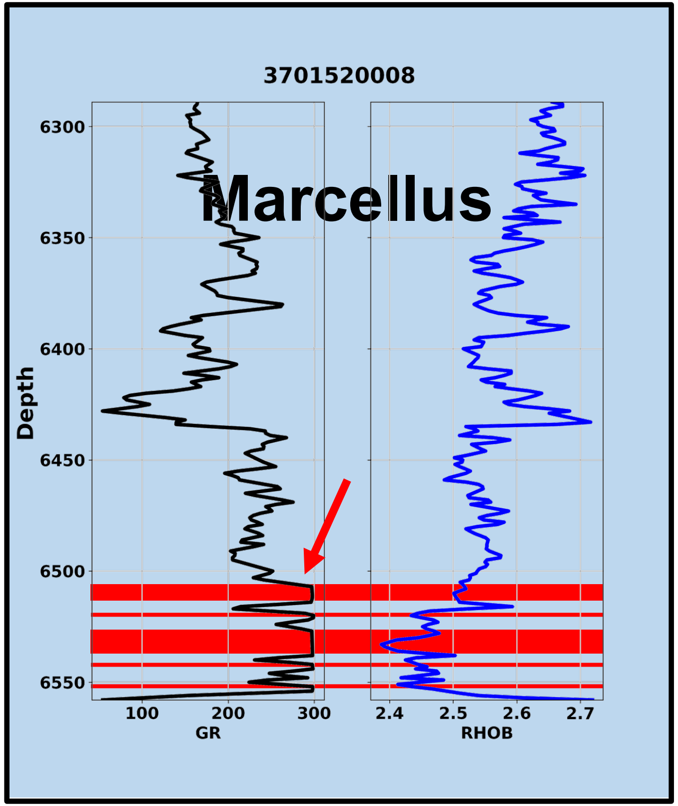


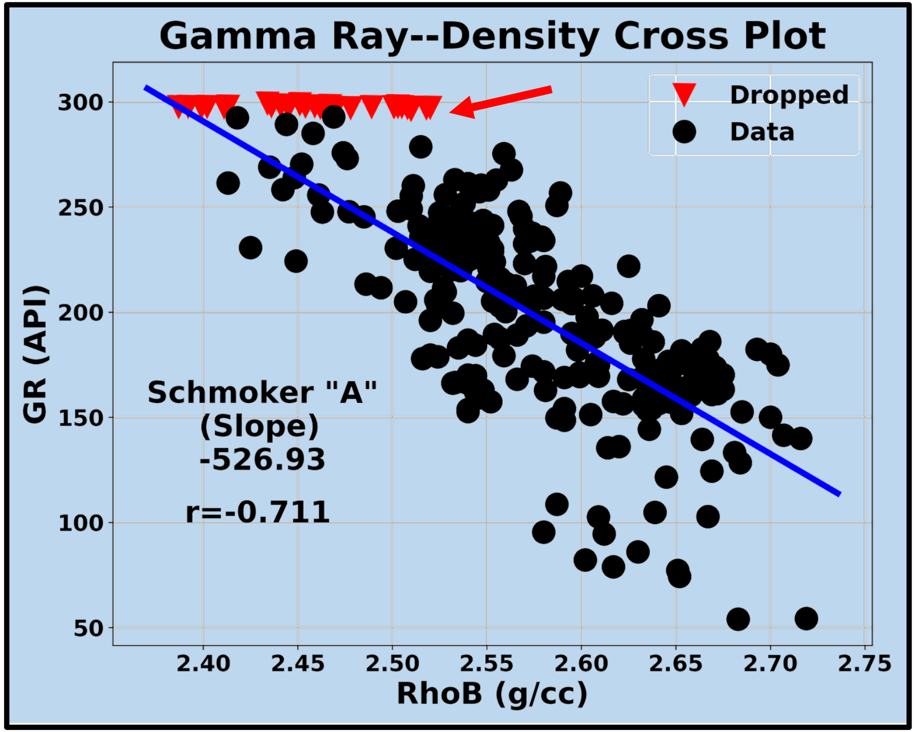
Marcellus Digital Data Review

- 517 wells
- Data quality
  - Missing curves
  - Clipped at track edge
  - Review digitizing
- Determine default Schmoker “A” coefficient



Log Data Checks





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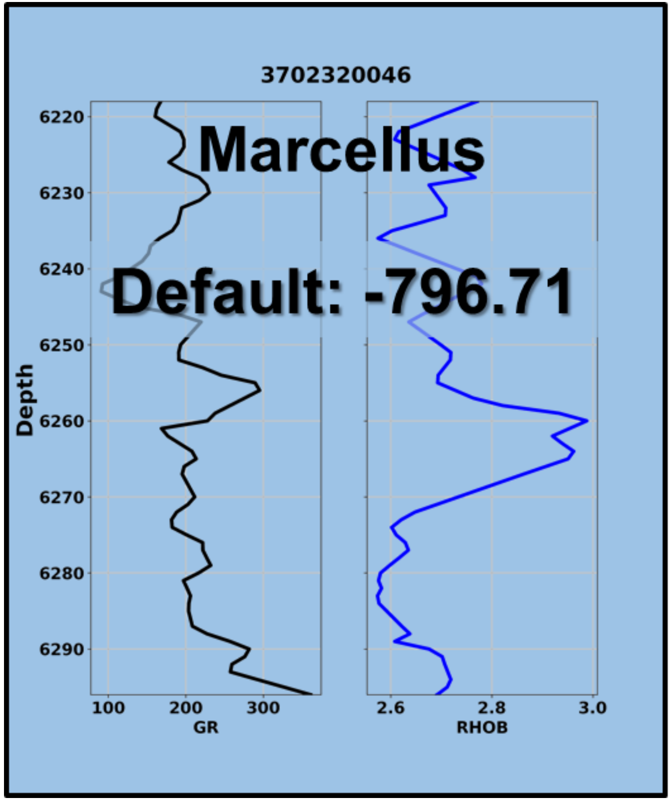
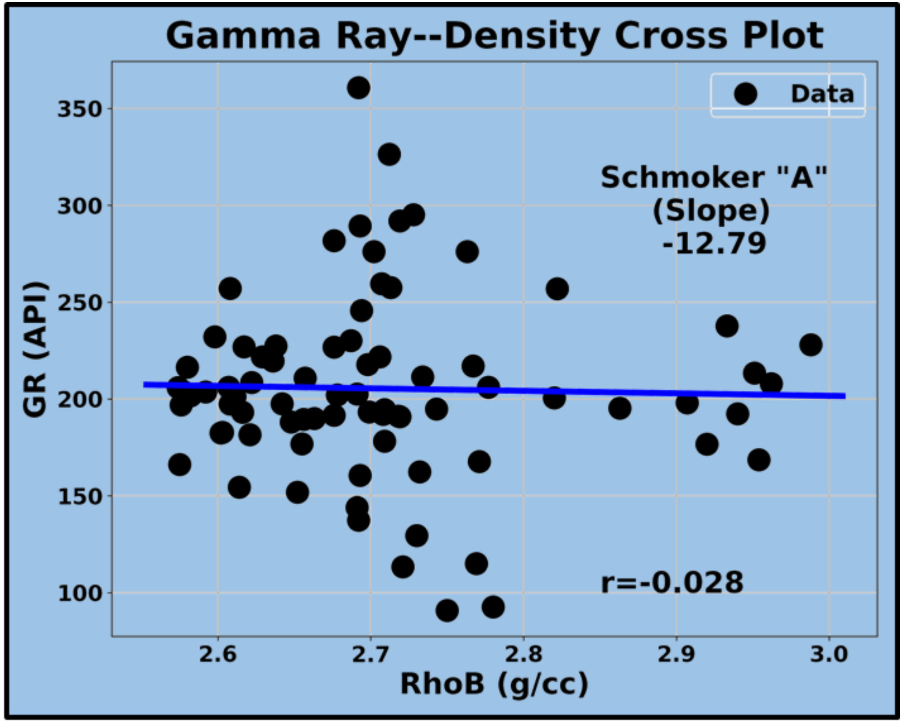
Assume Default Slope, Schmoker "A"





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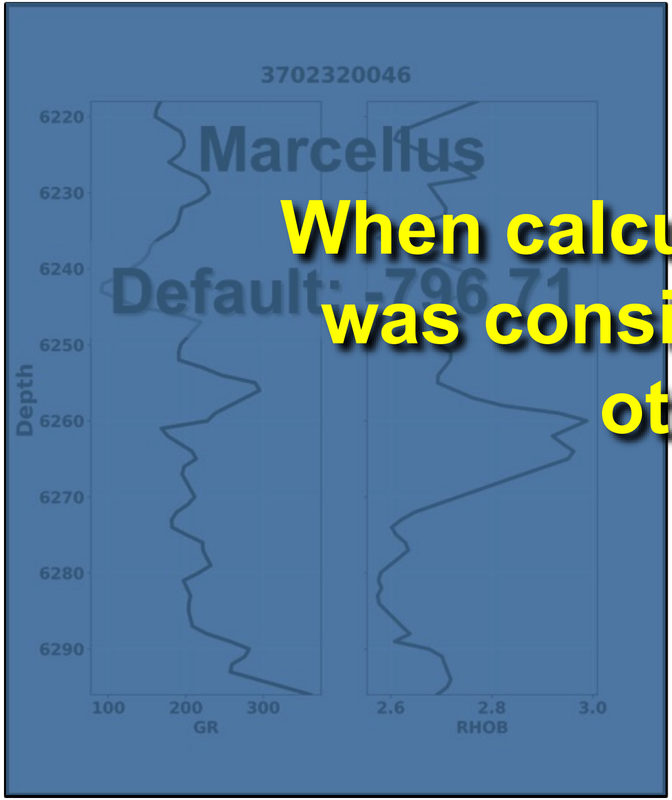
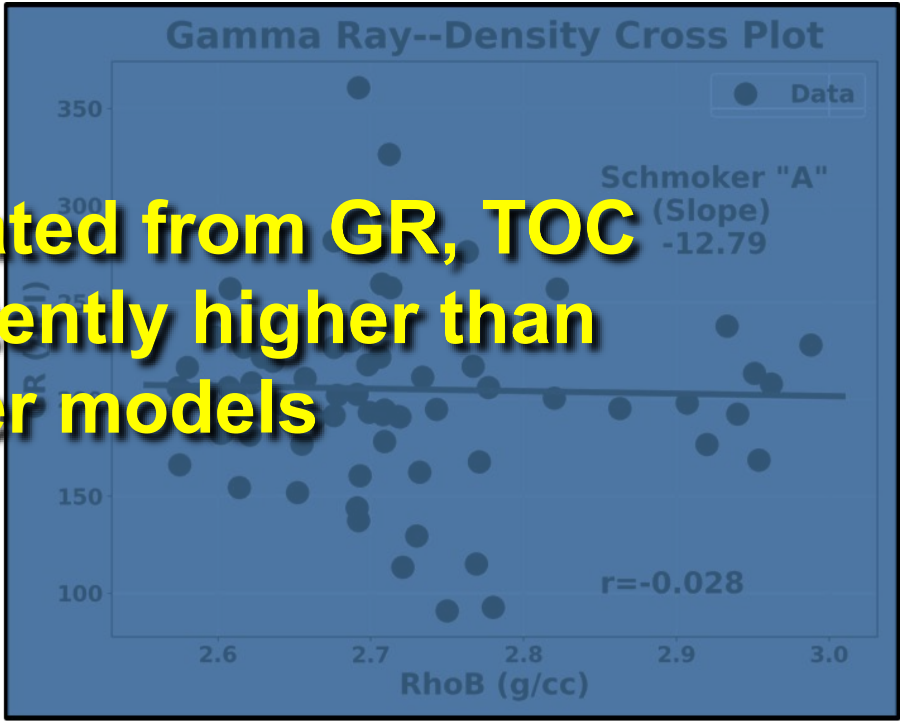
Assume Default Slope, Schmoker "A"





When calculated from GR, TOC was consistently higher than other models

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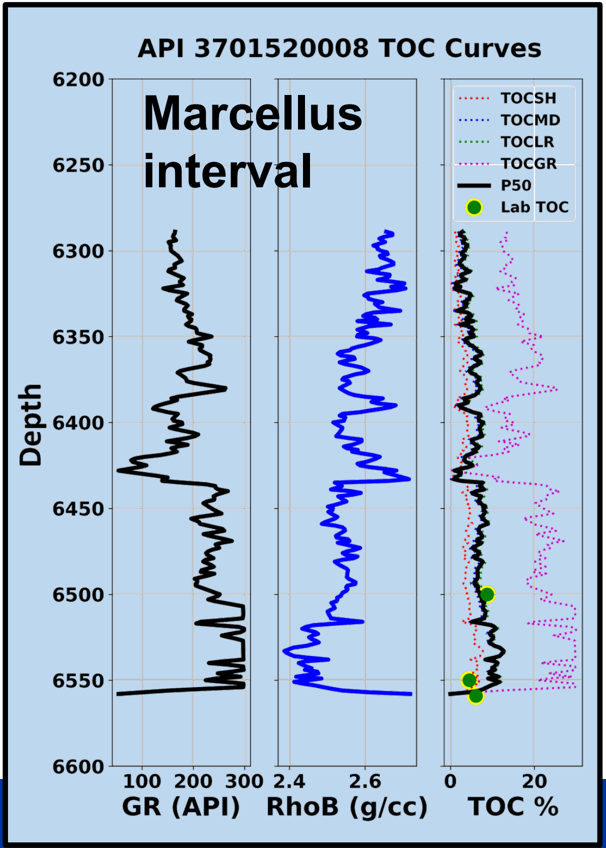
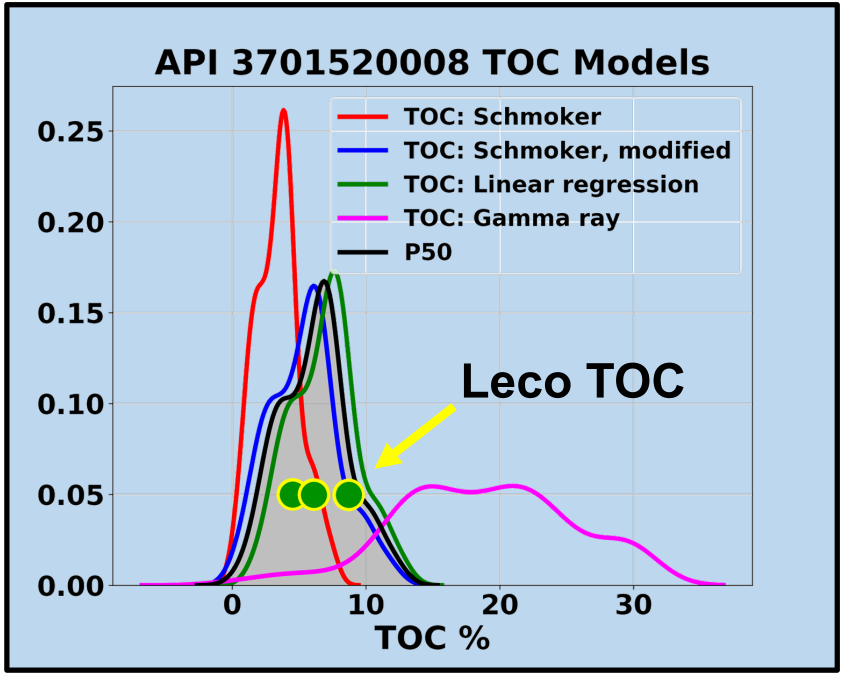
Vertical scale of logs varies

TOC Calculated from Logs



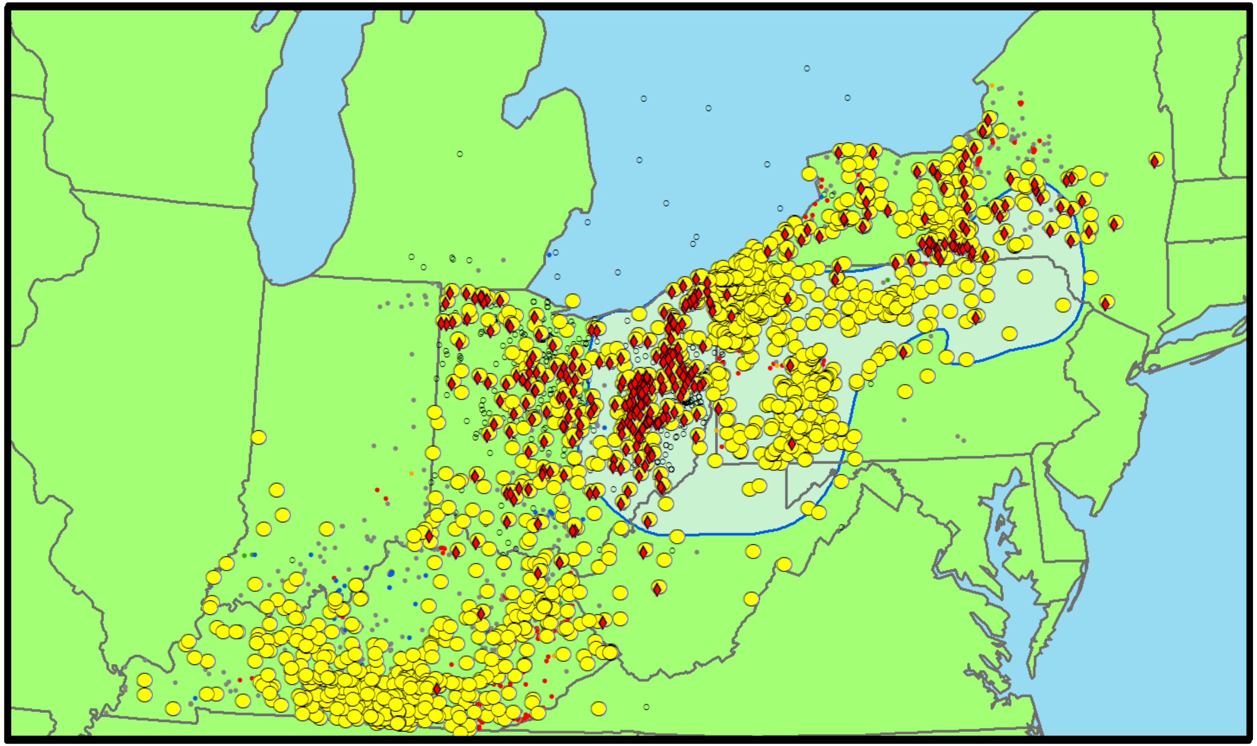


Smoothed histogram (KDE plot)

Upper Ordovician Utica/Point Pleasant

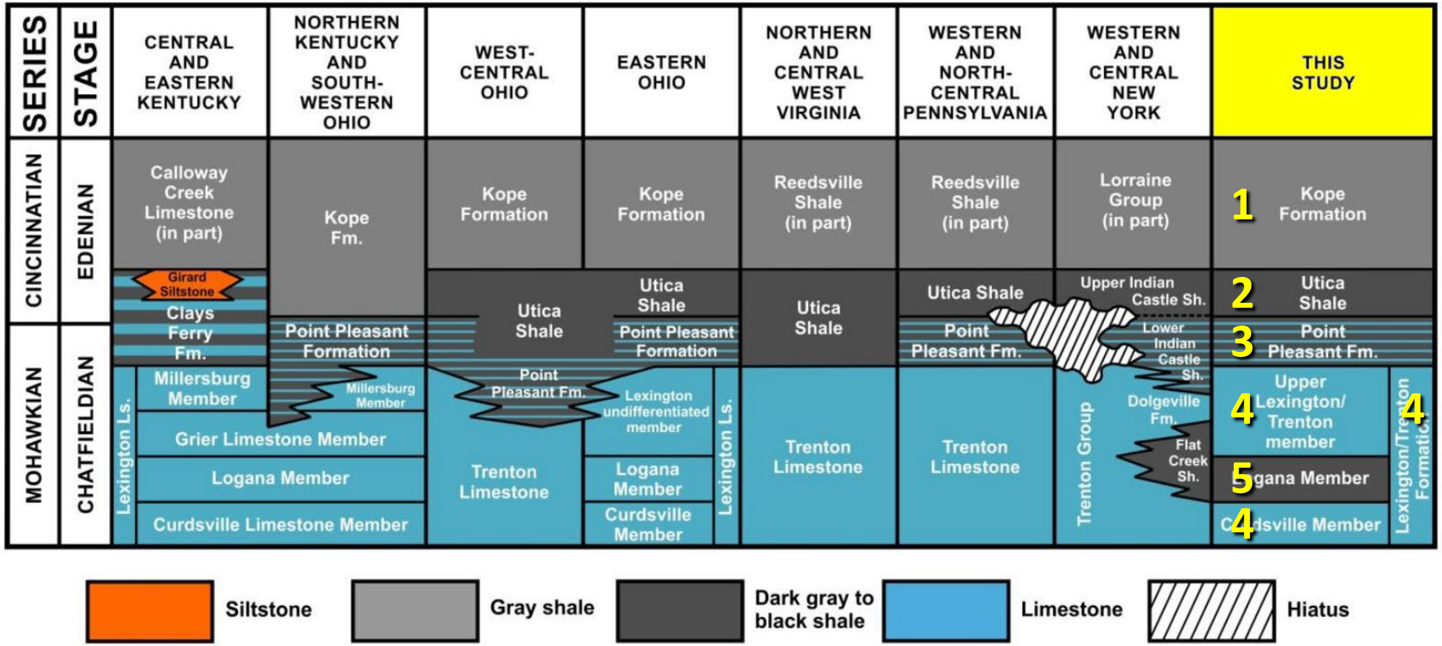
- Light gray
- Thin interbedded
  - Carbonate
  - Shale
- Low organic content
- Fractured

Utica Research Consortium Playbook



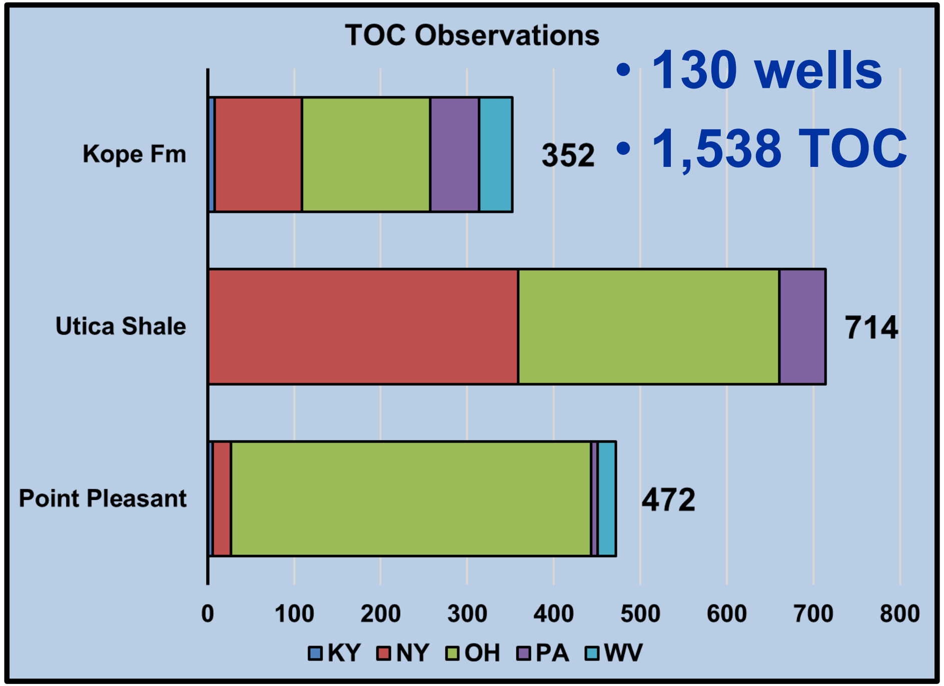
- 10,000+
- 1,993 with LAS
- **340 with TOC**
- **Includes other formations**

Stratigraphic Nomenclature



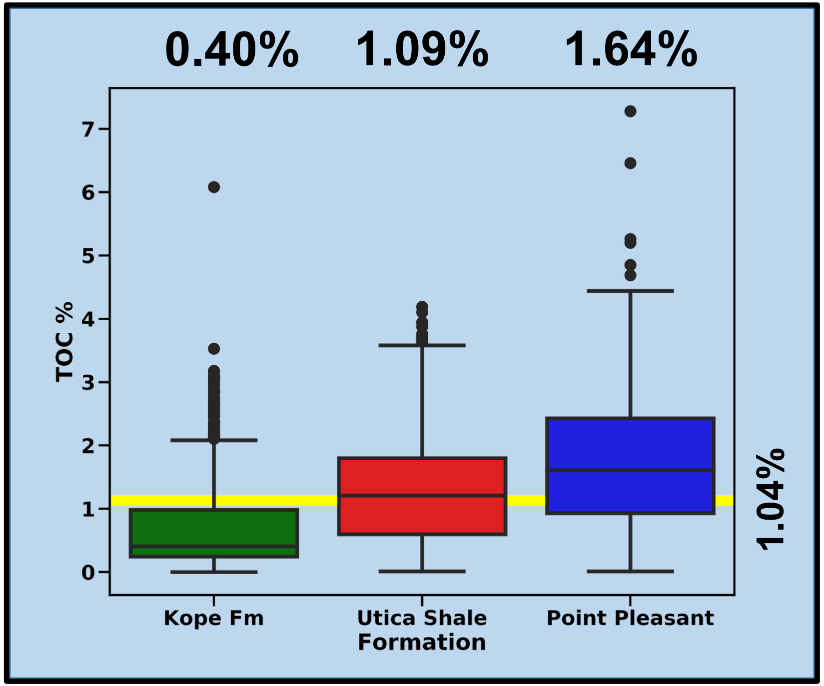
- Many names across states

Upper Ordovician TOC Data Set

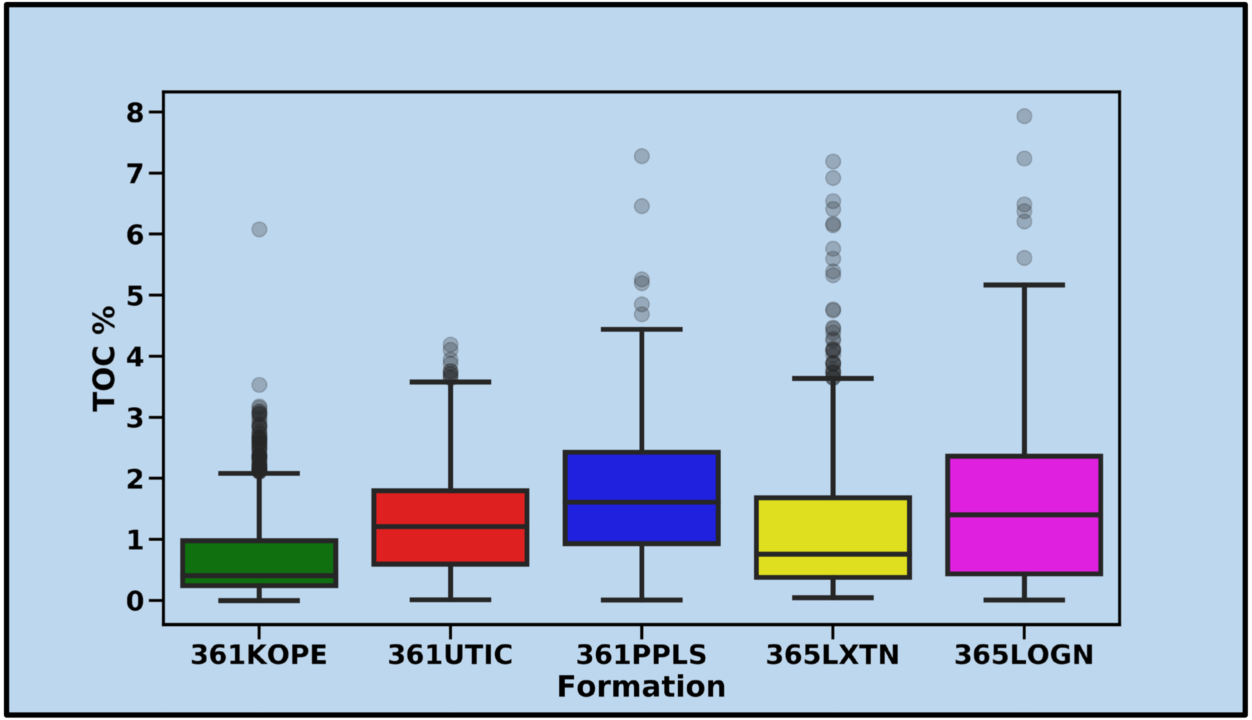


- 130 wells
- 1,538 TOC

Median (50th percentile)



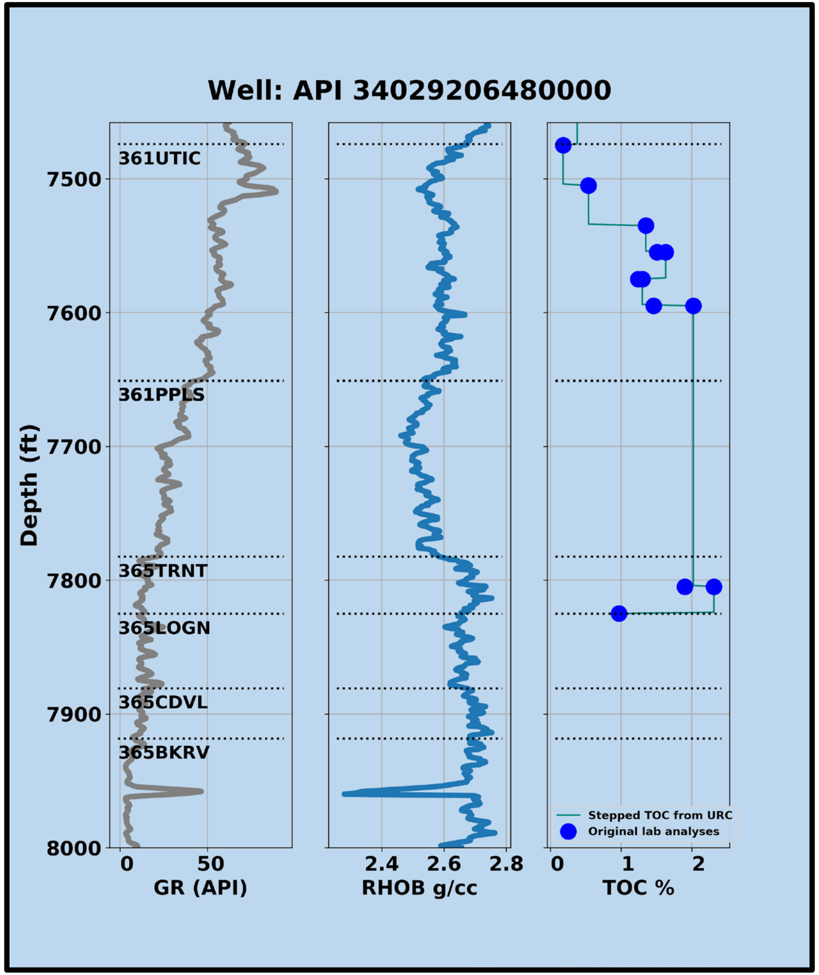
An Observation for the Future?



Is the Logana Member of the Lexington a possible target?

Approach to Utica TOC Modeling

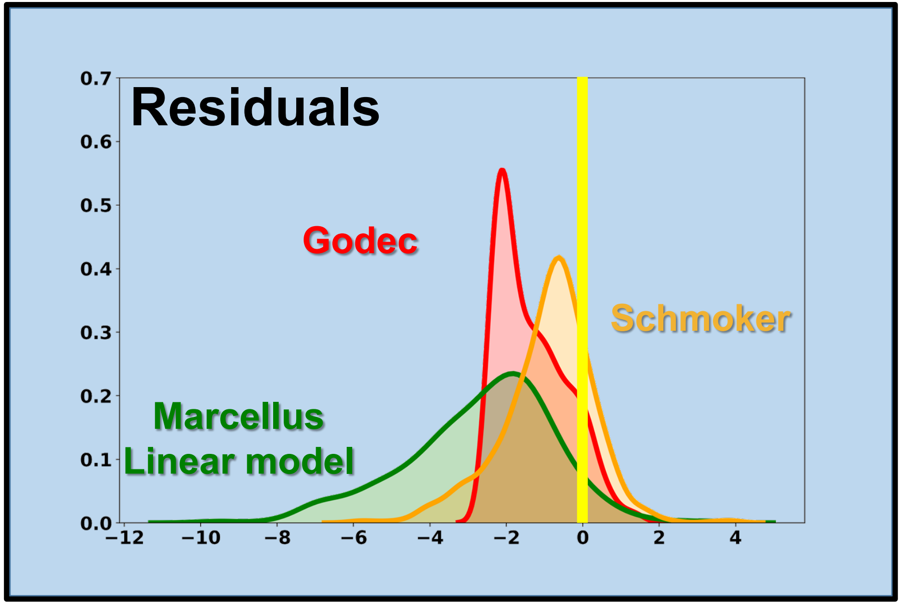
- Review
  - Literature
  - Nomenclature
- Select wells
  - Laboratory TOC
  - GR and RHOB logs
- Depth match TOC and logs
- Visualize data
- Model TOC



Why a New Model for TOC in the Utica?

- Geology
  - Marcellus – Fissile clay-rich dysoxic to anoxic marine shale
  - Utica – Carbonate open marine shelf with thin shaley interbeds

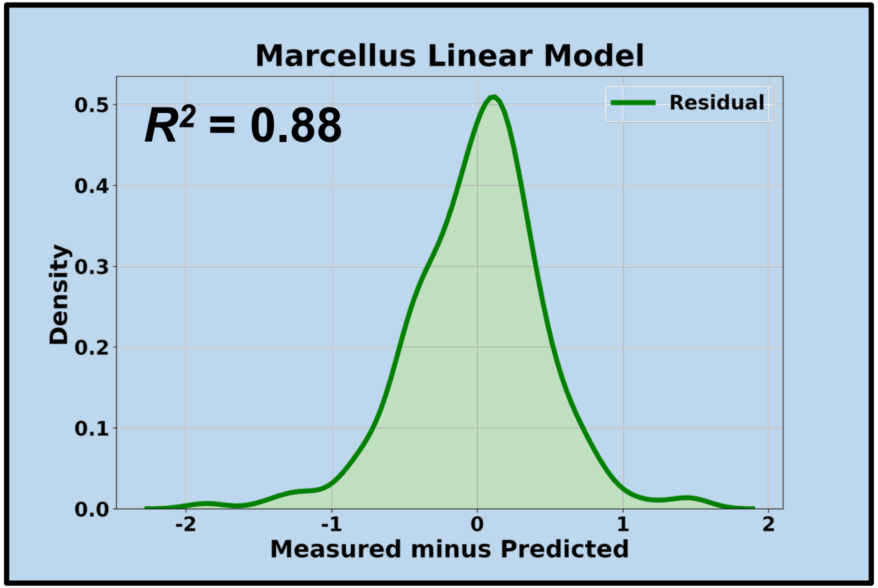
- Predictions not optimum



Tend to overestimate TOC

On Model Optimization

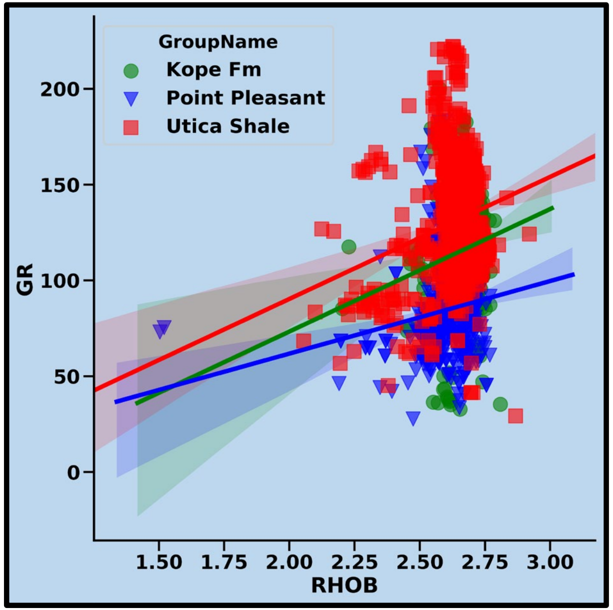
- Either
  - Maximize coefficient of determination, R^2
  - Minimize RMSE
- Residuals
  - Measured – Calculated
  - Near 0
  - Narrow spread

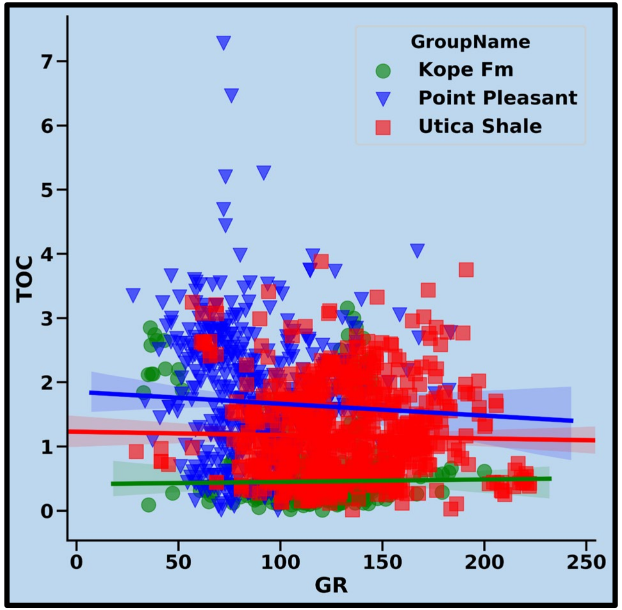


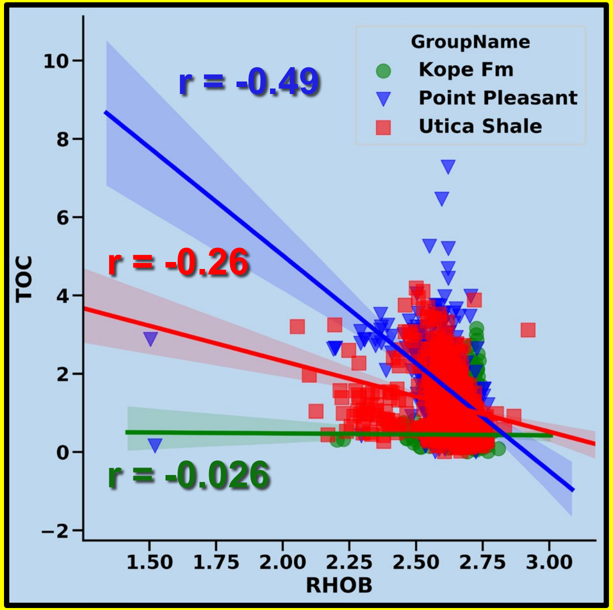
Smoothed histogram (KDE plot)

TOC and Digital Log Data

TOC *vs* RhoB







All r values less than 0.2 – very weak to no correlation

Not all TOC observations have both GR and RHOB data

Kentucky Geological Survey

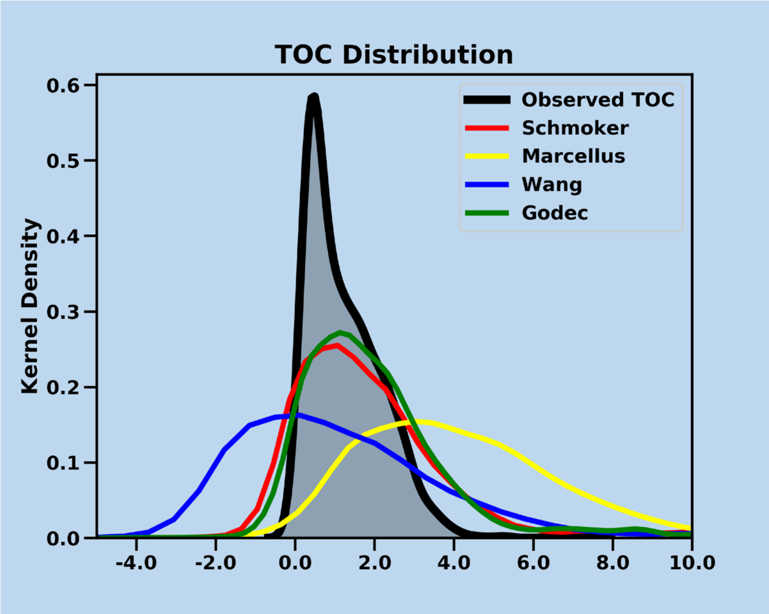
Utica TOC Models: *TOC=f(RhoB)*

$$TOC_{Schmoker} = 55.822 * \left(\frac{2.72}{RhoB} - 1\right)$$

$$TOC_{Marcellus} = -35.211 * RhoB + 97.169$$

$$TOC_{Wang} = \left(\frac{238.1}{RhoB}\right) - 89.1$$

$$TOC_{Godec} = \frac{(RhoB - 2.73)}{-0.05}$$



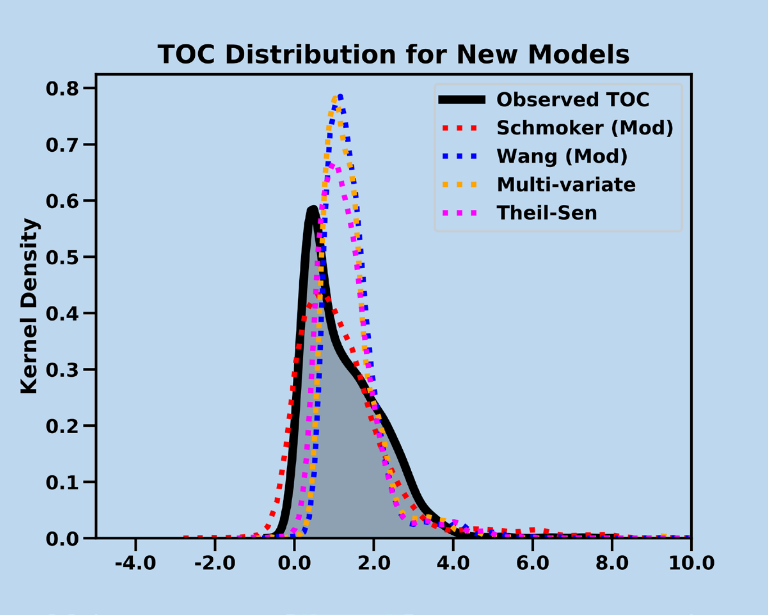
New Models Tested

$$TOC_{SchmokerMod} = 32.5 * \left(\frac{2.73}{RhoB} - 1\right)$$

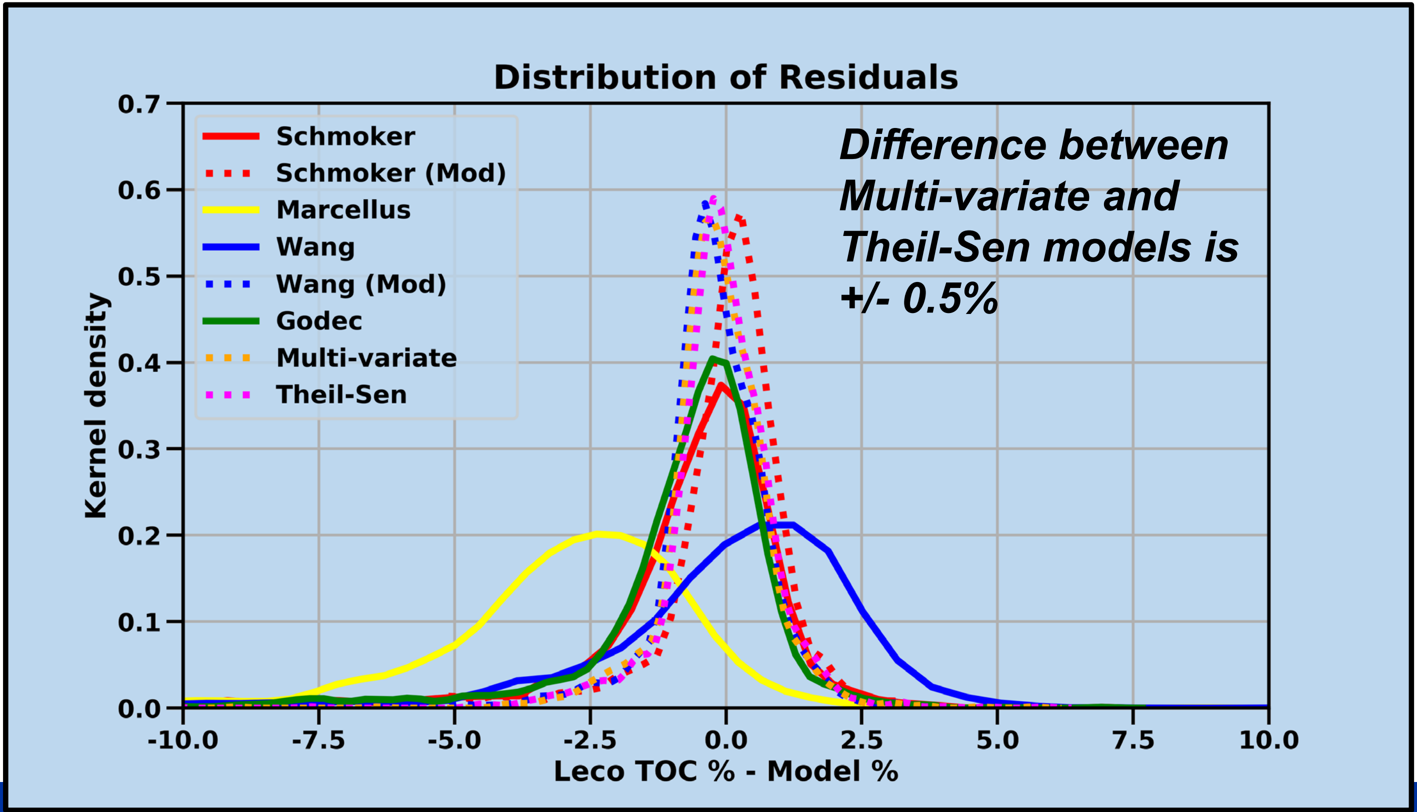
$$TOC_{WangMod} = \left(\frac{49.331}{RhoB}\right) - 17.327$$

$$TOC_{MV} = 19.9 - 6.87 * RhoB - 0.003 * GR$$

$$TOC_{TS} = -8.137 * RhoB + 22.746$$



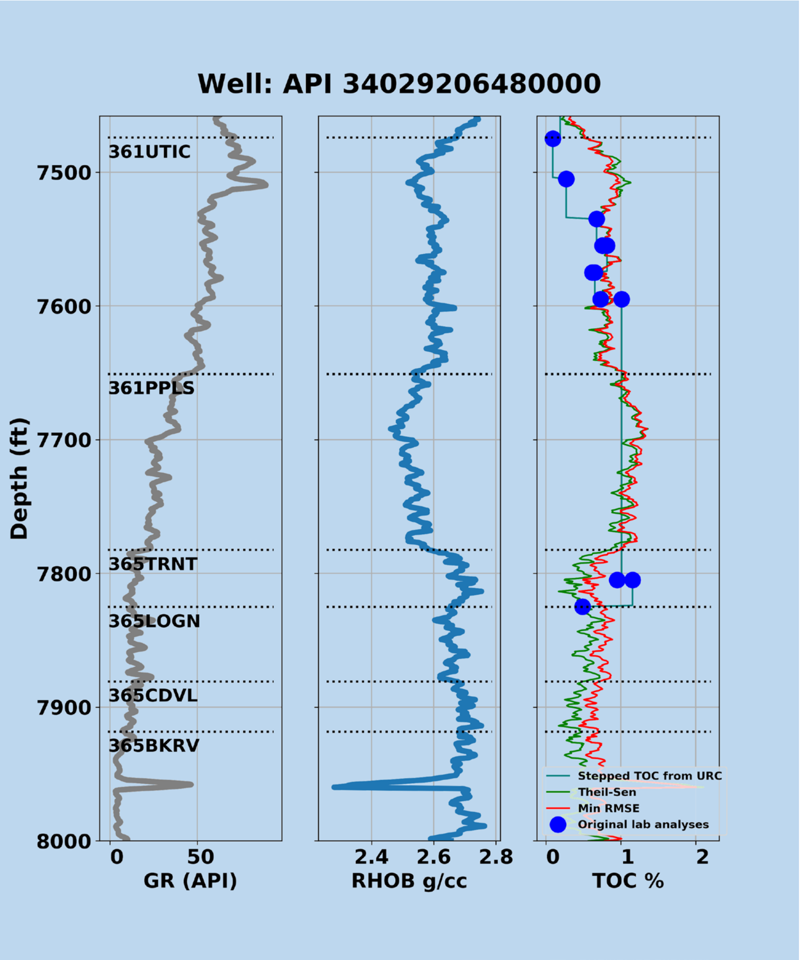
Narrowing the Choices



- Overestimate
  - Marcellus
- Underestimate
  - Wang
- Rest
  - +/- 2.5%

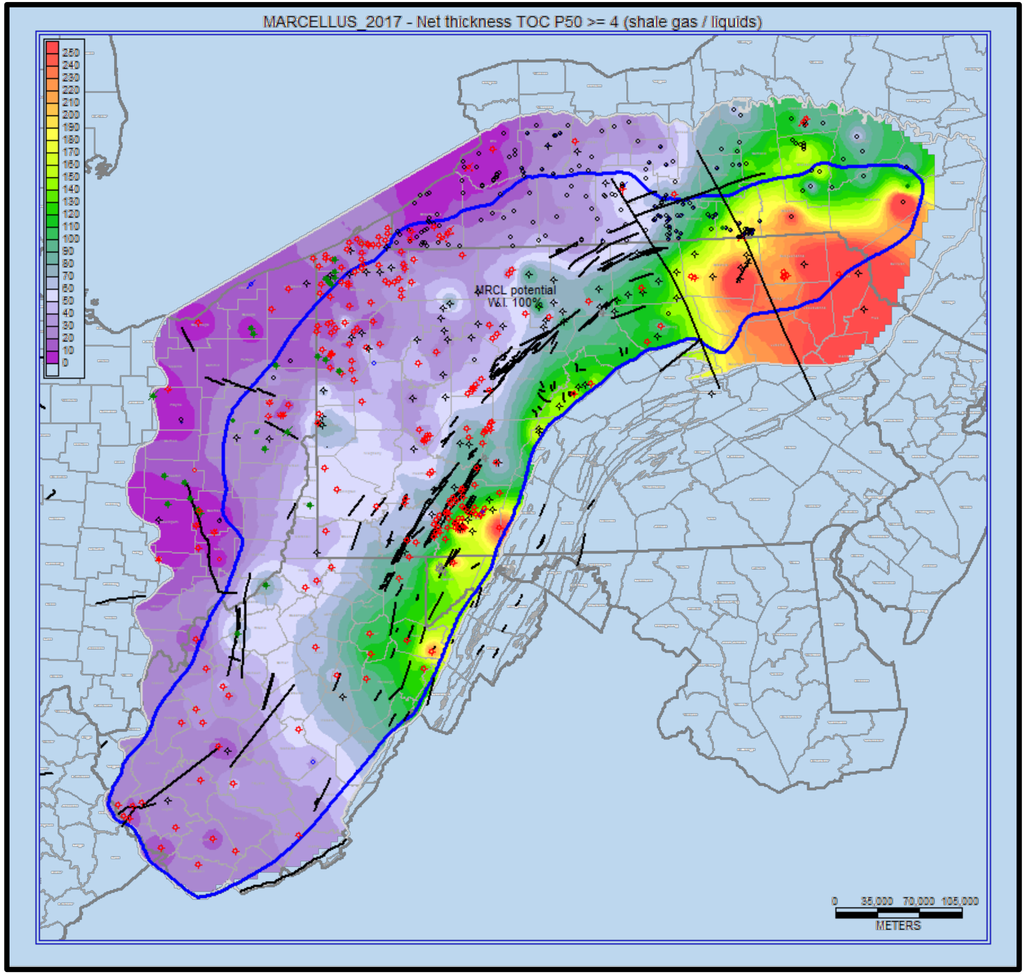
TOC Calculations

- Models can now be used to estimate net thickness of zone with greater than selected TOC



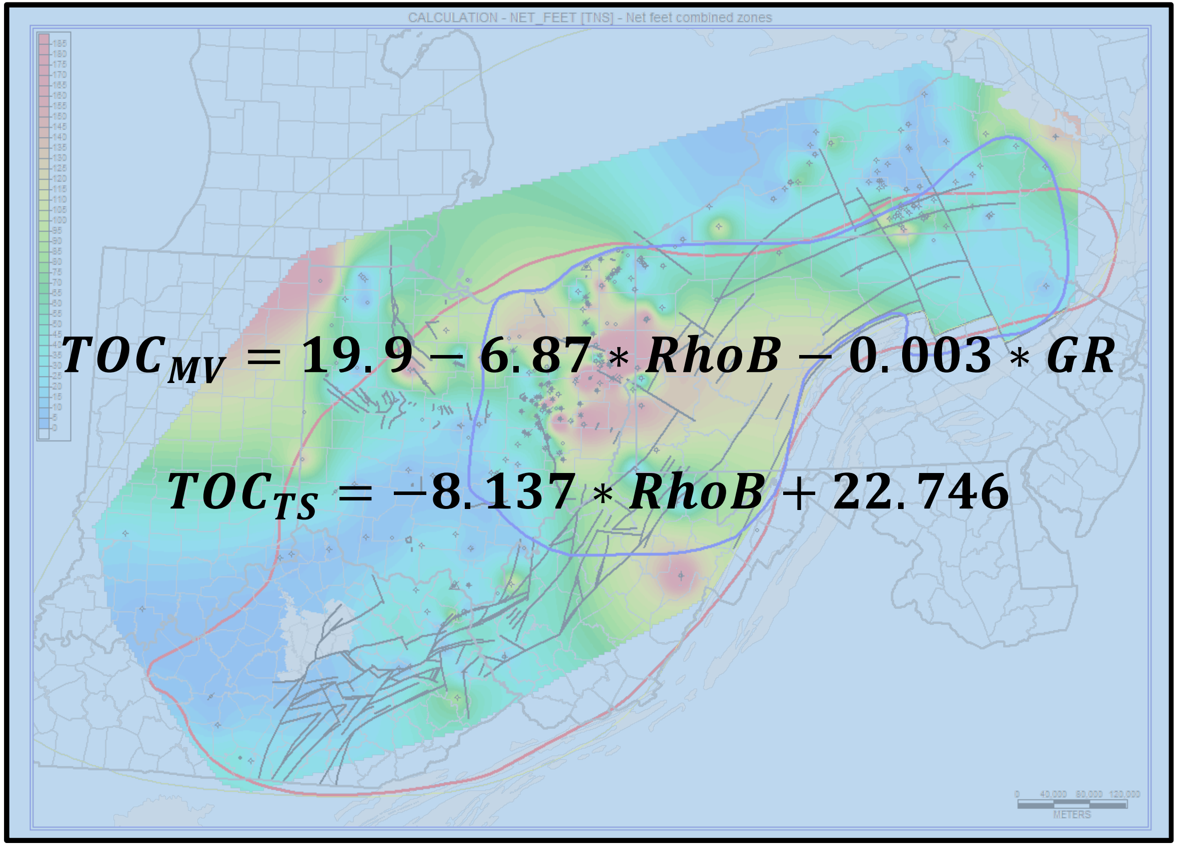
For the Marcellus

- Isopach of net thickness with TOC >= 4%
- “P50” median of TOC by depth from multiple models



For the Utica

- Isopach of net thickness of Utica/Point Pleasant intervals combined with TOC >= 1.5%
- Best models
  - Multi-variate
  - Theil-Sen regression



$$TOC_{MV} = 19.9 - 6.87 * RhoB - 0.003 * GR$$

$$TOC_{TS} = -8.137 * RhoB + 22.746$$

To Conclude

- Multiple models for estimating TOC from borehole logs are available but provide variable results
  - A gamma ray model consistently overestimates TOC
- Models that work well for the Marcellus don’t necessarily work for the Utica/Point Pleasant
- For the Utica, non-parametric and multi-variate models can provide improvements over existing models
- Maps developed can provide nuanced insights to geospatial distribution of organic matter

Future

- Re-evaluate Marcellus models
  - Minimize *RMSE*
  - Maximize R^2
- Examine iterative techniques to better fit selected model to individual wells
  - Linear solver on a per well basis

Questions?

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(It’s all his fault.)

Selected references:

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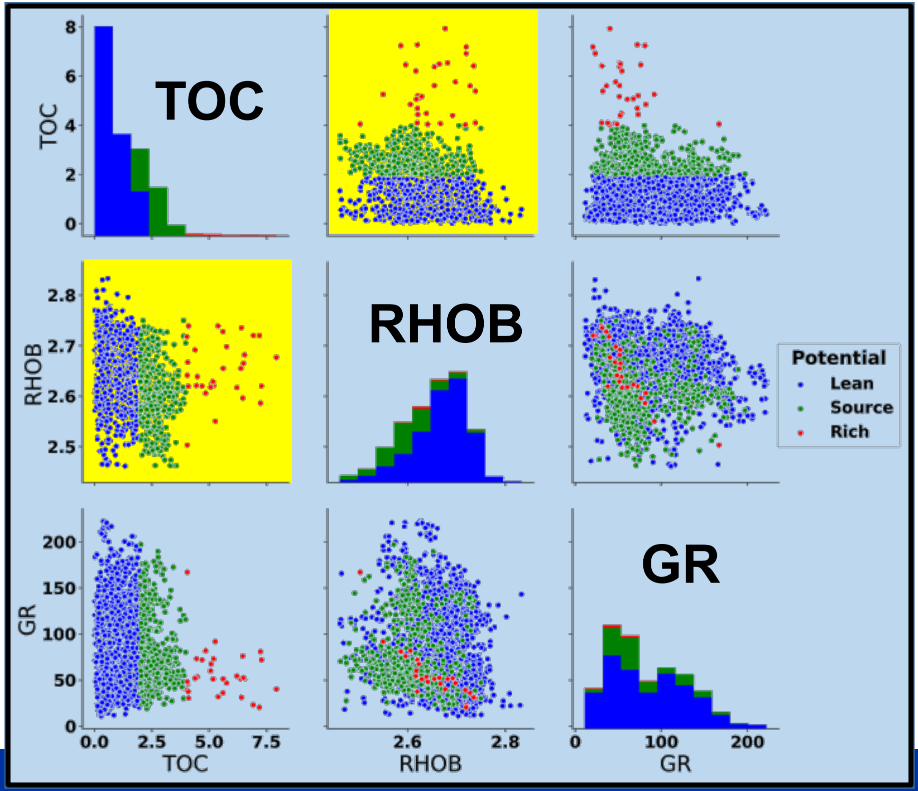
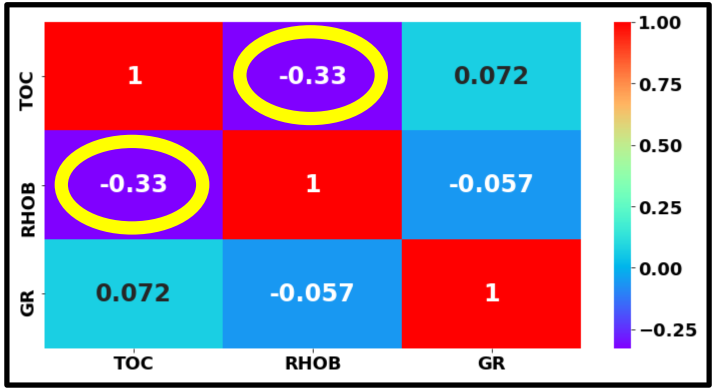
Supplemental Slides

Utica: Identifying Relationships

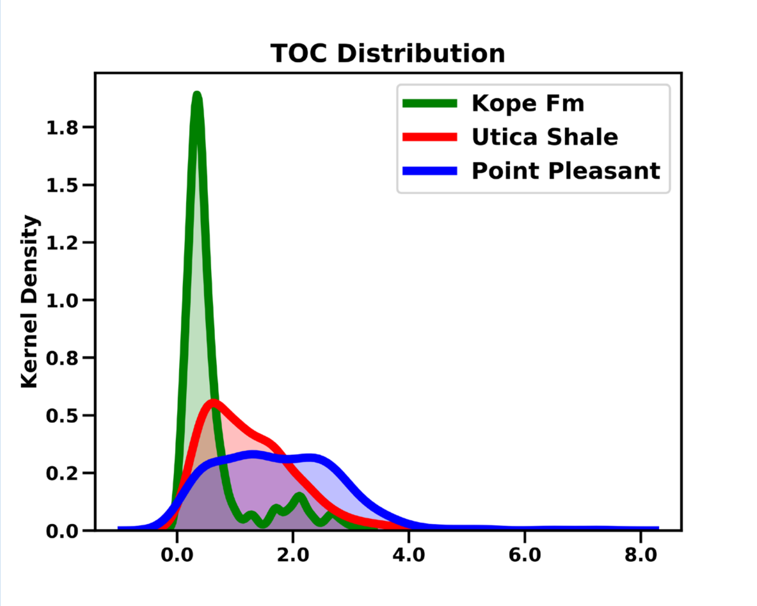


Lean: TOC<2%
Source: 2%<=TOC<4%
Rich: TOC>=4%



Not enough data to include NPHI or PE

TOC in Upper Ordovician Units



Median

(50th percentile)

- 0.40 – Kope
- 1.04 – Overall
- 1.09 – Utica Shale
- 1.64 – Point Pleasant

KDE plot