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


Wang, G., Shahkarami, A., and Bruno, J., 2016, TOC Prediction Analysis of Utica-Point Pleasant Formations in the Appalachian Basin: Search and Discovery #51283, Accessed on February 2, 2019,

Explorations in TOC Assessment of CO$_2$ Storage and Enhanced Gas Recovery for the Middle Devonian Marcellus and Upper Ordovician Utica Shales

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)
  - Passey and others (1990)
  - 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

Photo courtesy of K. Carter
Data Distribution for Marcellus: 813 LAS files

Count

<table>
<thead>
<tr>
<th>State</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>MD</td>
<td>3</td>
</tr>
<tr>
<td>NY</td>
<td>352</td>
</tr>
<tr>
<td>OH</td>
<td>53</td>
</tr>
<tr>
<td>PA</td>
<td>361</td>
</tr>
<tr>
<td>WV</td>
<td>44</td>
</tr>
</tbody>
</table>
Rock-Eval and Laboratory Data

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

\[ y = -35.211x + 97.169 \]
TOC Models

\[ TOC_{Schmoker} = 55.822 \times \left( \frac{Rho_{max}}{RhoB} - 1 \right) \]

\[ TOC_{mod} = 88.55 \times \left( \frac{Rho_{max}}{RhoB} - 1 \right) \]

\[ TOC_{Linreg} = -35.21 \times RhoB + 97.17 \]

\[ TOC_{GR} = \frac{(GR_{min} - GR)}{1.378 \times A} \]
Marcellus Digital Data Review

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

Digitizing and data problems
Log Data Checks

API: 3701520008

Marcellus

Gamma Ray--Density Cross Plot

Schmoker "A"
(Slope) -526.93
r=-0.711

API: 3701520008

Vertical scale of logs varies
Assume Default Slope, Schmoker “A”

Marcellus

Default: -796.71

Gamma Ray--Density Cross Plot

Schmoker “A” (Slope) -12.79

r=-0.028

API: 3702320046

Vertical scale of logs varies
When calculated from GR, TOC was consistently higher than other models.
TOC Calculated from Logs

**API 3701520008 TOC Curves**

- **Marcellus interval**

**API 3701520008 TOC Models**

- TOC: Schmoker
- TOC: Schmoker, modified
- TOC: Linear regression
- TOC: Gamma ray
- P50

Smoothed histogram (KDE plot)

Leco TOC
Upper Ordovician Utica/Point Pleasant

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

Point Pleasant, near Maysville, Ky, photo by author
Utica Research Consortium Playbook

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

www.wvgs.wvnet.edu/utica/playbook/pb_consortium.aspx
## Stratigraphic Nomenclature

<table>
<thead>
<tr>
<th>SERIES</th>
<th>STAGE</th>
<th>CENTRAL AND EASTERN KENTUCKY</th>
<th>NORTHERN KENTUCKY AND SOUTHWESTERN OHIO</th>
<th>WEST-CENTRAL OHIO</th>
<th>EASTERN OHIO</th>
<th>NORTHERN AND CENTRAL WEST VIRGINIA</th>
<th>WESTERN AND NORTH-CENTRAL PENNSYLVANIA</th>
<th>WESTERN AND CENTRAL NEW YORK</th>
<th>THIS STUDY</th>
</tr>
</thead>
<tbody>
<tr>
<td>CINCINNATIAN EDENIAN</td>
<td></td>
<td>Calloway Creek Limestone (in part)</td>
<td>Kope Fm.</td>
<td>Kope Formation</td>
<td>Kope Formation</td>
<td>Reedsville Shale (in part)</td>
<td>Reedsville Shale (in part)</td>
<td>Lorraine Group (in part)</td>
<td>Kope Formation</td>
</tr>
<tr>
<td>MOHAWKIAN</td>
<td>CHATINGFIELDIAN</td>
<td>Millersburg Member</td>
<td>Grier Limestone Member</td>
<td>Logana Member</td>
<td>Curdsville Limestone Member</td>
<td>Trenton Limestone</td>
<td>Trenton Limestone</td>
<td>Trenton Group</td>
<td>Upper Lexington/Trenton Member</td>
</tr>
</tbody>
</table>

- Many names across states

**Utica Research Consortium Final Report, 2015**
Upper Ordovician TOC Data Set

- **130 wells**
- **1,538 TOC**

**Median (50th percentile):**

- **Kope Fm: 0.40%**
- **Utica Shale: 1.09%**
- **Point Pleasant: 1.64%**
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

Model from Godec (2013b) and Utica Consortium Final Report (2014)
On Model Optimization

• Either
  • Maximize coefficient of determination, $R^2$
  • Minimize RMSE

• Residuals
  • Measured – Calculated
  • Near 0
  • Narrow spread

For linear regression $R^2 = r^2$, the correlation coefficient

$R^2 = 0.88$

Smoothed histogram (KDE plot)
TOC and Digital Log Data

$r = -0.49$

$r = -0.26$

$r = -0.026$

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

Not all TOC observations have both GR and RHOB data
Utica TOC Models: \( TOC = f(RhoB) \)

\[
TOC_{\text{Schmoker}} = 55.822 \times \left( \frac{2.72}{RhoB} - 1 \right)
\]

\[
TOC_{\text{Marcellus}} = -35.211 \times RhoB + 97.169
\]

\[
TOC_{\text{Wang}} = \left( \frac{238.1}{RhoB} \right) - 89.1
\]

\[
TOC_{\text{Godec}} = \frac{(RhoB - 2.73)}{-0.05}
\]
New Models Tested

\[ TOC_{\text{SchmokerMod}} = 32.5 \times \left( \frac{2.73}{RhoB} - 1 \right) \]

\[ TOC_{\text{WangMod}} = \left( \frac{49.331}{RhoB} \right) - 17.327 \]

\[ TOC_{MV} = 19.9 - 6.87 \times RhoB - 0.003 \times GR \]

\[ TOC_{TS} = -8.137 \times RhoB + 22.746 \]
Narrowing the Choices

• Overestimate
  • Marcellus

• Underestimate
  • Wang

• Rest
  • +/- 2.5%

**Distribution of Residuals**

*Difference between Multi-variate and Theil-Sen models is +/- 0.5%*
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 $\geq 4\%$
- "P50" median of TOC by depth from multiple models
For the Utica

- Isopach of net thickness of Utica/Point Pleasant intervals combined with TOC \( \geq 1.5\% \)

- Best models
  - Multi-variate
  - Theil-Sen regression

\[
TOC_{MV} = 19.9 - 6.87 \times RhoB - 0.003 \times GR
\]

\[
TOC_{TS} = -8.137 \times RhoB + 22.746
\]
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?
bnuttall@uky.edu

(It’s all his fault.)
Selected references:


http://www.wvgs.wvnet.edu/utica/playbook/pb_consortium.aspx


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