Explorations in TOC for Assessment of CO₂ Storage and Enhanced Gas Recovery for the Middle Devonian Marcellus and Upper Ordovician Utica Shales for the Midwest Regional Carbon Sequestration Partnership*

Brandon C. Nuttall¹, Thomas N. Sparks¹, and Stephen F. Greb¹

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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


http://www.wvgs.wvnet.edu/utica.


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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.

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

Sample variation of calculated TOC logs and Leco TOC from samples

Storage distribution

Total CO2 storage capacity.

Features of the Marcellus Shale

- Black organic-rich shales are shaded gray.
- The Marcellus Shale is highlighted in yellow. Adapted from Patchen and others (1985), de Witt and others (1993), and Milici (1996).

Structure contour map on top of the Marcellus Shale

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

Leco TOC is proportional to GR and inversely proportional to density

Basic idea is the TOC increases with increasing gamma ray intensity and is inversely proportional to density.

\[ \text{TOC}_{\text{GR}} = \frac{\text{GR}}{\text{RhoB}} \]

(Schmoker, 1979 & 1993)

Leco TOC and laboratory density

Leco TOC compared to modeled TOC

Models for determining TOC from wireline data

- Basic idea is the TOC increases with increasing gamma ray intensity and is inversely proportional to density.

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Leco TOC compared to modeled TOC

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

Method using gridded data developed by processing LAS files:

- TOC = f(GR) or f(RhoB)
- ScfCO2 = f(TOC)
- Tons = Area * thickness * RhoB
- Storage = Tons * 5% efficiency

Caveats

1. Maximum bulk density, RhoB varies across region
2. Does not directly account for relationship between porosity and maturity

CO2 Storage Marcellus Shale (million tons)

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

Storage distribution

- Revised Marcellus assessment area outlined in blue is >2,500 ft. deep and net thickness with TOC >2.5%.

<table>
<thead>
<tr>
<th>State</th>
<th>3% Efficiency Factor</th>
<th>10% Efficiency Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kentucky</td>
<td>0.88</td>
<td>2.92</td>
</tr>
<tr>
<td>Maryland</td>
<td>19.02</td>
<td>63.40</td>
</tr>
<tr>
<td>New York</td>
<td>124.37</td>
<td>414.36</td>
</tr>
<tr>
<td>Ohio</td>
<td>23.73</td>
<td>79.99</td>
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<tr>
<td>Pennsylvania</td>
<td>444.16</td>
<td>1,480.55</td>
</tr>
<tr>
<td>Virginia</td>
<td>6.37</td>
<td>1.71</td>
</tr>
<tr>
<td>West Virginia</td>
<td>274.07</td>
<td>913.55</td>
</tr>
<tr>
<td>Total</td>
<td>388.51</td>
<td>2,955.24</td>
</tr>
</tbody>
</table>

Original storage estimate

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

General Nomenclature

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

Type Log

- Marcellus Shale
- Skaneateles Fm
- Onondaga Ls
- Permian Shale
- Appalachian Basin

Structure contour map on top of the Marcellus Shale

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**ToC Models Tested, most significant are shaded**

<table>
<thead>
<tr>
<th>Model</th>
<th>Notes</th>
<th>$r^2$</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>$TOC_{calc}$</td>
<td>From Marcellus</td>
<td>-0.22</td>
<td>1.23</td>
</tr>
<tr>
<td>$TOC_{calc}$</td>
<td>From Wang and others (2018)</td>
<td>-0.32</td>
<td>1.90</td>
</tr>
<tr>
<td>$TOC_{calc}$</td>
<td>From Godec (2010)</td>
<td>-0.56</td>
<td>1.16</td>
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<tr>
<td>$TOC_{calc}$</td>
<td>From Godec (2010)</td>
<td>-0.20</td>
<td>0.84</td>
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<tr>
<td>$TOC_{calc}$</td>
<td>From Godec (2010)</td>
<td>0.25</td>
<td>0.71</td>
</tr>
<tr>
<td>$TOC_{calc}$</td>
<td>From Godec (2010)</td>
<td>0.28</td>
<td>0.70</td>
</tr>
<tr>
<td>$TOC_{calc}$</td>
<td>From Godec (2010)</td>
<td>0.63</td>
<td>0.58</td>
</tr>
</tbody>
</table>

**Distributions of TOC for selected Upper Ordovician units**

- **State**
  - **Utica Shale and Point Pleasant Combined**
    - **Adsorbed CO₂ with TOC**
      - **Kentucky**: 1.87, 76.42, 78.28
      - **Maryland**: 1.50, 142.36, 144.09
      - **New York**: 2.35, 153.18, 155.53
      - **Ohio**: 23.05, 1,855.77, 1,878.82
      - **Pennsylvania**: 48.81, 1,747.94, 1,796.77
      - **Virginia**: 0.02, 1.62, 1.64
      - **West Virginia**: 22.40, 1,747.94, 1,796.77
    - **Total**: 100.03, 7,725.23, 7,825.32

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**Residuals**

- **Train-test split optimization for $TOC_{calc}$**
  - $r^2 = 0.86$
  - RMSE = 1.16

- **Updated models**
  - $r^2 = 0.86$
  - RMSE = 0.70

**Adsorbed CO₂ associated with TOC**

- **Distribution of Leco TOC (box plot) compared to calculated TOC from wireline data**

**TOC measured by Leco**

- **State**
  - **Utica Shale and Point Pleasant Combined**
    - **Adsorbed Matrix**
      - **Kentucky**: 1.87, 76.42, 78.28
      - **Maryland**: 1.50, 142.36, 144.09
      - **New York**: 2.35, 153.18, 155.53
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**Carbon Storage at 10% Efficiency Factor**

**Challenges**

- **Stratigraphy varies across basin**
- **Density (RHOB) and gamma ray cross plots show little correlation.**
- **Relationships of TOC to density (RHOB) are weak to moderate.**
- **With classic models, distribution of residuals of Leco ToC to modeled TOC suggest they may not be optimum.**

**Adsorbed CO₂ associated with TOC**

- **Free Gas Stored in Matrix Porosity**

**Overall, the Point Pleasant has a larger extent and greater porosity so will have a larger storage capacity.**

**State**

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