Assessing Thermal Maturity in Cambrian Source Rocks, Rome Trough, Appalachian Basin: Organic Petrology Complexities*

Tim E. Ruble¹, Wayne R. Knowles², Samuel D. Ely³, and Albert S. Wylie³

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¹Weatherford International Ltd., Houston, TX, USA (tim.ruble@weatherfordlabs.com)
²Weatherford International Ltd., Bideford, Devon, UK EX39 2AU
³Cabot Oil & Gas Corporation, Pittsburgh, PA, USA

Abstract

Interpretations of thermal maturation provide critical data needed for both conventional and unconventional resource assessments. The absence of true vitrinite in pre-Devonian sediments eliminates one of the most commonly measured geothermometers used for thermal maturity determination. Programmed pyrolysis parameters like Tmax can be of limited utility given the maturity regime. However, other organic macerals are potentially available to constrain thermal maturity. The current organic petrology study has been undertaken to provide a very detailed comparison of reflectance measurements on pyrobitumens, “vitrinite-like” material and graptolites.

In the Appalachian Basin of North America, Cambrian-aged source rocks were deposited in shallow water mixed carbonate-siliciclastic depositional environments. Solid pyrobitumen material is found to occur in both lenticular lens/layer morphology as well as distinct pore-filling angular varieties. Published formulas to calculate Equivalent Reflectance (Eq. Ro) from solid bitumens have been applied to these discrete morphological populations. In addition, a newly developed formula to calculate Eq. Ro from angular pyrobitumen (VRc=0.866*BRo ang + 0.0274) is introduced based upon statistical evaluation of reflectance readings from a global dataset. “Vitrinite-like” organic macerals were found in rare abundance within these potential source rocks, but their occurrence enables an independent comparison to pyrobitumen Eq. Ro values. Graptolites are another organic maceral that can be evaluated via organic petrology, but caution should be utilized since these tend to show a high degree of
anisotropy. The results of this investigation provide additional geochemical guidance to assist geologists in more accurately interpreting thermal maturity in the Rome Trough region of the Appalachian Basin.

References Cited


Knowles, W., 2016, Weatherford Laboratories confidential research study, unpublished.


ASSESSING THERMAL MATURITY IN CAMBRIAN SOURCE ROCKS, ROME TROUGHL, APPALACHIAN BASIN: ORGANIC PETROLOGY COMPLEXITIES

Tim E. Ruble¹, Wayne R. Knowles², Samuel D. Ely³ and Albert S. Wylie Jr.³

¹ Weatherford International Ltd., Houston, TX, USA
² Weatherford International Ltd., Bideford, Devon, UK
³ Cabot Oil & Gas Corp., Pittsburgh, PA, USA
Opening Remark

- Published formulas to calculate equivalent vitrinite reflectance from solid bitumen/pyrobitumen reflectance are inadequate.

- Appears to be two distinct morphologies (lens/layer & angular) and appropriate conversions need to be applied.

- Statistical evaluation of global dataset enables application of unique conversions of solid bitumen reflectance to Eq. Ro for both types.

- Application of this approach to data from Cambrian Rogersville source rocks in the Rome Trough, Appalachian Basin will be used to illustrate the new methodology.
Oil & Gas Generation Scheme

From Jarvie et al. (2007)
Generic Classification Scheme for Bitumens

from Jacob (1989)
Correlation of Bitumen to Vitrinite Reflectance

from Jacob (1989)

from Landis and Castaño (1995)
Cambrian Source Rocks in Rome Trough, Appalachian Basin

Study Base map – Wells with Conasauga Penetrations

Extent of Rome Trough

Modified from Roen and Walker (1996)
Fault Nomenclature from Drahovzal and Noger (1995)
Rome Trough Strata: Equally spaced cross section A – A’ [Actual Distance: ~107 miles]
Flattened on Nolichucky Shale (Top of Conasauga Group)

**Log Units –**
- Bulk Density: RHOB, g/cc
- Neutron Porosity: NPHI, PU
- Gamma Ray: GR, API
- Measured Depth in Feet

**Fault Nomenclature from**
Drahovzal and Noger (1995)

**Precambrian Basement**

**Kentucky River Fault System**

**Irvine Paint Creek Fault System**

**Rogersville Shale**

**Rome Trough**

**Ohio**

**Kentucky**

**West Virginia**

**Faults**
- Kentucky River Fault System
- Irvine Paint Creek Fault System
- Rockcastle River Fault System
- Utica Shale
- Trenton/Black River
- Knox Group
- Conasauga Group
- Rome Sands, Carbonates, Shales

**Inland Gas**
- Sam. McKeand (1968)
- Roberta Young (1971)
- Exxon Jay P Smith (1975)
- US Signal Elkhorn Coal (1972)
- Signal Henry Stratton (1971)

**Study Well**
- Exxon Jay P Smith (1975)

**Commonwealth Newell**
- Roberta Young (1971)

**Inland Gas**
- Sam. McKeand (1968)
Trilobite Carapace

Epoxy

Detrital Quartz

Dispersed Organic Matter

TOC: 2.35%
Clays: 45%
Carbonates: 26%
Quartz: 13%

50x Thin Section

11,200'

Modified from Ryder et al. (2005)

CORE: Exxon Jay P Smith (1975)

Nolichucky Shale

Maryville Limestone

Rogersville Shale

Rutledge Limestone

Pumpkin Valley Shale

~5 inches

~10mi

WV

KY

OHIO

Rutledge Limestone

Pumpkin Valley Shale
### Harris et al. (2015) Bitumen Reflectance

#### Exxon Smith Bitumen Reflectance

<table>
<thead>
<tr>
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<th>11167</th>
<th>11178</th>
<th>11191</th>
<th>11197</th>
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</thead>
<tbody>
<tr>
<td>Average Ro random</td>
<td>1.76</td>
<td>1.80</td>
<td>1.80</td>
<td>1.84</td>
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<tr>
<td>Maximum Ro random</td>
<td>2.11</td>
<td>2.11</td>
<td>2.04</td>
<td>2.10</td>
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<tr>
<td>Minimum Ro random</td>
<td>1.50</td>
<td>1.47</td>
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<tr>
<td>Standard deviation</td>
<td>0.14</td>
<td>0.16</td>
<td>0.13</td>
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<tr>
<td>Observations</td>
<td>50.00</td>
<td>50.00</td>
<td>50.00</td>
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</tbody>
</table>

**Calculated Ro equivalent**

\[(\text{Ro random} \times 0.618) + 0.4\]  
(Jacob, 1989)

<table>
<thead>
<tr>
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<th>11167</th>
<th>11178</th>
<th>11191</th>
<th>11197</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculated Ro equivalent</td>
<td>1.49</td>
<td>1.51</td>
<td>1.51</td>
<td>1.54</td>
</tr>
</tbody>
</table>

**Indicated Tmax from calculated Ro equiv.**

<table>
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<tr>
<th></th>
<th>480</th>
<th>482</th>
<th>482</th>
<th>484</th>
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</table>
Photomicrographs appear to document the occurrence of lenticular forms of pyrobitumen in samples from the Exxon Jay P Smith #1 well.

Appears to have a more granular solid hydrocarbon appearance.

Likely produced reflectance data lower than autochthonous vitrinite equivalent.

Photomicrographs appear to also document the occurrence of pyrobitumen type filling mineral pore spaces or fractures, taking on an ‘angular’ appearance.

Appears to have a more homogeneous solid hydrocarbon appearance.

Likely produced higher reflectance data than autochthonous vitrinite equivalent.
Harris et al. (2015) applied Jacob (1985) conversion to all measured solid bitumen Ro values in samples from Exxon Jay P Smith #1 well. Considerable spread in min/max Ro readings as shown by error bars on depth plot. Resultant Eq. Ro values avg. 1.51% Ro suggest Cambrian Rogersville source interval is within the wet gas window.
Macerals

Vitrinite-like Material

- Vitrinite-like material (VLM).
- Correlation between VLM and vitrinite reflectance represented by three linear equations corresponding to three maturity stages <0.75% VLMRo, 0.75-1.50% VLMRo and >1.50% VLMRo. (Xianming et al., 2000)
- Wide range of morphologies.
- More data needed.

Graptolites

- Zooclasts – Graptolites, Chitinozoa etc.
- Graptolites optically anisotropic at high maturities.
- Can possess readily identifiable morphologies and patterns.
Bitumen types (within same sample)

- Pyrobitumen distributed through rock matrix.
- Tends to take on a lenticular form but same type can be found as infilling in foraminifera tests.
- Usually associated with actual source rock matrix.
- Produces reflectance data lower than autochthonous vitrinite equivalent.

- Pyrobitumen type usually found filling mineral pore spaces or fractures, taking on an ‘angular’ appearance.
- Associated with carbonate stringers etc.
- Produces higher reflectance data than autochthonous vitrinite equivalent.
- Can show signs of optical anisotropy at high maturities.
Organic Petrology Histogram

Exxon, JP Smith: 11200’

<table>
<thead>
<tr>
<th></th>
<th>Vitrinite-like material</th>
<th>Lens/layer Pyrobitumen</th>
<th>Angular Pyrobitumen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average $R_o$ rand</td>
<td>1.58</td>
<td>1.34</td>
<td>1.84</td>
</tr>
<tr>
<td>Minimum $R_o$ rand</td>
<td>1.49</td>
<td>1.23</td>
<td>1.75</td>
</tr>
<tr>
<td>Maximum $R_o$ rand</td>
<td>1.68</td>
<td>1.45</td>
<td>1.92</td>
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<tr>
<td>St. deviation</td>
<td>0.06</td>
<td>0.07</td>
<td>0.06</td>
</tr>
<tr>
<td>Observations</td>
<td>9</td>
<td>21</td>
<td>10</td>
</tr>
</tbody>
</table>

Calculated Ro equivalent (Knowles, 2016)

1.60  1.62

Approximate range of Harris et al. (2015) data
New possibilities...

• Ca. 90% of data gathered from unconventional shale plays, predominantly in the US.
• Minimizes risk of contamination from long-distance migration oils.
• Large dataset. High confidence.
• ‘Angular’ bitumen/pyrobitumen trapped in mineral pore spaces or fractures readily identifiable.
New possibilities...

- **lens/layer bitumen**
  \[ y = 0.0063x^5 - 0.0881x^4 + 0.4222x^3 - 0.7936x^2 + 1.5431x + 0.1994 \]
  \[ R^2 = 0.995 \]
  \[ n=1981 \]

- **angular bitumen**
  \[ y = 0.8664x + 0.0257 \]
  \[ R^2 = 0.9927 \]
  \[ n=836 \]
Why the non-linear trend?

Estimated linear trends based on curve inflection points

- >1.8% VR
- 1.0-1.8% VR
- <1.0% VR

Onset of oil cracking ca. 1.0% VR_0?

End of cracking zone ca. 1.8% VR_0?

y = 1.0415x + 0.2907
R² = 0.9208

y = 0.8773x + 0.4138
R² = 0.9618

y = 1.1662x - 0.0233
R² = 0.9861
Vitrinite-like Material

- Although sparse in occurrence, vitrinite-like material (VLM) was identified in samples from the Exxon Jay P Smith #1 well.
- Measured Ro values avg. 1.64% Ro suggest Cambrian Rogersville source interval is within the early dry gas window in deep Rome Trough.
Lens/layer Solid Bitumen

- Lens/layer solid bitumen material was identified in samples from the Exxon Jay P Smith #1 well.
- Measured Ro values are lower than VLM.
- Knowles (2016) conversion specific to lens/layer solid bitumen was applied.
- Resultant Eq. Ro values avg. $1.68\%$ Ro suggest Cambrian Rogersville source interval is within the early dry gas window in deep Rome Trough.
Angular solid bitumen material was identified in samples from the Exxon Jay P Smith #1 well.

- Measured Ro values are higher than VLM.
- Knowles (2016) conversion specific to angular solid bitumen was applied.
- Resultant Eq. Ro values avg. 1.64% Ro suggest Cambrian Rogersville source interval is within the early dry gas window in deep Rome Trough.
Eq. Ro Comparison

- Harris et al. (2015) Eq. Ro values using all solid bitumen data average 1.51% Ro, which is ~8% lower in comparison to average Ro values determined in the current study.
- Measured Ro values on vitrinite-like material average 1.64% Ro.
- Eq. Ro values using Knowles (2016) conversion on lens/layer solid bitumen average 1.68% Ro.
- Eq. Ro values using Knowles (2016) conversion on angular solid bitumen average 1.64% Ro.
Eq. Ro Comparison

- Extrapolation to a surface Ro intercept of 0.5% Ro provides a comparison of predicted thermal maturity depth profiles.
- Harris et al. (2015) trendline suggests most of Cambrian Rogersville source interval in deep Rome Trough is in wet gas window.
- Trendlines from all data in current study suggest Cambrian Rogersville source rocks >11,000’ in deep Rome Trough are likely into early dry gas window.
Summary Thoughts

- Appears to be two morphologies of solid bitumen/pyrobitumen and appropriate conversion to equivalent VR needs to be applied.
  
  ▪ **Lens/layer solid bitumen** has lower reflectance than autochthonous vitrinite. Tends to occupy the source rock matrix.
  
  ▪ **Angular solid bitumen** fills mineral pore spaces and/or fractures. This type has higher reflectance than autochthonous vitrinite. Commonly encountered in carbonates within or immediately adjacent to source rock.
  
- Statistical evaluation of global dataset enables application of unique conversions of solid bitumen reflectance to Eq. Ro for both types.

- Application of this approach to data from Cambrian Rogersville source rocks in the Rome Trough suggests a slightly higher thermal maturity (~1.65% Eq. Ro in Exxon Jay P Smith #1 well).

- Differences in interpreted thermal maturity from previous work suggest deep Rome Trough is in early dry gas rather than wet gas window.
Exxon Jay P Smith #1 well, Rogersville Shale, 11460’: Angular pyrobitumen with a reflectance reading of 1.79% BRo which equated to a 1.58% Eq. Ro using Knowles (2016) conversion.
References


• Harris, D.C., Hickman J.B., and Eble, C.F., 2015, Cambrian Rogersville Shale (Conasauga Group), Kentucky and West Virginia: a potential new unconventional reservoir in the Appalachian Basin, AAPG Search and Discovery Article #10787 (2015).


• Jacob, H., 1985, Disperse solid bitumens as an indicator for migration and maturity in prospecting for oil and gas, Erdöl und Kohle-Erdgas-Petrochemie, v. 38, no. 8, p. 365.


• Knowles, W., 2016, Weatherford Laboratories confidential research study, unpublished.


