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

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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.

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

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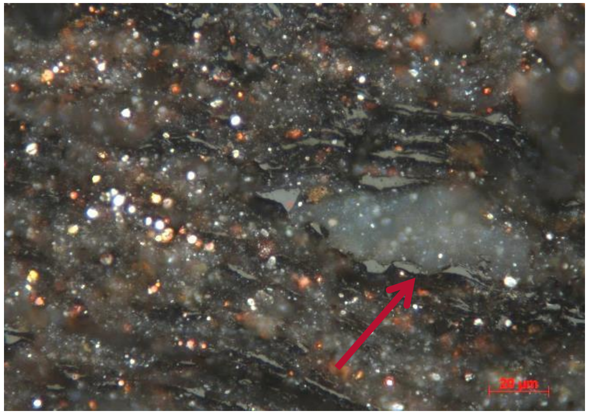
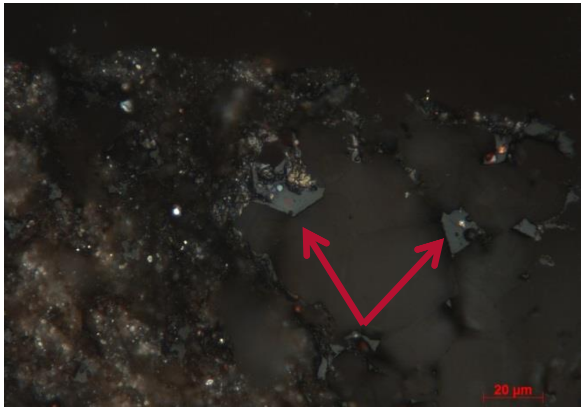
Opening Remark

- 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.



lens/layer bitumen



angular bitumen

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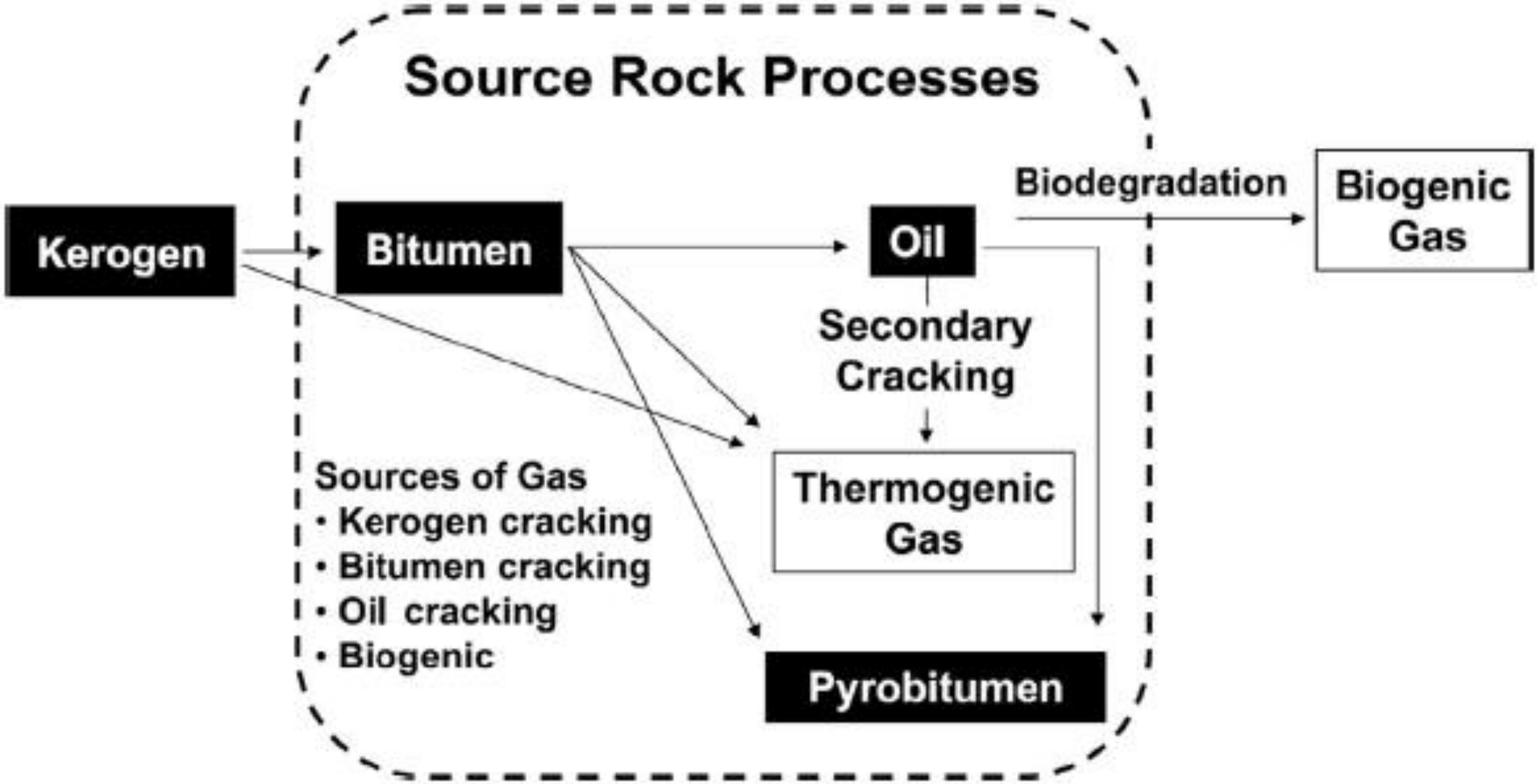
Oil & Gas Generation Scheme



from Jarvie et al. (2007)

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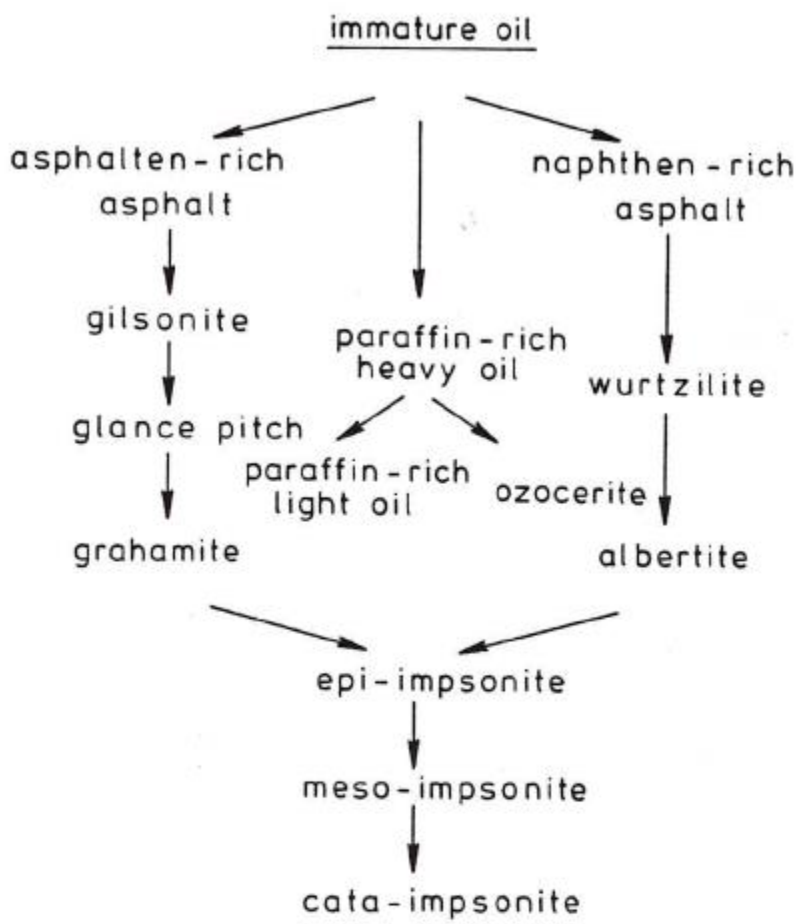
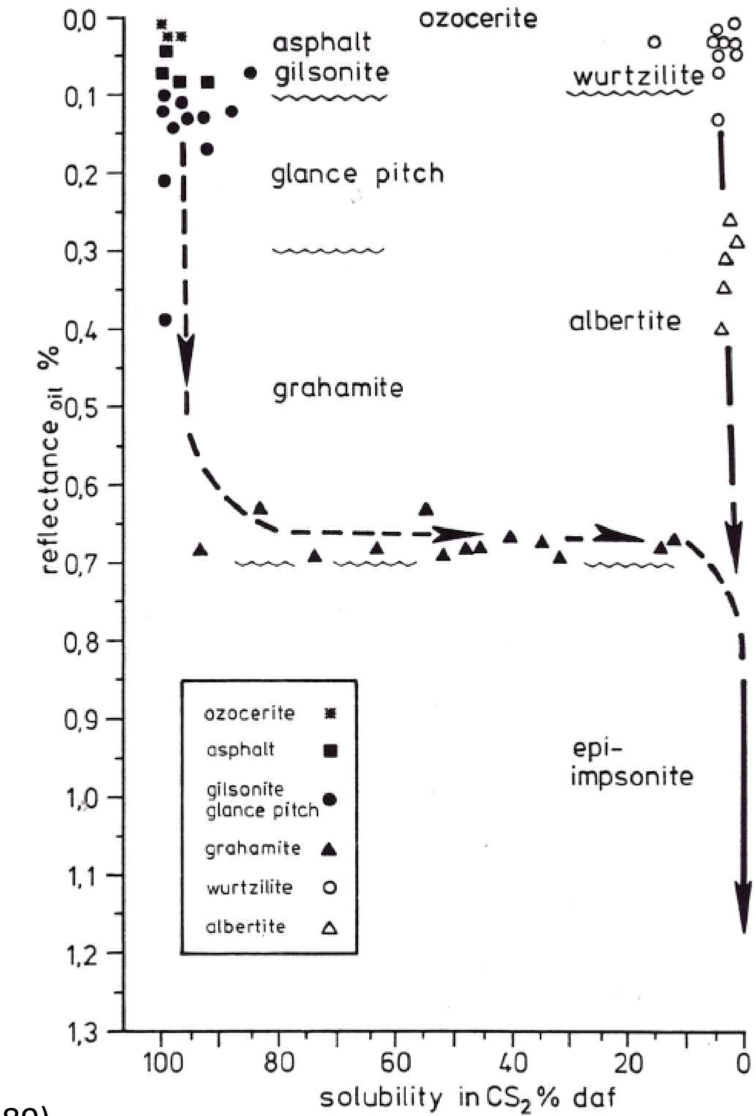
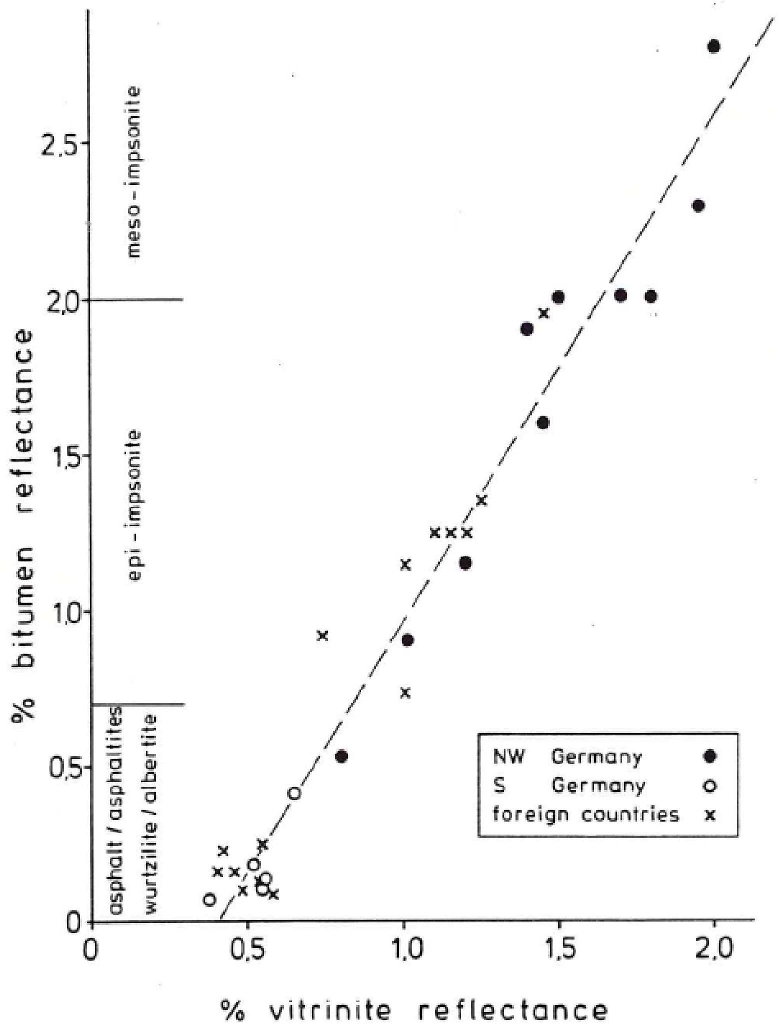
Generic Classification Scheme for Bitumens





from Jacob (1989)

Correlation of Bitumen to Vitrinite Reflectance



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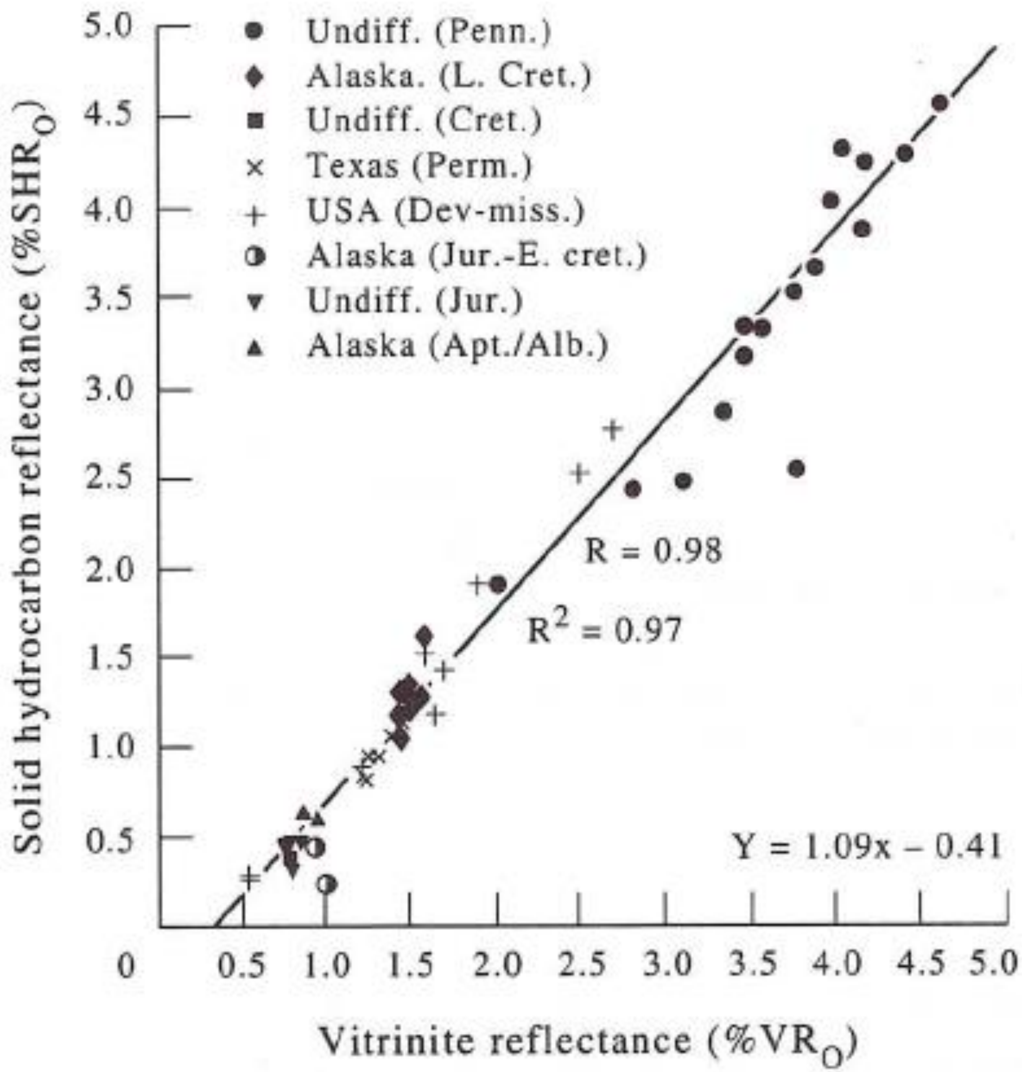

from Landis and Castaño (1995)

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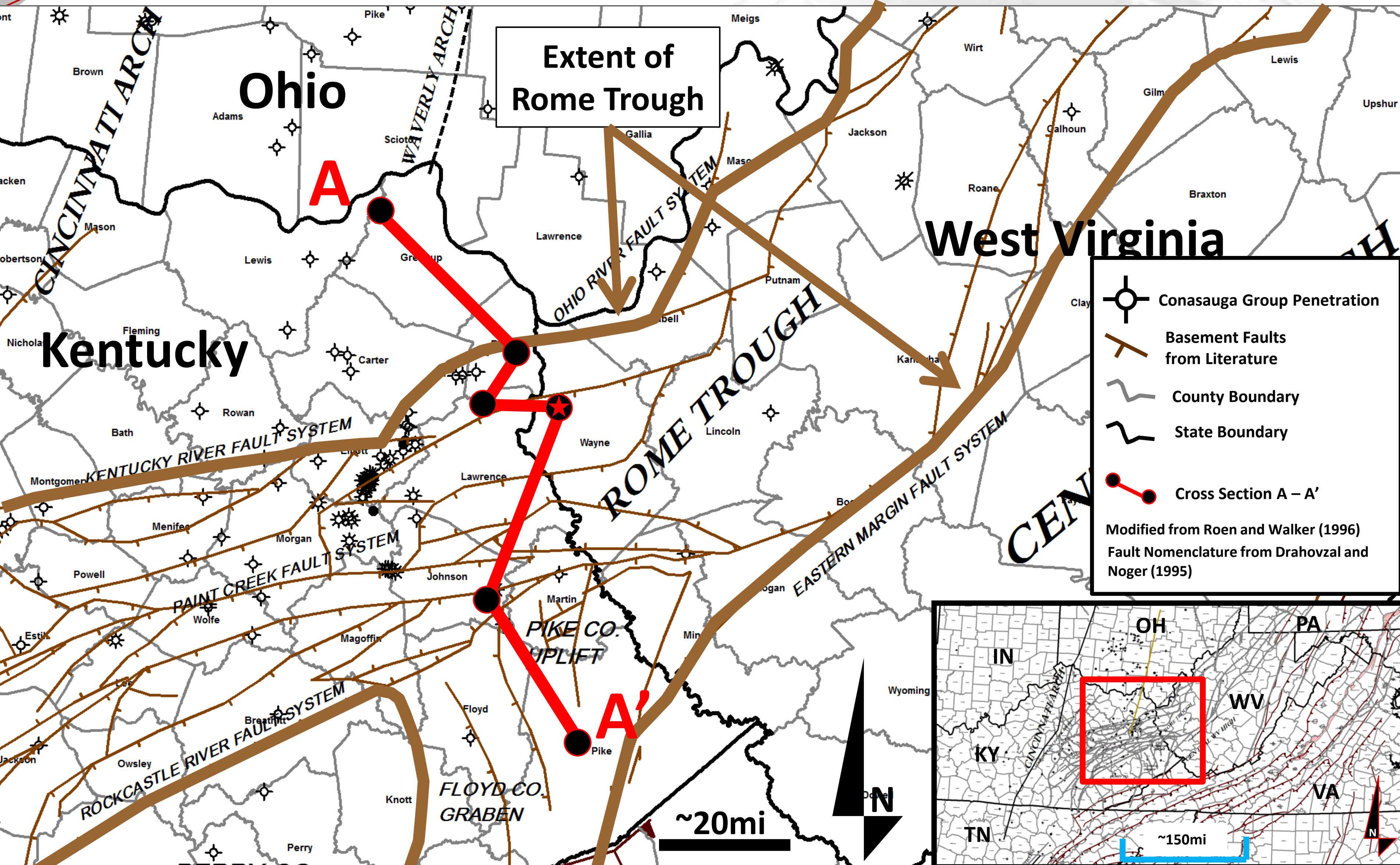
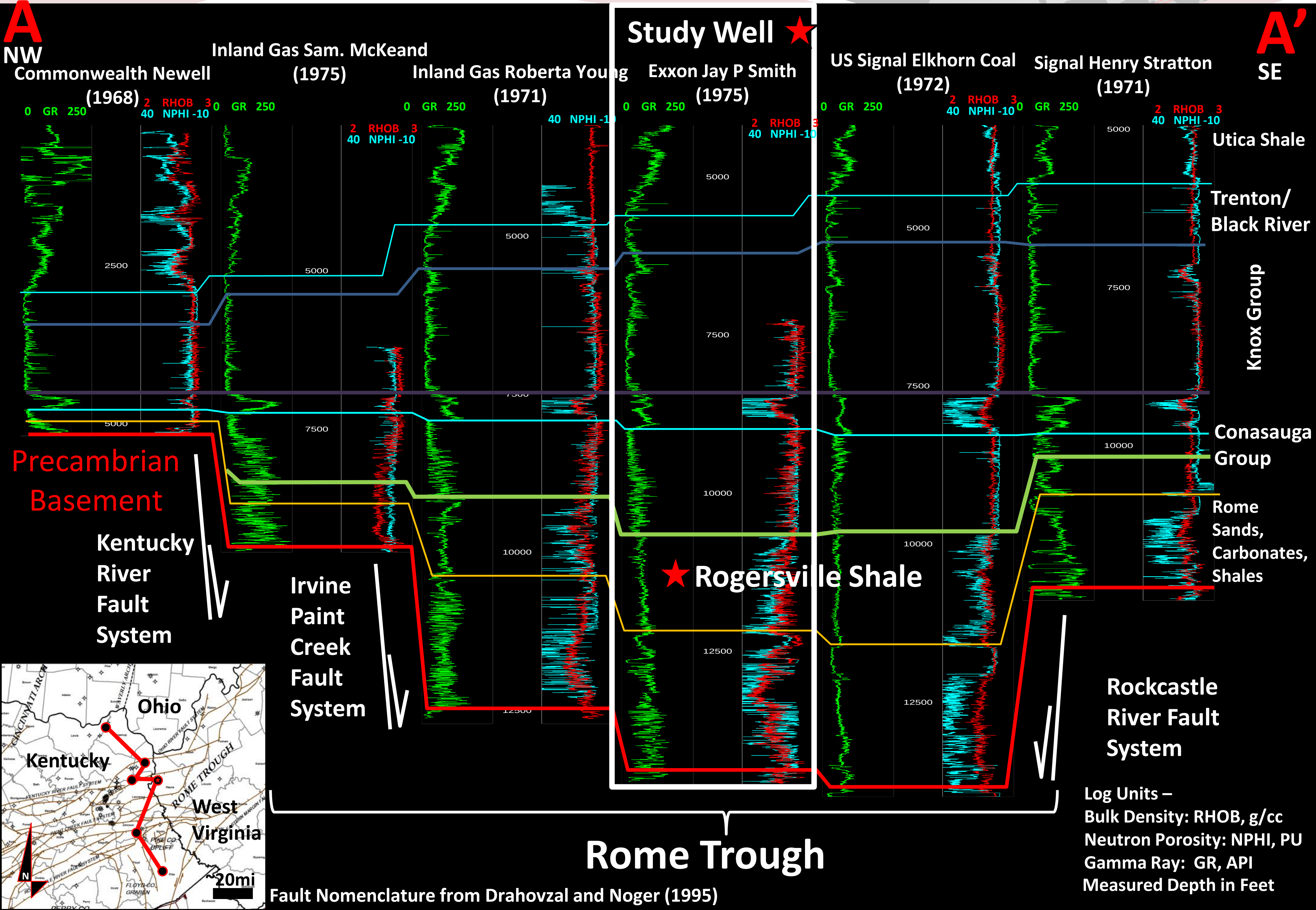
Cambrian Source Rocks in Rome Trough, Appalachian Basin

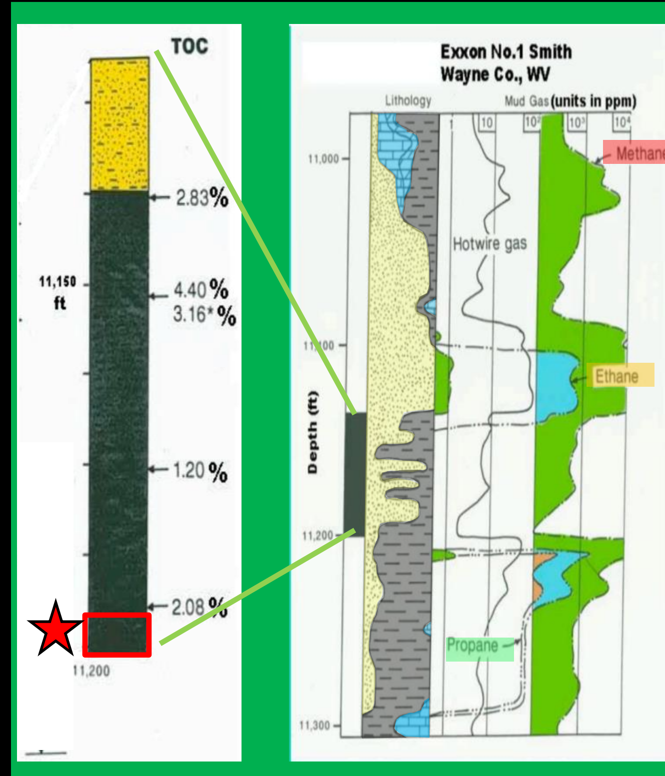
Study Base map – Wells with Conasauga Penetrations



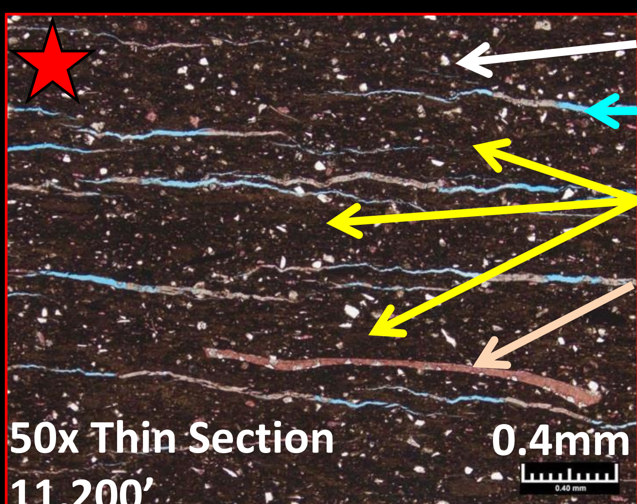
Rome Trough Strata: Equally spaced cross section A – A’ [Actual Distance: ~107 miles]

Flattened on Nolichucky Shale (Top of Conasauga Group)





Modified from Ryder et al. (2005)



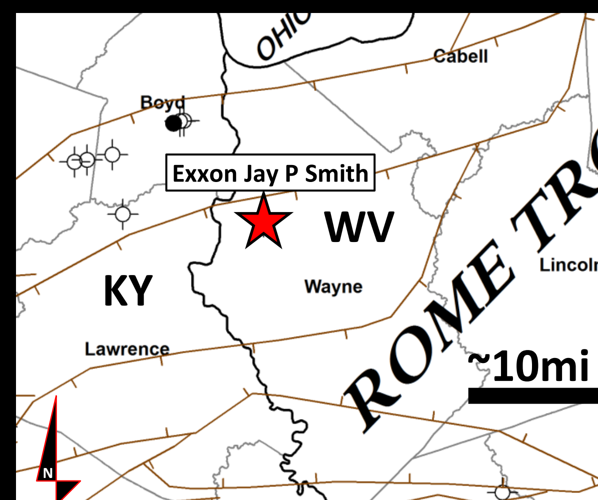
Detrital Quartz

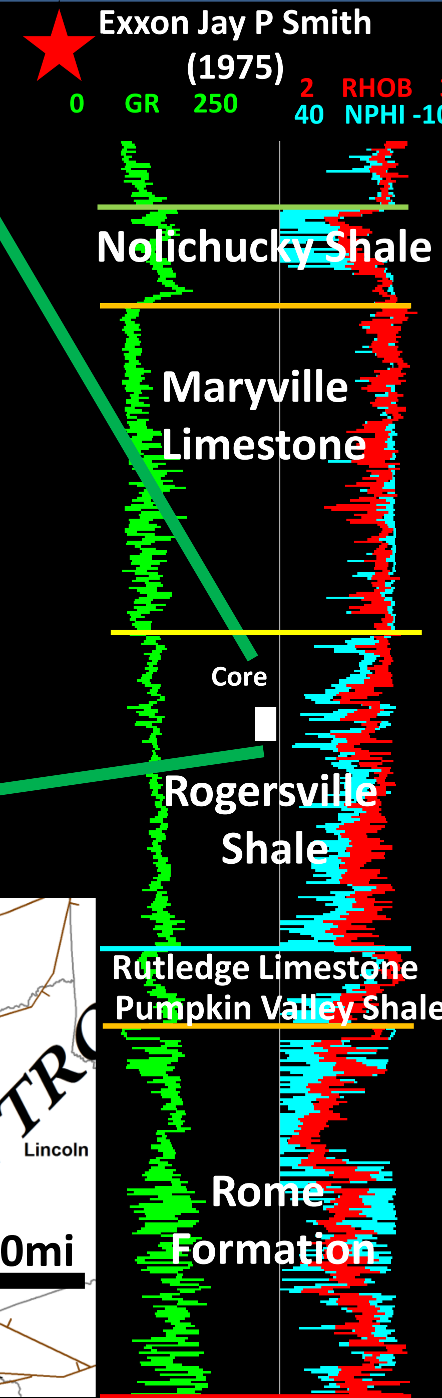
Epoxy

Disseminated Organic Matter

Trilobite Carapace

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





Harris et al. (2015) Bitumen Reflectance

Exxon Smith Bitumen Reflectance

	11167	11178	11191	11197
Average Ro random	**1.76**	**1.80**	**1.80**	**1.84**
Maximum Ro random	2.11	2.11	2.04	2.10
Minimum Ro random	1.50	1.47	1.53	1.59
Standard deviation	0.14	0.16	0.13	0.13
Observations	50.00	50.00	50.00	50.00
Calculated Ro equivalent (Ro random * 0.618) + 0.4 (Jacob, 1989)	**1.49**	**1.51**	**1.51**	**1.54**
Indicated Tmax from calculated Ro equiv.	**480**	**482**	**482**	**484**

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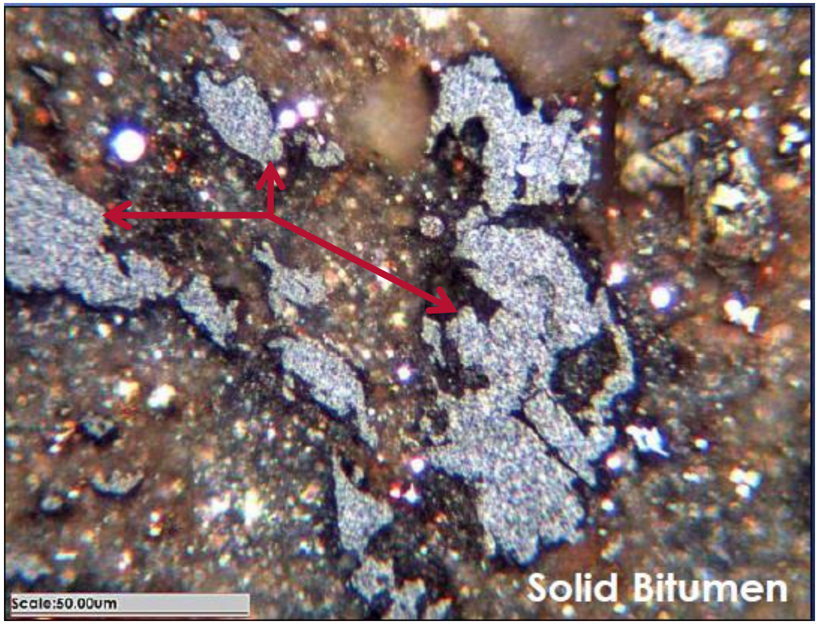
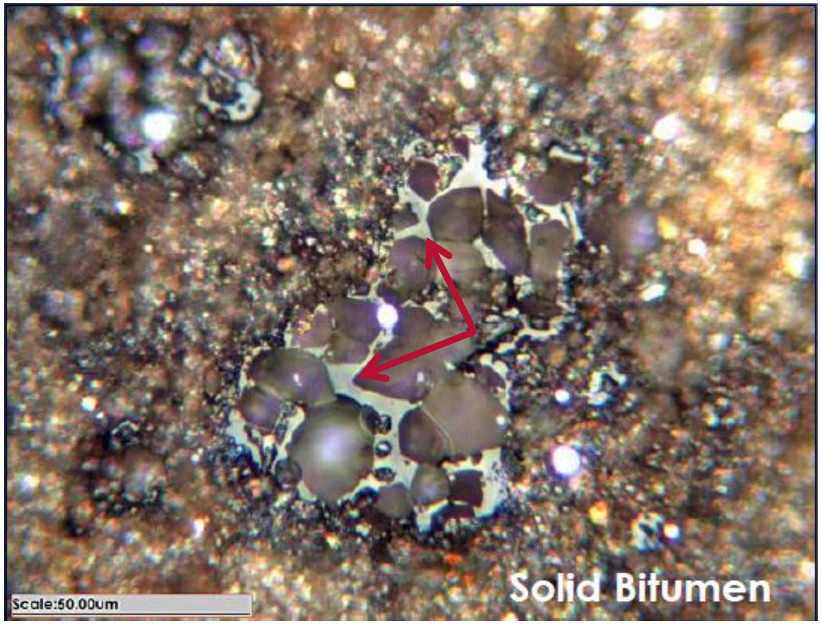
Harris et al. (2015) Organic Petrology



- 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.

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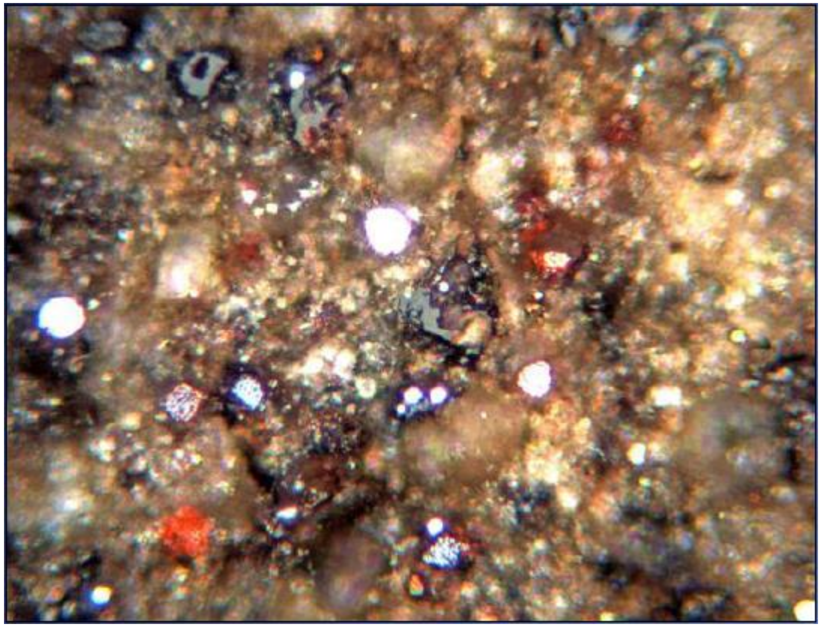
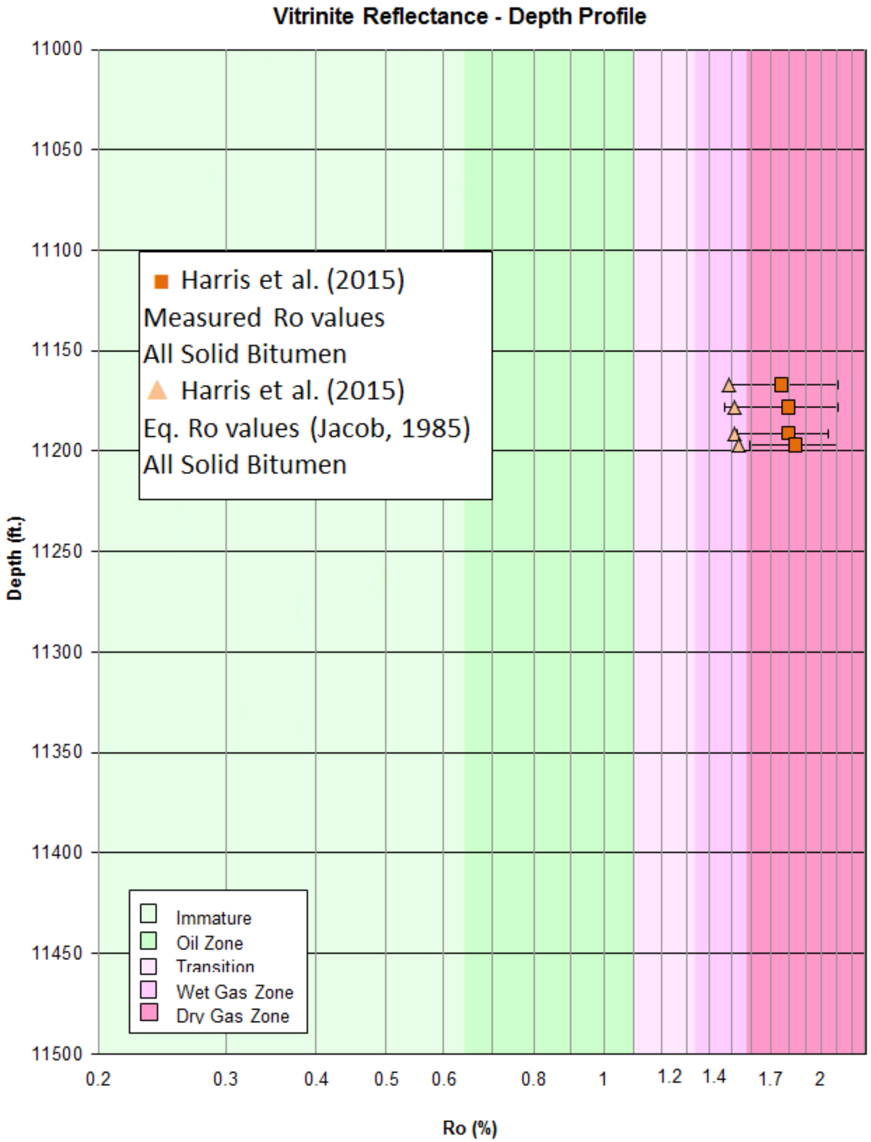
Harris et al. (2015) Organic Petrology





- Harris et al. (2105) 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.

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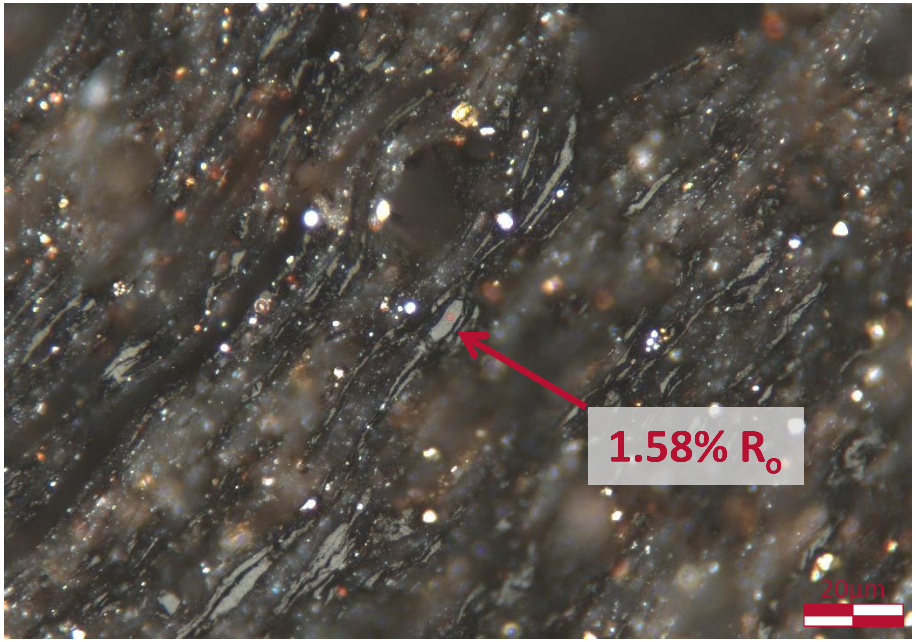
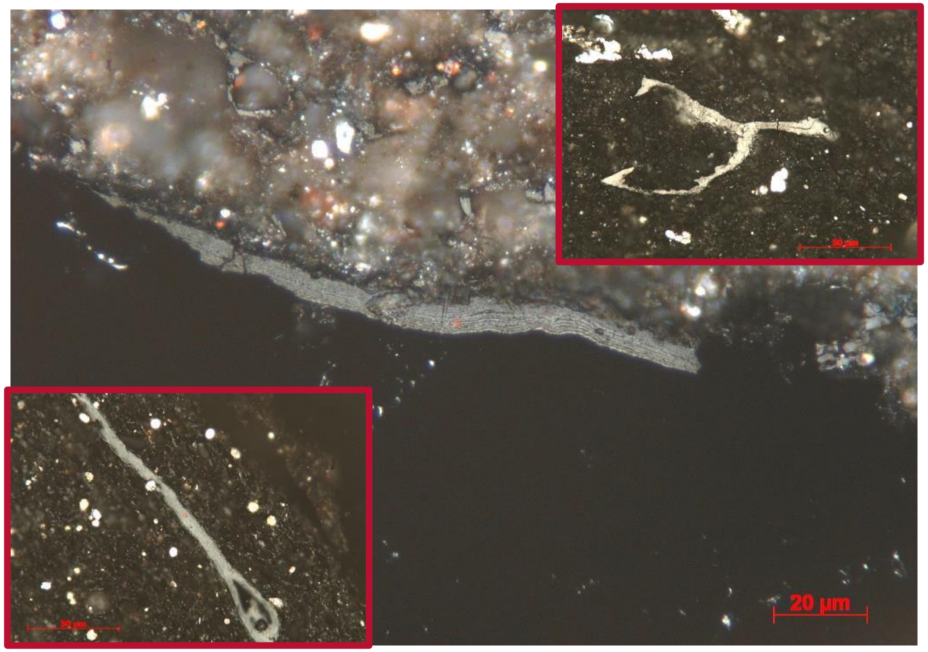
Macerals

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 morpholgies.
- More data needed.

Graptolites



- Zooclasts – Graptolites, Chitinozoa etc.
- Graptolites optically anisotropic at high maturities.
- Can possess readily identifiable morphologies and patterns.

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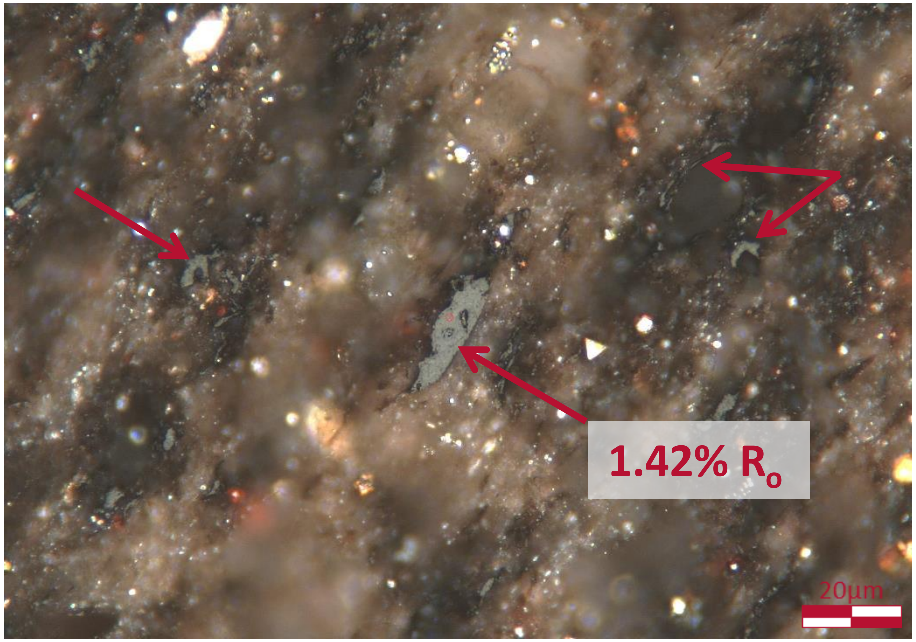
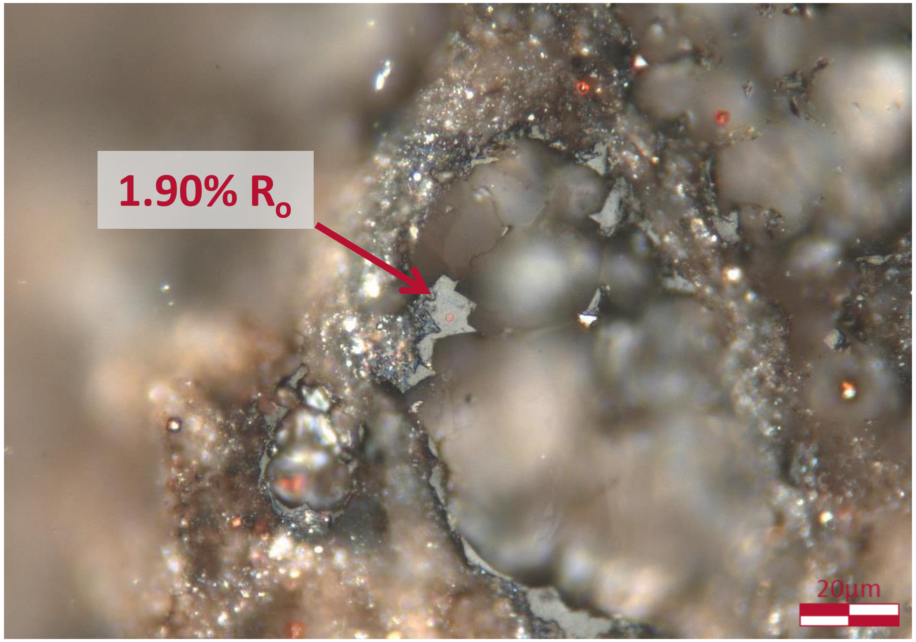
Bitumen types (within same sample)

Lens/layer Solid Bitumen



- 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.

Angular Solid Bitumen



- 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.

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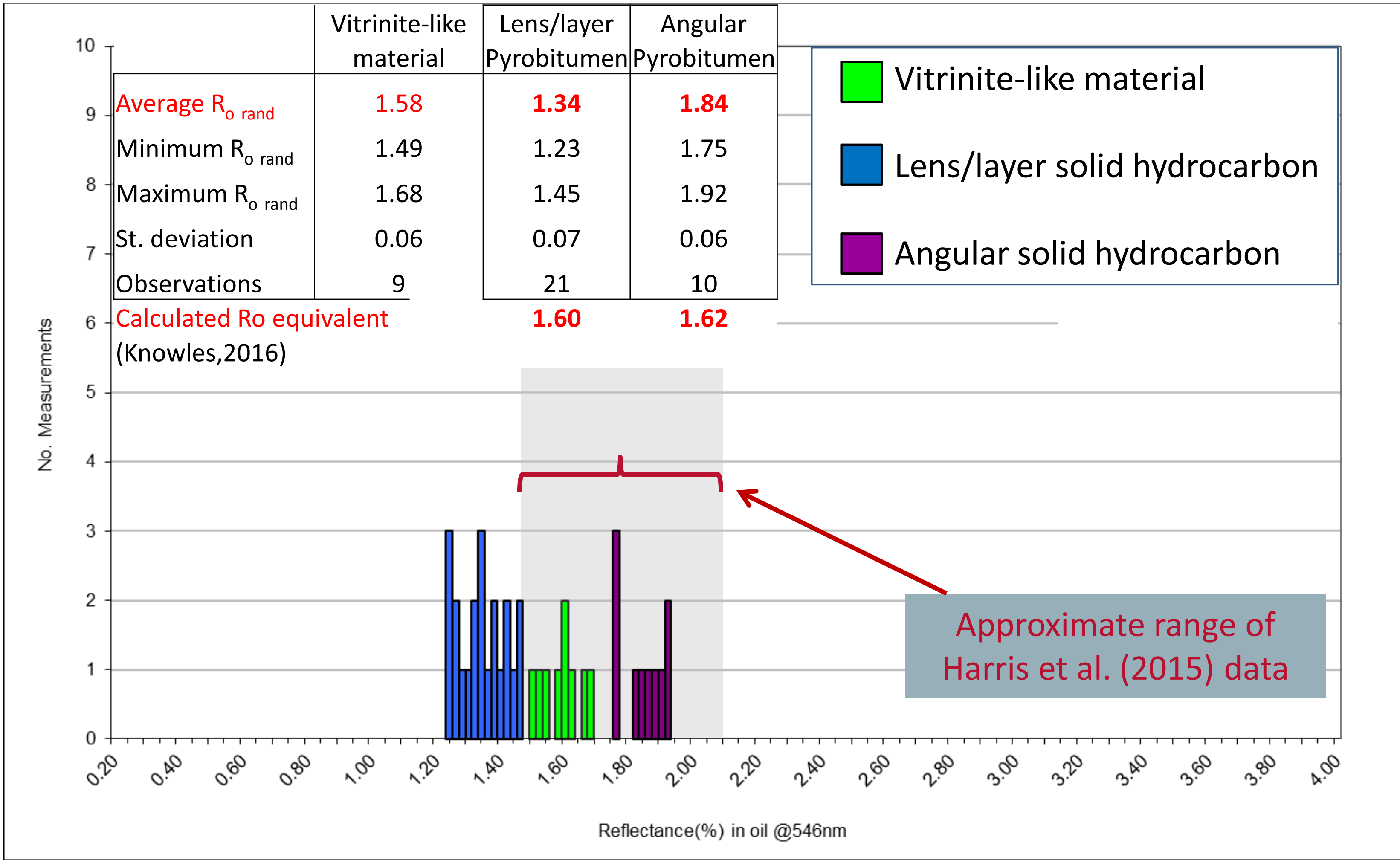
Organic Petrology Histogram

Exxon, JP Smith: 11200'

	Vitrinite-like material	Lens/layer Pyrobitumen	Angular Pyrobitumen
Average $R_{o\ rand}$	1.58	**1.34**	**1.84**
Minimum $R_{o\ rand}$	1.49	1.23	1.75
Maximum $R_{o\ rand}$	1.68	1.45	1.92
St. deviation	0.06	0.07	0.06
Observations	9	21	10
Calculated Ro equivalent (Knowles,2016)		**1.60**	**1.62**



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.

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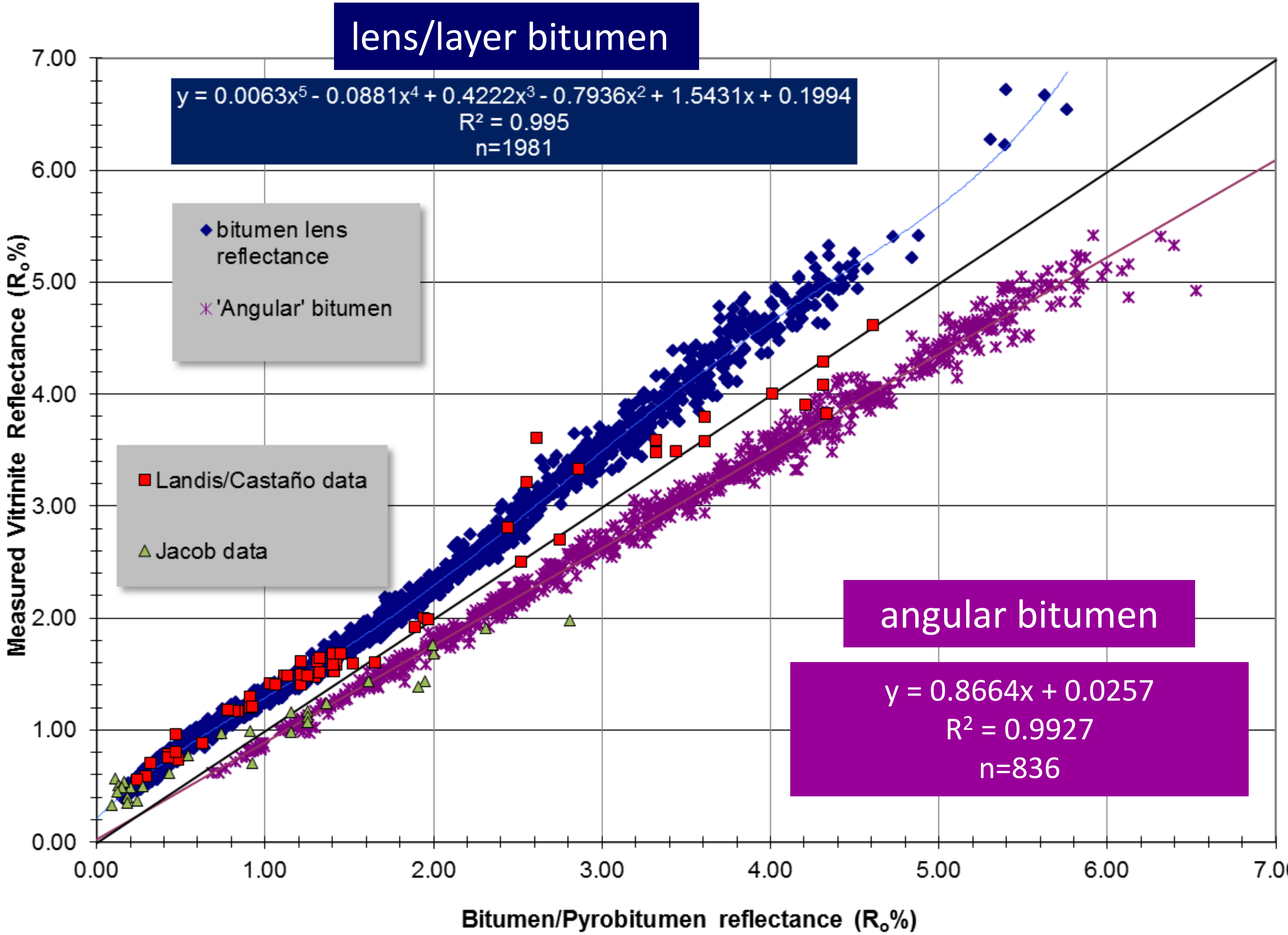
New possibilities…



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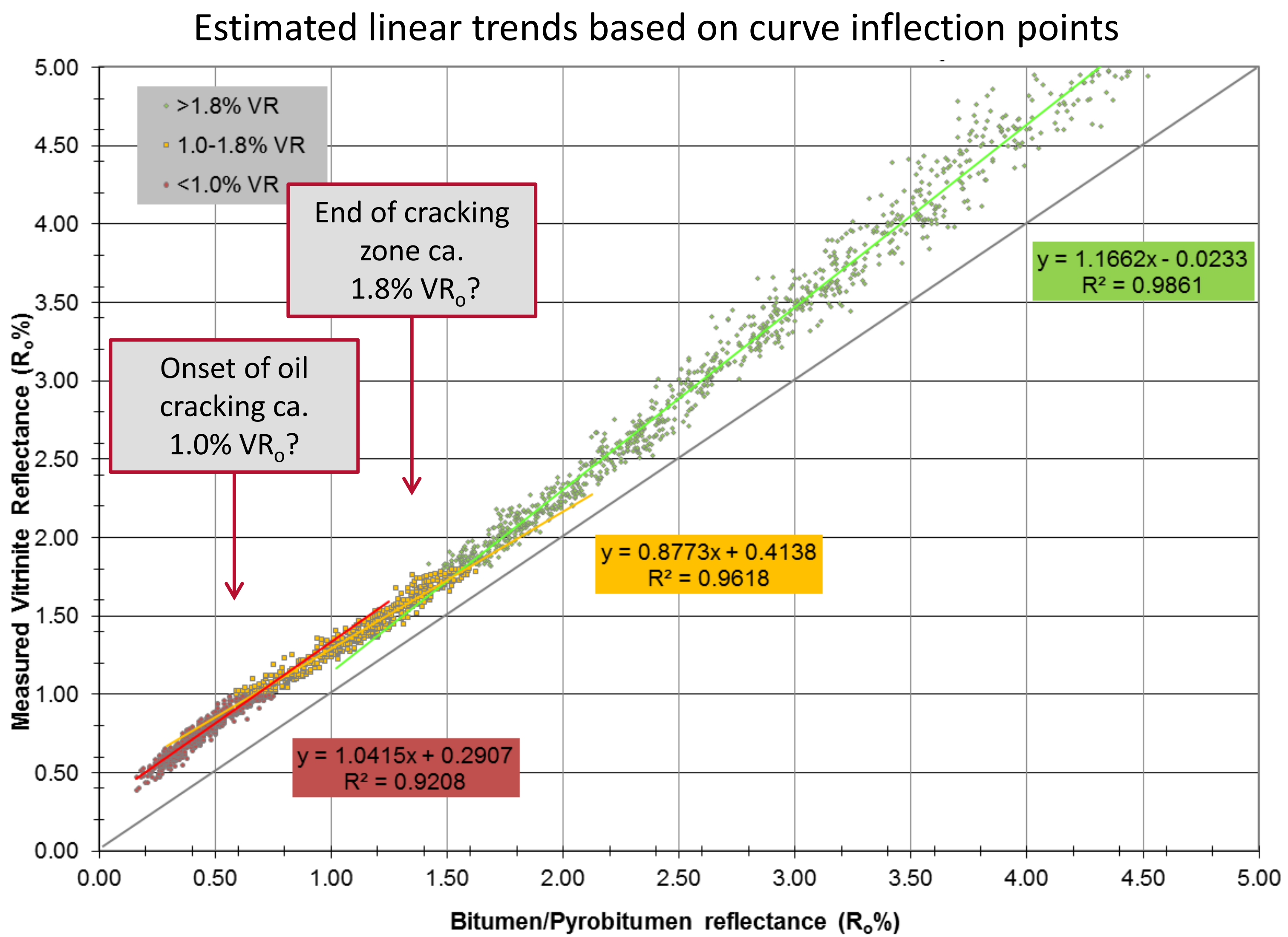
Why the non-linear trend?



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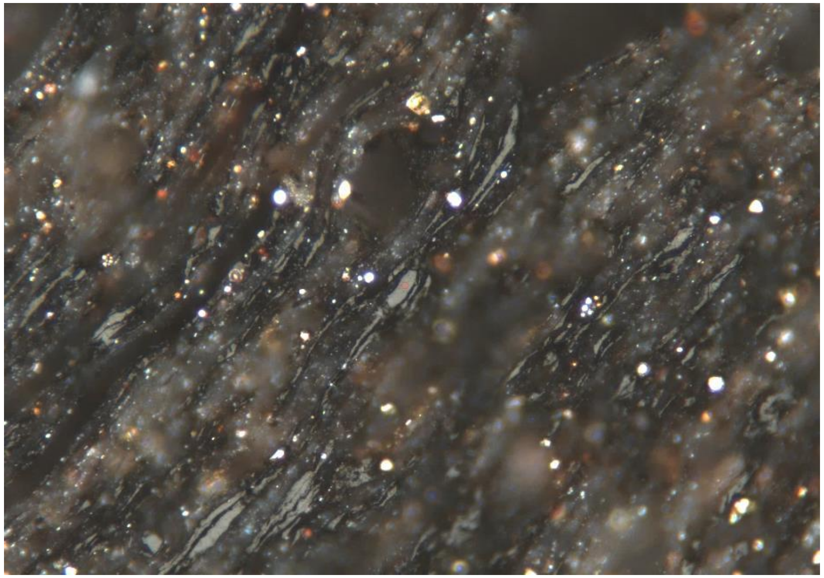
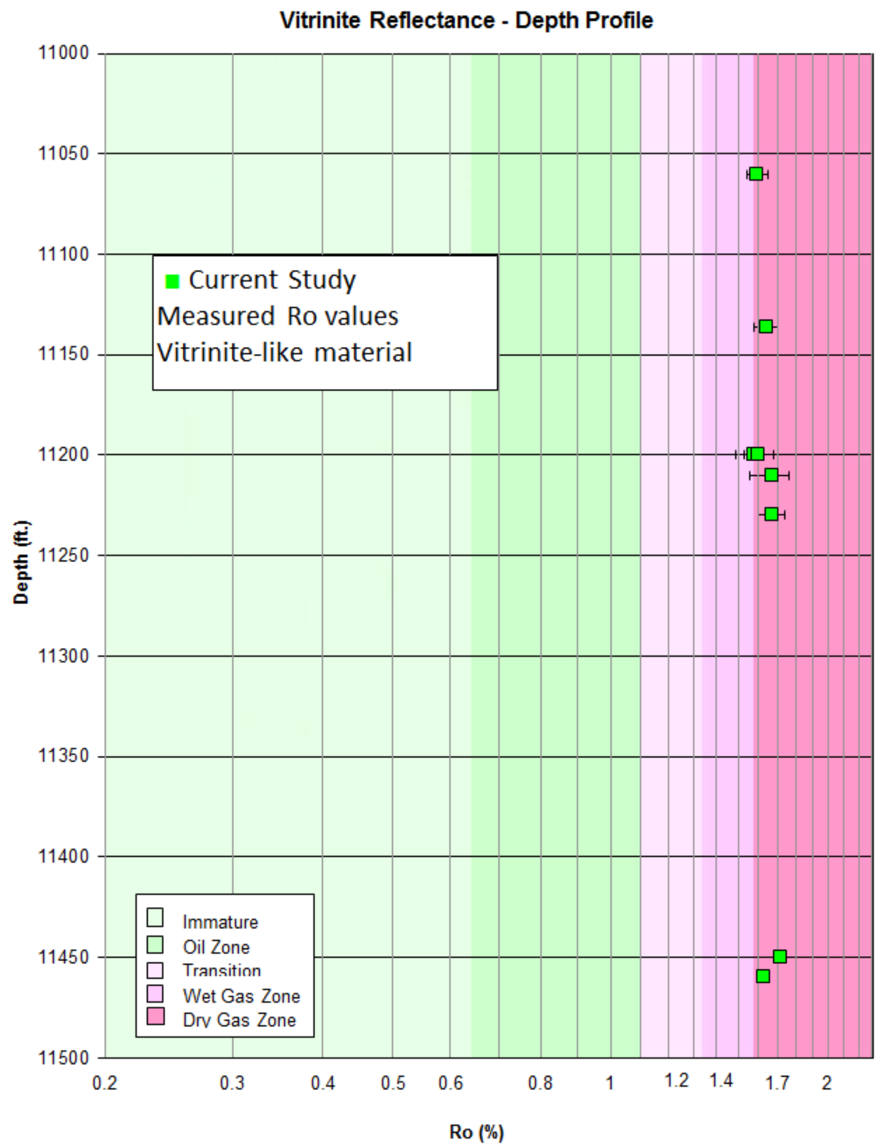
Vitrinite-like Material





- 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.

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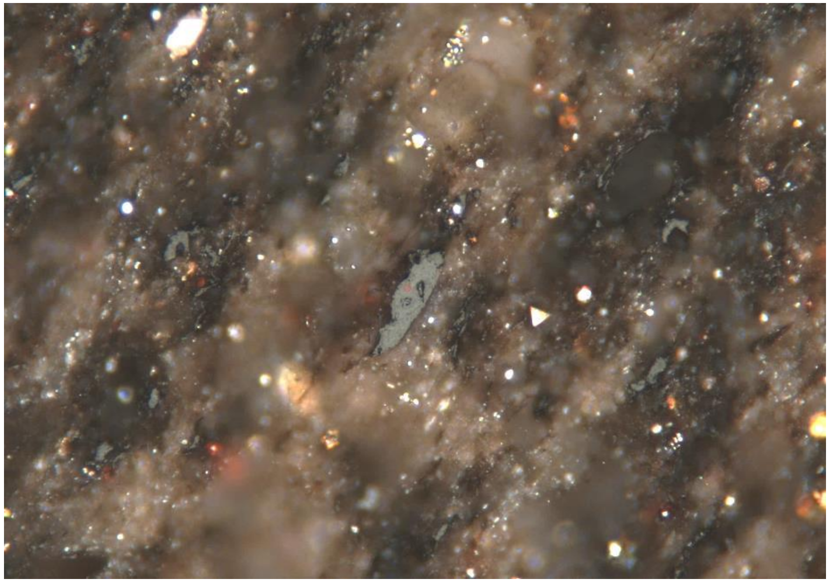
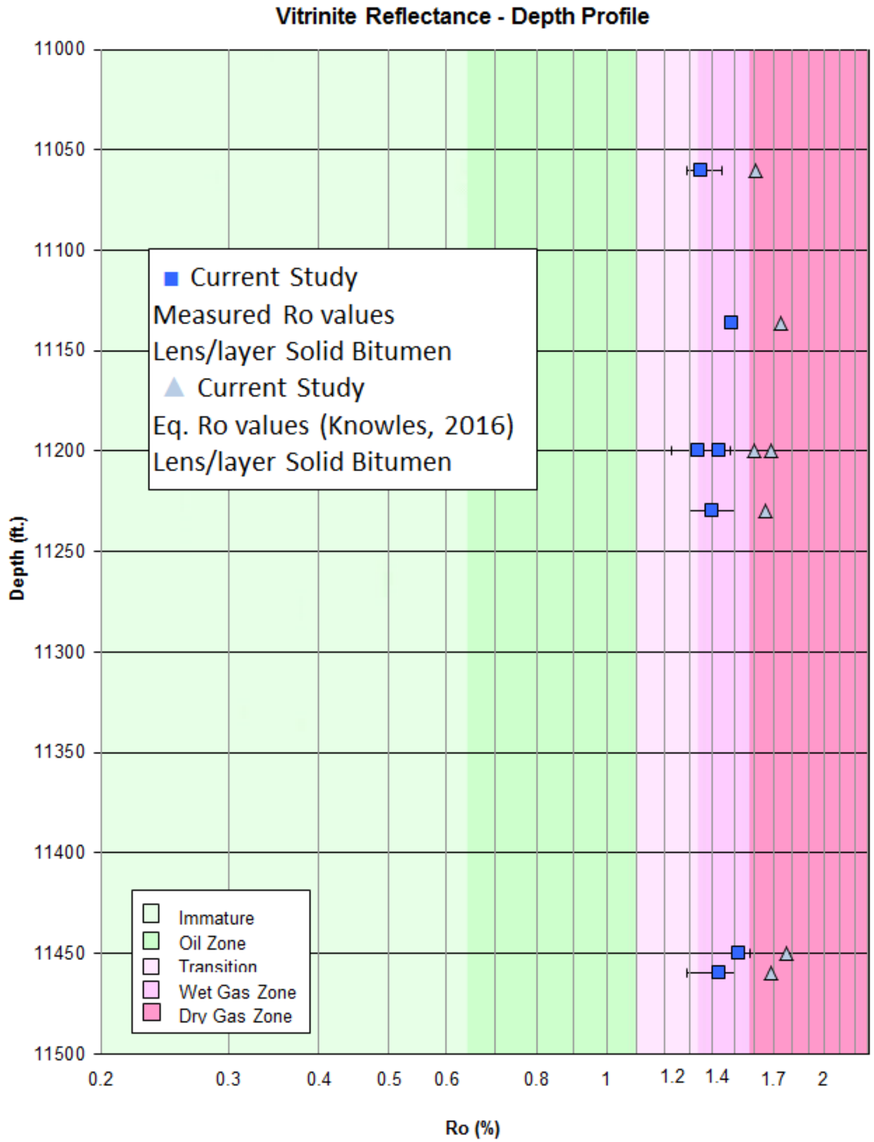
Lens/layer Solid Bitumen





- 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.

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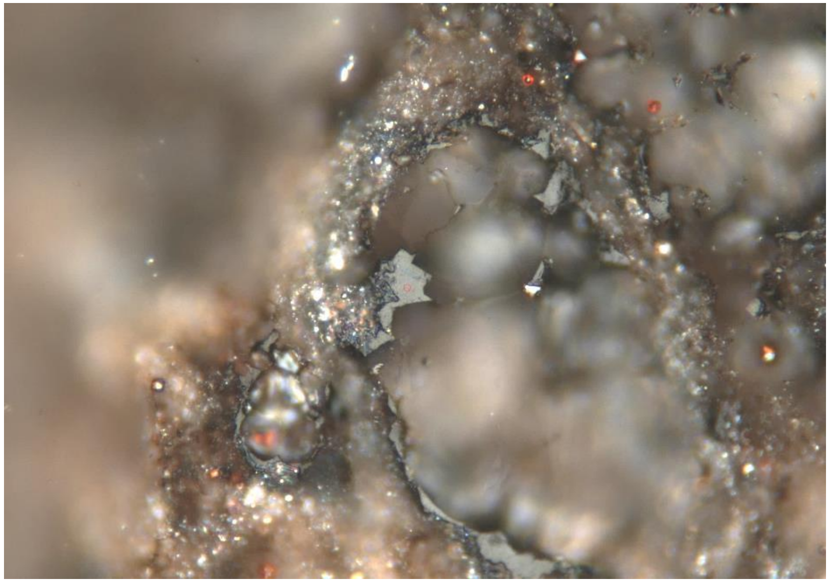
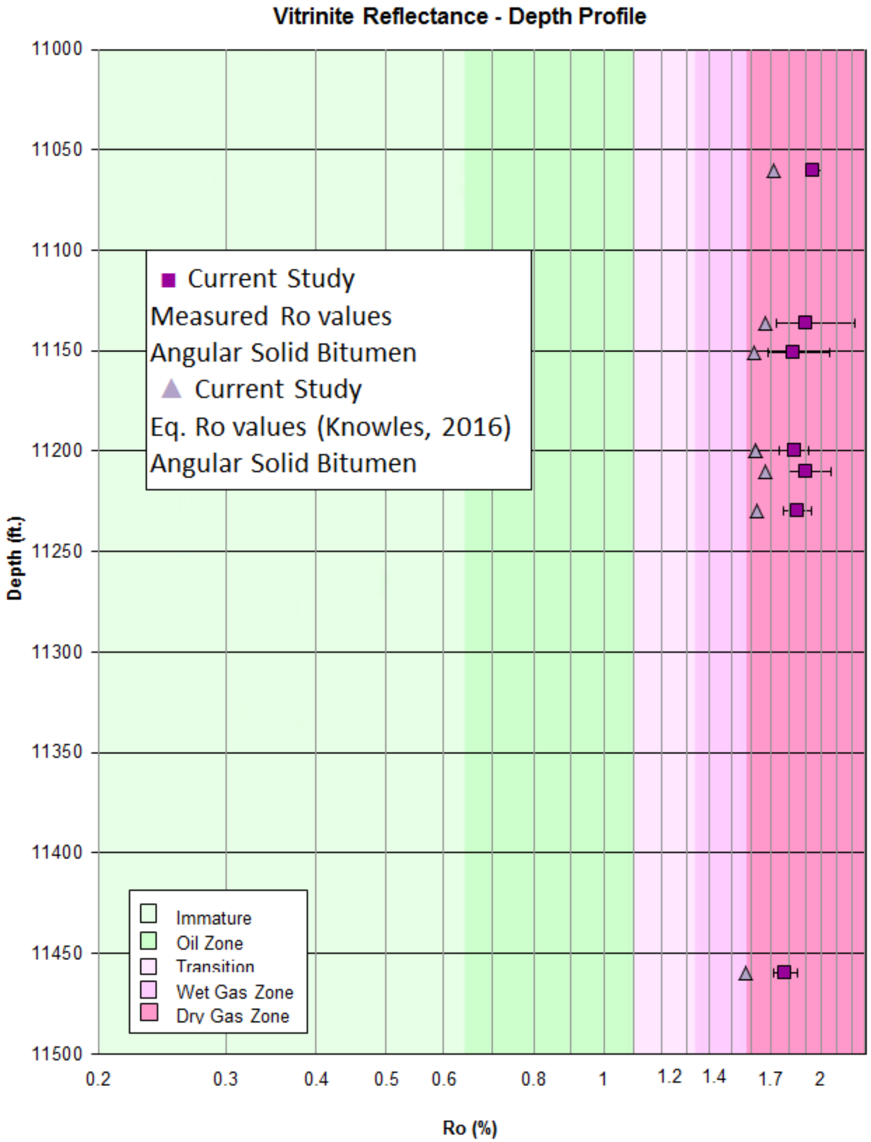
Angular Solid Bitumen





- 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.

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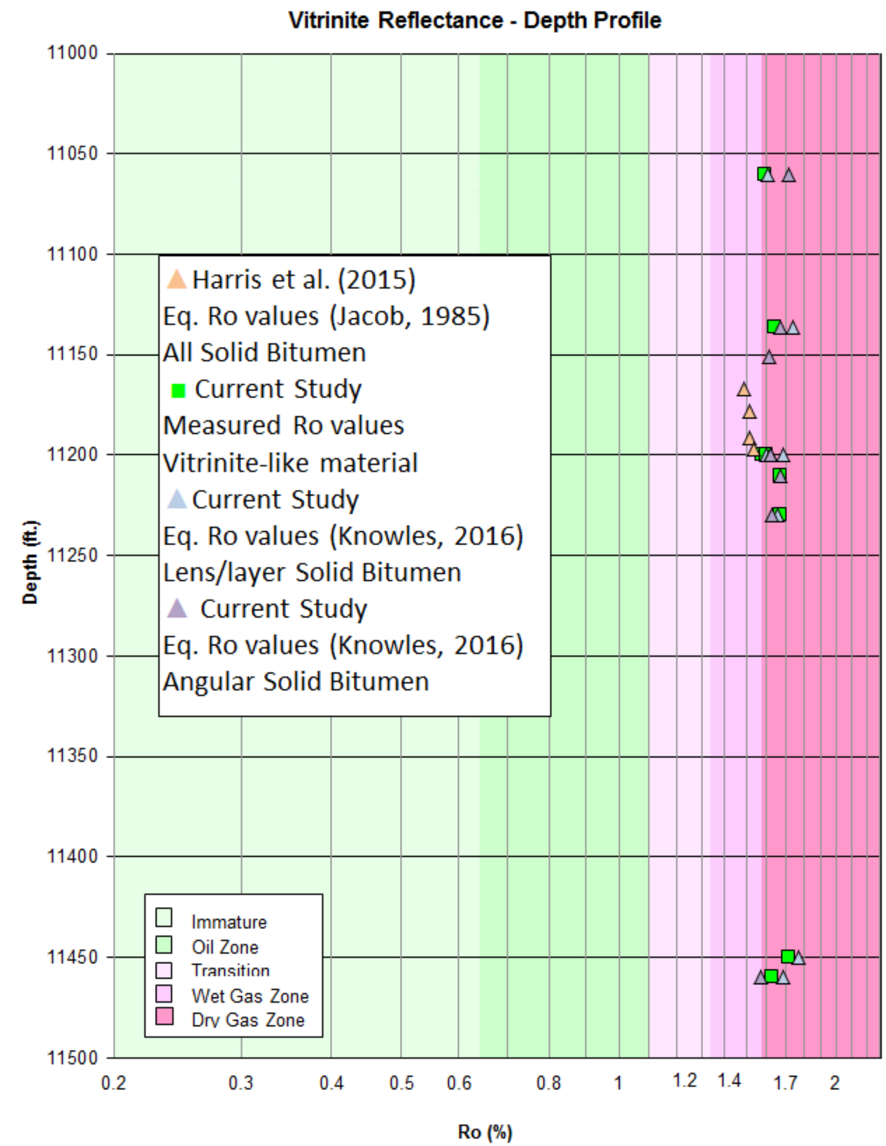
Eq. Ro Comparison

- 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.



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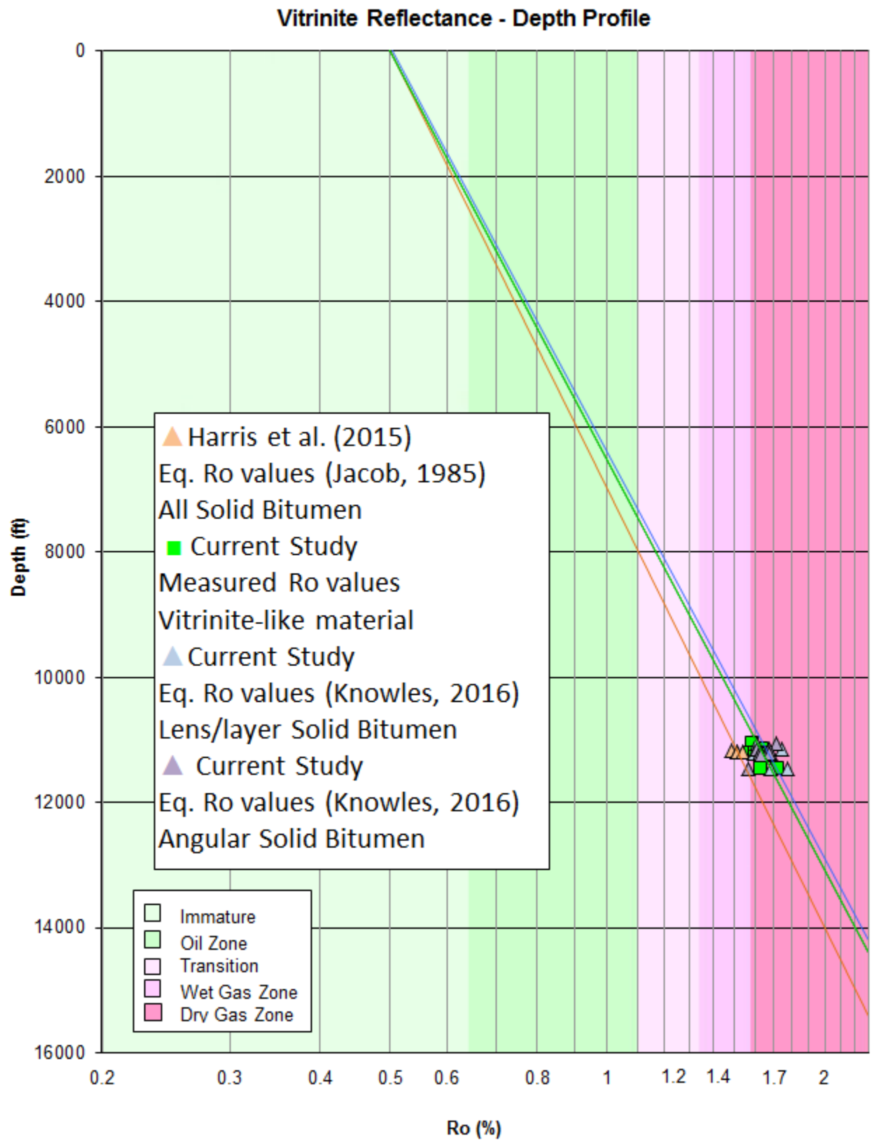
Eq. Ro Comparison

- 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.



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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.

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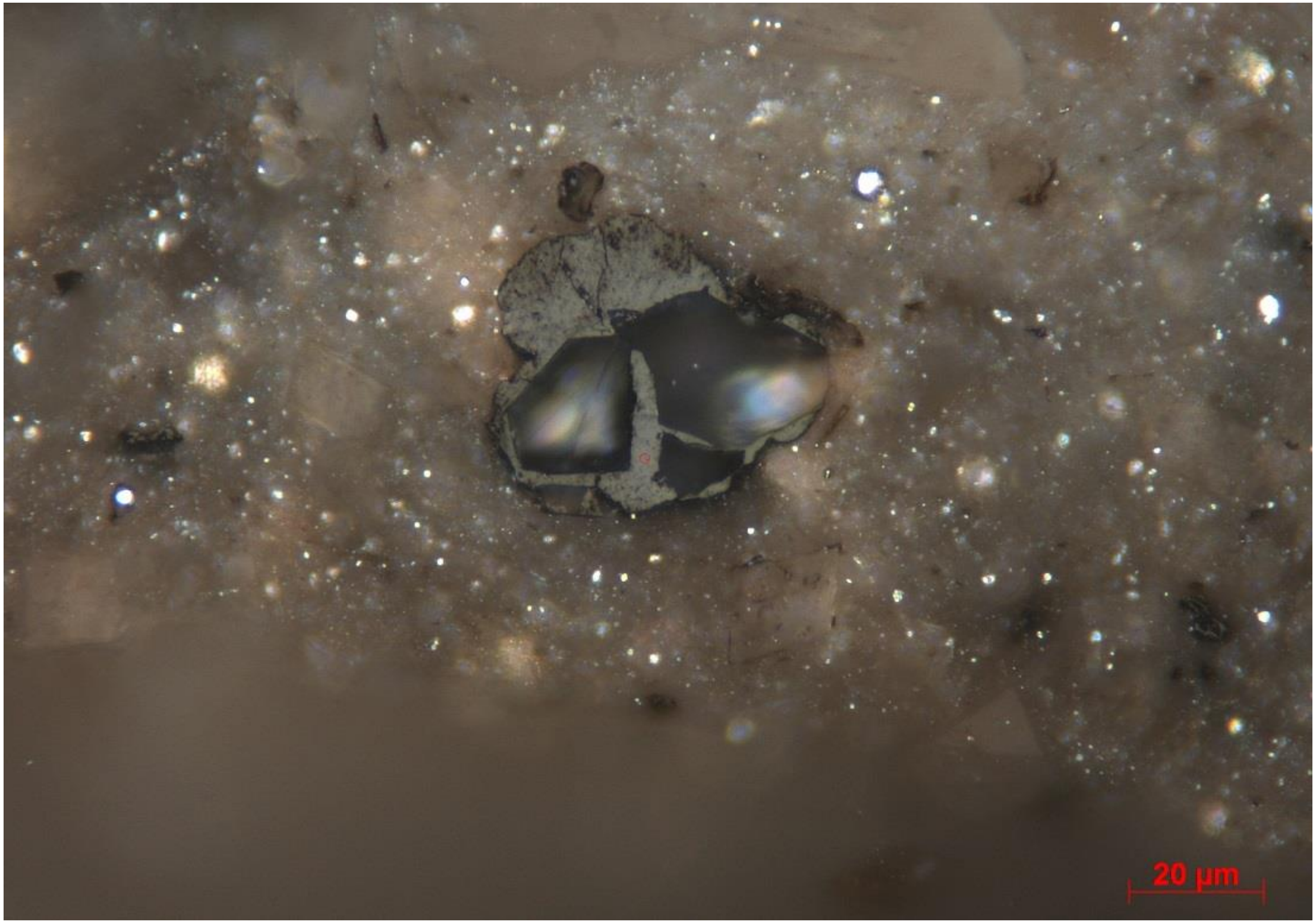
Questions?



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.

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