Understanding Unconventional Resource Potential by Conventional Petroleum Systems Assessment*

Daniel M. Jarvie1 and Ronald J. Hill2

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Abstract

The Permian Basin has a long standing history of oil and gas production and has attained yet another renaissance due to unconventional shale resource systems for gas and, currently, for oil and natural gas liquids. Although these are unconventional systems, understanding conventional petroleum systems enables a description of potential unconventional resource systems by inferences derived from the geochemistry of conventionally produced oils. While only limited information on Permian Basin petroleum systems has been made public, most source rocks have been identified by those working the basin, although some potential source intervals, and certainly variability in source rocks, have not been studied or reported extensively.

Inferences from geochemical oil analyses suggest at least six different source rocks with organofacies variations. These conventionally produced dead oil samples have been typed using high-resolution gas chromatography, carbon isotopes, biomarkers, and sulfur contents. The following source and lithofacies inferences can be made from these results:

Inferred source rock and lithofacies
1. Permian (Leonardian) Bone Springs
   a. marly shale
   b. carbonate
2. Permian (Guadalupian) shale
3. Permian Wolfcamp
   a. shale
   b. carbonate
4. Pennsylvanian shale source
5. Mississippian Barnett Shale source
6. Upper Devonian - Mississippian Woodford Shale source
7. Ordovician
   a. *Gloeocapsomorpha prisca* (G. prisca)
   b. non-*G. prisca*

One key point from these inferred lithofacies is that carbonate- and marly-shale-sourced oils will have variable hydrocarbon generation kinetics with carbonates generating at lower thermal stress than shales, but having lower API gravity due to higher amounts of resins and aspartames, also with higher concentrations of sulfur-bearing compounds that can impact fluid handling and economics.

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Establishing the effective source rock for various conventional reservoirs requires correlation of source rock extracts to oils. Effective source rocks are targets for unconventional resource development depending on various factors, such as thickness and depth to the interval. Analytical work confirms various source rock intervals and their characteristics as well as identifying additional sources that have not been documented. For example, prospective source rocks in the basin, such as the Bell and Cherry Canyon formations.

Understanding the potential production of unconventional oil from tight reservoirs requires a detailed understanding of the system as much as unconventional shale gas, but with different parameters. One basic parameter that demonstrates the presence of potentially producible oil is the oil crossover effect or oil saturation index (OSI) (Jarvie, 2011). In addition, while quartz content is very important in shale gas plays as it reflects increased brittleness, in shale oil resource plays, carbonate contents become equally important.

A shale resource system can be described as an unconventional resource by using the terms “typical” and “atypical” for description of a reservoir rock. As such, shales are not typical reservoir rocks, although they have served as such for some time. An unconventional or atypical system could be predominantly a quartz-clay system, such as the Barnett Shale oil play where a clay/quartz-rich system is the productive horizon, or a hybrid shale resource system where an organic-rich source rock may contribute to production, but primary production is from juxtaposed (overlying, interbedded, or underlying) organic-lean horizons, typically carbonates that are tight but productive with stimulation.

References


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Marathon Oil Co.
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Acknowledgements

• International Sample Library Midland
• Jeff Bryden, J. Cleo Thompson
• David Martineau, Dallas Production
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• Jack Burgess, retired (Humble, Chevron)
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1. Introduction
2. Geochemical principles
3. Oil Systems in the Permian Basin
4. Source Rocks in the Permian Basin
5. Summary of Petroleum Systems
6. Keys to Production from Shale Resource Systems
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Issues in Industry

• Stimulation
  – Over 43,000 wells have had high energy stimulations with few problems

• Ground water contamination
  – Establish background before drilling
  – Range Resources case

2. Some Geochemical Principles
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2. Some Geochemical Principles
**Key to Geochemical Identification of Producible Oil (conventional or unconventional)**

**Oil Crossover Effect**

\[ \frac{S1}{TOC} > 1 \]

or when

**Oil Saturation Index**

\[ (S1 / TOC \times 100) > 100 \text{ mg oil/g TOC} \]

---

**How is the total oil content measured?**

\[ \text{Total Oil} = (S1_{\text{whole rock}} - S1_{\text{extracted rock}}) + (S2_{\text{whole rock}} - S2_{\text{extracted rock}}) + EL \]
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**Comparison of GC Fingerprints (histograms)**

**Key Observations**

1. U. Bakken Shale has lost very little oil, may be less than the produced dead oil sample.

2. Middle Member has lost most hydrocarbons less than C15.

**Key Point**

- Shale holds the oil very tightly, whereas the dolomitic member retains very little light oil.

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**Variability in TOC: Cuttings vs. Core TOC Values**

- Variability formula: \( y = 2.3611x - 0.3906 \)
- Variability coefficient: \( R^2 = 0.7307 \)

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Dan Jarvie, Energy Institute at TCU / Worldwide Geochemistry
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**Variability in TOC: Cuttings vs. Core TOC Values**

![Variability in TOC: Cuttings vs. Core TOC Values](image)

- \( y = 2.3611x - 0.3906 \)
- \( R^2 = 0.7307 \)
Cuttings vs. Core

- Geochemical measurements dependent on oil type, rock lithofacies (adsorption), dilution from cavings, oxidation, storage and handling conditions

- Variations between cuttings and core can be significant depending on above:
  - TOC can be lower by 0-250%, Avg: 1.50x
  - Free oil (S1) can be lower by 100-500%, Avg: 3x
  - Kerogen (S2) can be lower by 0-50%, Avg.: 1.35x
  - Tmax and Ro lower by about 0.15% Roe

Model of TOC: Prior to Maturation

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Jarvie, 2011, AAPG Memoir 97, 2011
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Change in TOC after 50% conversion, i.e., ca. 0.80% Roe

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Total Organic Carbon (TOC) (wt.%)

- 50% of GOC
- GOC (wt.%)
- NGOC (wt.%)

HIo Dependent TOC Reductions (and recalculation of TOCoriginal)

For example,

\[ \text{TOC}_{pd} = 10.00 \]
\[ \text{HI}_o = 400 \]
\[ \text{TOC}_0 = 15.80 \]
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### HI₀ Dependent TOC Reductions (and recalculation of TOC$_{original}$)

For example, TOC$_{pd}$ = 10.00, HI$_0$ = 400, TOC$_0$ = 15.80
Hypothesis: Why are organic pores not typically seen in the oil window?

Solubility of oil in kerogen and kerogen expansion

Literature reports fractionation of aromatics from saturated hydrocarbons in kerogen swollen with different solvents (Ertas et al., 2006)
Organic Porosity Development in the oil window

at 50% TR

2.31

4.62 vol.% at full conversion

0.0 1.0 2.0 3.0 4.0 5.0 6.0

Organic Porosity Potential (vol. %)

Hypothesis: Why are organic pores not typically seen in the oil window?

Solubility of oil in kerogen and kerogen expansion

Kerogen

Swollen Kerogen with sorbed oil

Literature reports fractionation of aromatics from saturated hydrocarbons in kerogen swollen with different solvents (Ertas et al., 2006)
Adsorption Index (AI)
the ability of OM to hold onto petroleum

1 gram of organic matter can absorb/adsorb approximately 80 mg petroleum (Sandvik et al., 1992; Pepper, 1992)

Adsorption: Saturates < Aromatics < Resins < Asphaltenes

Optimized Oil Window
marine sourced oils

Marine Shales: 0.70 to 1.20%Roe
Marine Carbonates: 0.90 to 1.20%Roe
Adsorption Index (AI)
the ability of OM to hold onto petroleum

1 gram of organic matter can absorb/adsorb approximately 80 mg petroleum
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Adsorption: Saturates < Aromatics < Resins < Asphaltenes

Optimized Oil Window
marine sourced oils

- Immature
- Oil Window
- Condensate-Wet Gas Window
- Dry Gas Window

Marine Shales: 0.70 to 1.20%Roe
Marine Carbonates: 0.90 to 1.20%Roe
3. Oil Systems in the Permian Basin

Distribution of Ordovician Simpson Sourced Oils

- %S = 0.3 – 0.5
- δ13Csat = -32.5 – 34.5
- δ13Ccar = -32.4 – 34.0
- Pr/Phy = 0.5 – 1.0

Hill et al., 2003
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Jarvie and Hill, Energy Institute at TCU / Worldwide Geochemistry

**Distribution of Devonian Woodford Oils**

- %S = 0.3 – 0.6
- δ¹³C₅sat = -29.5 – -30.5
- δ¹³C₅are = -28.5 – -29.9
- Pr/Phy = 1.1 - 1.4

**Distribution of Mississippian Barnett Sourced Oils**

- %S = 0.2 – 0.5
- δ¹³C₅sat = -29.0 - -30.0
- δ¹³C₅are = -28.5 – -29.5
- Pr/Phy = 12. – 1.5

Hill et al., 2003
Jarvie and Hill presentation

Distribution of Devonian Woodford Oils

- %S = 0.3 – 0.6
- δ¹³CSat = -29.5 – -30.5
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Jarvie and Hill presentation
Distribution of Pennsylvanian Sourced Oils

- $\%S = 0.2 - 0.6$
- $\delta^{13}C_{Sat} = -29.0 - -30.5$
- $\delta^{13}C_{Ar} = -29.5 - -30.0$
- $Pr/Phy = 1.10 - 1.35$

Ozona Arch

Hill et al., 2003

Distribution of Permian Wolfcamp Oils

- $\%S = 0.2 - 0.4$
- $\delta^{13}C_{Sat} = -29.0 - -30.0$
- $\delta^{13}C_{Ar} = -28.5 - -29.5$
- $Pr/Phy = 1.2 - 1.5$

Ozona Arch

Hill et al., 2003
**Distribution of Permian Guadalupian Oils**

- %S = 0.7 – 1.6
- δ¹³C<sub>Sat</sub> = -29.0 – -30
- δ¹³C<sub>Aro</sub> = -28.5 – -29.5
- Pr/Phy = 0.9 – 1.0

**Distribution of Permian Lower Bone Springs Oils**

- %S = 1.5 – 3.0
- δ¹³C<sub>Sat</sub> = -29.0 – -29.5
- δ¹³C<sub>Aro</sub> = -28.5 – -29.0
- Pr/Phy = 0.9 – 0.95
Distribution of Permian Guadalupian Oils

%S = 0.7 – 1.6
δ¹³C_sat = -29.0 – 30
δ¹³C_arro = -28.5 – 29.5
Pr/Phy = 0.9 – 1.0

Distribution of Permian Lower Bone Springs Oils

%S = 1.5 – 3.0
δ¹³C_sat = -29.0 – 29.5
δ¹³C_arro = -28.5 – 29.0
Pr/Phy = 0.9 – 95
Distribution of Permian Upper Bone Springs Sourced Oils - Carbonate

%S = 1.5 – 3.0
δ13Csat = -26.5 – -27.5
δ13Caro = -26.0 - -27.0
Pr/Phy = 0.60 – 0.85

Ozona Arch

Hill et al., 2003

Distribution of Permian Upper Bone Springs Sourced Oils - Shale

%S = 0.05 – 0.3
δ13Csat = -28.0 - -29.5
δ13Caro = -28.0 - -29.0
Pr/Phy = 1.5 – 1.8

Hill et al., 2003
**Distribution of Permian Upper Bone Springs Sourced Oils - Carbonate**

- %S = 1.5 – 3.0
- $^{6}{^{13}}C_{Sat} = -26.5 – -27.5$
- $^{6}{^{13}}C_{Aro} = -26.0 – -27.0$
- Pr/Phy = 0.65 – 0.85

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**Jarvie and Hill presentation**
Biodegraded or Mixed Oils

S > 1.0%,
Pr / Phy > 1.0

Oil Inversion Geochemistry:
inferred source rock for various oils

• Permian (Leonardian) Bone Springs
  • Marly Marine Shale
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• Ordovician
  • G. prisca (Simpson)
  • Marine Shale (non-G. prisca)
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4. Source Rocks in the Permian Basin

Average Cuttings TOC Values by Horizon, Permian Basin
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Average Cuttings TOC Values by Horizon, Permian Basin
Leonardian Bone Springs: carbonate and TOC contents

Comparison of Organic Carbon and Carbonate Carbon: Barnett Shale and Eagle Ford Shale
Leonardian Bone Springs: carbonate and TOC contents

Comparison of Organic Carbon and Carbonate Carbon: Barnett Shale and Eagle Ford Shale
Guadalupian Source Rocks:

Bell Canyon and Cherry Canyon

good to excellent TOCs in the oil generating window

5. Permian Basin Petroleum Systems
Guadalupian Source Rocks:

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5. Permian Basin Petroleum Systems
### Possible Petroleum Systems: Permian Basin

<table>
<thead>
<tr>
<th>Source</th>
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</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Marine shale</td>
</tr>
<tr>
<td>II</td>
<td>Simpson</td>
</tr>
<tr>
<td>III</td>
<td>Woodford</td>
</tr>
<tr>
<td>IV</td>
<td>Barnett Shale</td>
</tr>
<tr>
<td>V</td>
<td>Penn. (+Miss.?)</td>
</tr>
<tr>
<td>VI</td>
<td>Wolfcamp (L.L.)</td>
</tr>
<tr>
<td>VII</td>
<td>U. Leonard (Midland)</td>
</tr>
<tr>
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<tr>
<td>IX</td>
<td>Leonard (DMG)</td>
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<tr>
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<td>Barnett, Strawn</td>
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### Summary

- Various source rocks have been, first, inferred and then correlated to source rocks
- For shale oil resource plays, oil crossover effect provides a means to identify potential production
- Fingerprint residual oils to assess quality and production characteristics (API, GOR)
- Carbonate source rocks or marine shale with juxtaposed carbonates provide excellent resource potential due to low retention of oil
Possible Petroleum Systems: Permian Basin

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