Understanding Unconventional Resource Potential by Conventional Petroleum Systems Assessment*

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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.

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 characterstics 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.

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Outline

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
7. Summary

1. Introduction

Issues in Industry

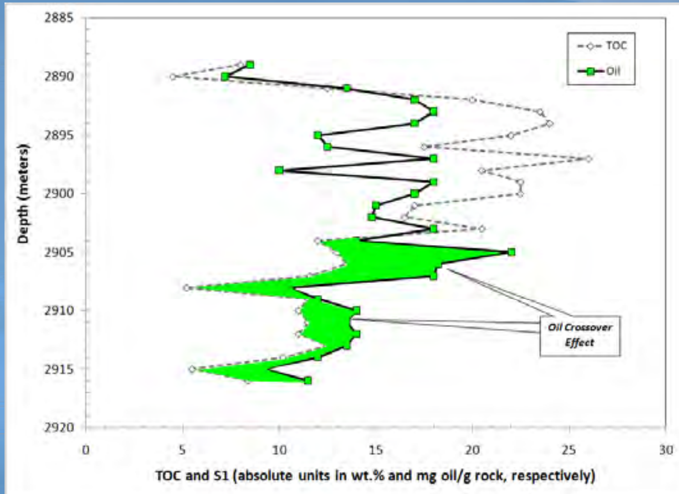
- Stimulation
  - Over 43,000 wells have had high energy stimulations with few problems
- Ground water contamination
  - Establish background before drilling
  - Range Resources case

2. Some Geochemical Principles

Key to Geochemical Identification of Producible Oil (conventional or unconventional)

Oil Crossover Effect

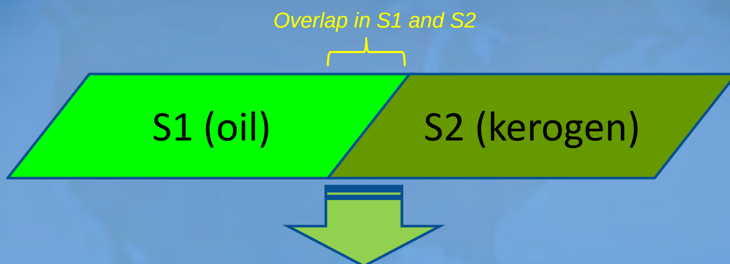
S1/TOC > 1
or when
Oil Saturation Index
(S1/TOCx100)
> 100 mg oil/g TOC



Data extracted from Lopatin et al., 2003

Jarvie, 2011, AAPG Memoir 97

How is the total oil content measured?



Total Oil = $(S1_{\text{whole rock}} - S1_{\text{extracted rock}}) + (S2_{\text{whole rock}} - S2_{\text{extracted rock}}) + EL$

Comparison of GC Fingerprints (histograms)

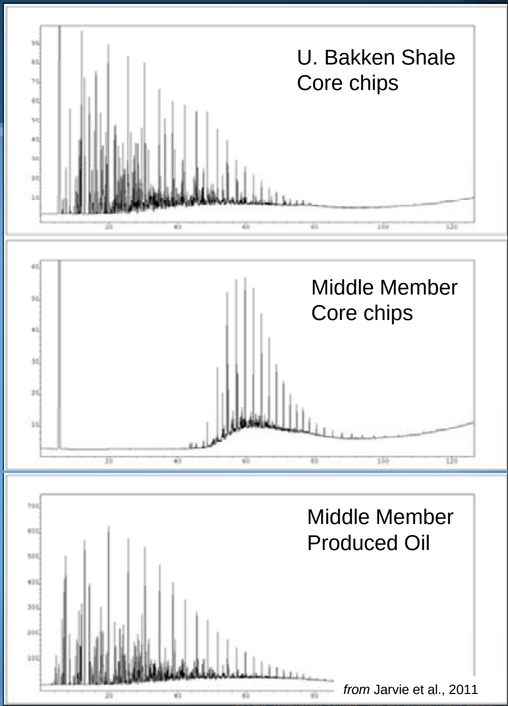
Key Observations

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

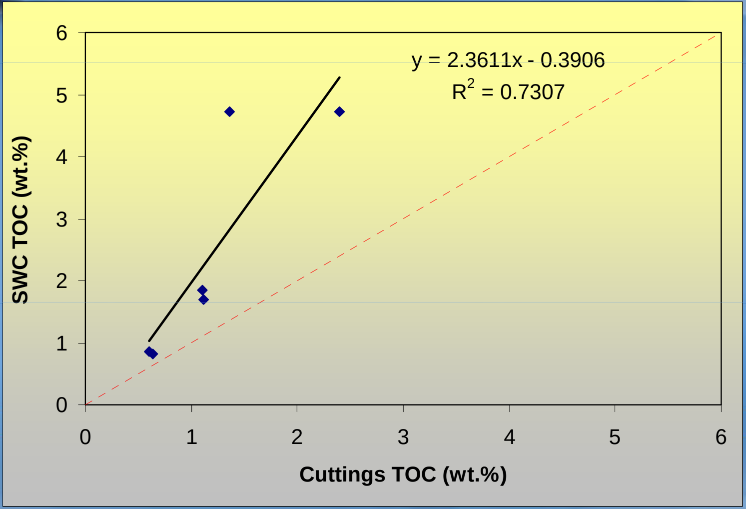
2. Middle Member has lost most hydrocarbons less than C15

Key Point

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



Variability in TOC:
Cuttings vs. Core TOC Values



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

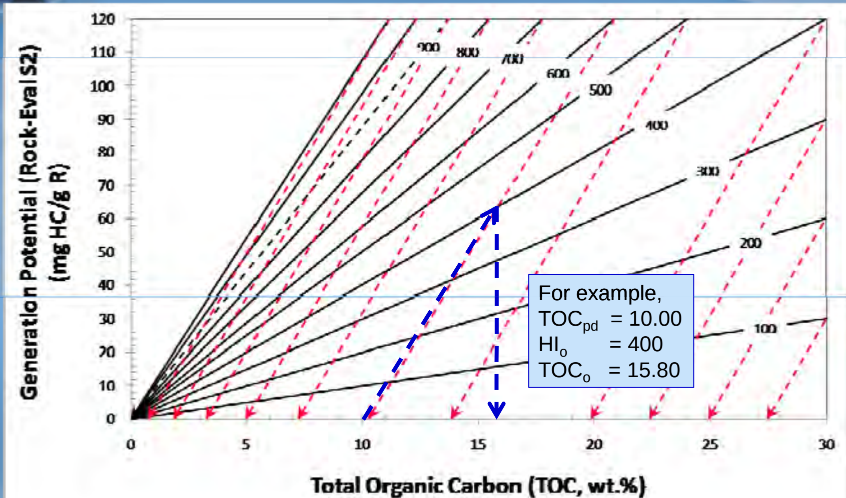
Total Organic Carbon (TOC) (wt.%)	
Generative Organic Carbon	Non-Generative Organic Carbon
GOC (wt.%)	NGOC (wt.%)

Jarvie, 2011, AAPG Memoir 97, *2011*

Change in TOC after 50% conversion, i.e., ca. 0.80%Roe

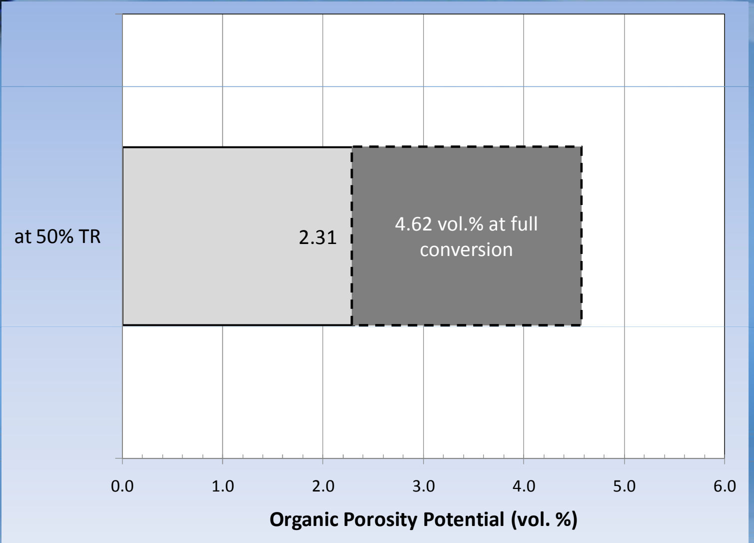
	Total Organic Carbon (TOC) (wt.%)	
Expelled Carbon	Total Organic Carbon (TOC) (wt.%)	
50% of GOC	Generative Organic Carbon	Non-Generative Organic Carbon
50% of GOC	GOC (wt.%)	NGOC (wt.%)

HI$_o$ Dependent TOC Reductions (and recalculation of TOC$_{original}$)



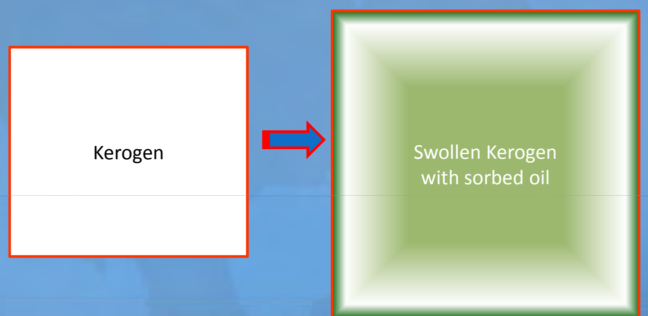
Jarvie, 2011, AAPG Memoir 97, *2011*

Organic Porosity Development in the oil window



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

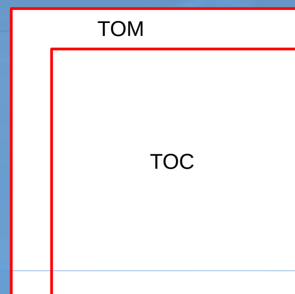
Solubility of oil in kerogen and kerogen expansion



Literature reports fractionation of aromatics from saturated hydrocarbons in kerogen swollen with different solvents (Ertas et al., 2006)

Adsorption Index (AI)

the ability of OM to hold onto petroleum

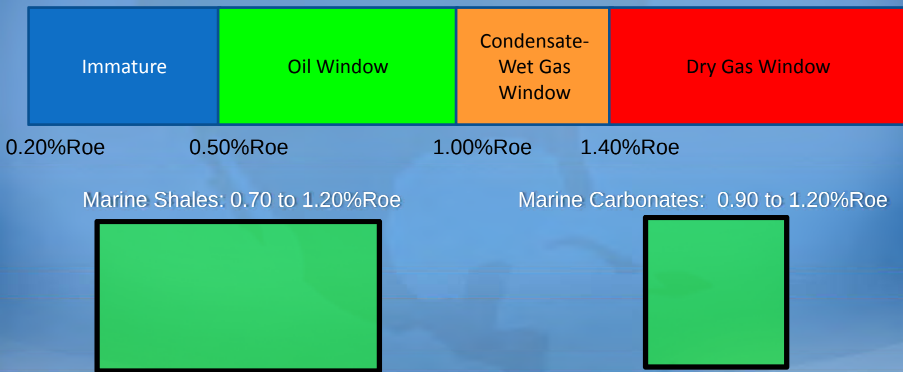


1 gram of organic matter can absorb/adsorb approximately 80 mg petroleum

(Sandvik et al., 1992; Pepper, 1992)

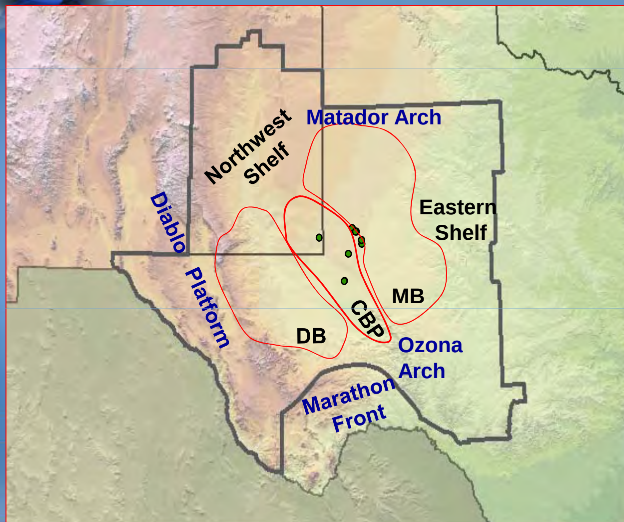
Adsorption: Saturates < Aromatics < Resins < Asphaltenes

Optimized Oil Window
marine sourced oils



3. Oil Systems in the Permian Basin

Distribution of Ordovician Simpson Sourced Oils



%S = 0.3 – 0.5

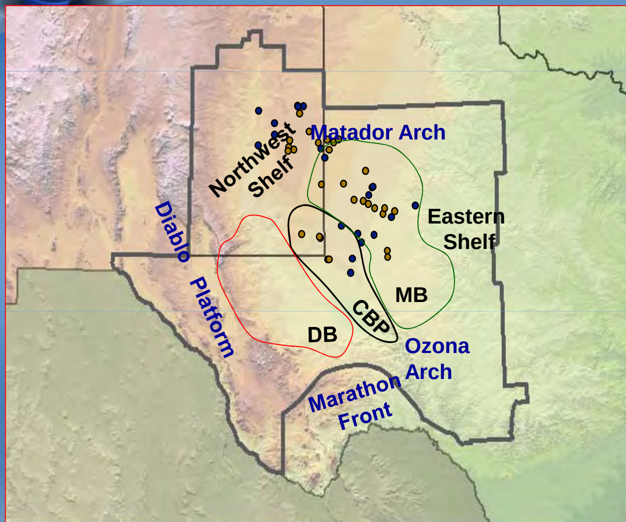
$\delta^{13}C_{Sat}$ = -32.5 – 34.5

$\delta^{13}C_{Aro}$ = -32.4 - 34.0

Pr/Phy = 0.5 – 1.0

Hill et al., 2003

Distribution of Devonian Woodford Oils



%S = 0.3 – 0.6

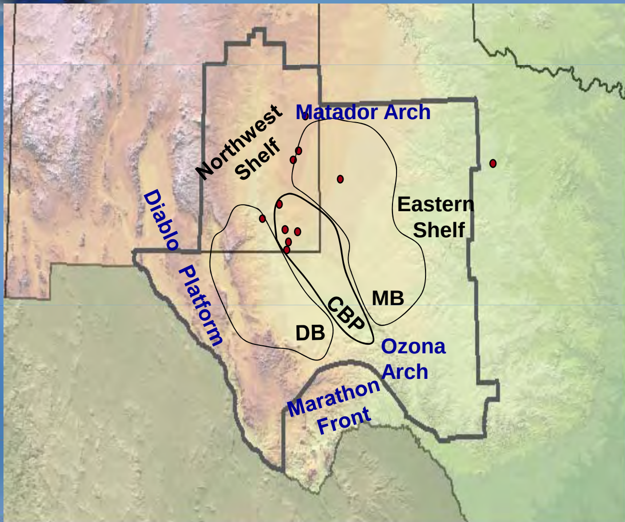
$\delta^{13}C_{Sat}$ = -29.5 – 30.5

$\delta^{13}C_{Aro}$ = -28.5 – 29.9

Pr/Phy = 1.1 - 1.4

Hill et al., 2003

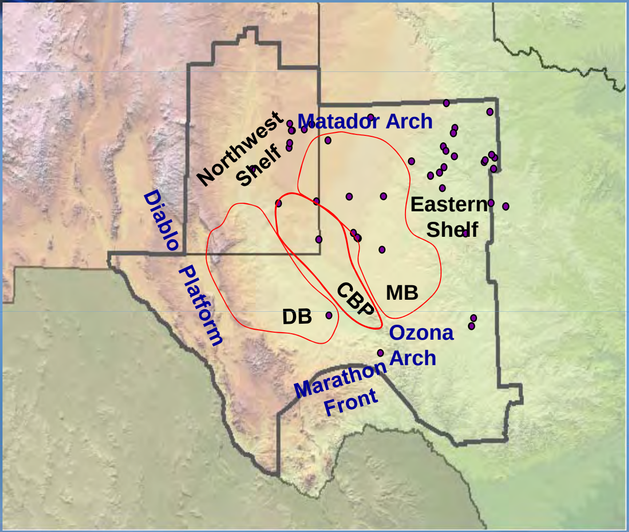
Distribution of Mississippian Barnett Sourced Oils



%S = 0.2 – 0.5
$\delta^{13}C_{Sat}$ = -29.0 - -30.0
$\delta^{13}C_{Aro}$ = -28.5 - -29.5
Pr/Phy = 12. – 1.5

Hill et al., 2003

Distribution of Pennsylvanian Sourced Oils



%S = 0.2 – 0.6

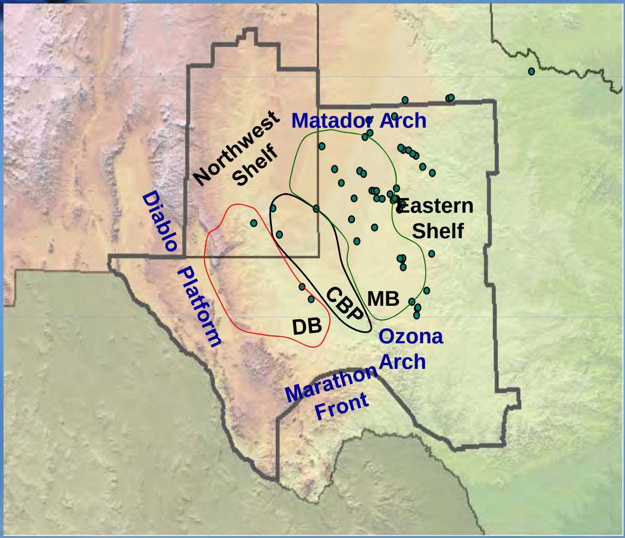
$\delta^{13}C_{Sat}$ = -29.0 - -30.5

$\delta^{13}C_{Aro}$ = -28.5 - -30.0

Pr/Phy = 1.10 – 1.35

Hill et al., 2003

Distribution of Permian Wolfcamp Oils



%S = 0.2 – 0.4

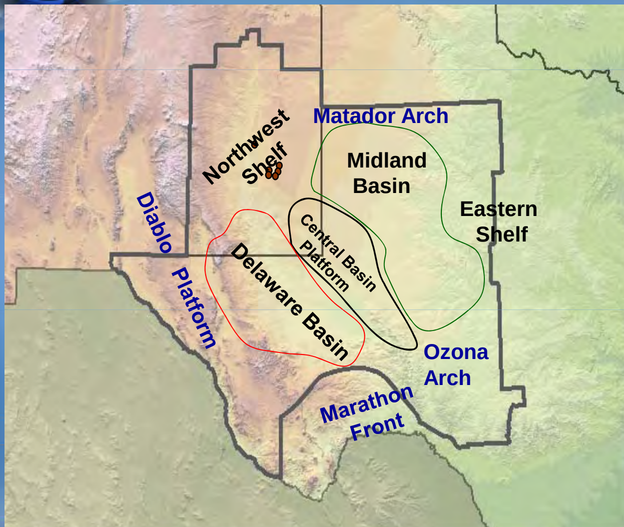
$\delta^{13}C_{Sat}$ = -29.0 - -30.0

$\delta^{13}C_{Aro}$ = -28.5 - -29.5

Pr/Phy = 1.2 – 1.5

Hill et al., 2003

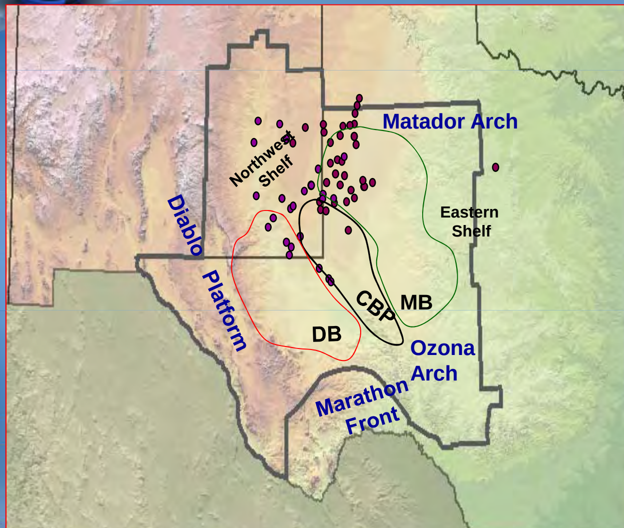
Distribution of Permian Guadalupian Oils



%S = 0.7 – 1.6
$\delta^{13}C_{Sat}$ = -29.0 - -30
$\delta^{13}C_{Aro}$ = -28.5 - -29.5
Pr/Phy = 0.9 – 1.0

Hill et al., 2003

Distribution of Permian Lower Bone Springs Oils



%S = 1.5 – 3.0

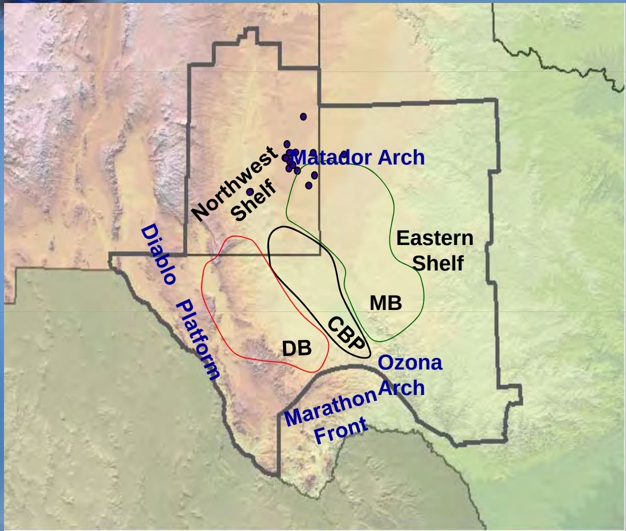
$\delta^{13}C_{Sat}$ = -29.0 – 29.5

$\delta^{13}C_{Aro}$ = -28.5 –29.0

Pr/Phy = 0.9 - 95

Hill et al., 2003

Distribution of Permian Upper Bone Springs Sourced Oils - Carbonate



%S = 1.5 – 3.0

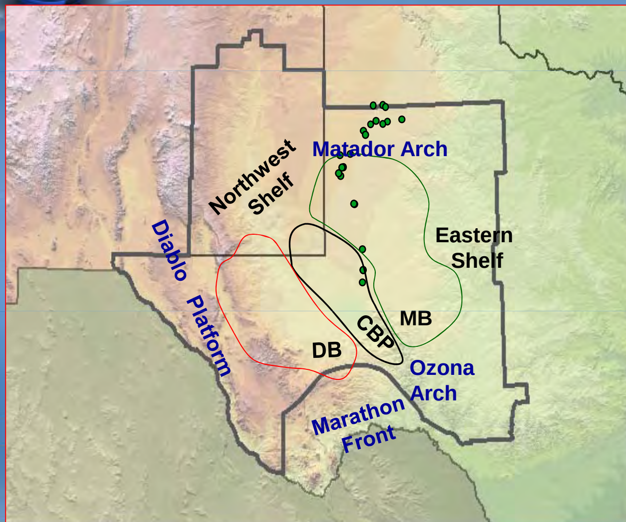
$\delta^{13}C_{Sat}$ = -26.5 – -27.5

$\delta^{13}C_{Aro}$ = -26.0 - -27.0

Pr/Phy = 0.60 – 0.85

Hill et al., 2003

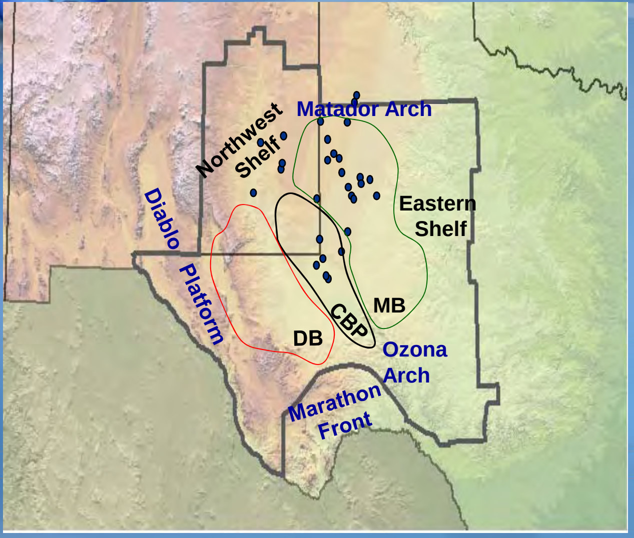
Distribution of Permian Upper Bone Springs Oils - Shale



%S = 0.05 – 0.3
$\delta^{13}C_{Sat}$ = -28.0 - -29.5
$\delta^{13}C_{Aro}$ = -28.0 - -29.0
Pr/Phy = 1.5 – 1.8

Hill et al., 2003

Biodegraded or Mixed Oils

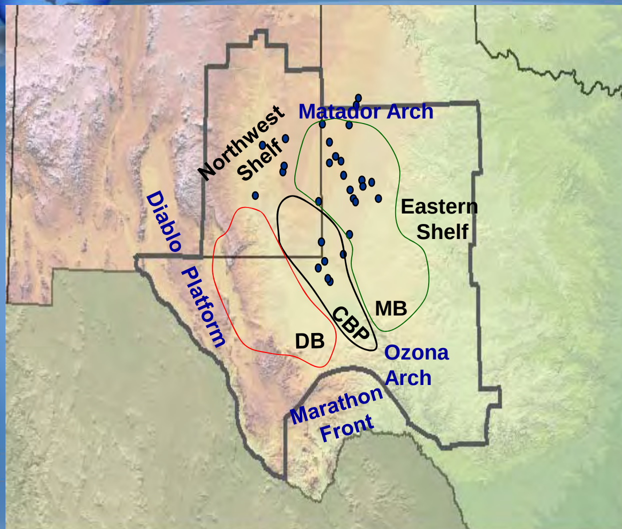


S > 1.0%,

Pr / Phy > 1.0

Hill et al., 2003

Biodegraded or Mixed Oils



S > 1.0%,

Pr / Phy > 1.0

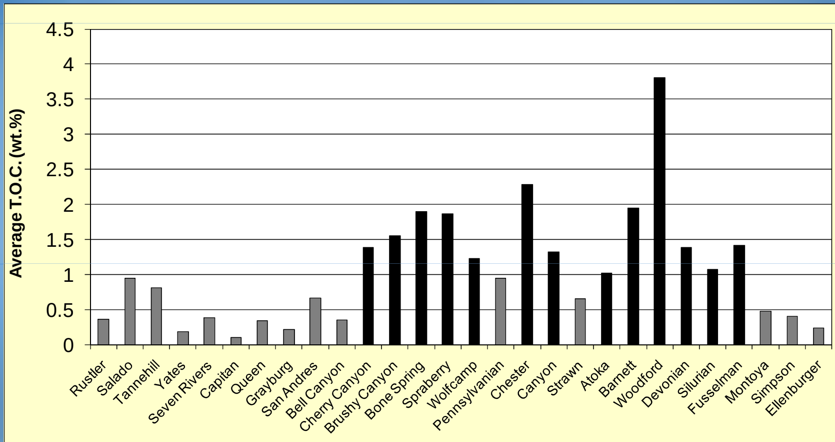
Hill et al., 2003

Oil Inversion Geochemistry: inferred source rock for various oils

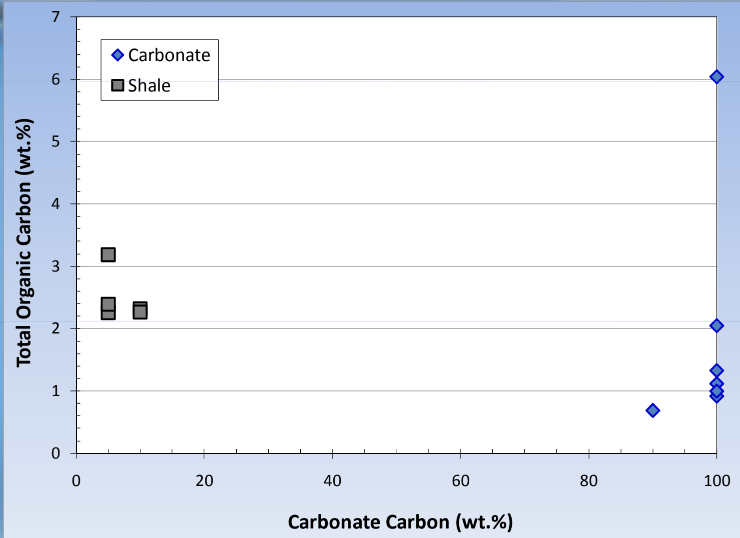
- Permian (Leonardian) Bone Springs
  - Marly Marine Shale
  - Marine Carbonate
- Permian (Guadalupian) shale
- Permian Wolfcamp
  - Marine Shale
  - Marine Carbonate
- Pennsylvanian shales
- Mississippian Barnett Shale
- U. Devonian-Mississippian Woodford Shale
- Ordovician
  - *G. prisca (Simpson)*
  - Marine Shale (non-*G. prisca)*

4. Source Rocks in the Permian Basin

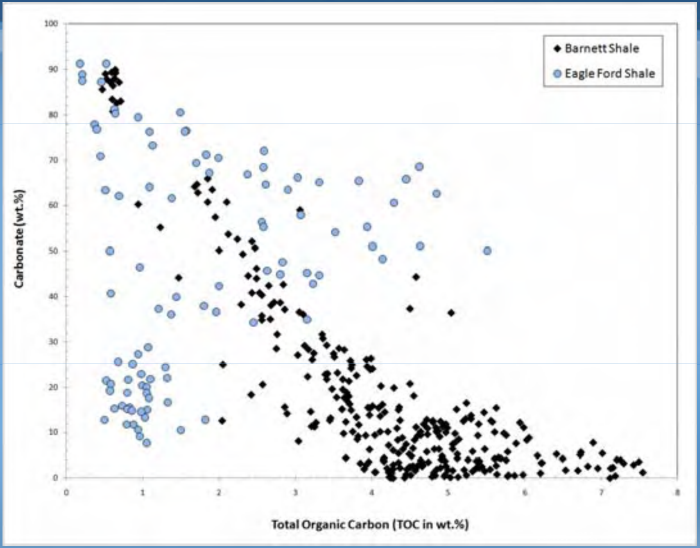
Average Cuttings TOC Values by Horizon, Permian Basin



Leonardian Bone Springs: carbonate and TOC contents



Comparison of Organic Carbon and Carbonate Carbon: Barnett Shale and Eagle Ford Shale

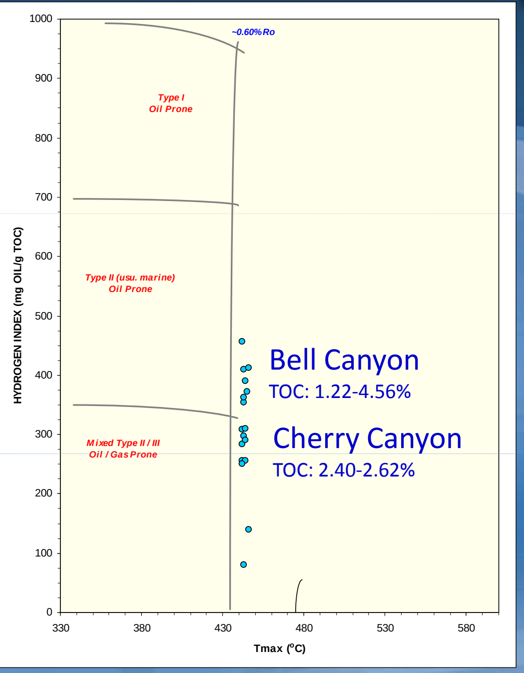


Jarvie, 2011, AAPG Memoir 97, *2011*

Guadalupian Source Rocks:

Bell Canyon and Cherry Canyon

good to excellent TOCs in the oil generating window



5. Permian Basin Petroleum Systems

Possible Petroleum Systems: Permian Basin

	Source	Principal Reservoirs
I	Marine shale	Abo
II	Simpson	Ellenburger
III	Woodford	Silurian, Devonian
IV	Barnett Shale	Barnett, Strawn
V	Penn. (+Miss.?)	Pennsylvanian
VI	Wolfcamp (L.L.)	Wolfcamp, Dean, Spraberry
VII	U. Leonard (Midland)	San Andres
VIII	L. Leonard (Midland)	Clearfork
IX	Leonard (DMG)	San Andres
X	L. Leon. (DMG)	Pennsylvanian, Wolfcamp, Abo
XI	Guadalupian (DMG)	Brushy Canyon, Queen

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

Thank you !

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