Big Three Tight Oil Plays, USA: Bakken, Eagle Ford, and Wolfcamp*

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Abstract

Approximately 50% of oil production in the United States is derived from three unconventional tight oil plays: the Bakken, Eagle Ford, and Wolfcamp tight oil systems. Success in tight oil systems starts with identification and subsequent characterization of the system that may include the source rock itself or organic-lean juxtaposed rocks.

The Bakken Formation of the Williston Basin consists of juxtaposed organic-lean intervals above, between, and below two very organic-rich Bakken Shale source rocks. The organic-lean intervals are the highly productive reservoir rocks yielding high API (ca. 42° API oil) with modest gas-to-oil ratios (GOR). High oil saturations are obvious in the Middle Member of the Bakken Formation at Parshall Field, Mountrail County, North Dakota. This unit has high carbonate (dolomitic) content and very lean TOC values. It also displays oil crossover indicative of producible intervals. This middle unit with low TOC and oil crossover is an ideal tight oil system with seals/barriers above and below (the shales), high oil saturation, and brittle rock fabric that responds to stimulation.

The Middle Member unit was cored and a gas chromatographic (GC) fingerprint shows high evaporative loss of oil, whereas the Bakken Shales show only minimal loss. The Middle Member GC fingerprints were characterized by their extended normal alkane slope factors that enabled restoration of the lost petroleum. This allowed further restoration of S1-oil yields as well as predictive GOR values.

The Eagle Ford Shale (mudstone) is a marine carbonate/marly shale that has modest TOC values but very high restored or original hydrogen indices. Published data from the 1980s-90s still showed oil crossover indicative of producible reserves. Although some samples/wells did not show crossover, evaporative losses were very high that required restoration of S1-oil by GC analysis. Many samples are penetrated by oil-based mud which requires special treatment when determining GC slope factors, but results allow ‘seeing through’ the OBM.

The Wolfcamp tight oil system is a thick siliciclastic shale with variable maturity especially between the Delaware and Midland basins. The generally deeper Delaware Basin Wolfcamp is more mature with slightly lower restored TOC and HI values compared to the Midland Basin Wolfcamp. These differences in maturity impact the composition of oil with lower maturity oils having higher contents of larger polar resins

and asphaltenes, which tend to occlude pore throats. GC slope factors derived from the Wolfcamp allowed very accurate prediction of GOR values.

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Big Three Tight Oil Plays in the USA: Bakken, Eagle Ford, and Wolfcamp

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- and...

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Who led the development of unconventional shale gas and tight oil plays?

Independent Oil Companies

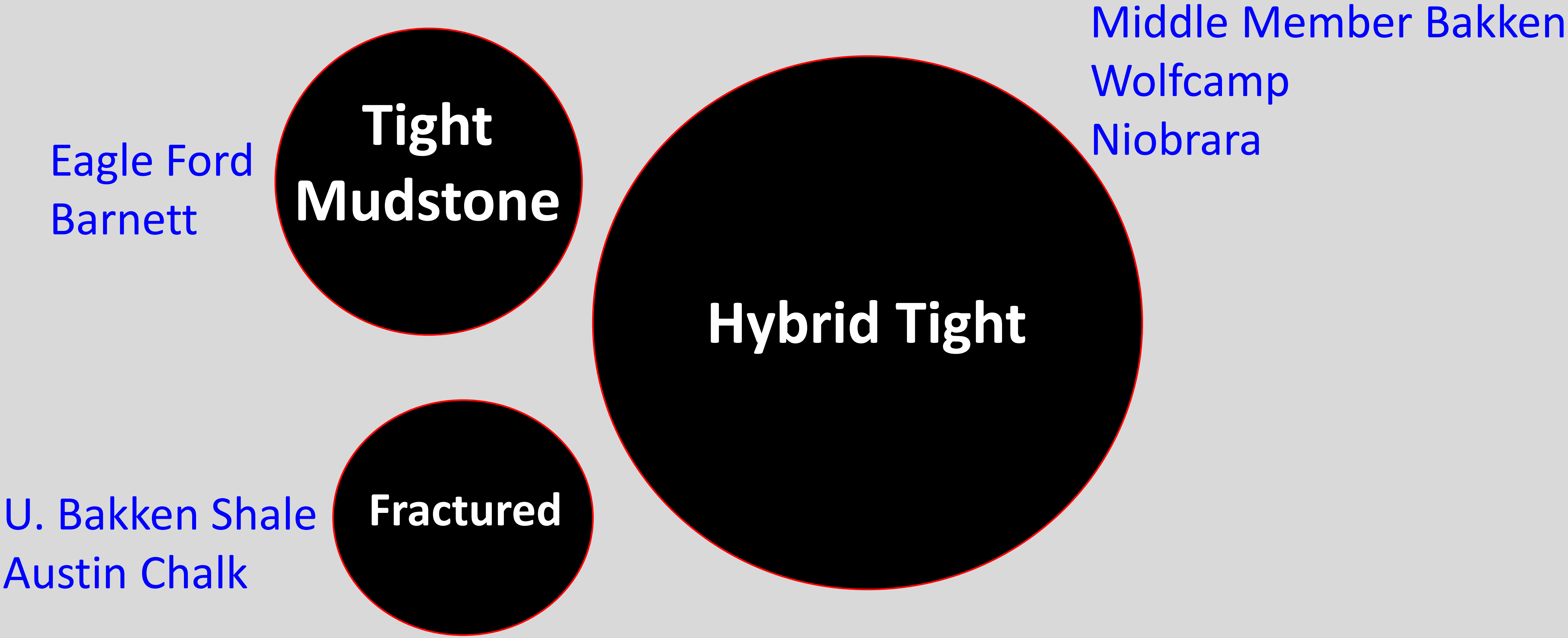
Company	Market Cap ($billions)
Mitchell Energy	3
Devon Energy	9
Southwestern	1
EOG Resources	45
Chesapeake	3
Marathon	10
Hess	20
Apache	8
Oxy	42

Outline

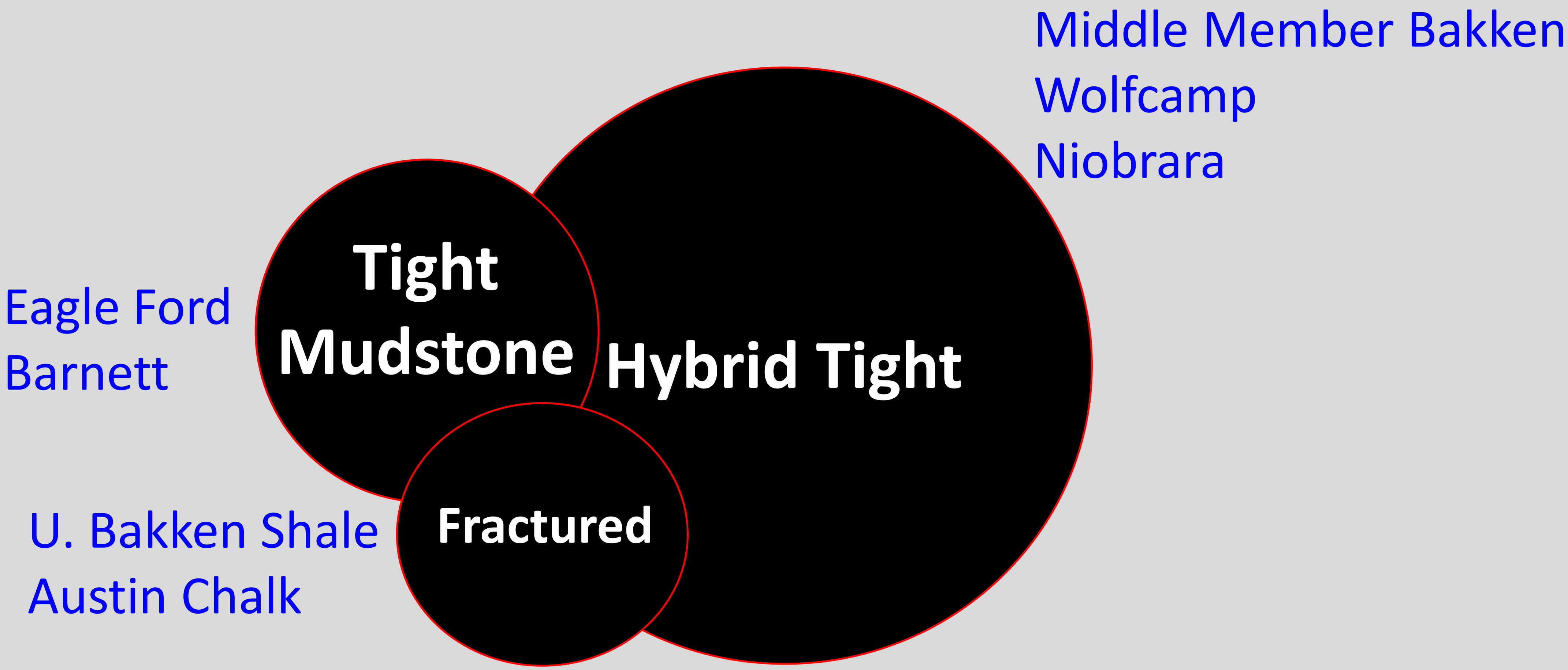
- Introduction
- Background
- Tight Oil Systems
  - Bakken Formation Unconventional Tight Oil System
  - Eagle Ford Unconventional Tight Oil System
  - Permian Basin Multiple Unconventional Tight Oil Systems
- Synopsis

Introduction

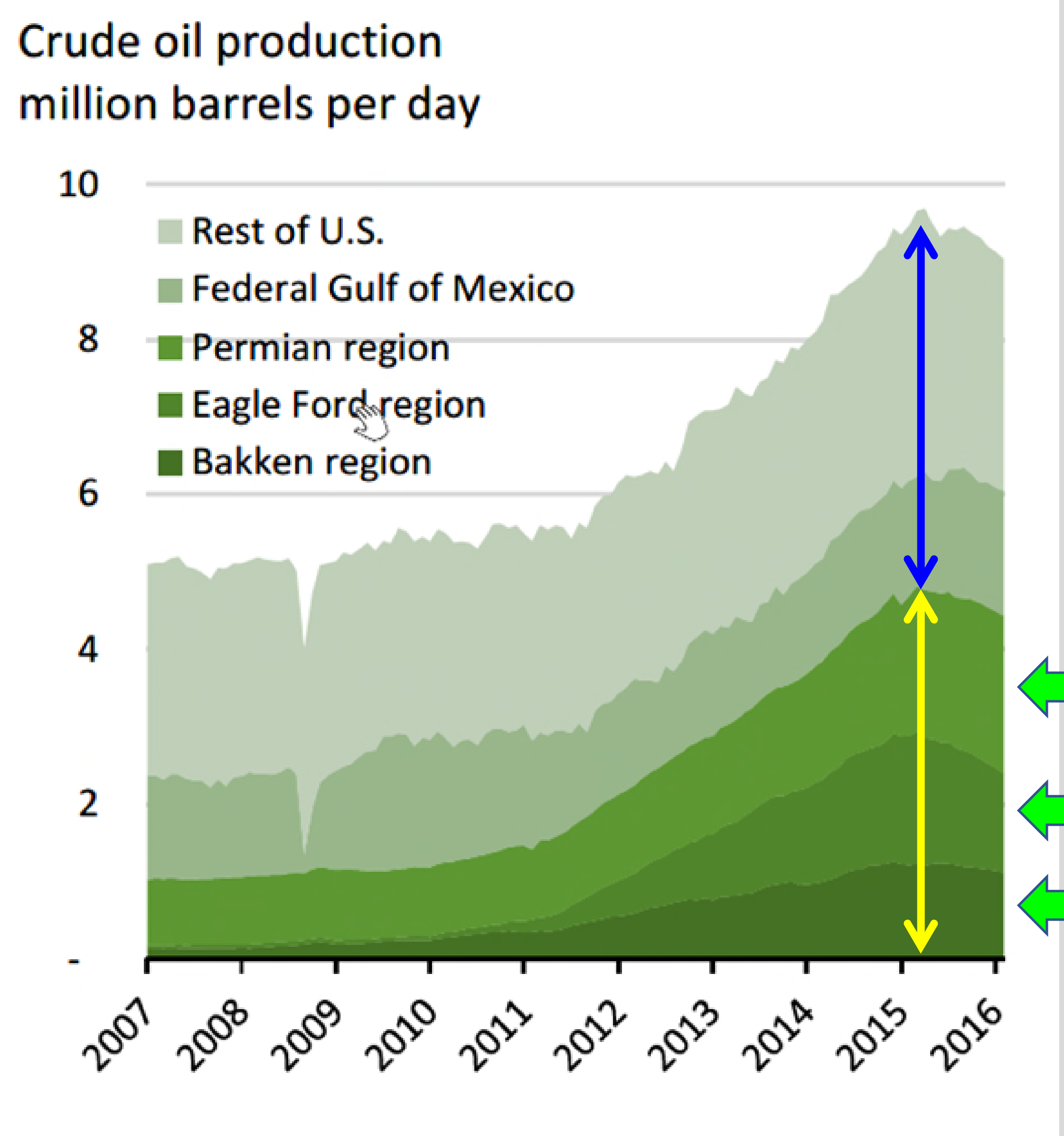
Generalized Characterization of Resource Oil Plays



…but they also often have overlapping characteristics



Why the Big 3?



Rest of USA

USA GOM

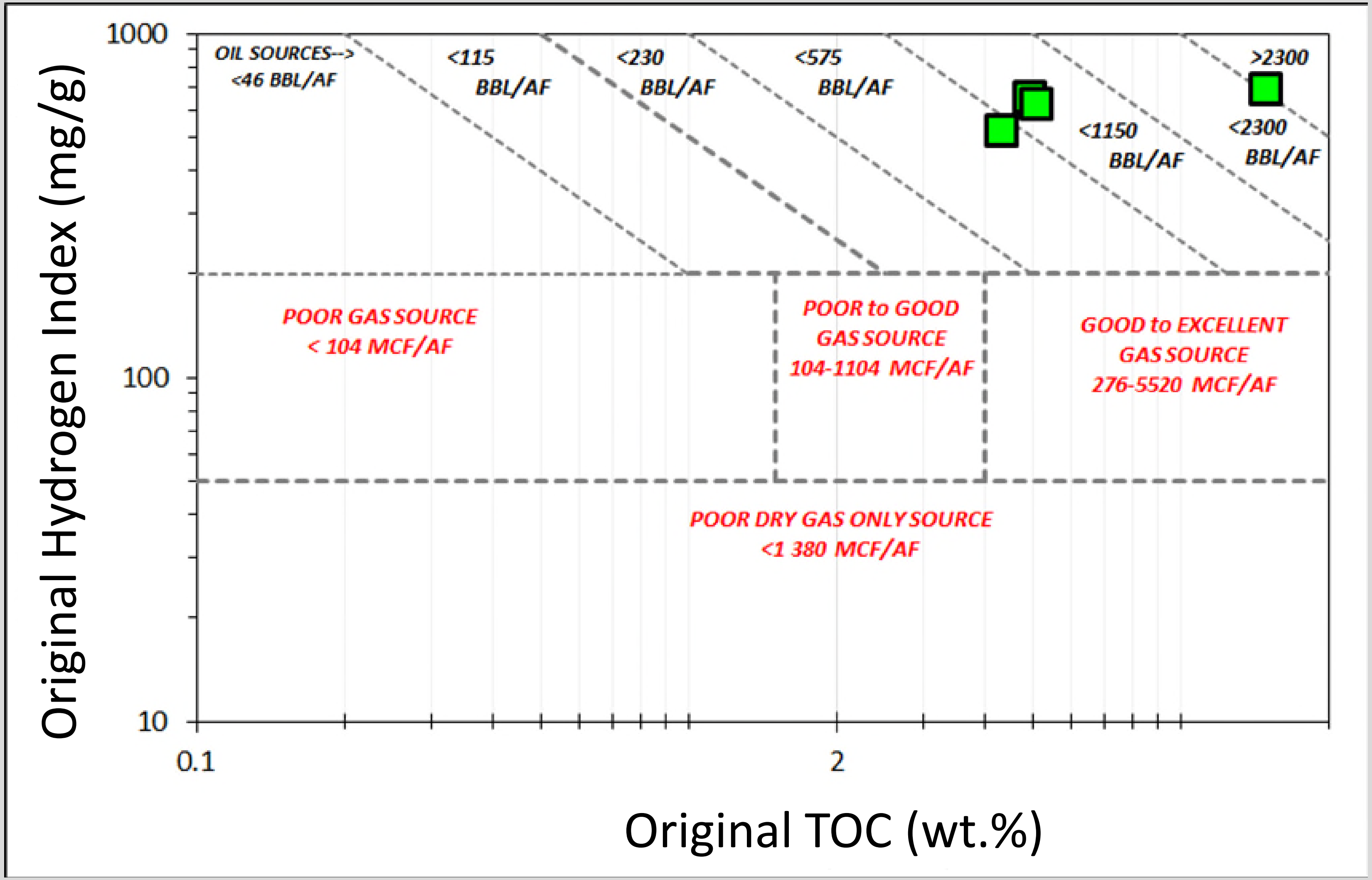
Permian region

Eagle Ford region

Bakken region

Sources: EIA, Petroleum Supply Monthly

The Big Three
Very High Petroleum Generating Source Rocks



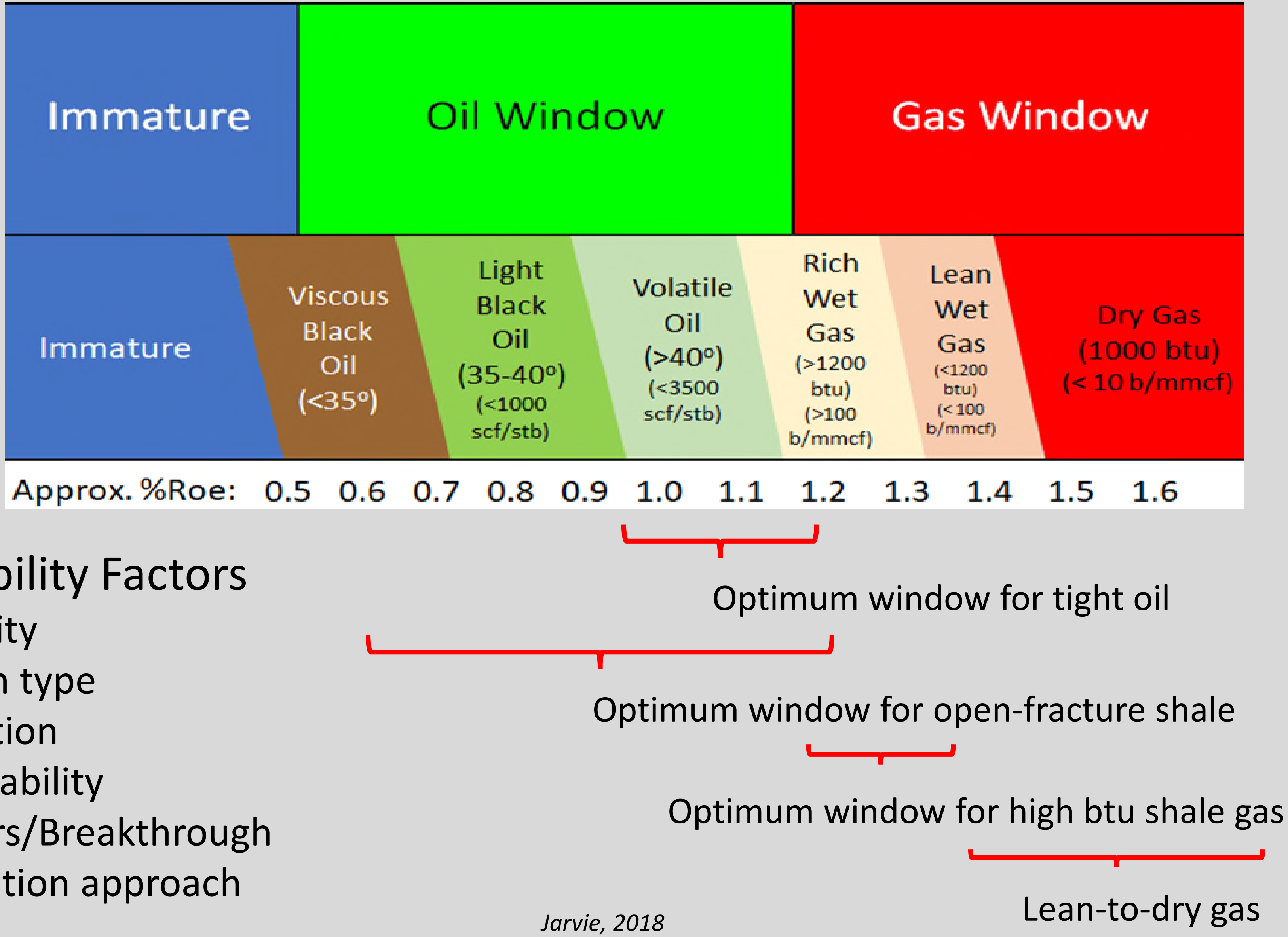
Wolfcamp:
- Midland basin
- Delaware basin

Eagle Ford Shale
Bakken Shale

are excellent to exceptional source rocks in their original (restored) states.

Background

Importance of Thermal Maturity in oil producibility from tight rocks

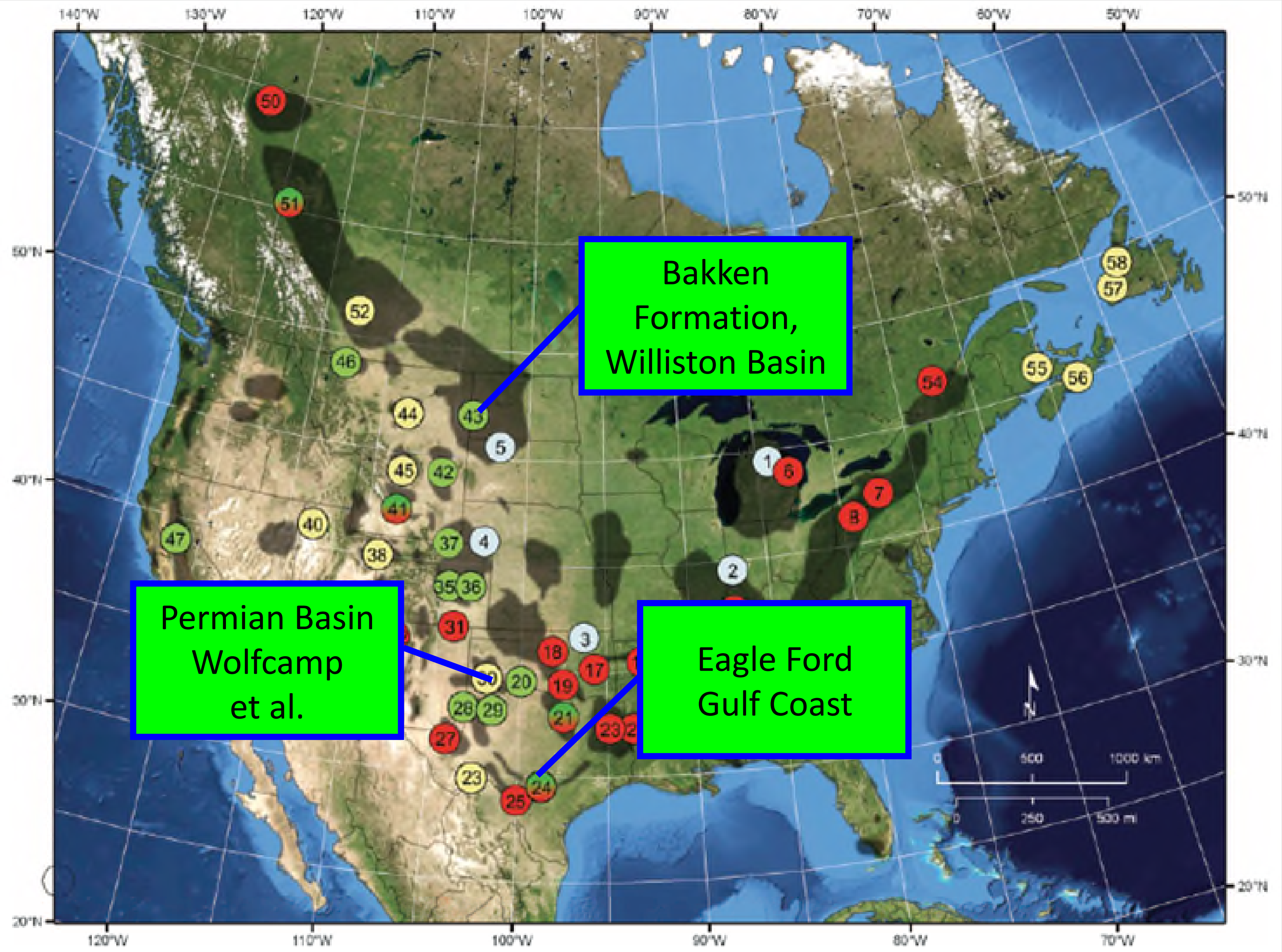


Jarvie, 2018

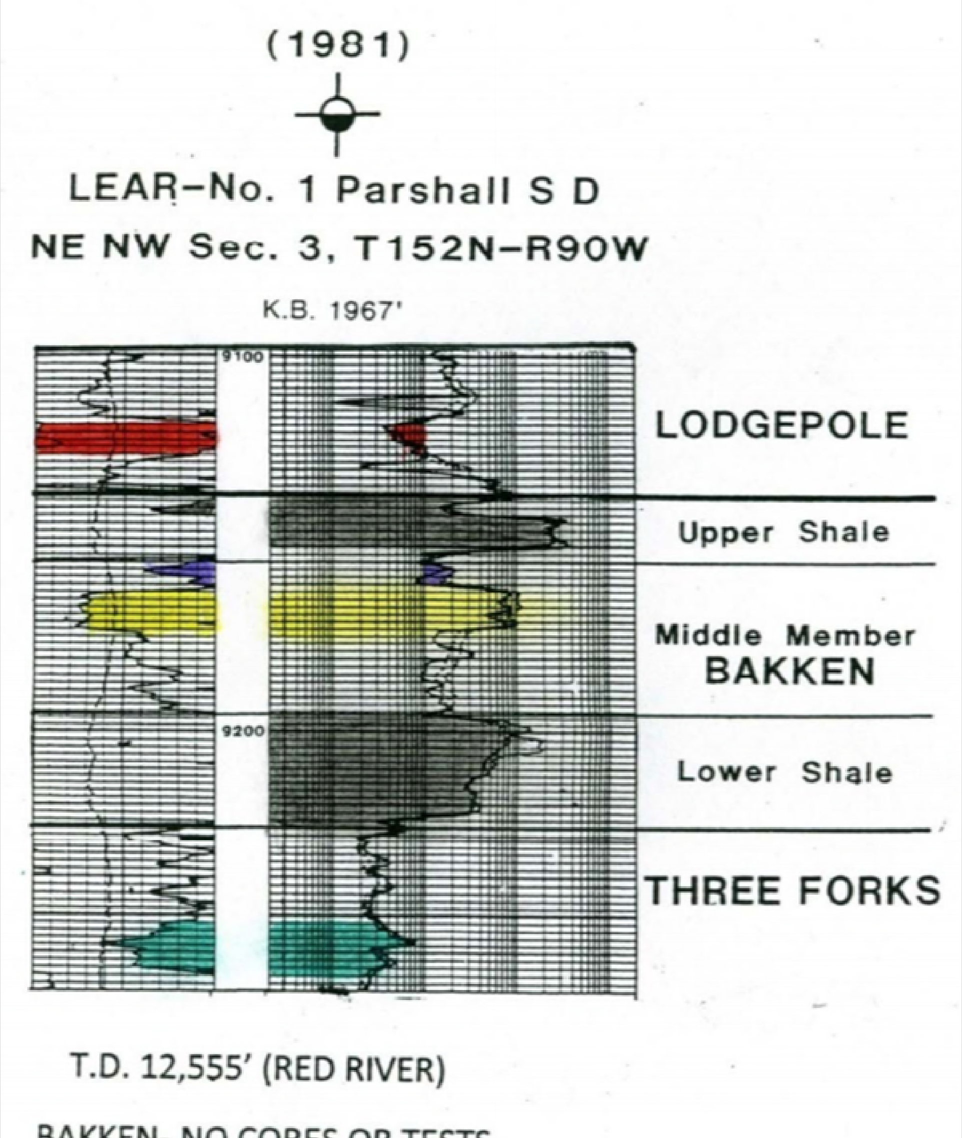
Many Producibility Factors

e.g.,
- Maturity
- System type
- Alteration
- Permeability
- Barriers/Breakthrough
- Simulation approach

Big Three Play Locations



Bakken Formation, Williston Basin



Michael Johnson, 2007

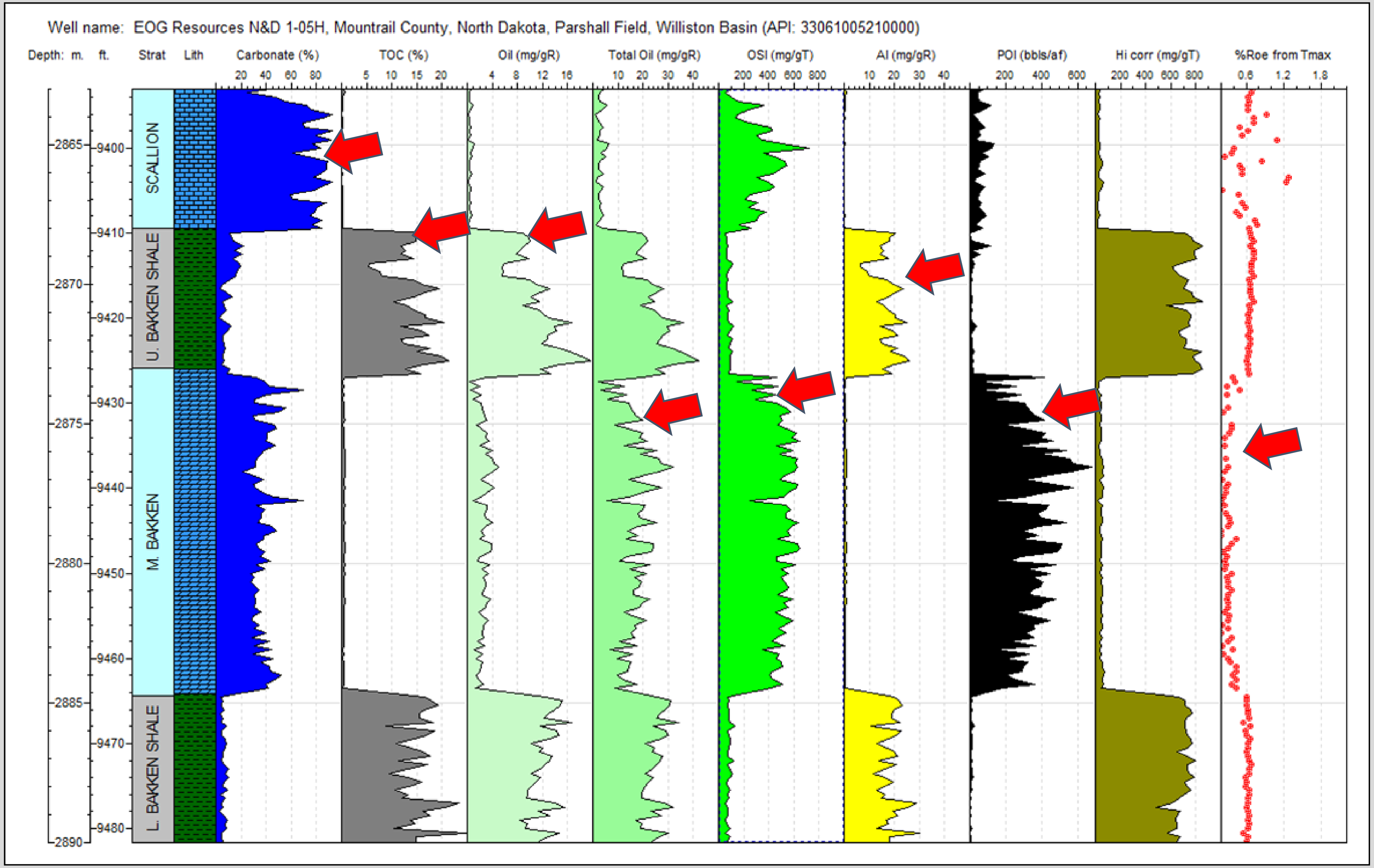
A great hybrid 'Oreo' cookie

<- Reservoir
<- Source rock
<- Reservoir
<- Source rock
<- Reservoir

Bakken production is now 1.4 mmbo/daily
with 3 billion+ barrels reserve

See Jarvie et al., 2011

Geochemical Logs of EOG Resources Parshall Field well, Williston Basin (ND)



Jarvie et al., 2011

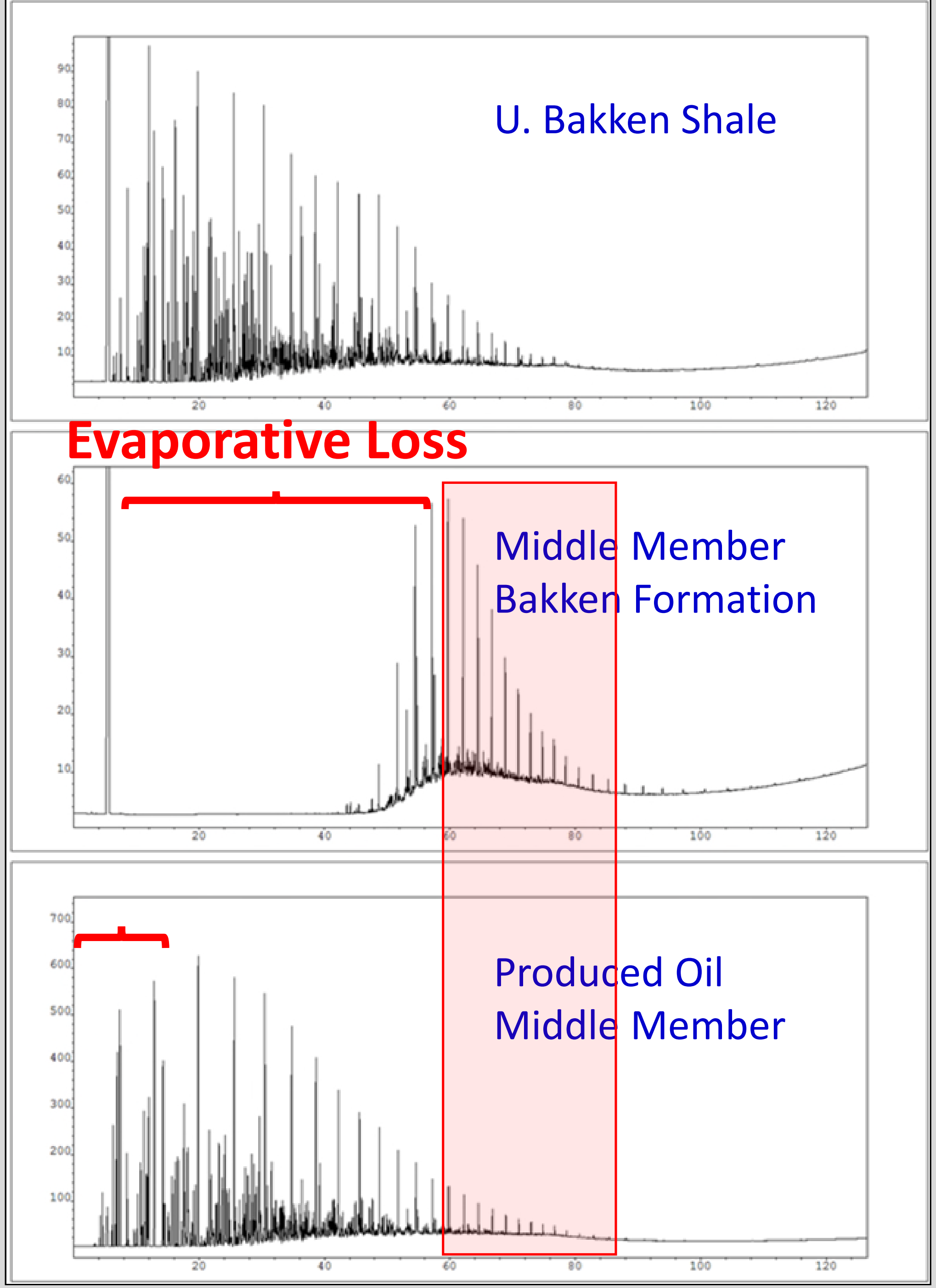
GC fingerprints

(GC=gas chromatography)

Such fingerprints show the yield (vertical y-axis) and distribution of resolvable compounds (horizontal x-axis). The major peaks are normal (straight-chained) alkanes (paraffins).

Produced Interval

Produced Oil (dead oil)



Jarvie et al., 2011

U. Bakken Shale shows high retention of total oil even more so than produced dead oil sample (bottom). TOCs average close to 15% providing high sorptive affinity.

The Middle Member has 'lost' much of its light oil although it is obviously present in the produced oil from that interval.

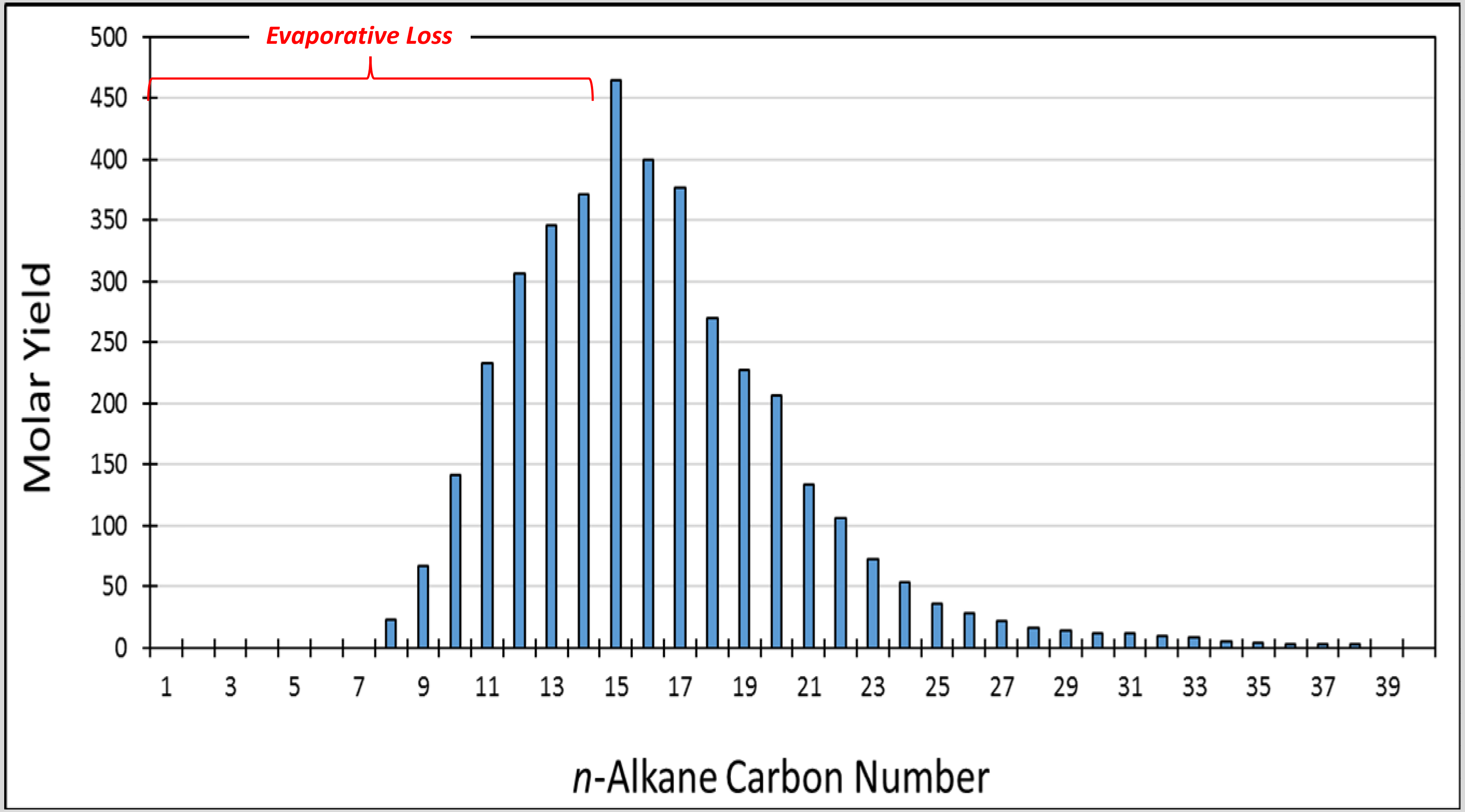
How to 'restore' this lost oil to obtain an idea of total oil content?

Compare unevaporated portions of GC…

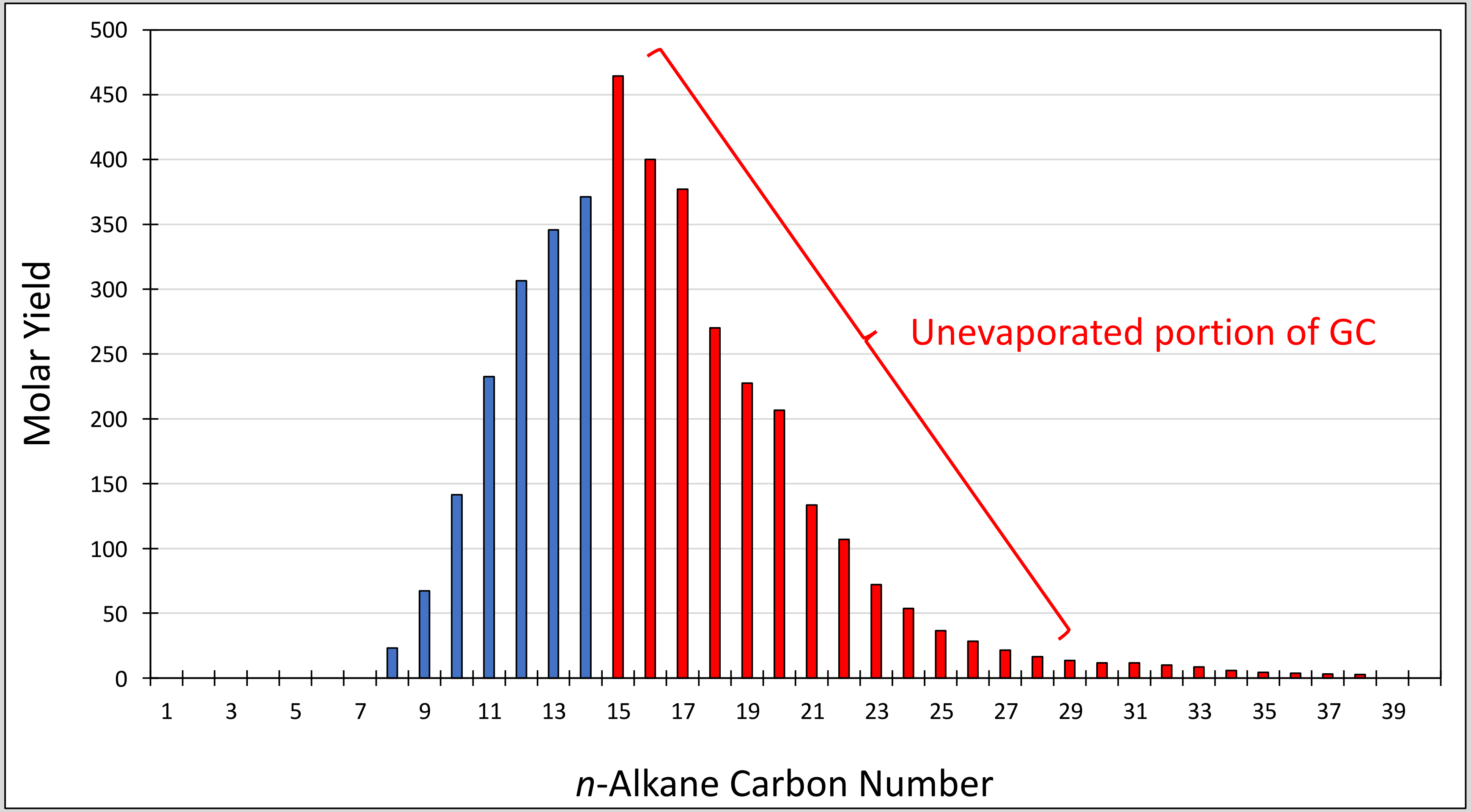
Restoring Lost Petroleum
(applicable to volatile oils and condensates)

Extract GC Histogram of Molar Yields of *normal* Alkanes (slide overlays)

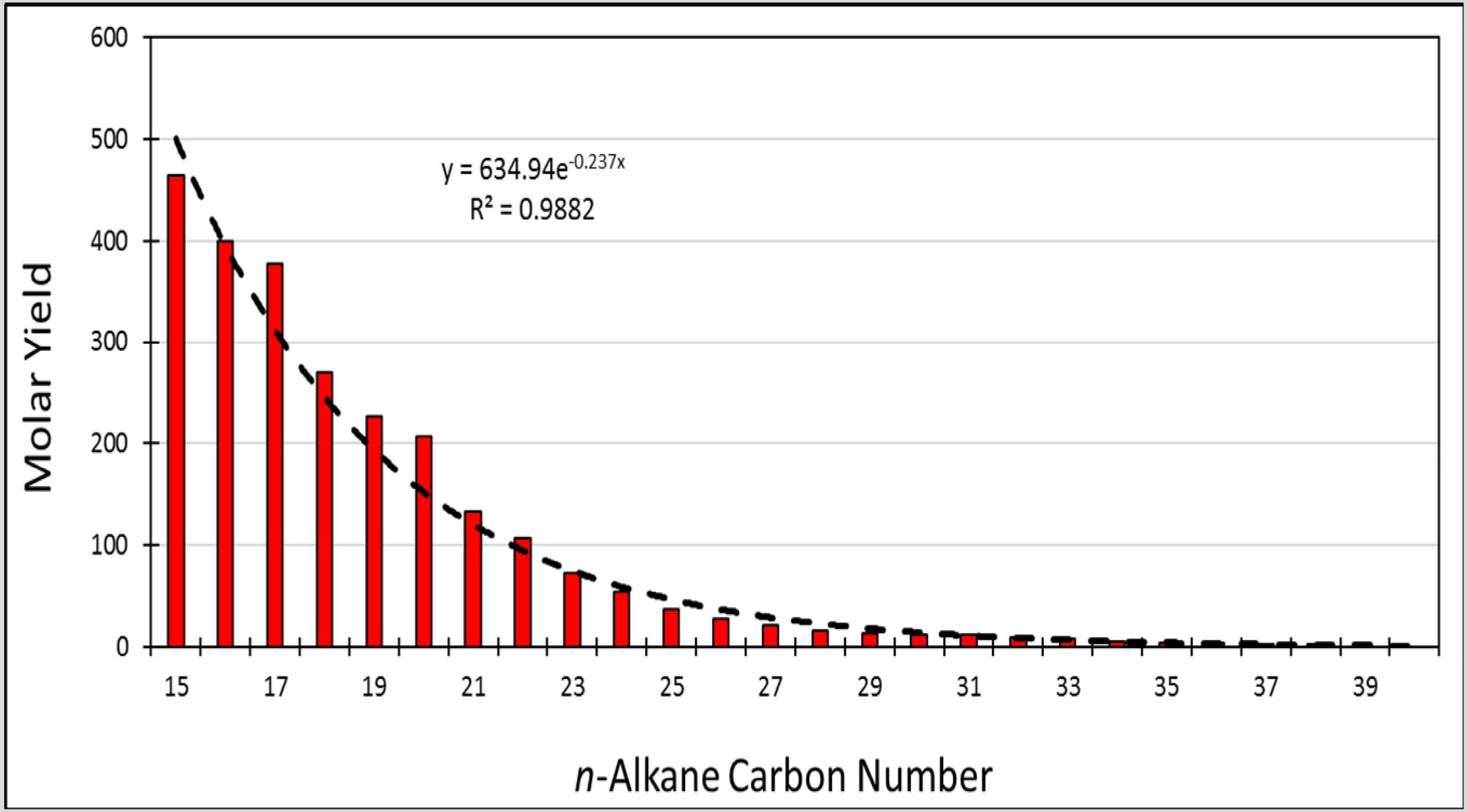
GC fingerprint converted to bar chart showing n-alkanes



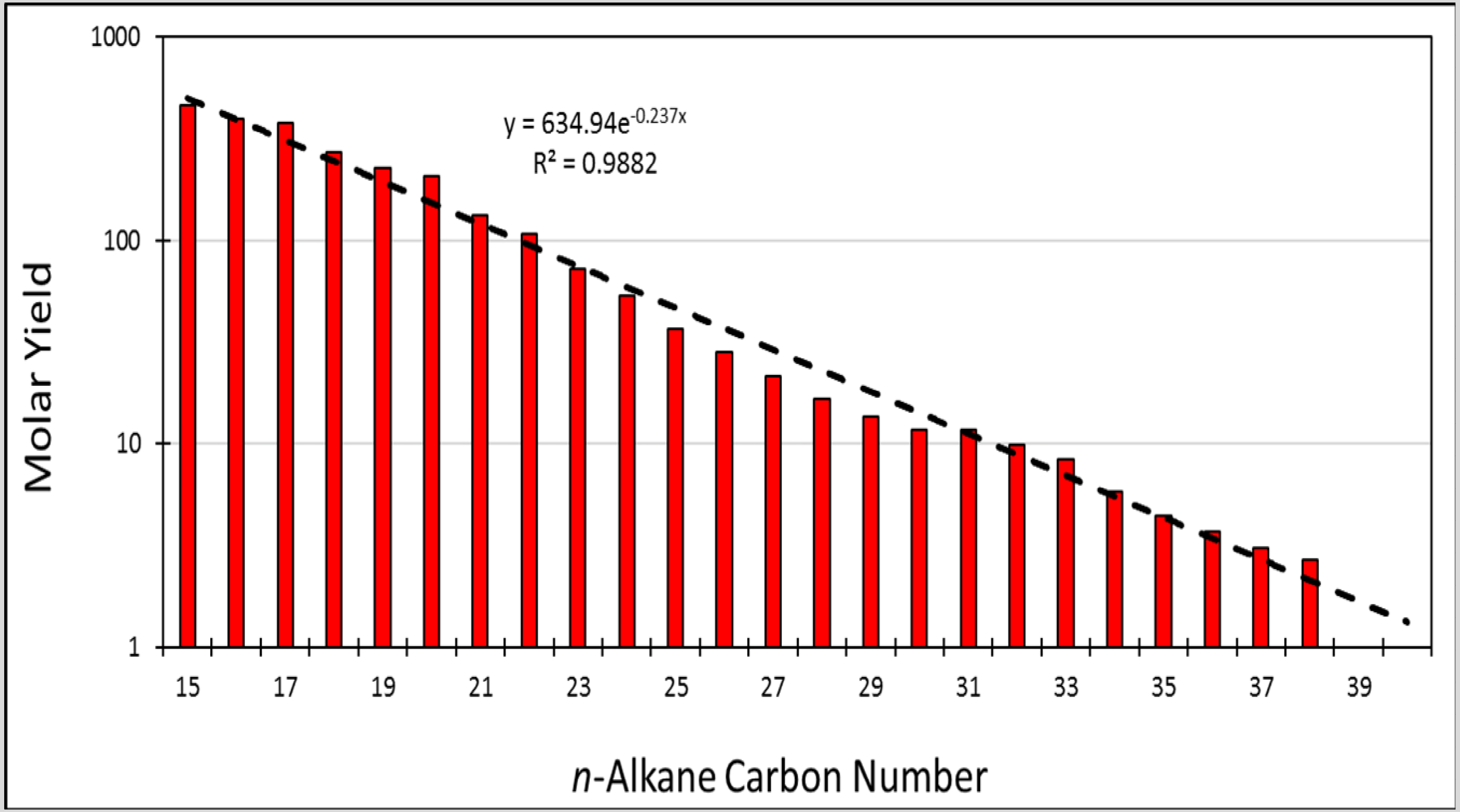
Restoring Lost Petroleum – 2
Determine unevaporated portion of GC



Restoring Lost Petroleum – 3
Exponential curve fit of unevaporated portion of GC



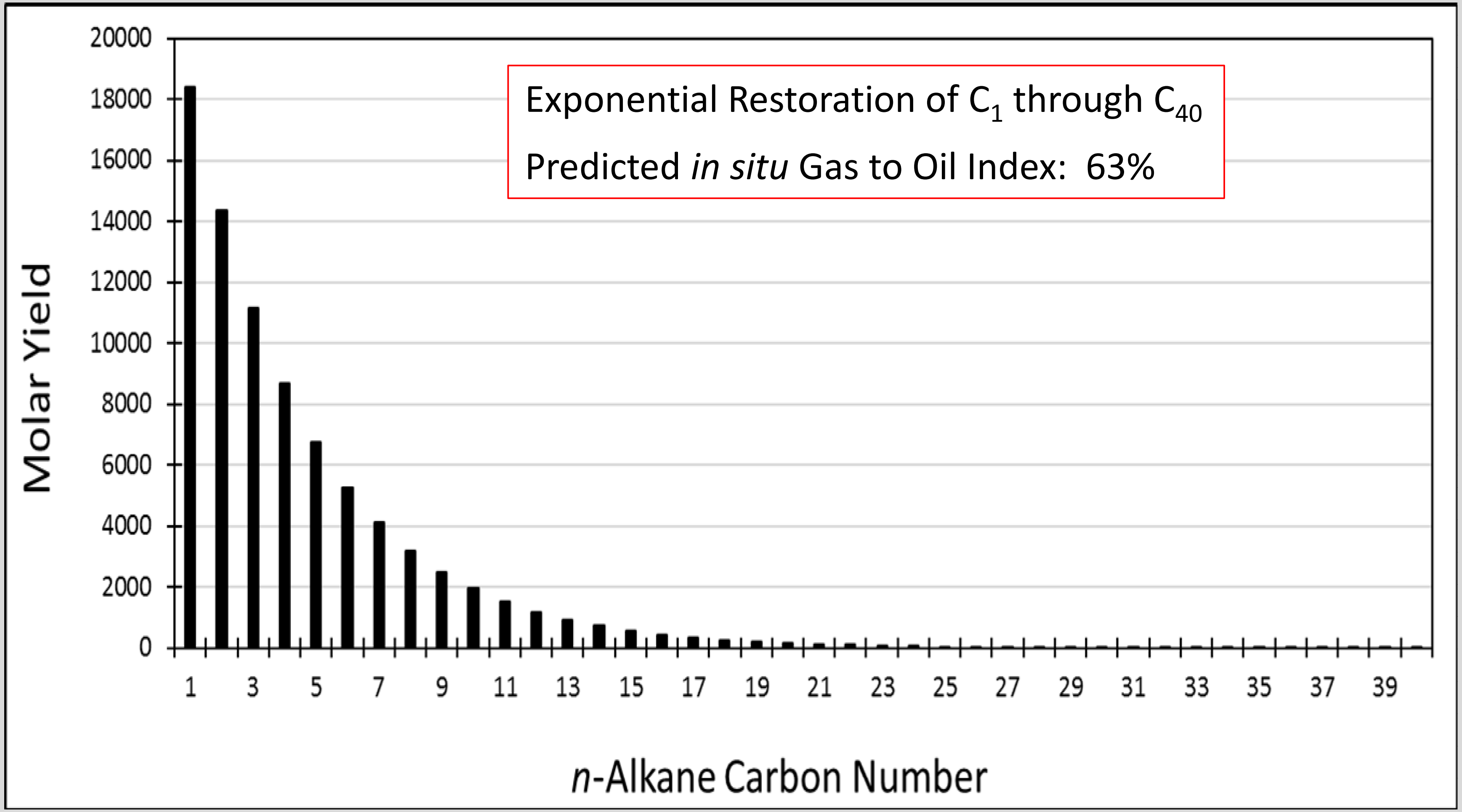
Restoring Lost Petroleum – 4
Log scale clearly shows slope



Restoring Lost Petroleum – 5
Restore entire GC from C1 to C40

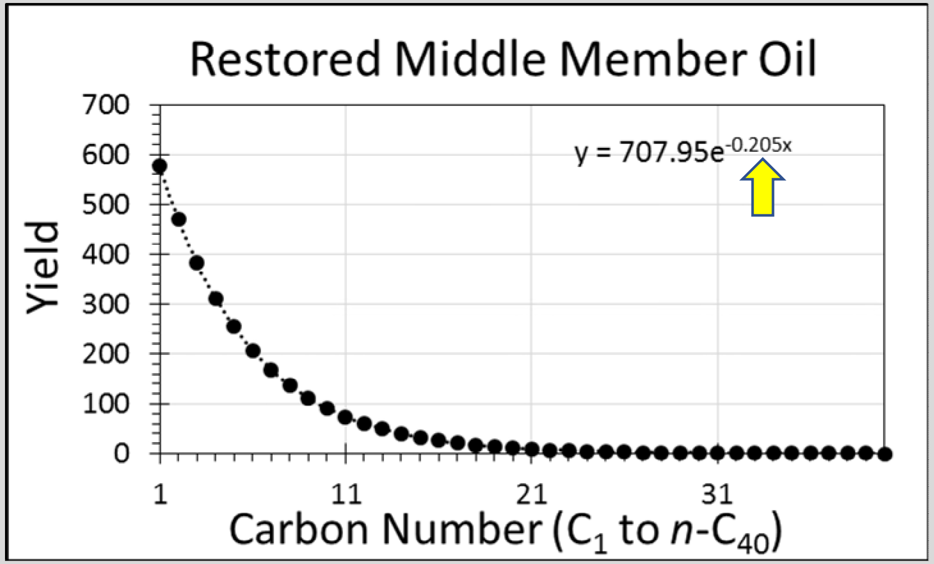
The exponential fitting equation can be used to restore gases and light oil.

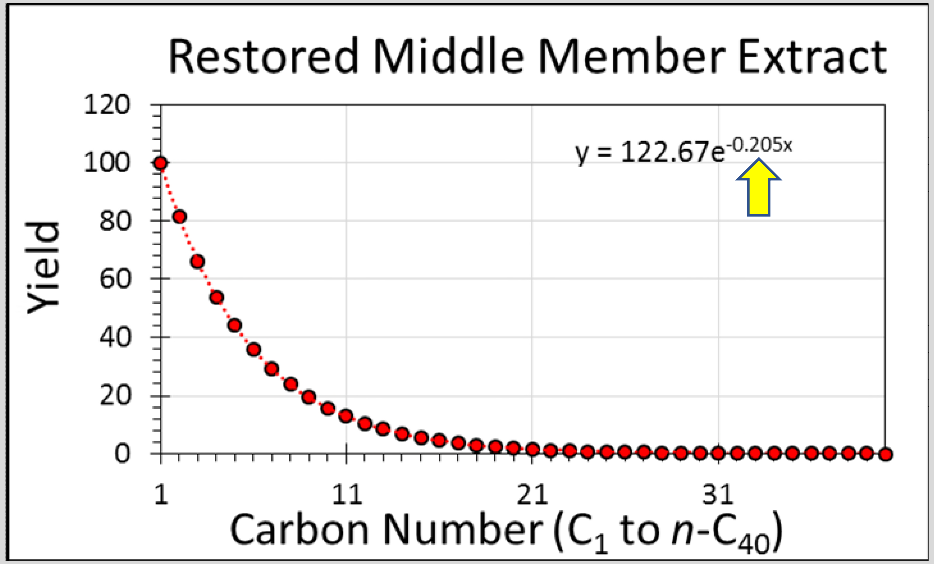
This is only appropriate for light oils and condensates.

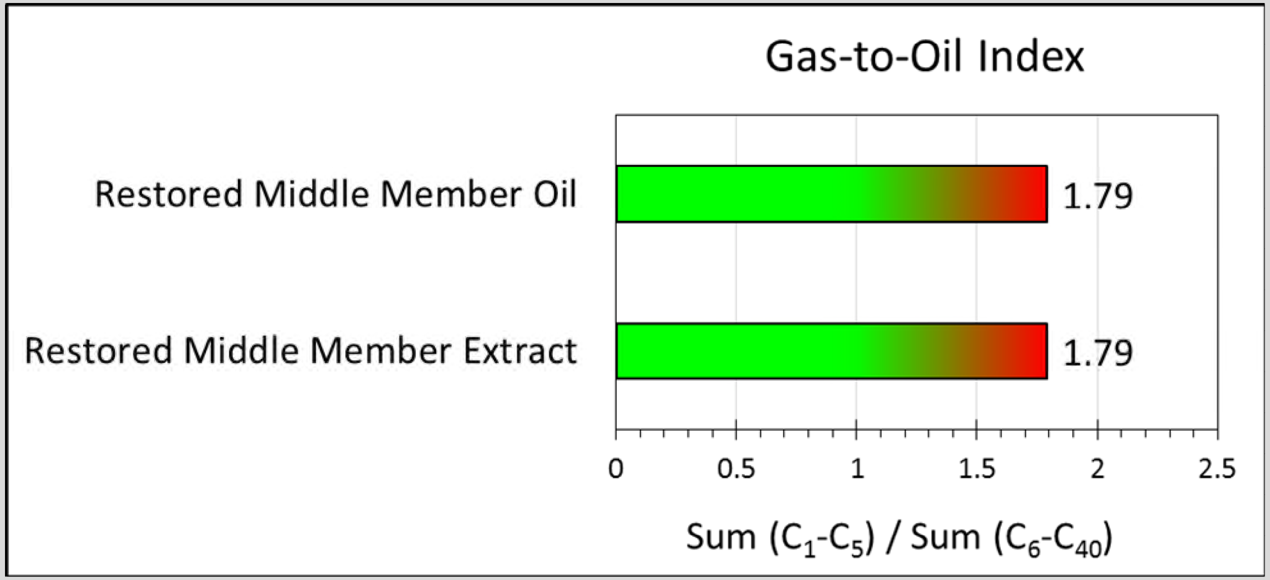


Result of Restoration on Bakken

Oil and highly evaporated Middle Bakken extract have same slopes







Restoration shows full compatibility with produced oil.

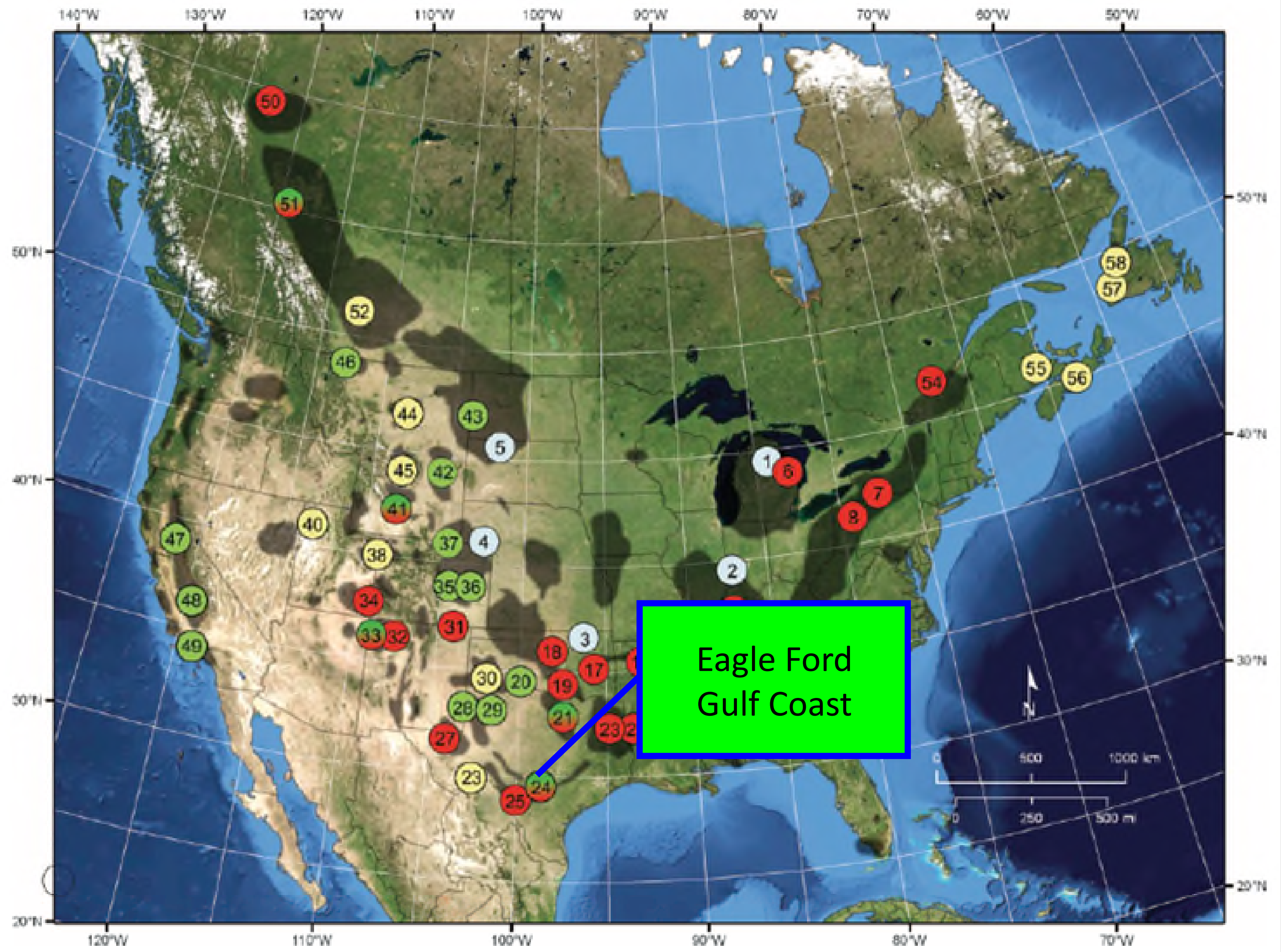
Such Restoration can be utilized to obtain the total S1-oil

Total S1 = measured S1-oil + ($S2_{\text{whole rock}}$ – $S2_{\text{extracted rock}}$) + Evaporative Loss

Resolved GC peak area results:	50	units
Restored GC peak area results:	100	units
Difference:	50	units
Evaporative loss:	50%	
S1 measured:	2.31	mg oil/g rock
Restored S1:	4.62	mg oil/g rock
Oil content:	53	boe/af
Oil content corrected:	106	boe/af

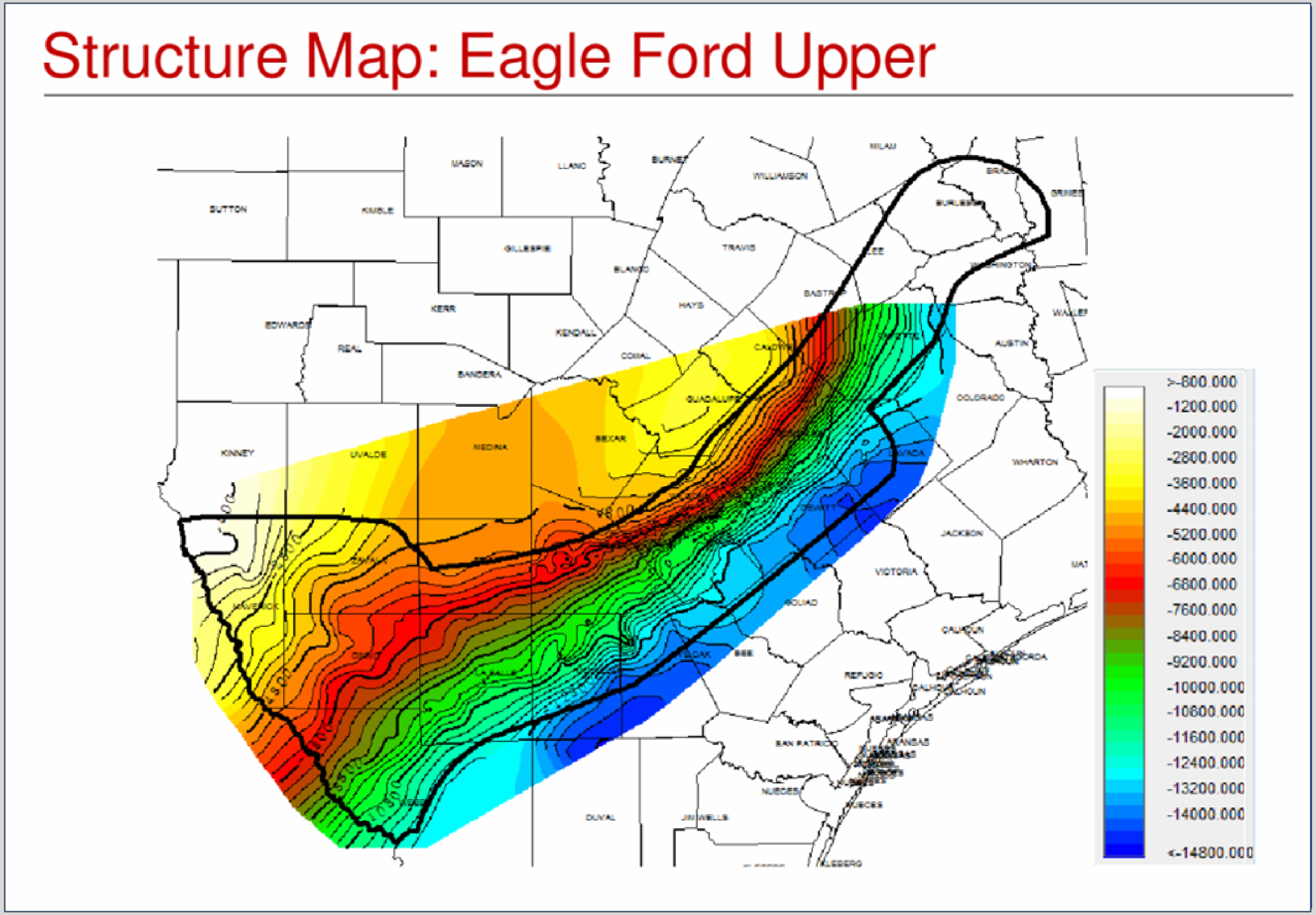
Evaporative losses in light oils and condensates represent the bulk of the petroleum

Eagle Ford Shale Tight Oil Play, South Texas Coastal Basin



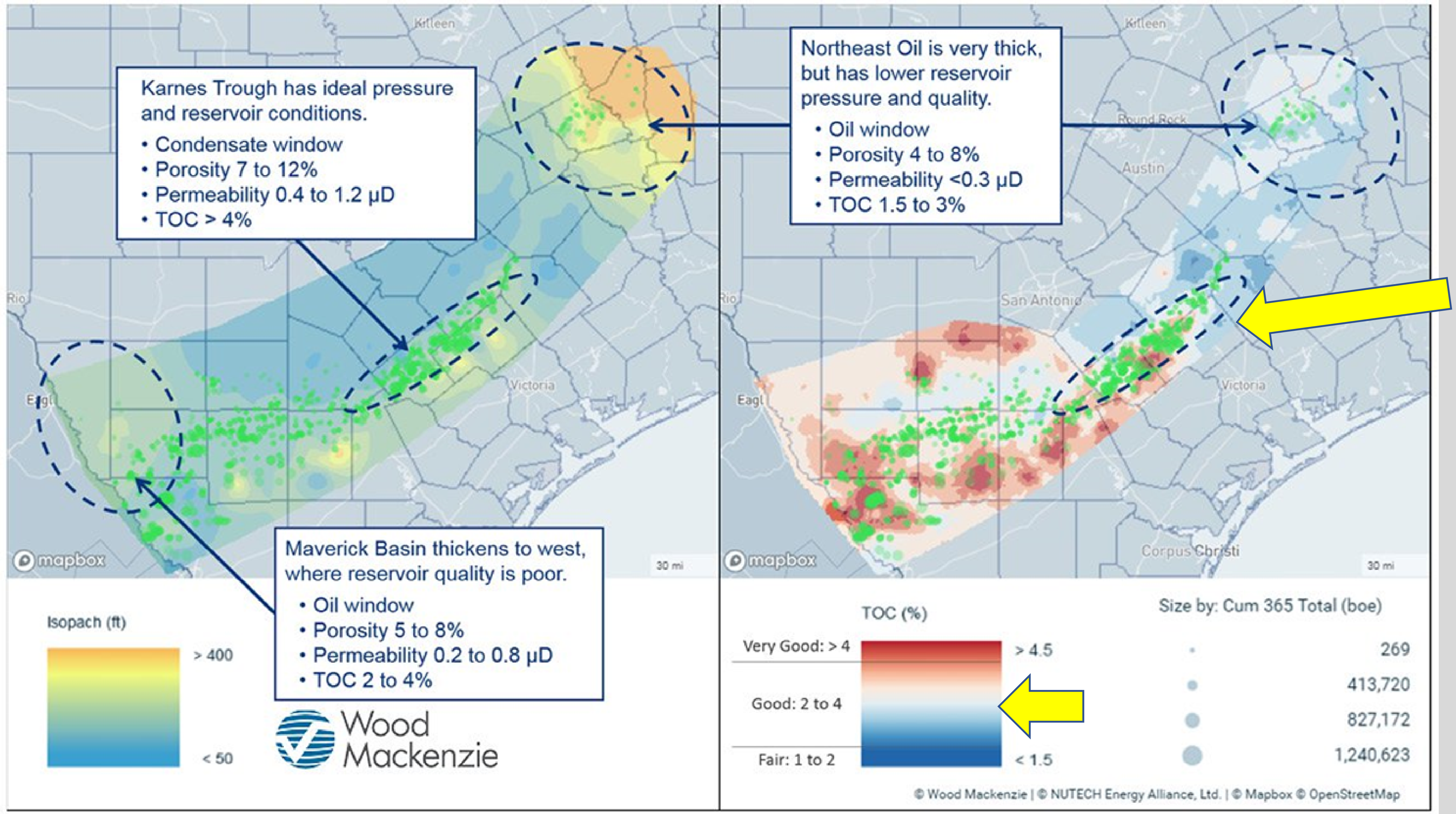
Eagle Ford Maturity and Structure

Depth to EFS correlates to approximate thermal maturity



Eagle Ford Shale, South Texas, USA

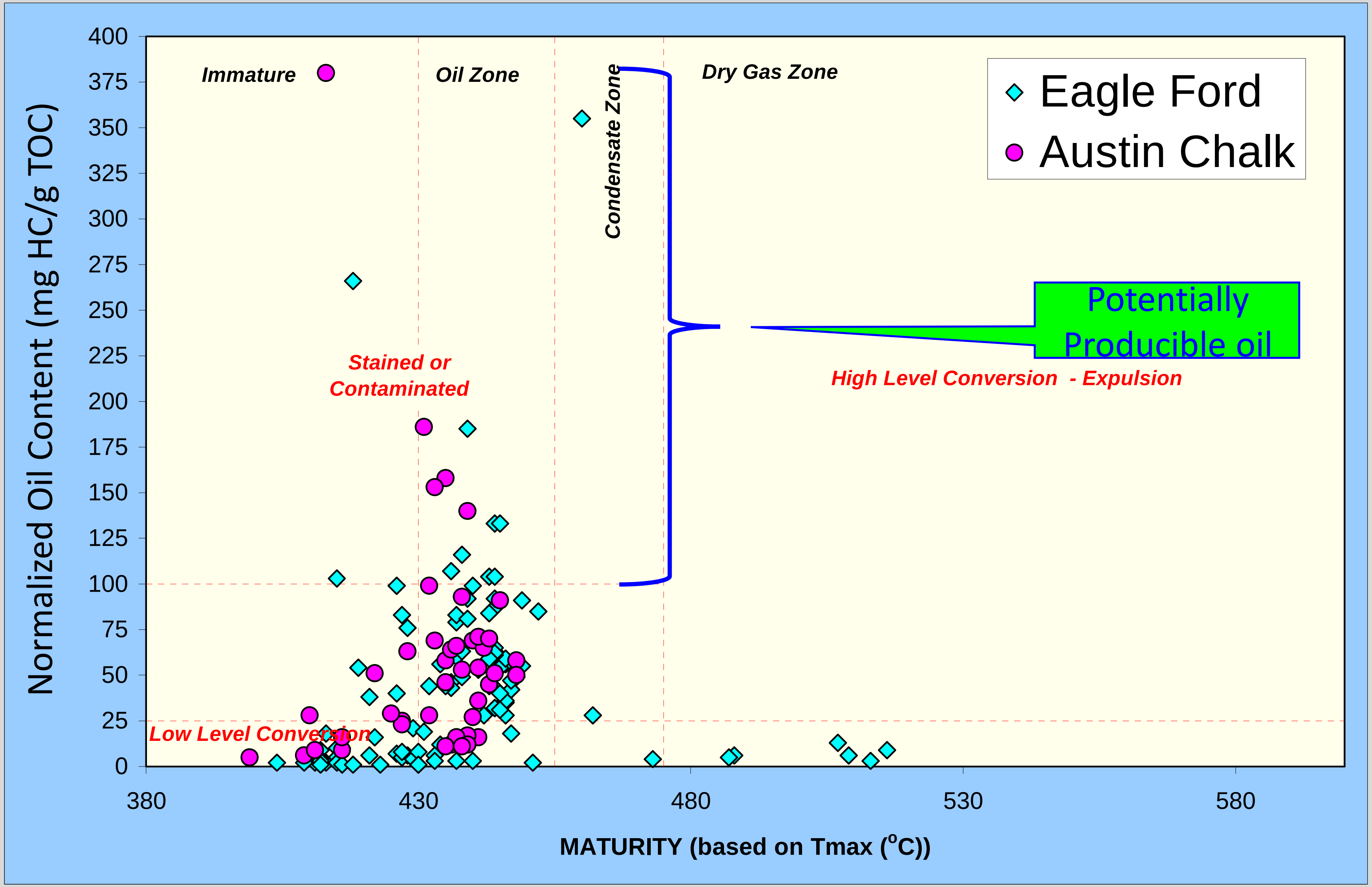
pressure, por/perm, TOC



Best part of oil play has modest TOC values due to ca. 70% conversion of organic matter

Note: TOC is important but the high hydrogen content is what makes these plays the Big Three

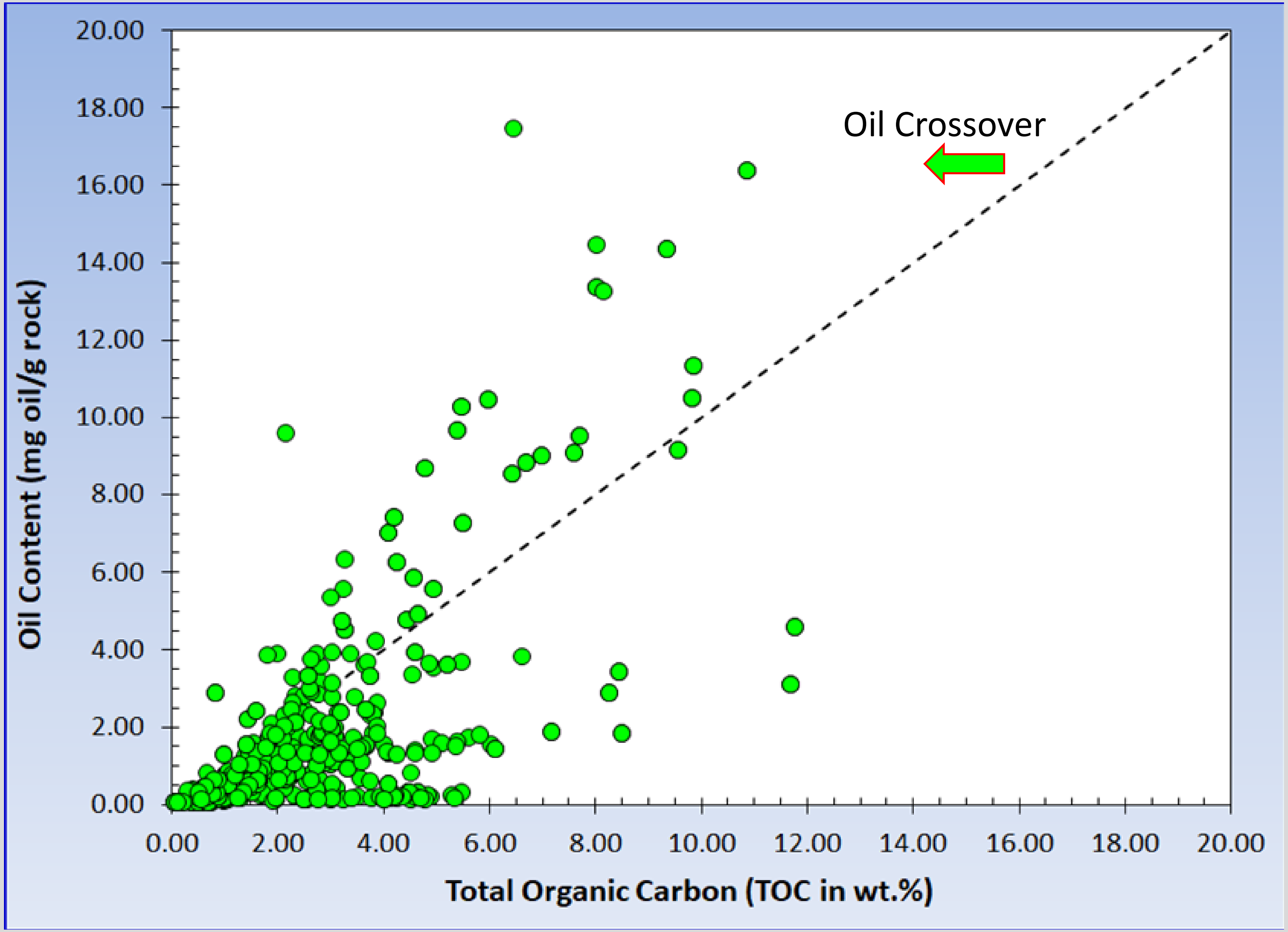
Published Data shows Oil Crossover (S1 x 100 / TOC), i.e., producible oil



Jarvie, 2007 Data from Grabowski, 1995

Low S1/TOC ratios often indicate evaporative losses especially in light oils > 40° API

Oil Crossover is not always present in production wells due to evaporative losses



Evaporative losses are often highest in best reservoir rocks:

- Volatile oil
- Good pressure
- High por/perm

Understanding Lab Measured Pyrolysis Oil Yields

Black Oil

Standard Pyrolysis Yields

S1 Oil

S2 (kerogen)

Evaporative losses occur throughout the sample collection, processing, and analysis process. Black oils have lower volatile components

Pyrolysis Yields after Extraction

Evaporative Loss of oil (S1')

S1 Oil

S2 extracted rock

S1" (oil in S2)

Total Oil = S1' + S1 + S1" + Evap. Losses

Jarvie, 2011

Understanding Lab Measured Pyrolysis Oil Yields

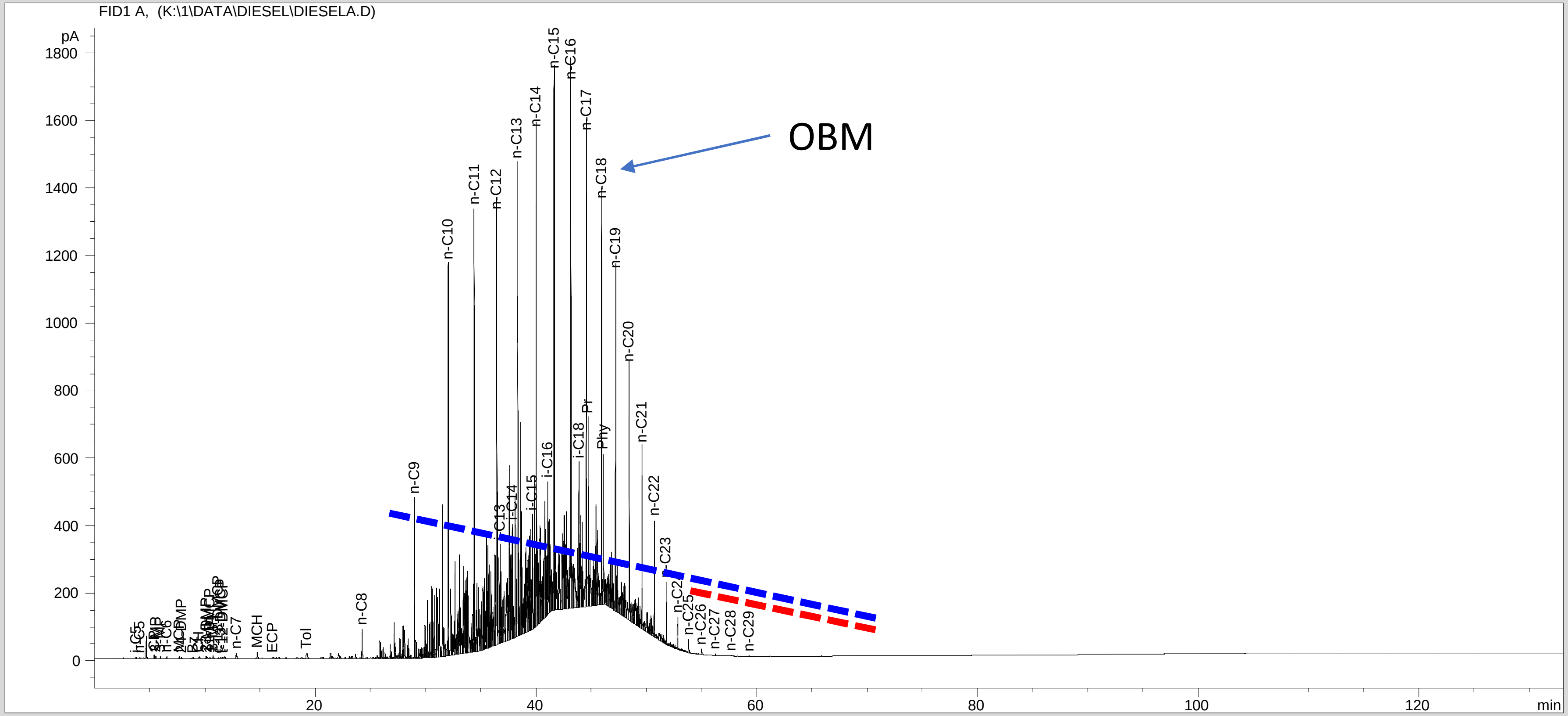
Light oil or condensate

Evaporative losses can be very high in volatile oils and condensates resulting in loss of 70%+ of the light hydrocarbons.

Losses from an organic-rich source rock are <u>lower</u> than from an organic-lean source rock

Jarvie, 2011

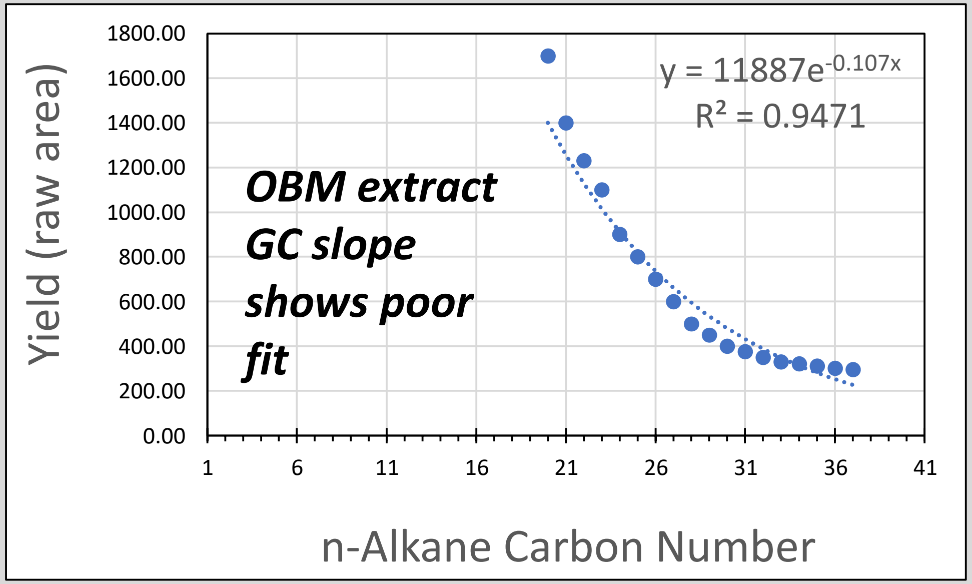
Removing Oil-Based, Polymer, or Water-Based Mud Contamination

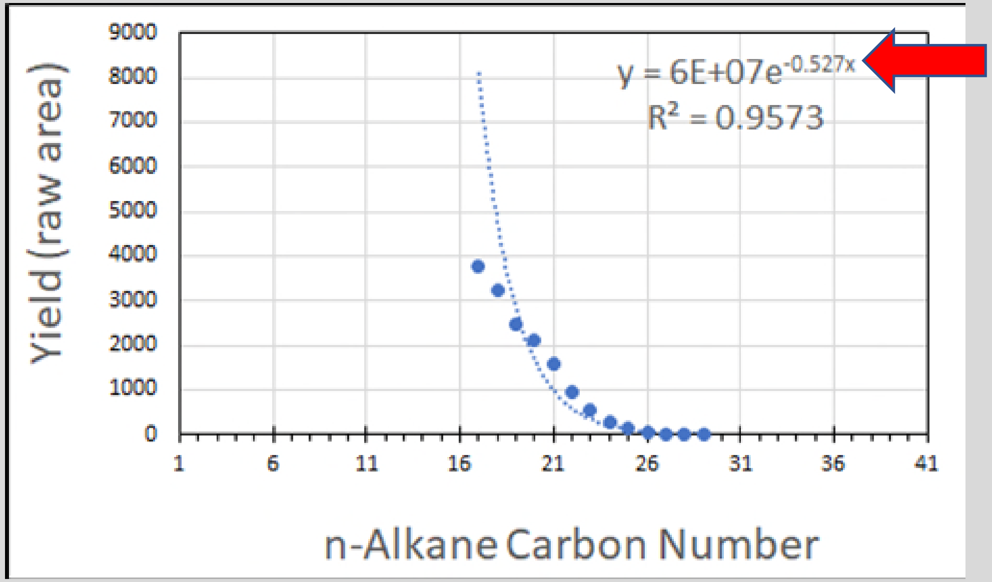


GC peaks are picked that show little or no influence of OBM as determined from analysis of slope factors

Evaluating slope factor restoration of GCs contaminated with oil-based Mud (diesel)

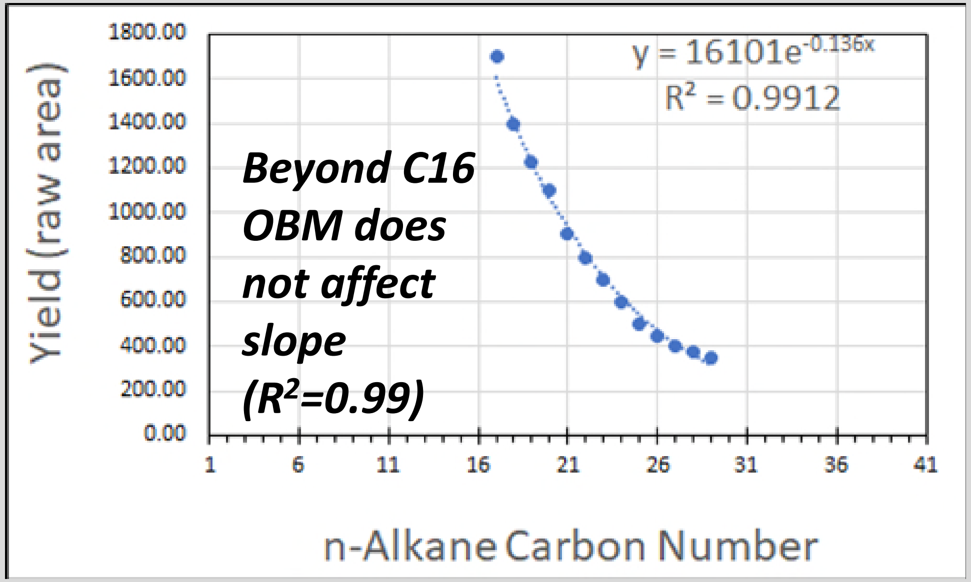
Exp factor is normal but obvious poor fit of data

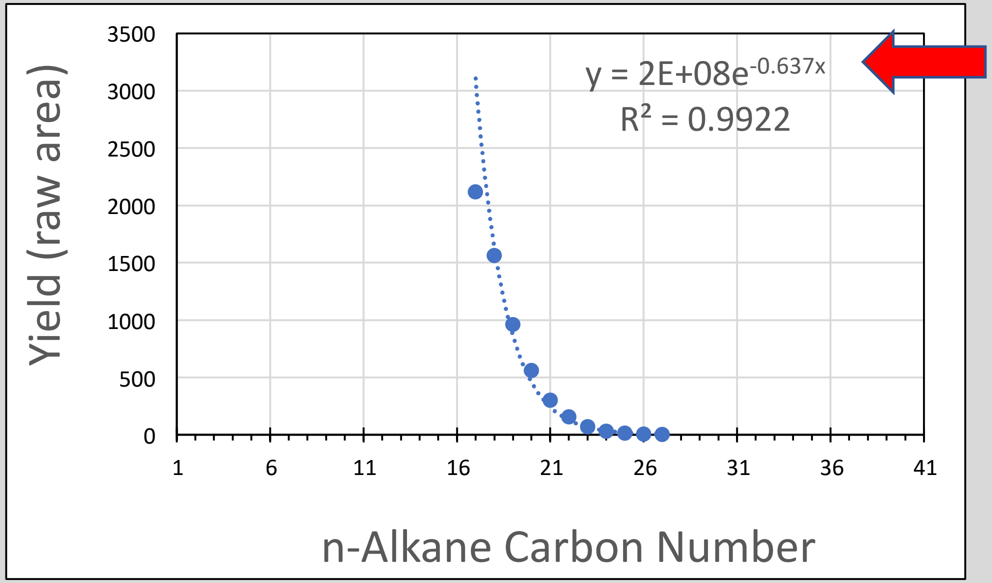




OBM (diesel) shows poor fit and unusually high exp factor; such high exp factors are not even seen in condensates

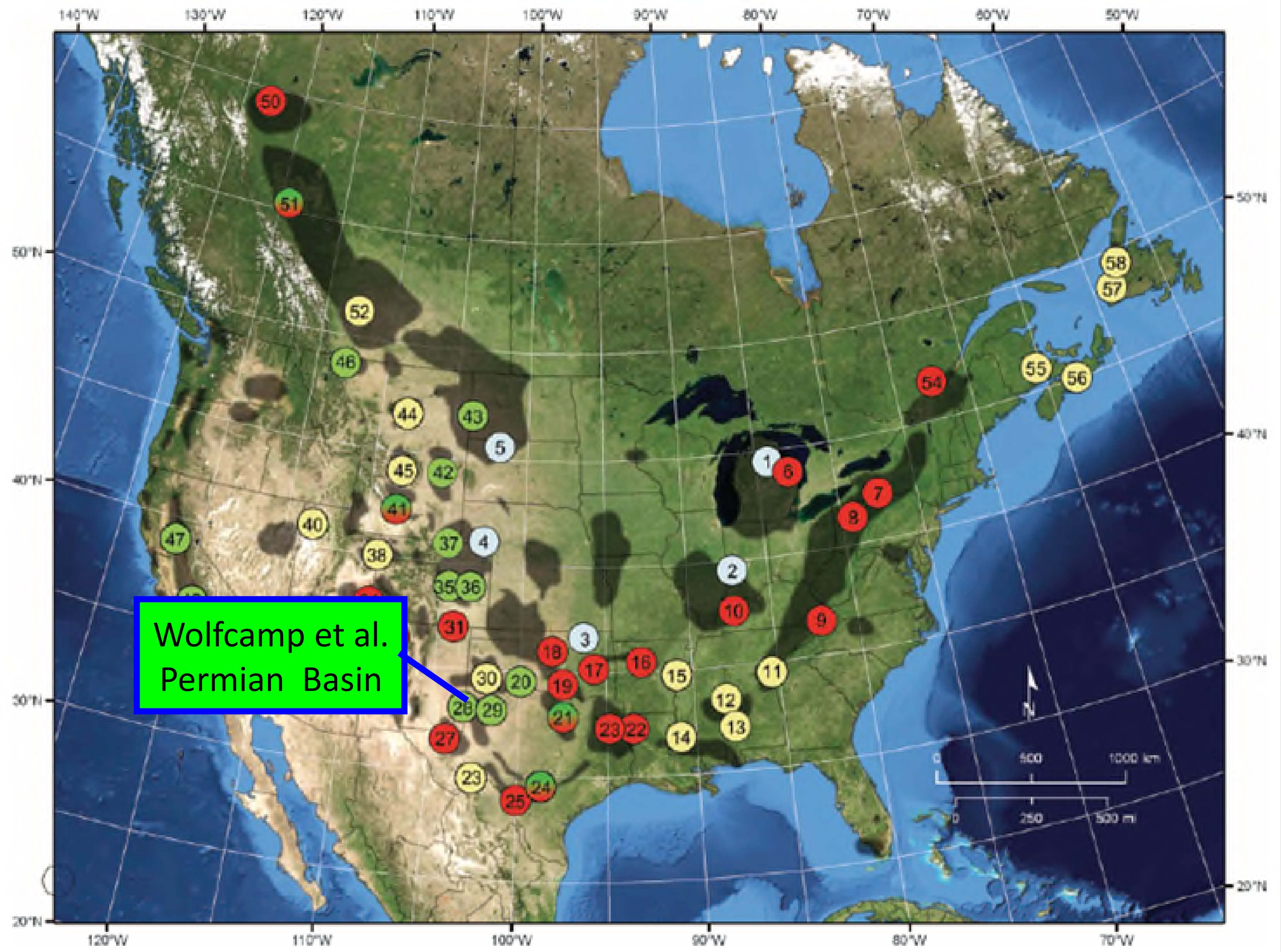
Exp factor is normal and good fit of data; can be used to restore evaporative losses



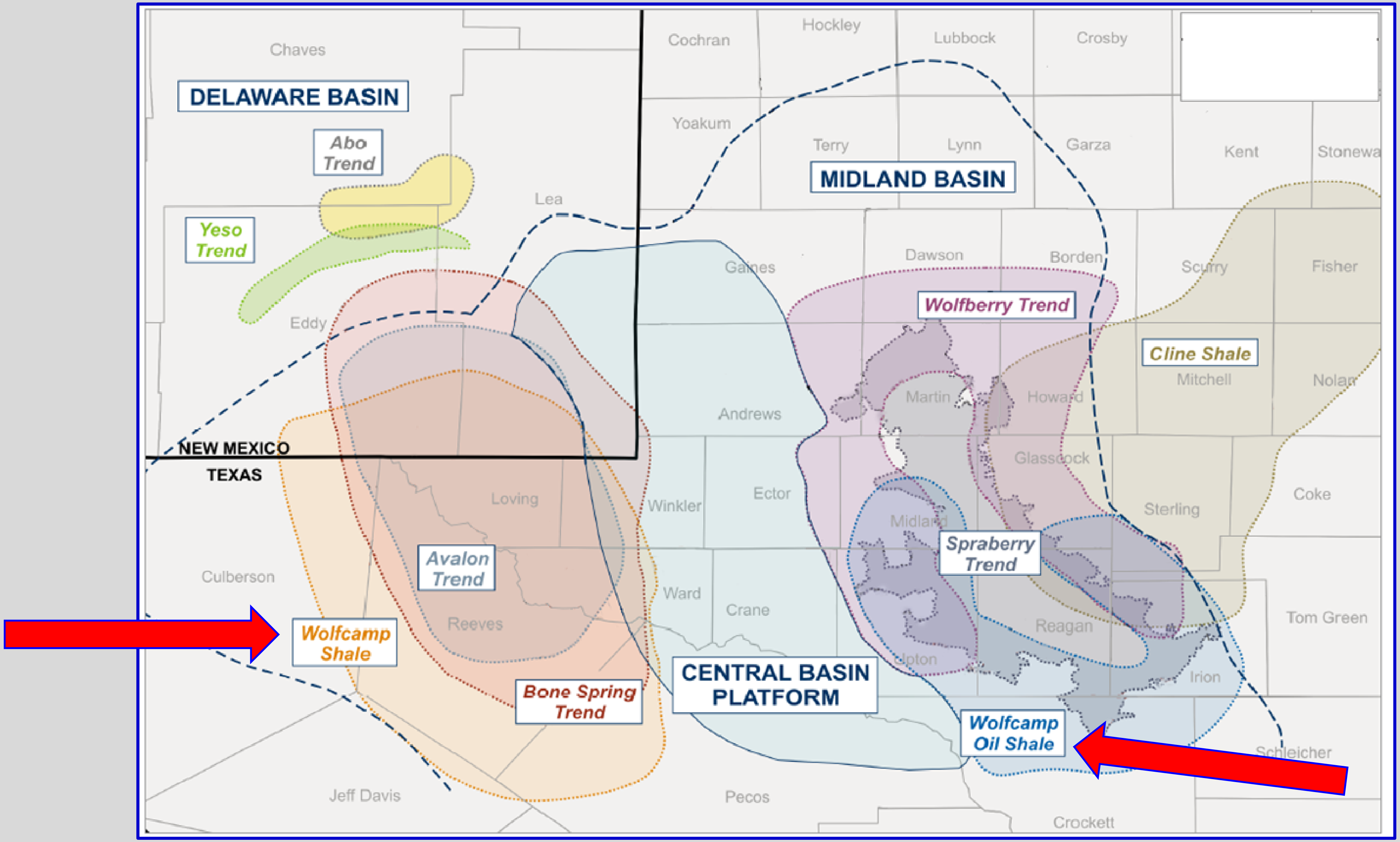


OBM (diesel) even when showing excellent R2 has unusually high exp factor

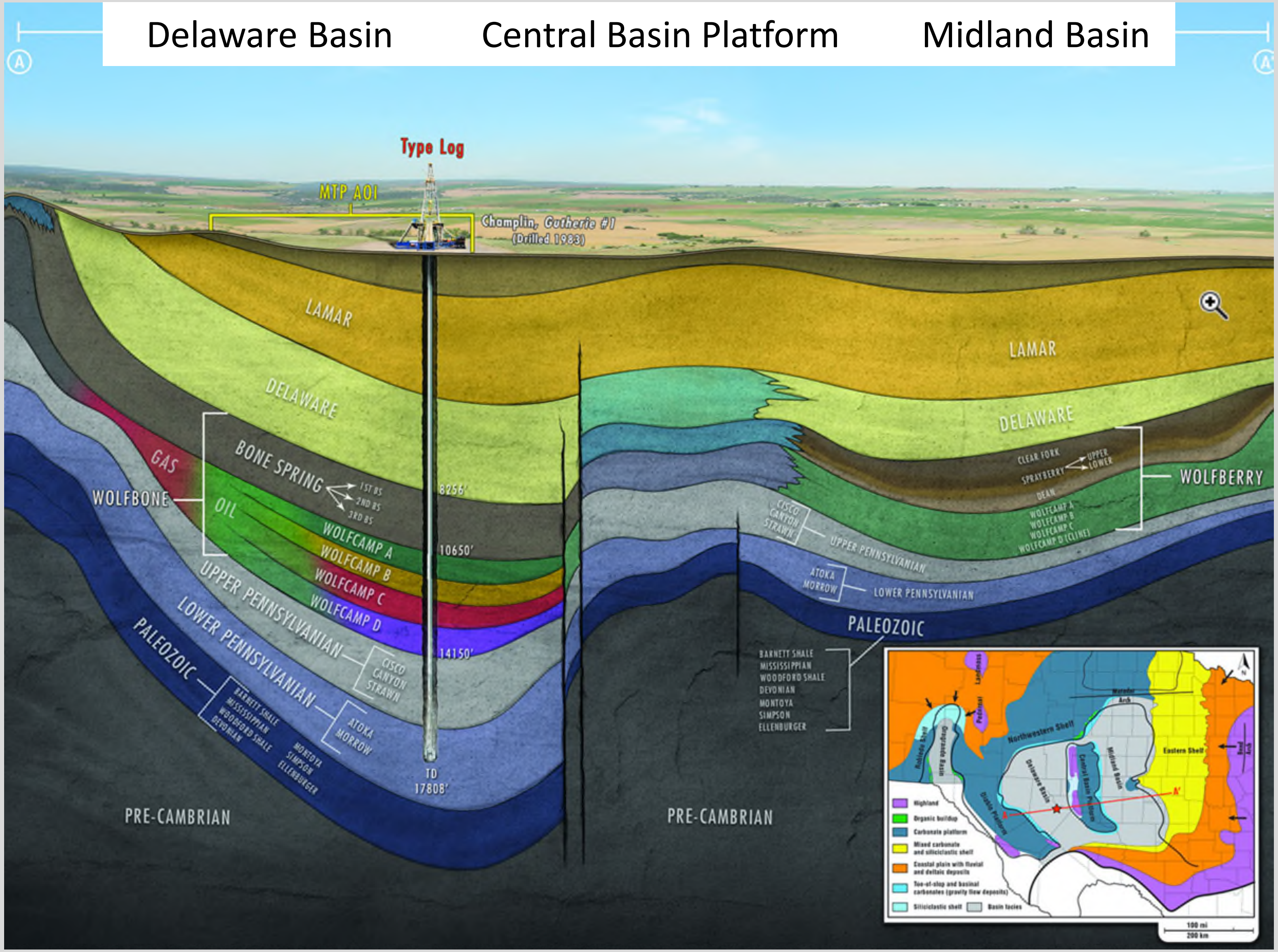
Wolfcamp Tight Oil System
Delaware and Midland basins (Permian basin)



Play Map Delaware and Midland Basins Multiple Plays: focus herein is on Wolfcamp



Permian Basin Diagrammatic Cross Section

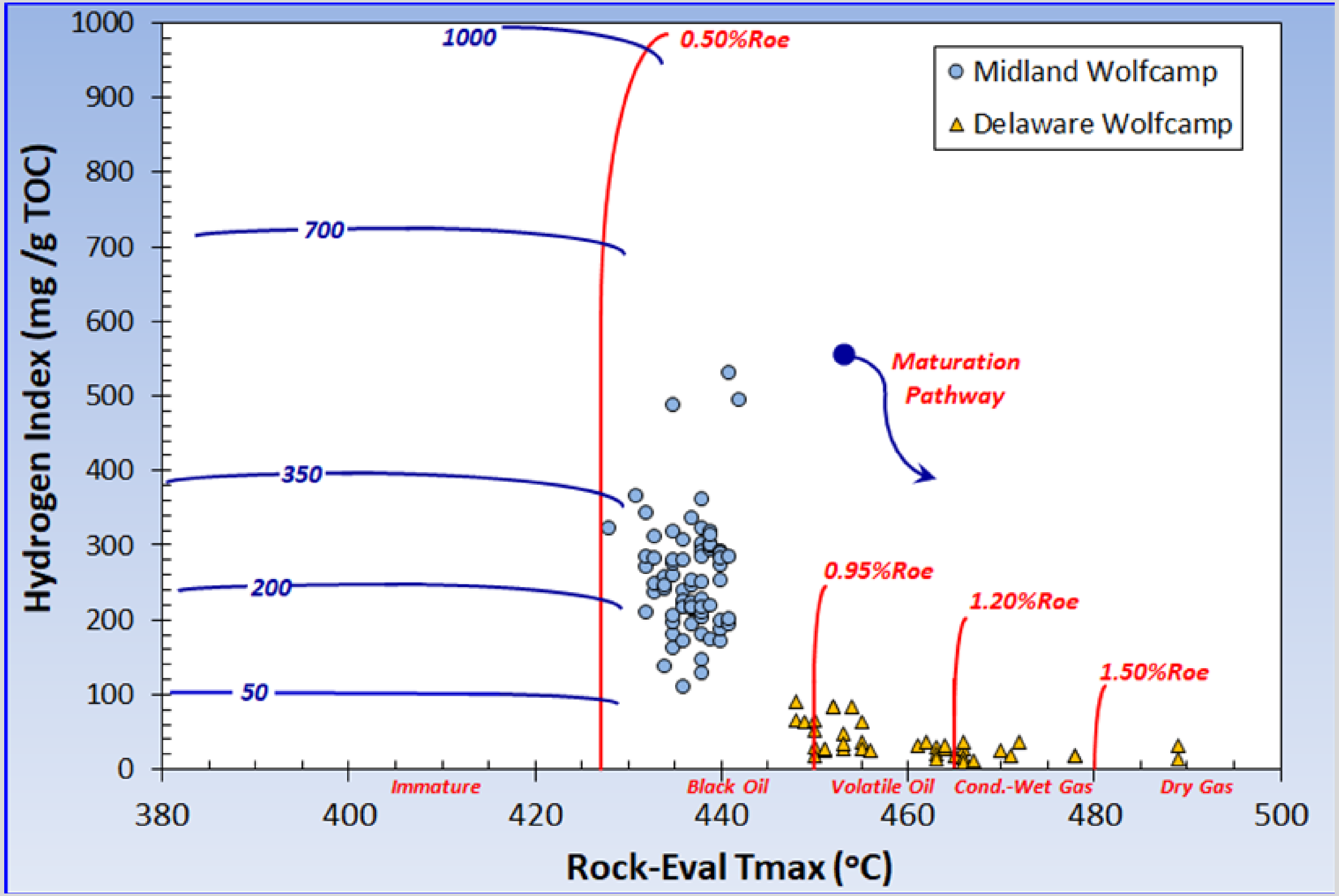


Cross Section provides generalized insight into thermal maturity differences between the two basins

Present-day HI versus Thermal Maturity

Midland Basin Wolfcamp is generally lower thermal maturity:

- lower pressures
- lower API gravity
- lower GOR
- lower saturated and aromatic hydrocarbons
- higher polars - resins and asphaltenes



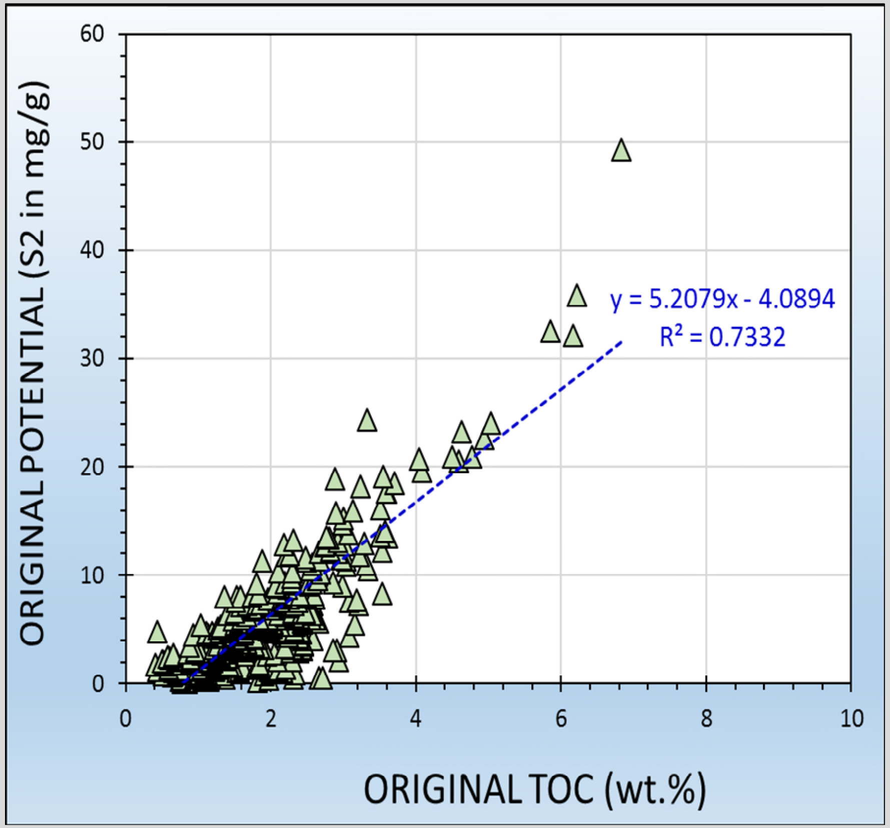
Delaware Basin Wolfcamp is generally higher thermal maturity:

- higher pressures
- higher API gravity
- higher GOR
- higher saturated and aromatic hydrocarbons,
- lower polars- resins and asphaltenes

Comparison of Delaware and Midland basins

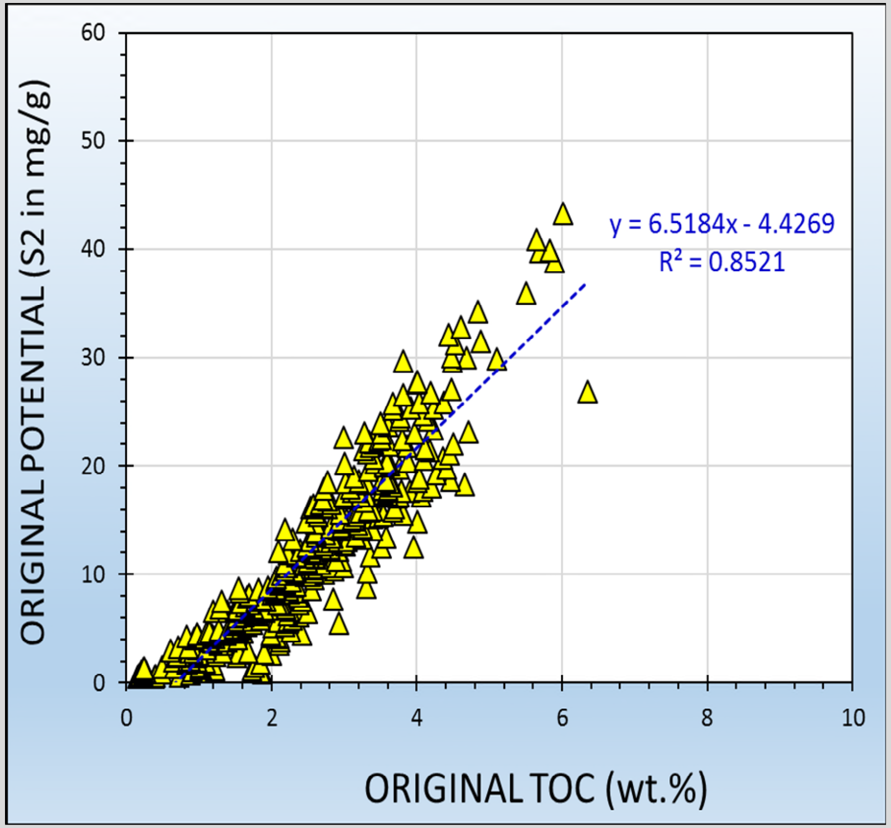
Restored S2-pyrolysis and TOC contents, and petroleum generation potentials

Delaware basin



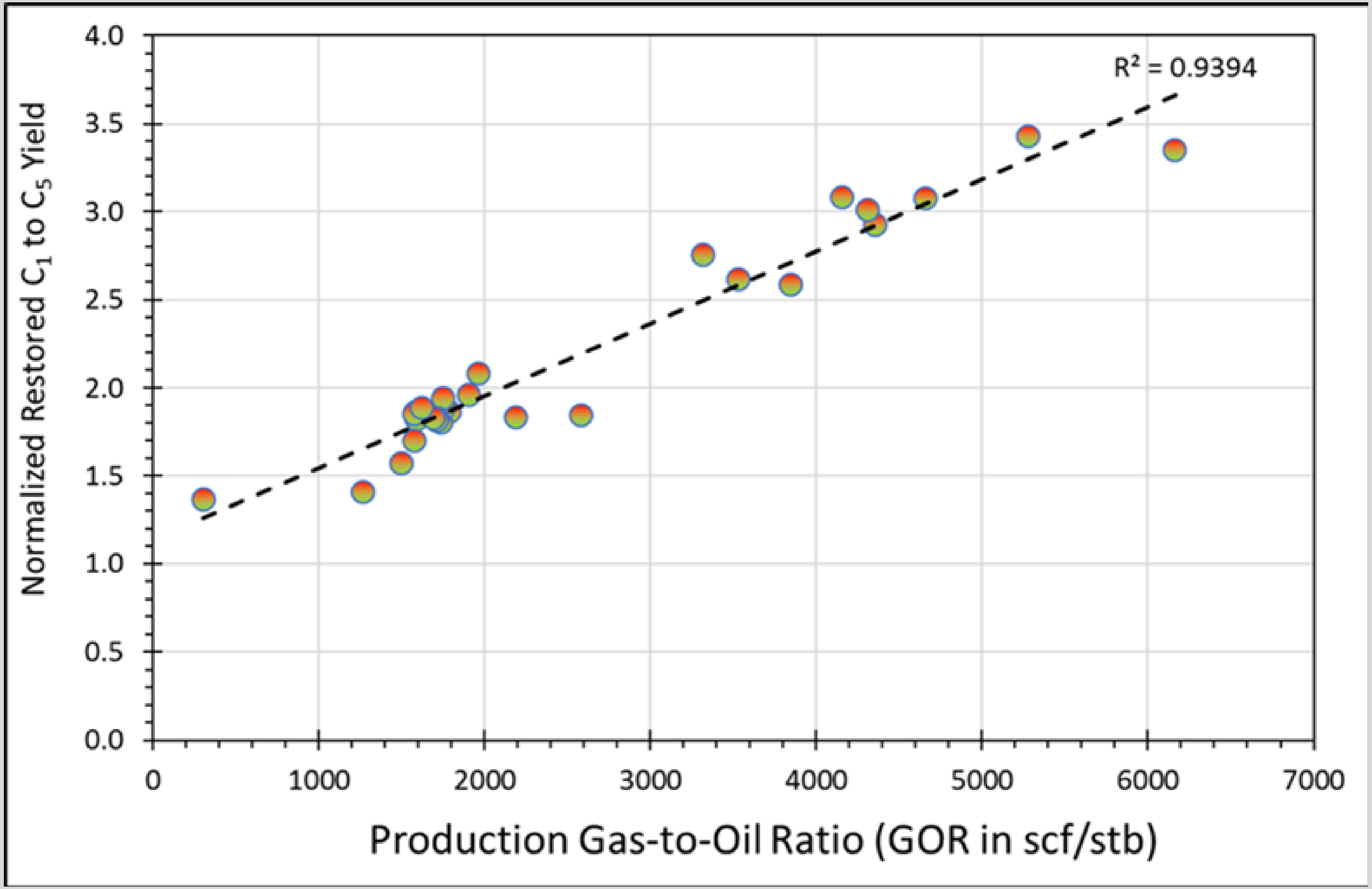
Projected HI_o = 521 mg/g
at TOC_o = 3.00 wt.%, = **360 boe/af**

Midland basin



Projected HI_o = 652 mg/g
at TOC_o = 3.00 wt.% = **469 boe/af**

Predicting Gas to Oil Ratio (GOR) Wolfcamp system from Restored GCs



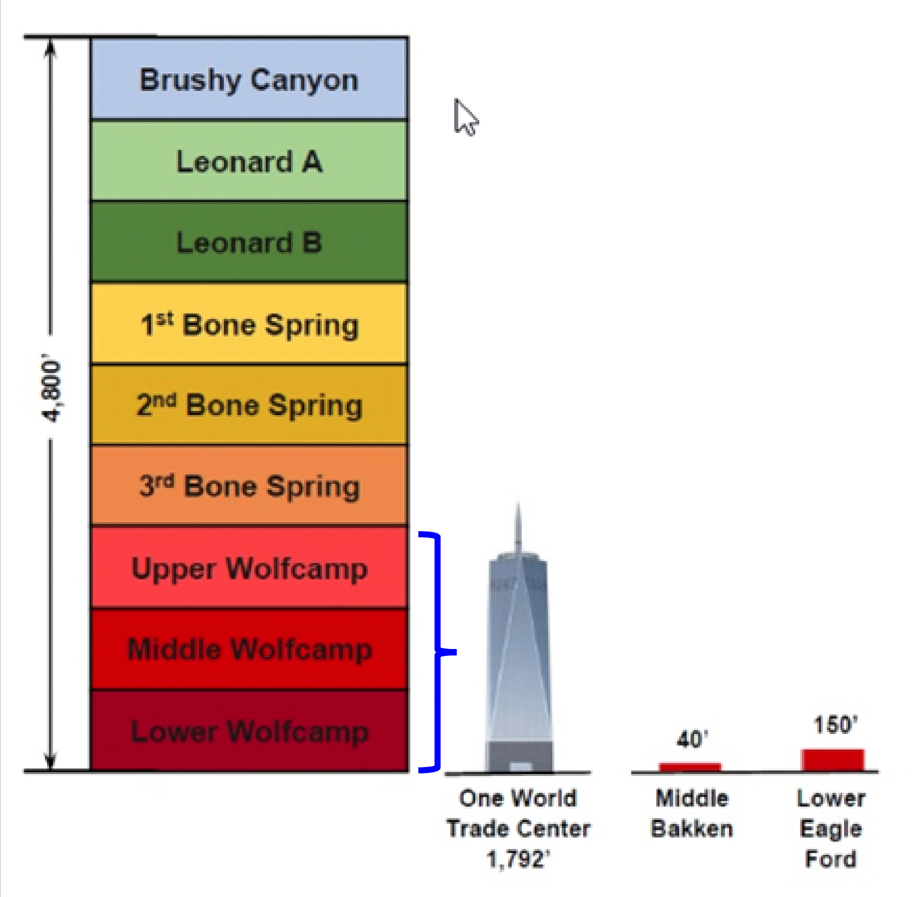
Jarvie, 2017

Peak fitting allows accurate prediction of GOR values from rock samples:

- C1-C5 yields
- C7+ yields

A Key to the Permian System Compared to other Plays: THICK HYBRID SYSTEM

Wolfcamp is often >1000 ft



Ref: EOG Resources May 2017

Synopsis

- The "Big 3" tight oil plays account for ca. 50% of total oil production in the United States
- Bakken Tight Oil System is a true hybrid system with organic-rich source rocks expelling oil into juxtaposed organic-lean tight rocks
- Eagle Ford Shale tight oil system is a carbonate-marly marine shale (mudstone) system with variable quality across the Gulf Coast basin and oil crossover often observable in archived cuttings or core; evaporative losses can be restored by GC
- The Wolfcamp Shale is a thick (~1000 ft) system with the Delaware basin having higher maturity than the Midland basin and with 360 and 469 boe/af total petroleum generation potential, respectively.
- Evaporative losses can be restored from GC data in both clean and contaminated oils and solvent extracts
- S1-petroleum may be fully restored from measured S2, difference in S2 of whole rock from extracted rock, and by GC restoration of evaporative losses
- GOR may be computed from restored GC data

Thank you !

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