Unconventional Oil Petroleum Systems: Shales and Shale Hybrids*

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Abstract

With a premium on energy resources as well as oil versus gas prices, it makes political and economic sense for further work to be undertaken to enhance the development of difficult resources such as those categorized as unconventional. Shale oil and shale oil hybrids are one such resource that already have had an impact on energy resources in North America.

Shale oil plays vary considerably from tight mudstones to shales with interbedded conventional reservoir lithofacies. Three basic play types are known that include fractured shale plays, such as the Monterey Shale in coastal California, tight mudstones such as the Mississippian Barnett Shale of the Fort Worth Basin, and the shale hybrid play, the Upper Devonian-Lower Mississippian Bakken Formation. Each system is comprised of a marine shale source rock with differences being in permeability and nearby associated lithofacies consisting of carbonates, sands, or silts.

Differences in shale permeability and lithofacies play key roles in ultimate producibility from these systems. Highly fractured areas of the Monterey Shale produce prodigious volumes of even low gravity crude oil. Hybrid systems flow large volumes of oil from conventional lithofacies due to increased storage capacity and certainly due to lower adsorption affinities in these rock types. While focus in shale gas has been on brittleness with high quartz contents, in shales in the oil window, high quartz content is associated with organic matter that has strong adsorption affinities for crude oil. On the other hand interbedded lithofacies often carbonates, but also sand or silt beds have little or no association with organic matter and adsorption does not restrict and ultimately occlude flow rates. In addition these lithofacies often have increased storage capacities due to increased matrix porosities, in carbonates thought to be derived from organic acids from kerogen that partially dissolve carbonates creating secondary porosity.

There are a variety of examples of shale oil systems including those listed above as well as with the following source rocks from various parts of the world: for example, Miocene Antelope Shale (California), Cretaceous Niobrara Shale (Colorado), Jurassic Kimmeridge Shale (U.K.), and Bazhenov Shale (Siberia). A comparison of all these plays provides insights into future shale oil resource plays.

Selected References

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Dan Jarvie

Worldwide Geochemistry

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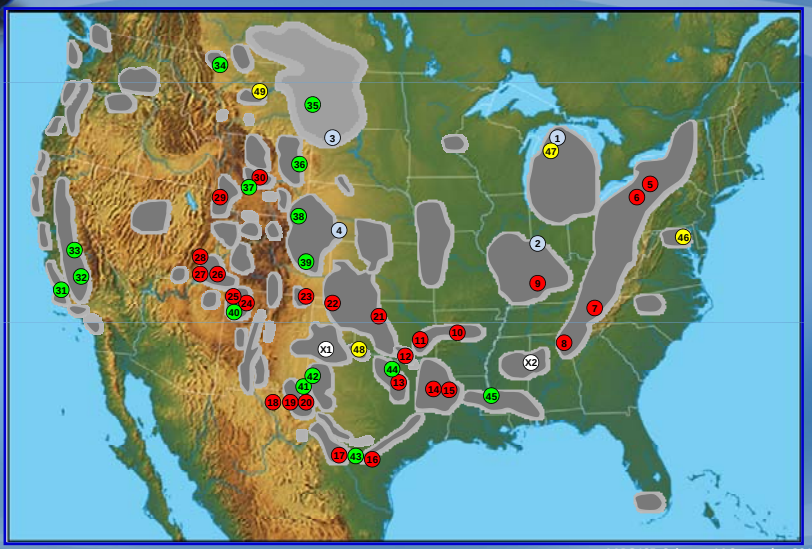
University of Oklahoma

Outline

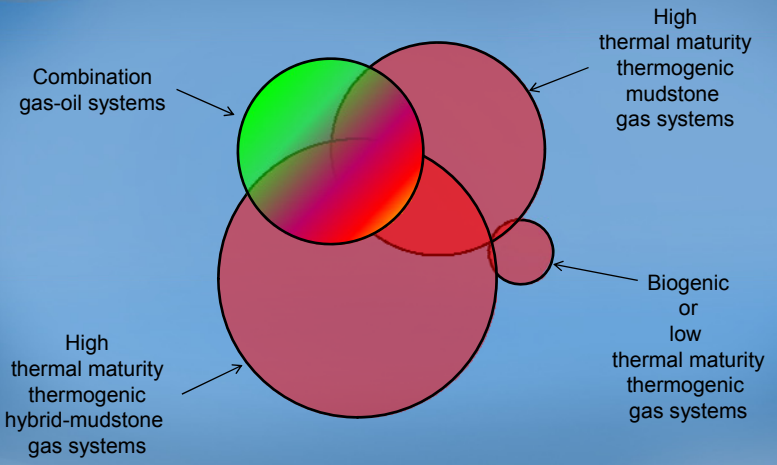
- Overview of North American Shale Resource Plays
- Background for evaluation of oil resource systems
- Geochemical logging of various oil resource systems:
  - Monterey
  - Antelope
  - Bakken
  - Niobrara
  - Eagle Ford
- Worldwide overview
- Summary

US Shale-Gas and Oil Resource Systems

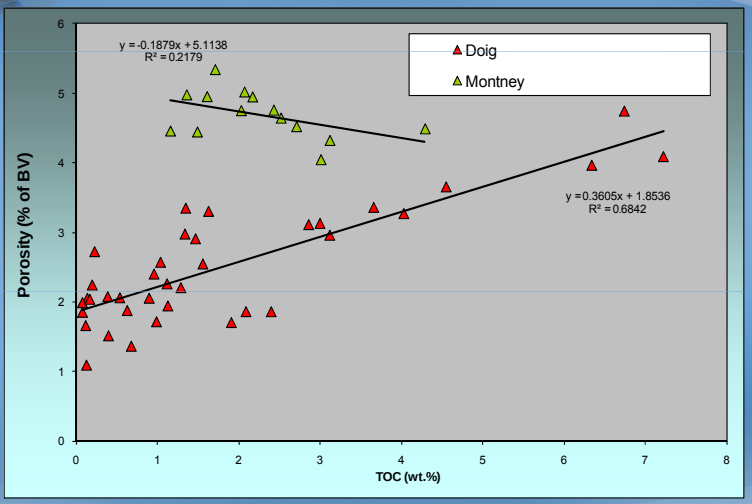


Canadian Shale Resource Plays and Prospects

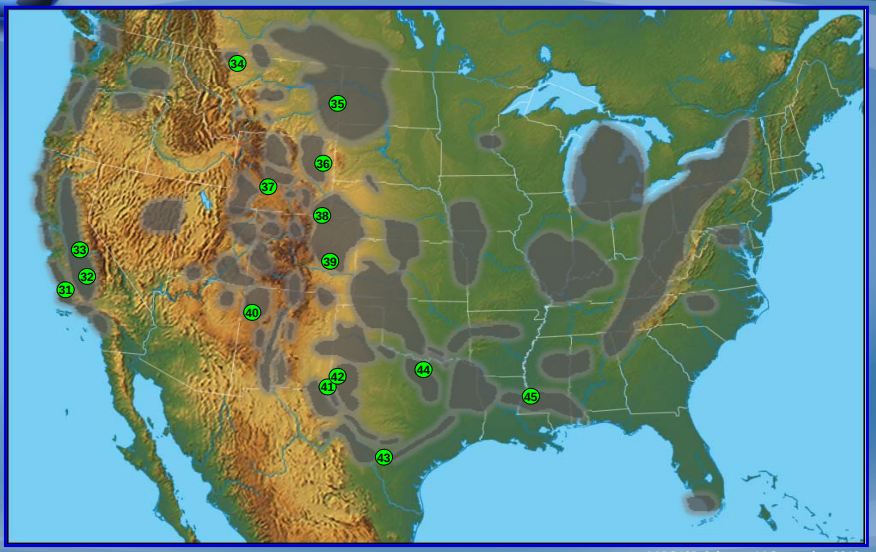
US Shale-Gas Resource Systems



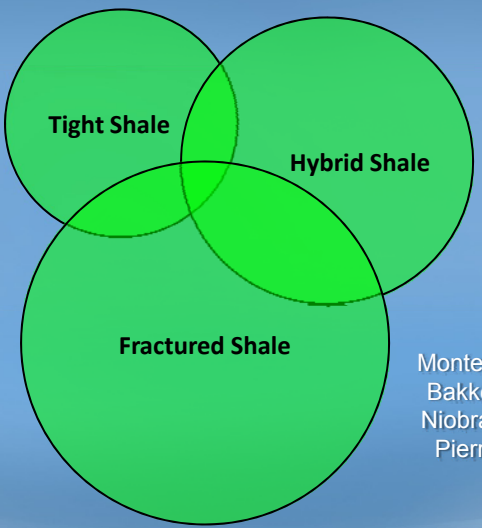
Organic Porosity vs Matrix and Fracture Porosity



U.S. Oil Resource Plays



Shale System Overlap and Production Potential



Barnett Shale
Tuscaloosa Shale

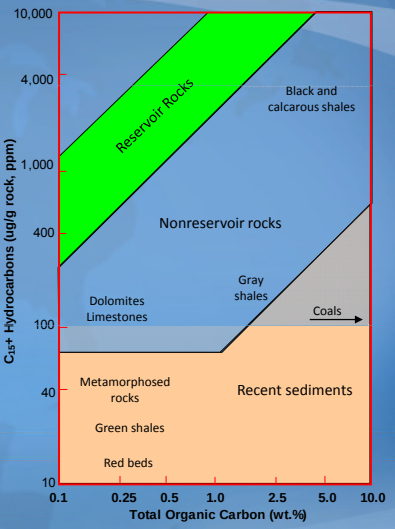
Bakken Formation
Niobrara Shale
Eagle Ford Shale

Monterey Shale
Bakken Shale
Niobrara Shale
Pierre Shale

Depiction of Rock Type based on extract and TOC contents

Solvent extraction of rock samples provides the amount of "free" oil.

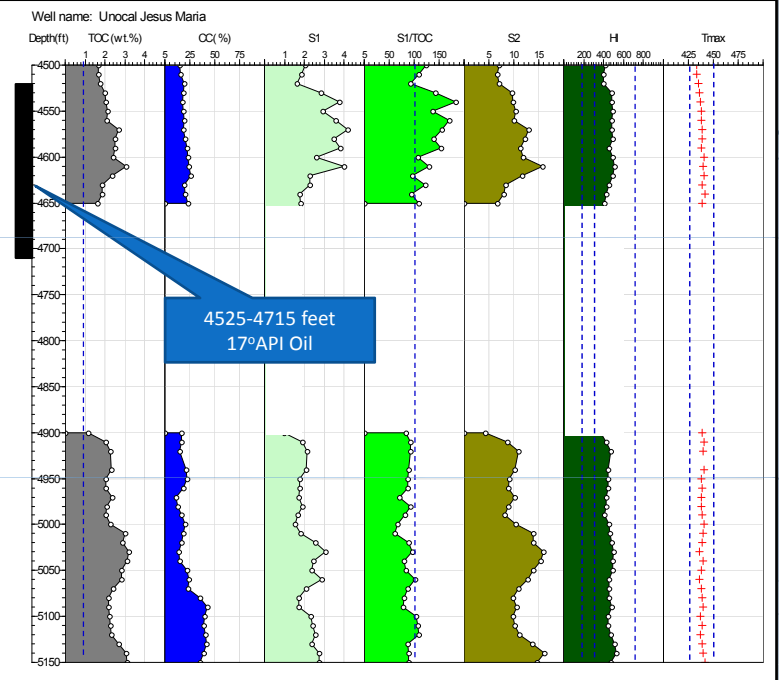
When compared to the TOC content, the rock type can often be inferred.



Baker, 1962; Hunt, 1995

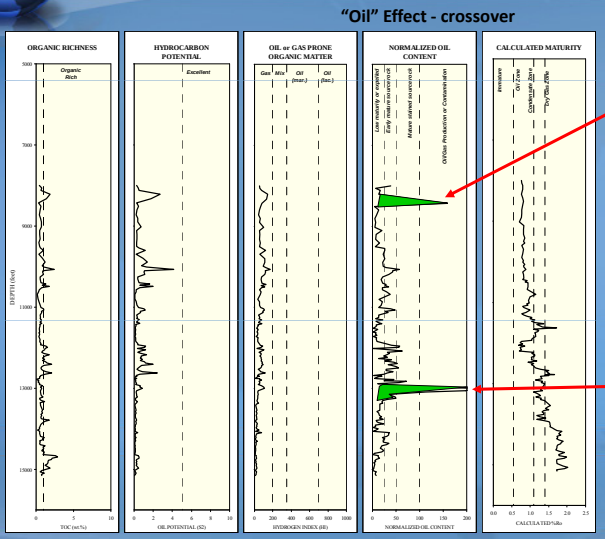
Unocal Jesus Maria A82-19

Santa Maria Basin



Geochemical Log: Cruson 1 Anadarko Basin

TOC, Free Oil, Hydrogen Index, Normalized Oil Content, and Thermal Maturity

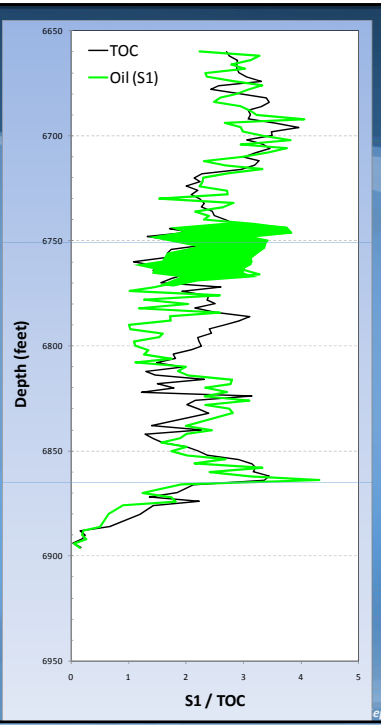


Jarvie and Baker, 1984

"Oil Effect": Oil Crossover

- a simple measure derived from basic geochemical analyses of cuttings (well site or laboratory) whereby high oil saturation can be predicted
- result is 100% effective at locating oil reservoirs:
  - Low resistivity sands
  - By passed pay
  - Shale oil

Niobrara Oil Resource Well Showing Crossover



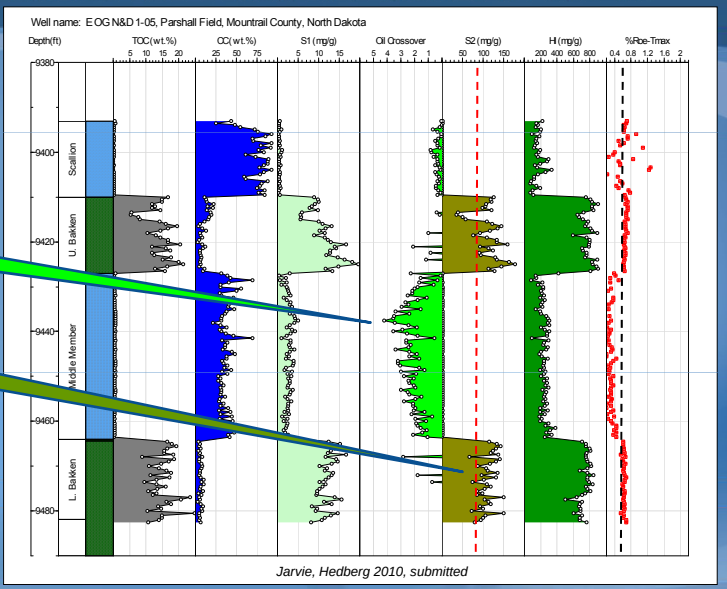
Geochemical Oil Crossover Effect

Indicative of two similar but different states:

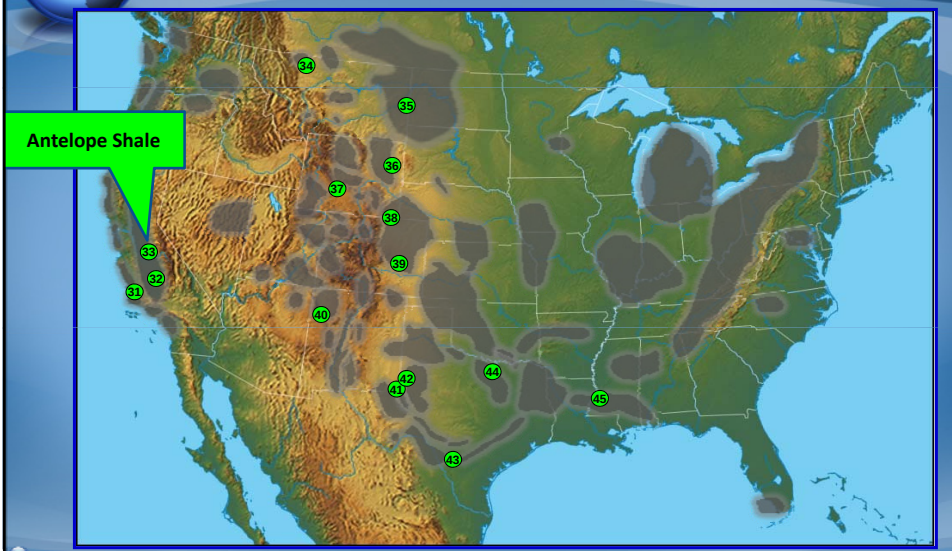
- **Saturation**
  - An organic-rich source rock will have crossover when:
    - Near maximum storage capacity
    - Actively expelling hydrocarbons
  - An organic-lean rock will have crossover when:
    - Saturated with migrated oil
    - Can be very high OIP with good EUR
- **Adsorption**
  - Organic-rich rocks will retain upwards of 50-80 mg HC/g TOC
  - This oil will be high OIP, low EUR

Jarvie, 2010

Bakken Formation:
Saturation and Adsorption Indices (SI and AI)



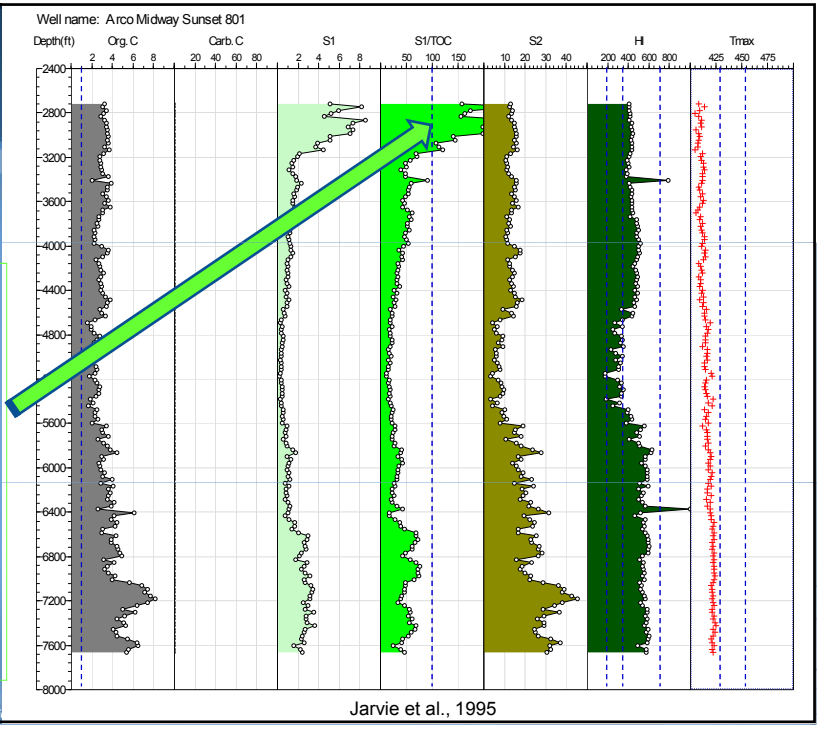
U.S. Oil Resource Systems:
Miocene Antelope Shale, San Joaquin Basin



Antelope Shale, San Joaquin Basin, California

not an objective for reservoir

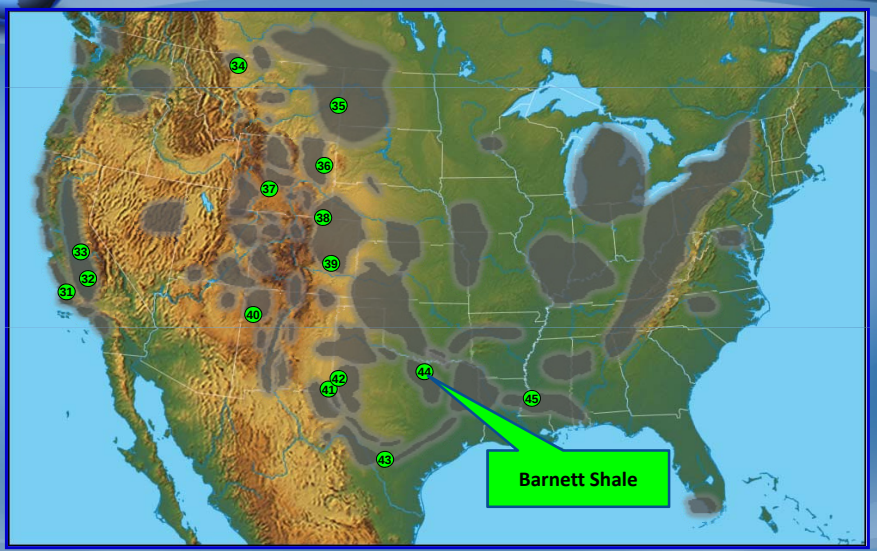
IP=245 bo/d ca. 4000 ft. shallower than original objective

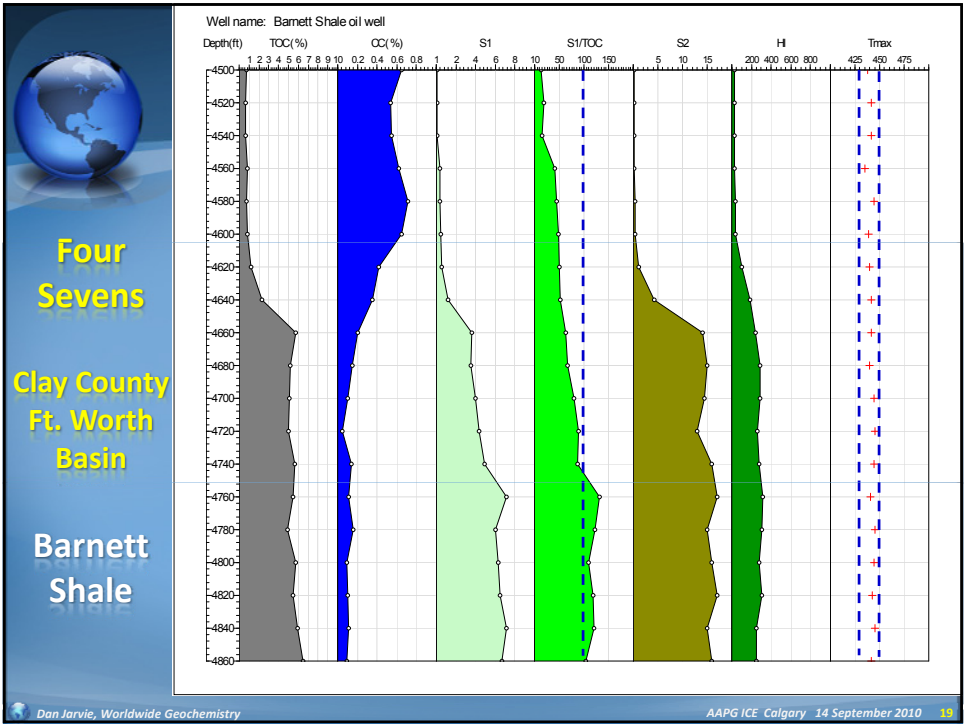


Jarvie et al., 1995

U.S. Oil Resource Systems:

Mississippian Barnet Shale, Fort Worth Basin




Four Sevens
Clay County Ft. Worth Basin
Barnett Shale
Well name: Barnett Shale oil well
Depth(ft)
TOC(%)
CC(%)
S1
S1/TOC
S2
HI
Tmax
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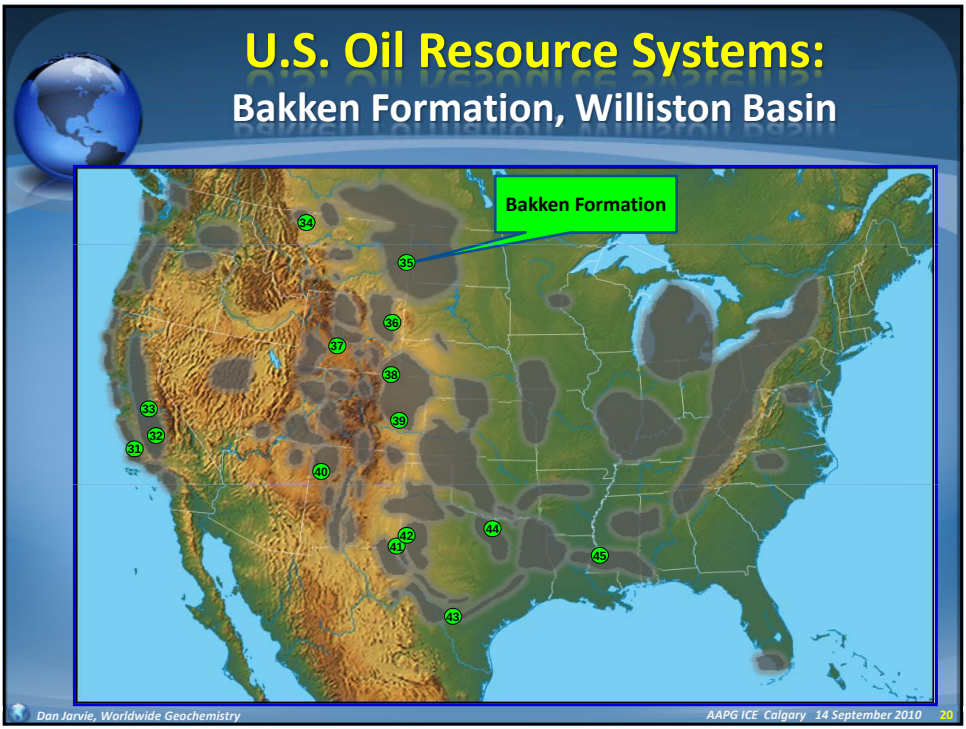
19


U.S. Oil Resource Systems:
Bakken Formation, Williston Basin
Bakken Formation
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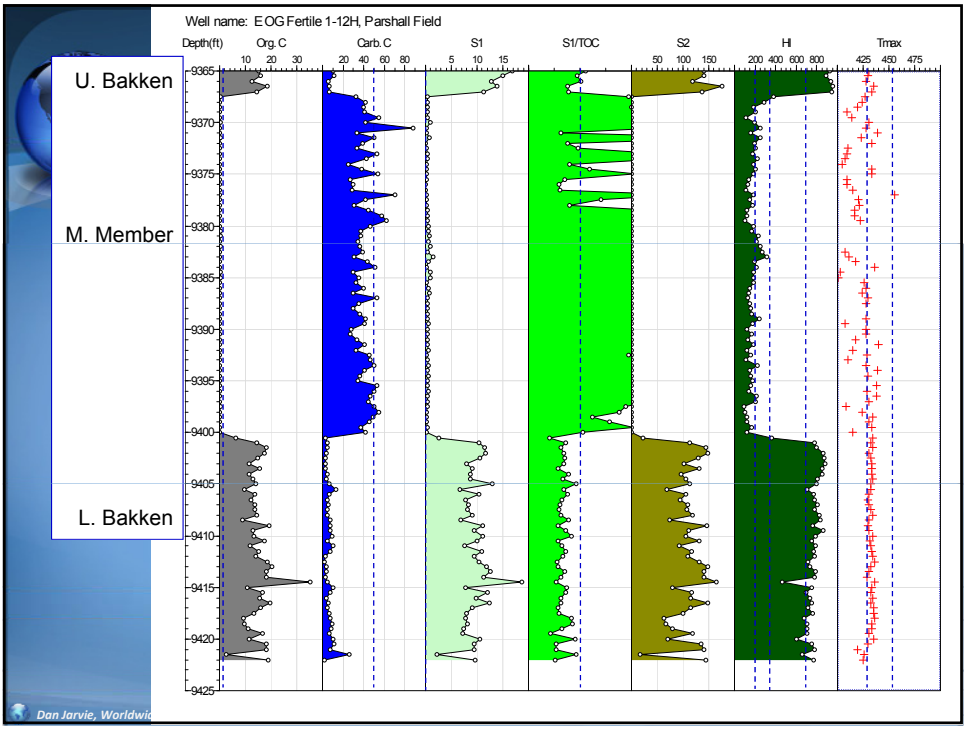
Well name: EOG Fertile 1-12H, Parshall Field
Depth(ft)
Org. C
Carb. C
S1
S1/TOC
S2
HI
Tmax
U. Bakken
M. Member
L. Bakken
9365
9370
9375
9380
9385
9390
9395
9400
9405
9410
9415
9420
9425
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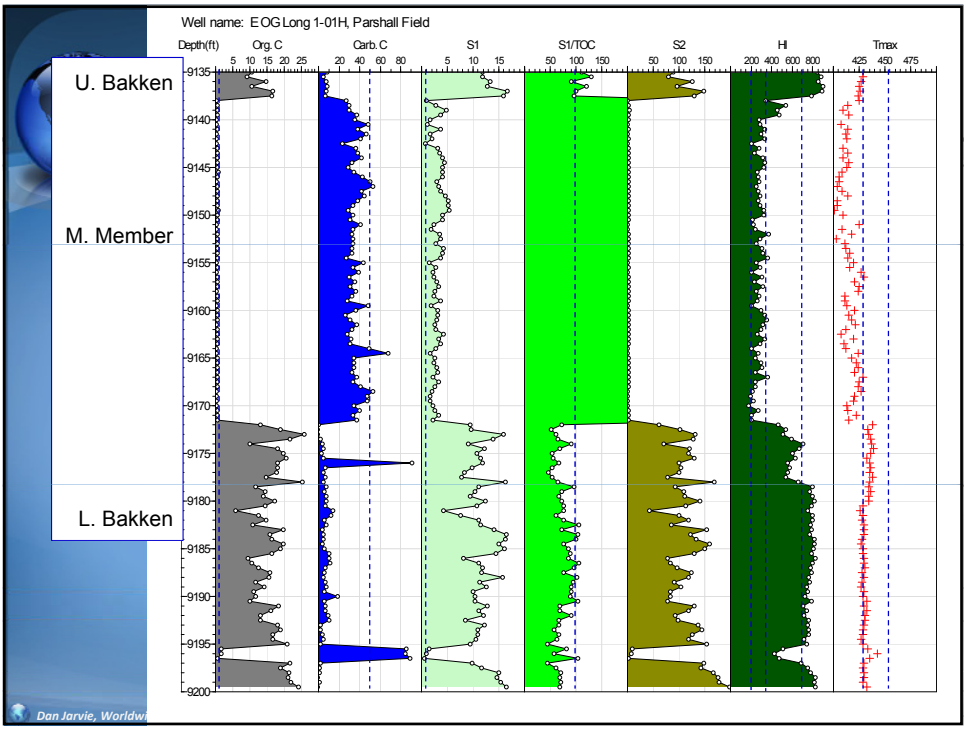
Well name: EOG Long 1-01H, Parshall Field
Depth(ft)
Org. C
Carb. C
S1
S1/TOC
S2
HI
Tmax
U. Bakken
M. Member
L. Bakken
9135
9140
9145
9150
9155
9160
9165
9170
9175
9180
9185
9190
9195
9200
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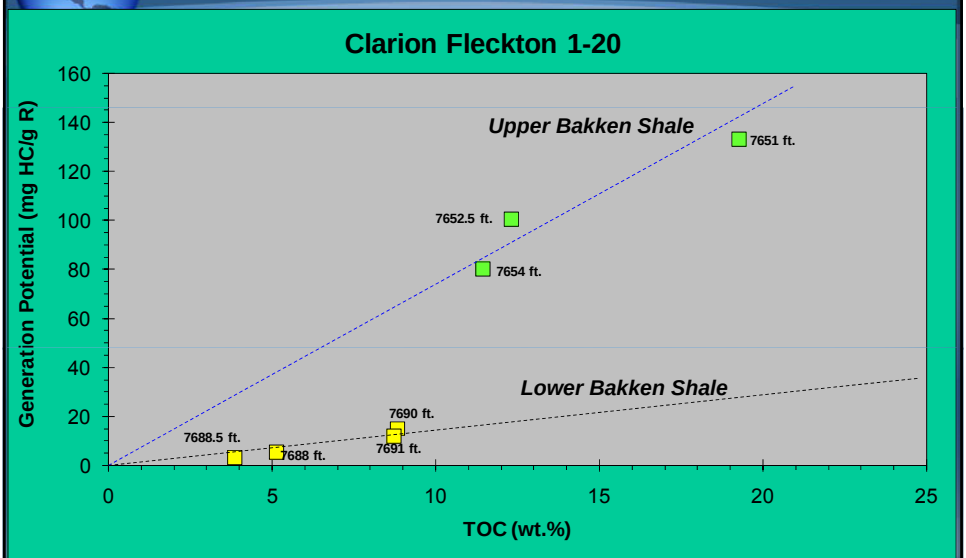
Bakken Shale EUR 5 billion bbls oil
So what is the key??

The "better Oreo cookie" model

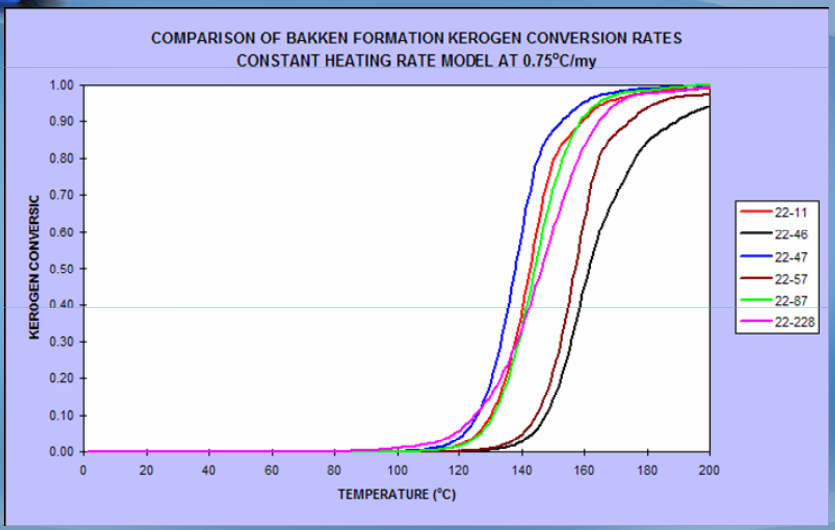
Carbonate
Shale
Carbonate
Shale
Carbonate

(in some areas, carbonate replaced by silty sand

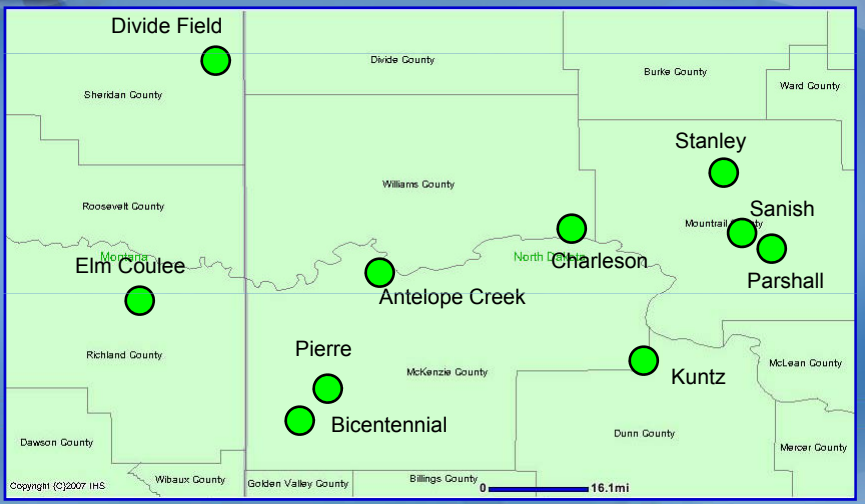
Organofacies Variation in Upper and Lower Bakken Shale: Fleckton 1-20



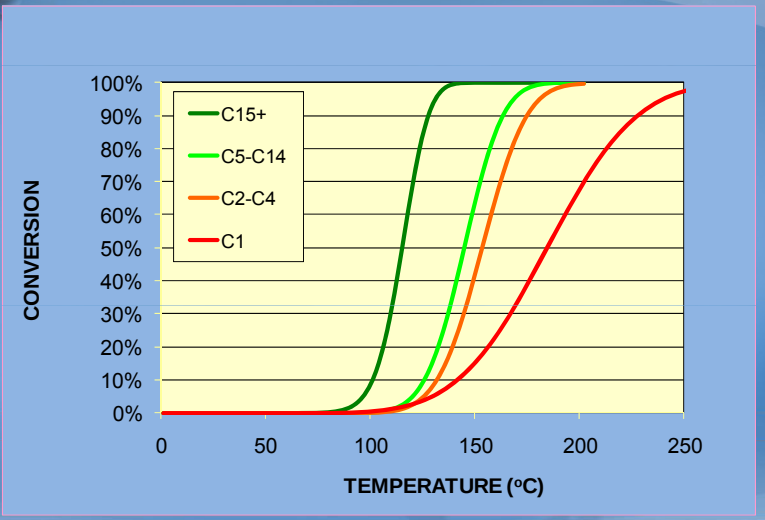
Variation in Bakken Shale Kerogen Conversion:



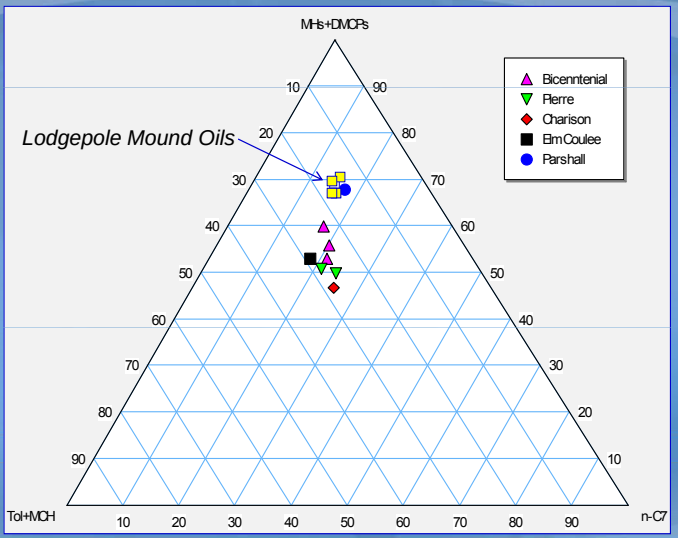
Select Oil Samples: Williston Basin



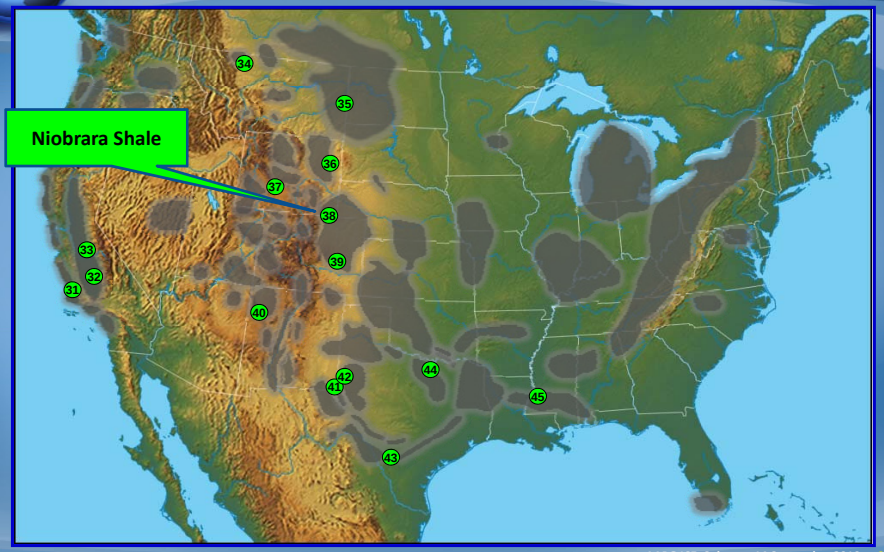
Rates of Kerogen Conversion by hydrocarbon fraction



Comparison of Bakken Oils: Using C_7 hydrocarbons

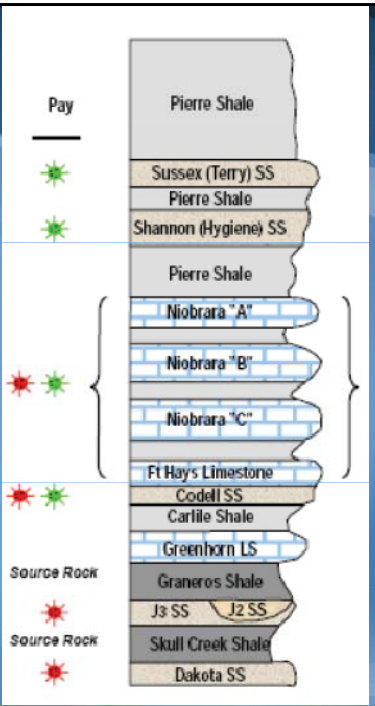


U.S. Oil Resource Systems:
Cretaceous Niobrara Shale, D-J Basin

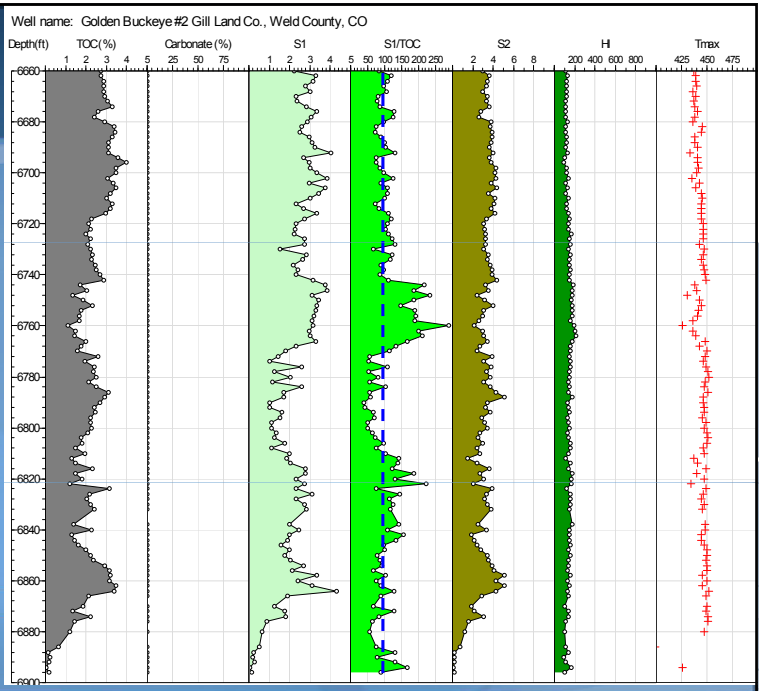


Niobrara Shale with closely associated carbonates

Ref: Encana, Wells Fargo

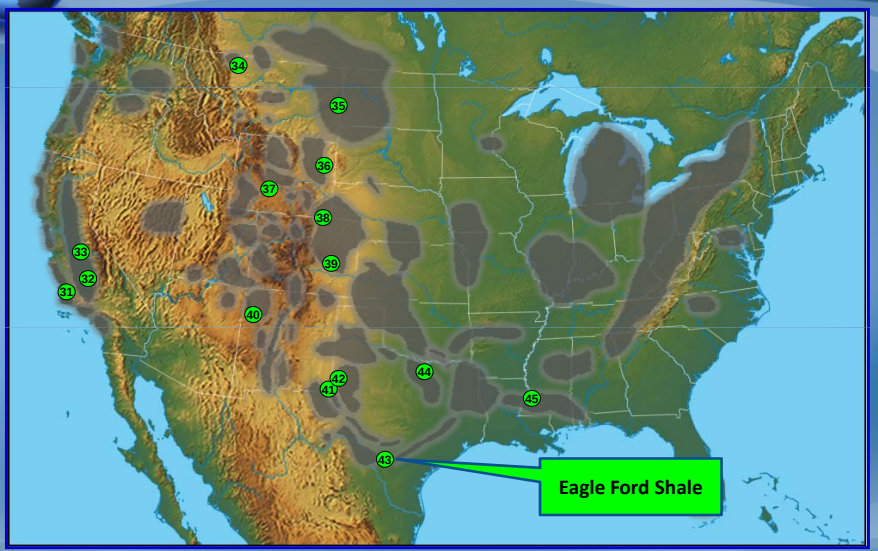


Niobrara Shale, Denver Basin



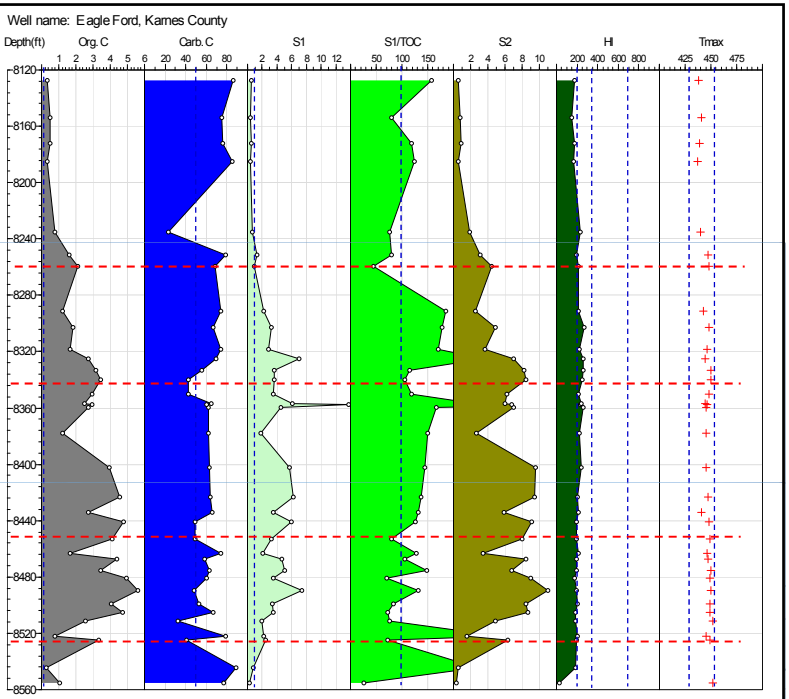
U.S. Oil Resource Systems:

Cretaceous Eagle Ford Shale, Austin Chalk Trend



Eagle Ford Shale

S. Texas
Austin Chalk Trend



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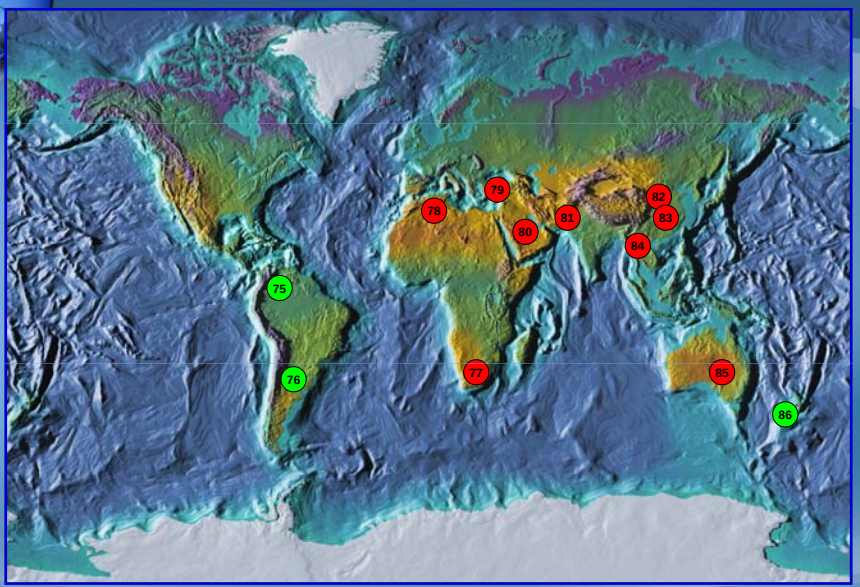
Worldwide Shale Resource Activity



Summary

- Oil window thermal maturity is important, but high oil saturation is the defining factor for productive shale-oil
- Adsorption affinity must be assessed in organic-rich productivity zones
- High quartz content may play a secondary role in shale-oil potential due to close association with highly adsorptive organic matter
- There appears to be a positive relationship between shale-oil productivity and closely associated carbonate lithofacies

Celebration of the life of a friend on a new journey

Cindy Riediger

Acknowledgements

- Don Baker and Wallace Dow (mentors)
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