Challenges to Black Oil Production from Shales*

Harry Dembicki[1]

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[1]Anadarko Petroleum Corp., Houston, TX (harry.dembicki@anadarko.com)

Abstract

Our understanding of unconventional play types, such as shale gas and shale oil, is still evolving. While scientific and engineering investigations into conventional petroleum exploration and development have been conducted for over 100 years, the study of the concepts and methods for unconventional petroleum has been pursued in earnest for only about 15 years. And most of this effort has been directed toward understanding shale gas systems.

As economic drivers, such as commodity prices, make liquids-rich plays more desirable, extra efforts are being made attempting to extract black oil from shales with limited success. This does not include the so called hybrid systems or source rock/reservoir sandwiches, such as the Bakken and Niobrara plays, where horizontal drilling allows us to exploit formerly poor reservoir rocks that are in direct contact with source rocks. Instead, the focus here is on getting black oil directly out of a shale.

Can we get black oil to flow from a shale in the oil window at commercial rates? To answer this question, we must examine whether black oil can escape from shales, under what conditions this might occur, and whether commercial flow rates are possible/probable. To address these issues, we will need to review what is meant by black oil, the oil window, and the essential elements of oil production to see how these apply to shales and examine what are the main obstacles to potential success. And finally, the conditions for the best chance for liquids production in shale plays will be discussed.

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Challenges to Black Oil Production From Shales

"The greatest enemy of knowledge is not ignorance, it is the illusion of knowledge."
Stephen Hawking

Harry Dembicki, Jr.
Distinguished Geological Advisor – Geochemistry
Anadarko Petroleum Corporation

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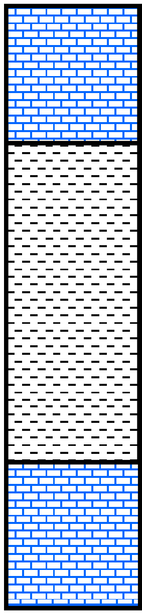
Gas Shale: A Source Rock/Reservoir Petroleum System



Gas Shale

Seal **– competent rock to act as fracture barriers during stimulation**
Source Rock **– an organic-rich shale in the gas window** ***Reservoir*** **– a shale with some porosity and permeability that can be fractured to recover the gas** ***Trap*** **– essentially a stratigraphic trap** ***Seal*** **– minimal open natural fractures to leak off gas**
Seal **– competent rock to act as fracture barriers during stimulation**

Source Rock Properties:

Sufficient organic richness
Proper kerogen type
High enough thermal maturity
Adequate thickness/volume

Reservoir Properties:

Porosity/Permeability
Rock Matrix

- Mineralogy
- Depositional Fabric
- Origin of grains - Biogenic vs. Detrital
- Fluid sensitivity/compatibility

Why Does Shale Gas Work?

Despite the inherently low permeabilities in shales, hydrocarbon gas can flow at commercial rates if…

… adequate pressure is present,

… the hydrocarbons stay in a single gas phase, and

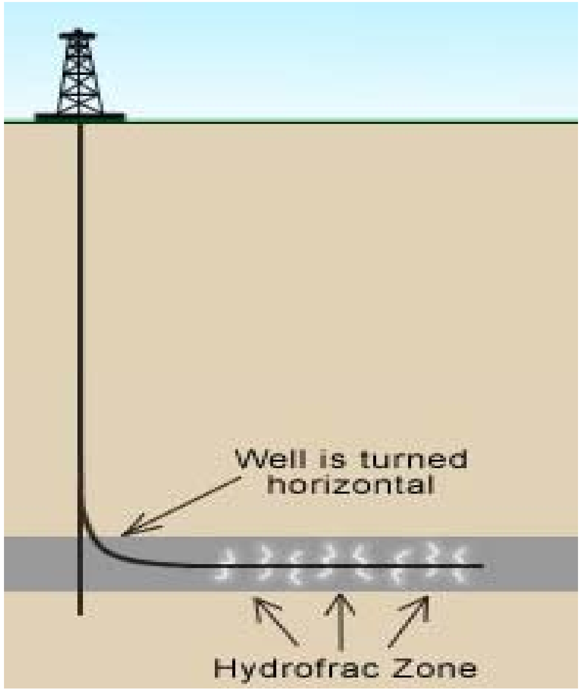
… we can increase the surface area over which the natural permeability can deliver the gas.

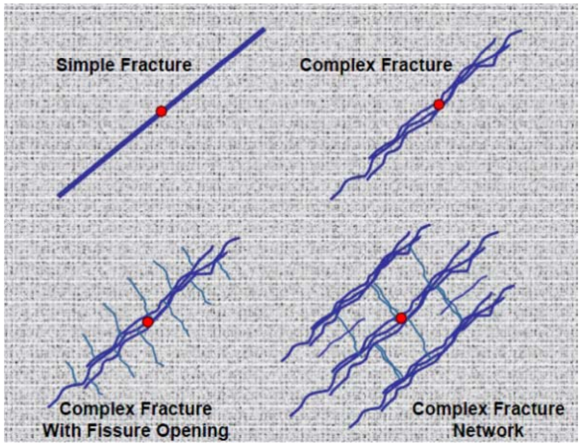
Gas Shale Production

- Gas shales have inherently low natural permeabilities which results in low recovery efficiencies.
- To increase the permeability of a shale and improve recovery, horizontal wells and hydraulic fracturing are required.
- Hydraulic fracturing pumps water, sand and additives at extremely high pressures out through perforated sections of the wellbore to fracture the surrounding formation and inject sand, or other proppants, into the cracks to hold them open.
- This fracturing does not significantly increase the permeability by connecting pores in the rock.
- Permeability is increased by…

  …opening migration pathways out into the rock away from the borehole, and

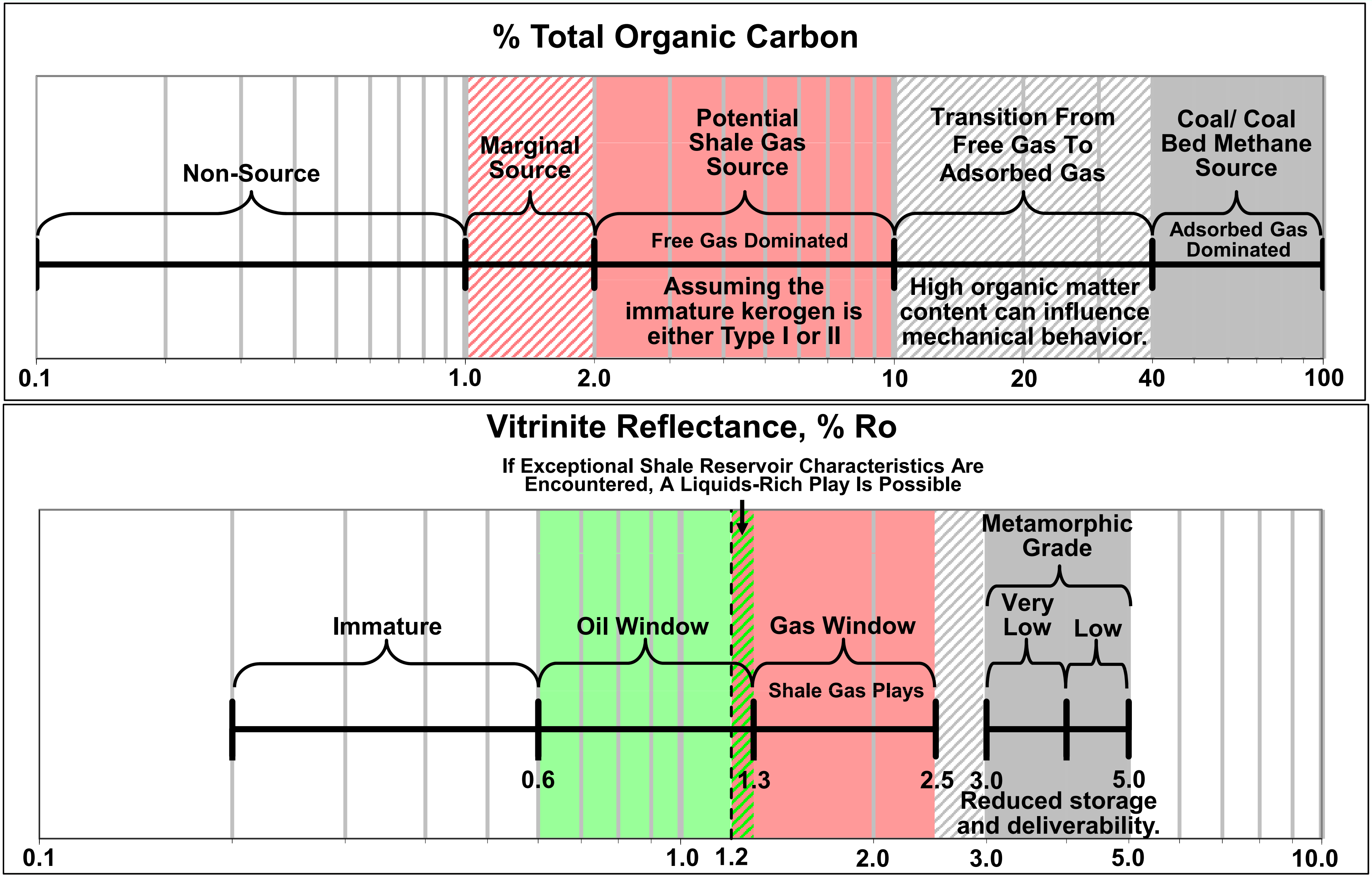
  …increasing surface area exposure of the matrix permeability for more efficient drainage.





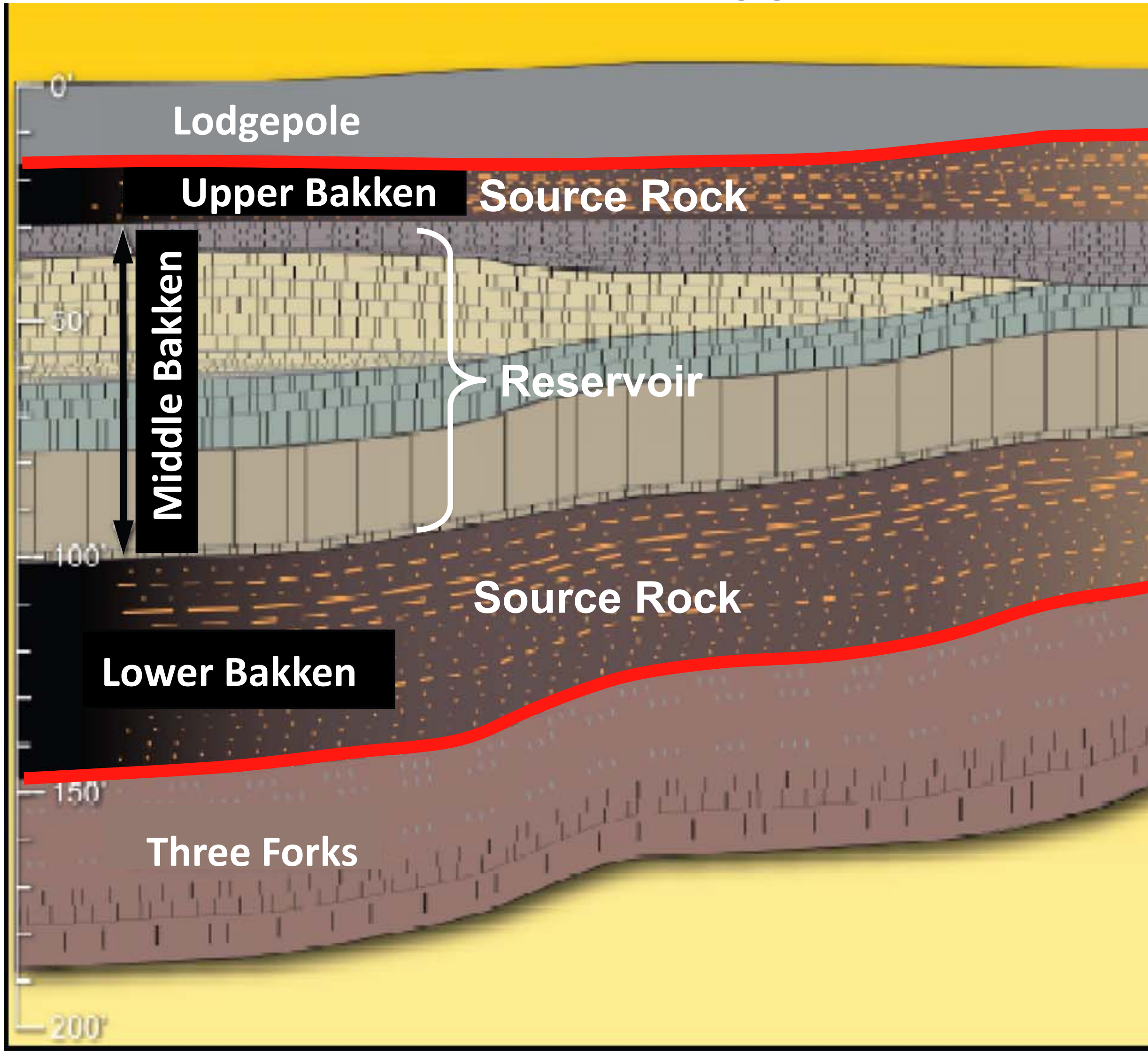
(Warpinski et al., 2008)

Shale Gas – Windows Of Opportunity



Tight Oil – "Source Rock/Reservoir Sandwiches"

Bakken Formation, Upper Devonian, Williston Basin



The Upper and Lower Bakken shale members are the source facies while the Middle Bakken member composed of fine-grained sandstones, coarse-grained siltstones, and porous carbonates is the reservoir facies.

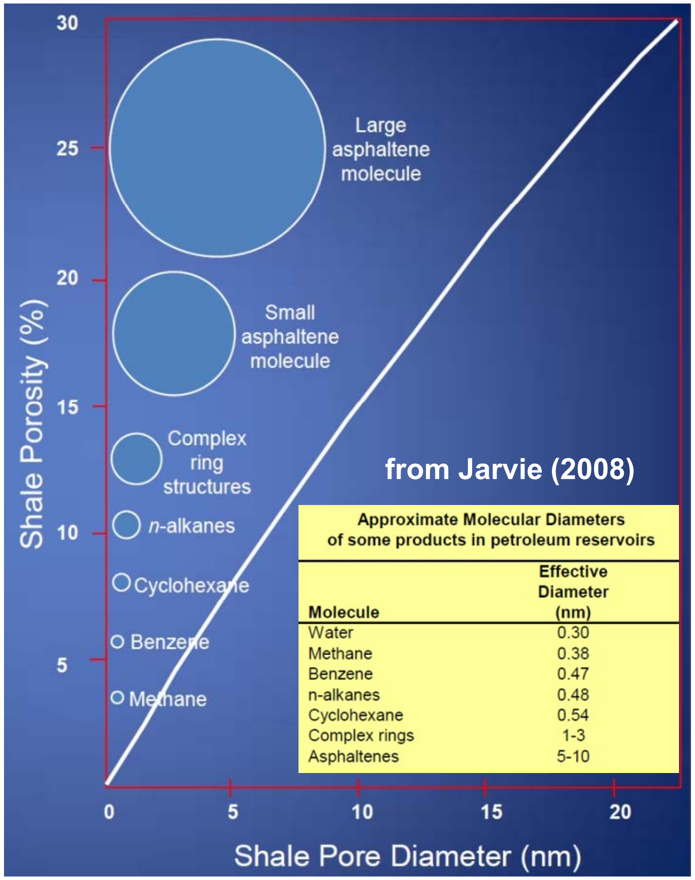
Except where naturally fractured, the permeability in the Middle Bakken is too low for economic production.

Horizontal drilling and well stimulation allows exploitation of the resource.

Similar "source rock/reservoir sandwiches" occur in the Niobrara and Monterey formations.

Oil From Shales? – Some Of The Concepts

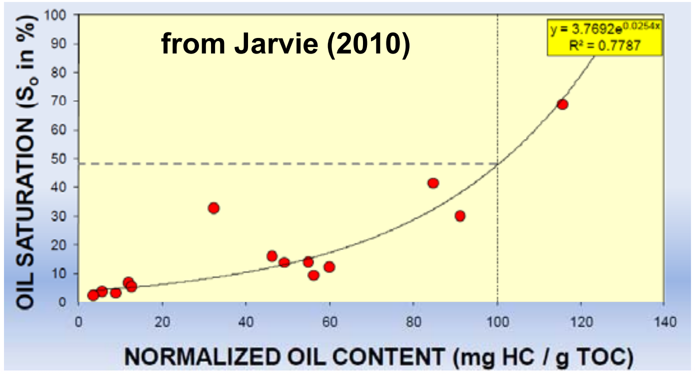
- **Molecular Size**
  - ***The effective diameters of liquid petroleum molecules are much smaller than the average pore throat in shales.***
  - ***Therefore, liquid petroleum should have no problem freely traveling through the pore network.***
  - **True, if the liquid petroleum molecules are in the gas phase, but in the liquid phase the properties of the liquid (viscosity, interactions with the mineral phases and pore water, etc.) make flow through the pore network much more difficult.**



Approximate Molecular Diameters of some products in petroleum reservoirs

Molecule	Effective Diameter (nm)
Water	0.30
Methane	0.38
Benzene	0.47
n-alkanes	0.48
Cyclohexane	0.54
Complex rings	1-3
Asphaltenes	5-10

- **Source Rock Saturation**
  - ***Once the hydrocarbon saturation in a source rock reaches 100 mg HC/g TOC, oil production from the shale is possible.***
  - **Saturation alone cannot indicate if oil can be produced from a shale.**



The Question

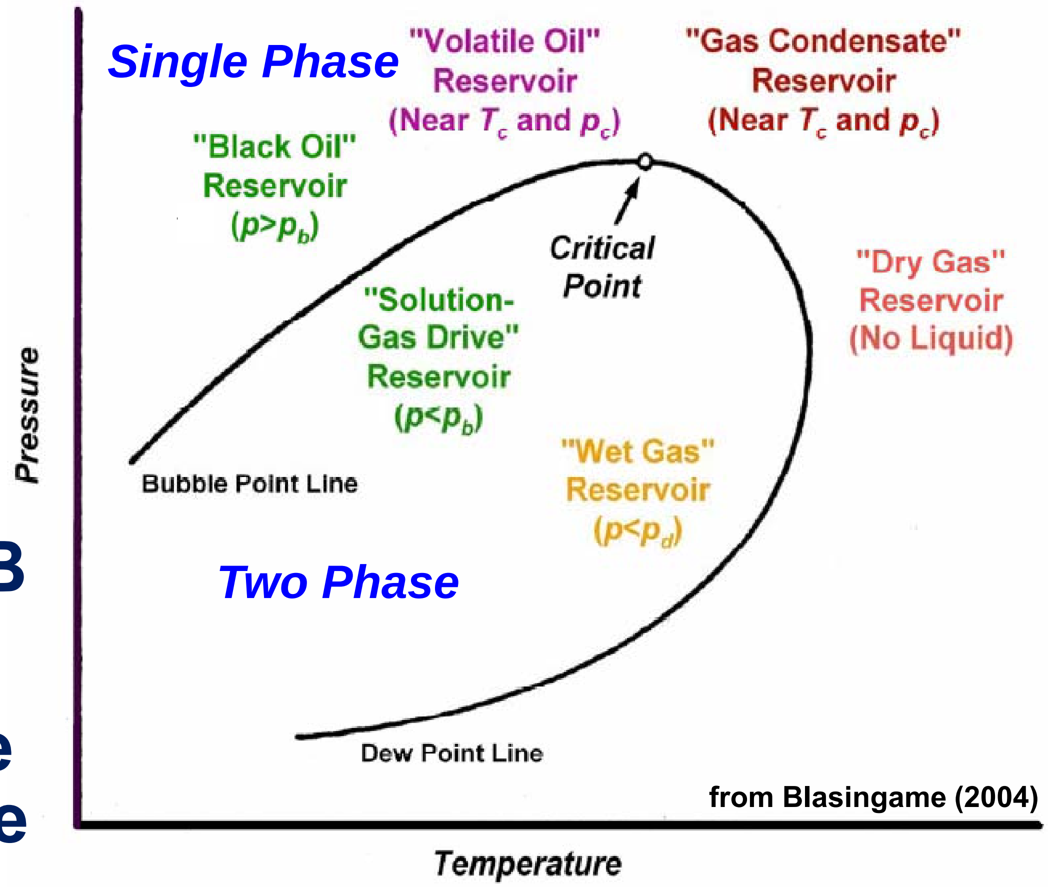
Can we get black oil to flow from a shale in the oil window at sustained commercial rates?

- *Can black oil escape from shales?*
- *Under what conditions does this occur?*
- *Are commercial flow rate possible/probable?*
- *What are the main obstacles to success?*

To answer these questions, we'll need to review what we mean by black oil, the oil window, and the essential elements of oil production to see how these apply to shales.

Black Oil

- Pressure > Bubble Point
  - *Single phase*
- API Gravity: 20° to 45°
  - *Depending on composition*
- Viscosity: 2 – 100 cp
- Initial GOR: < 2000 scf/STB (under saturated with gas)
- Relatively high percentage of long, heavy, non-volatile molecules.

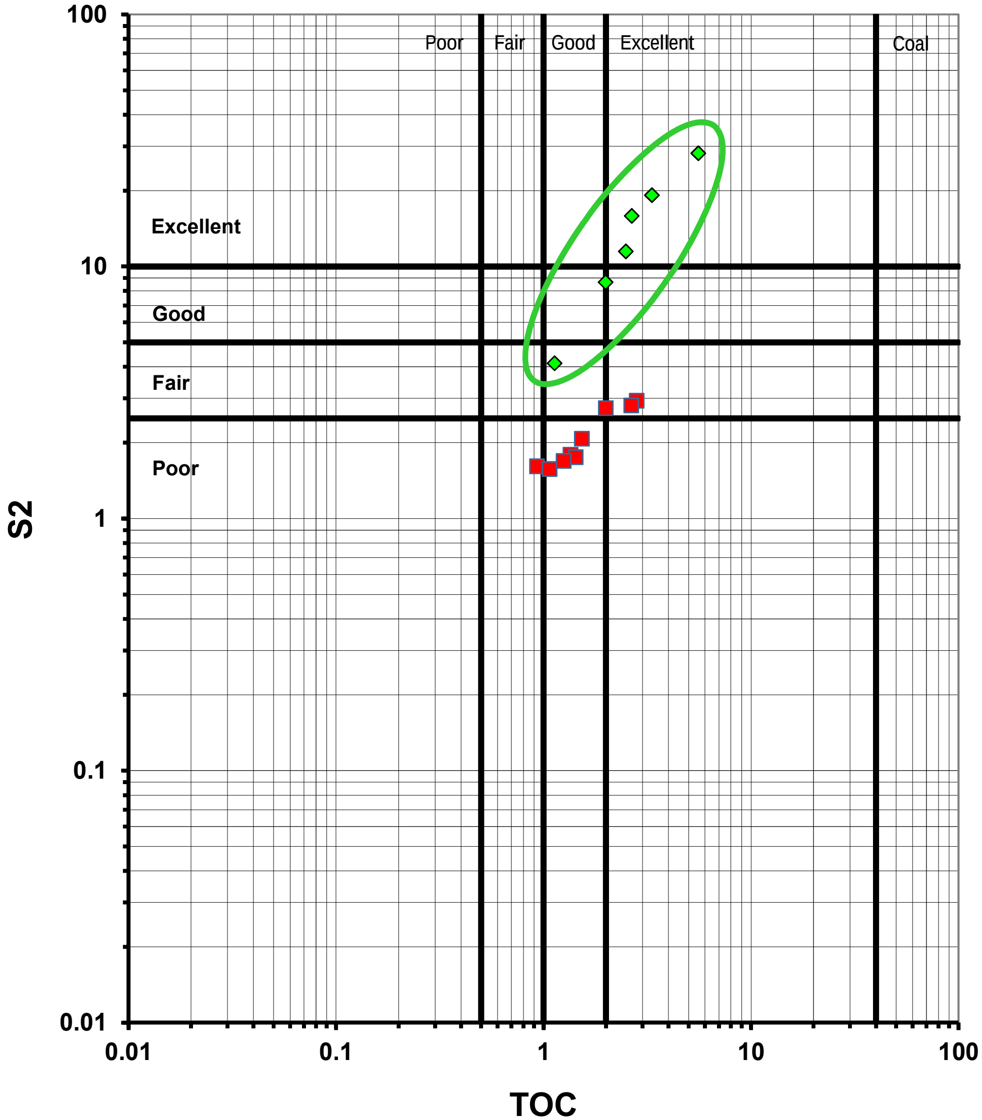


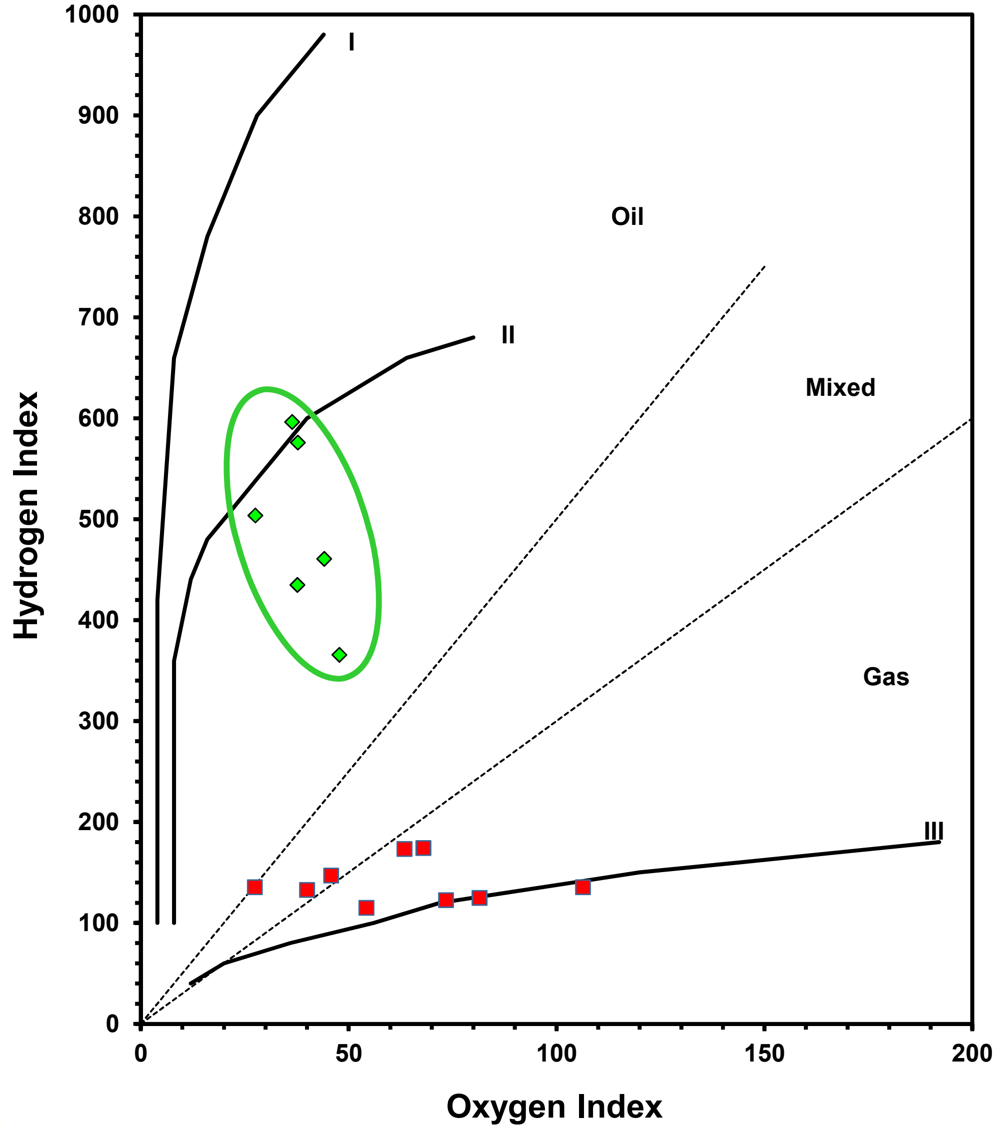
from Blasingame (2004)

Based on these properties, a Black Oil is the product of generation within the Oil Window.

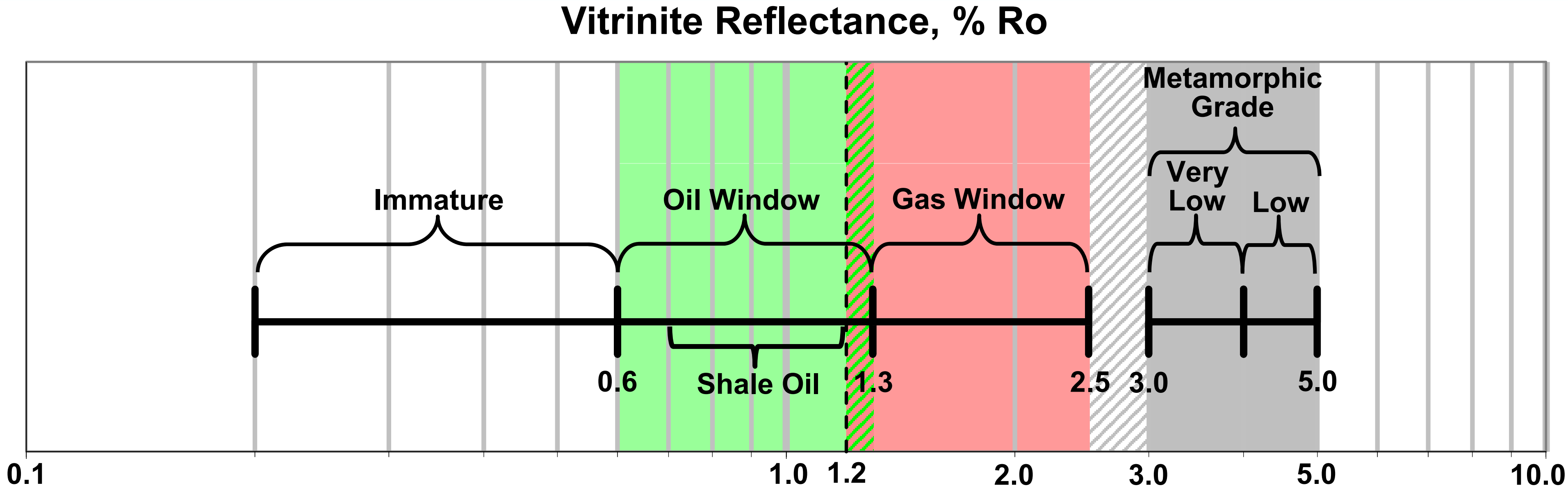
Shale Oil – Organic-Rich Oil-Prone Source Rock

Unlike a shale gas, a shale oil interval should be still recognizable as a good oil-prone source.





Shale Oil - Maturity



Black oil generation occurs from about 0.6 % Ro until about 1.1-1.2 % Ro.

Above about 1.1-1.2 % Ro, more gas is being generated making the product more like a volatile oil or gas condensate.

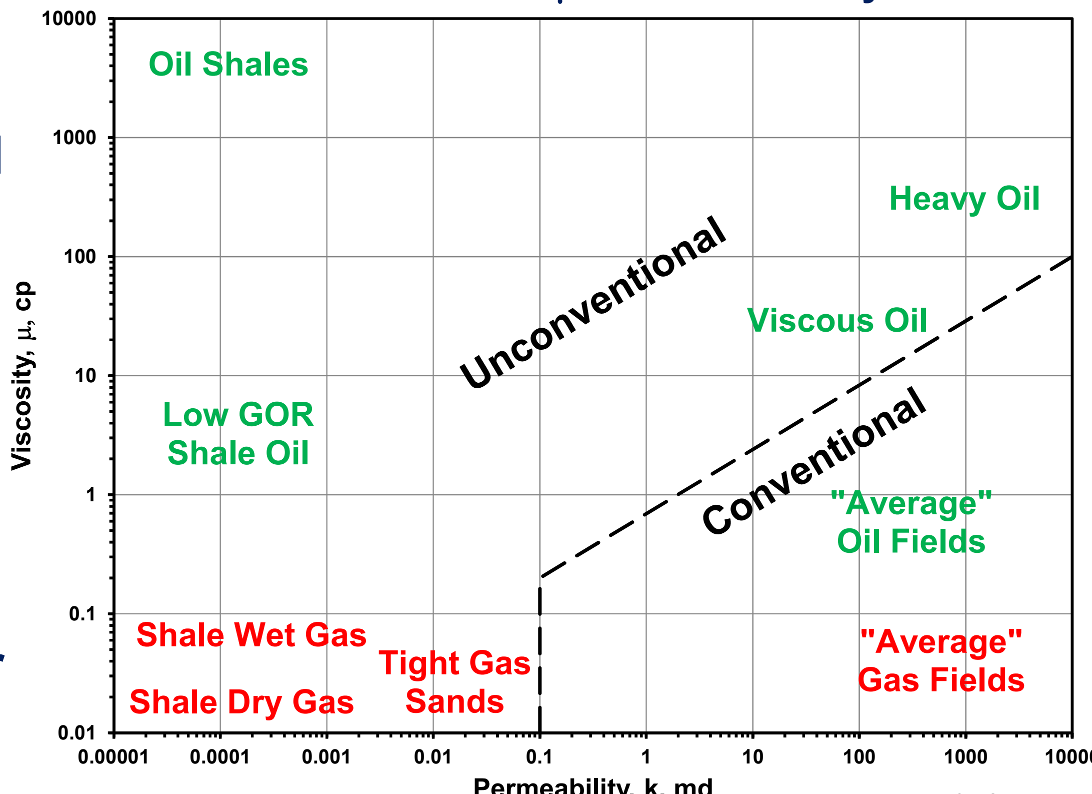
Depending on kerogen type and organic-richness, sufficient hydrocarbon saturation to allow expulsion is usually not reached until 0.7-0.9 % Ro.

Essentials Of Oil Production

- The amount of recoverable oil is determined by a number of factors including the
  - permeability of the rocks,
  - the viscosity of the oil, and
  - the strength of natural drives (the gas present, pressure from gas, adjacent water, or gravity).
- When the reservoir rocks are "tight“, such as shales, oil generally cannot flow easily in real time, but when they are more permeable, such as sandstone, oil can flow more freely.
- Flow of oil is often helped by natural pressures/forces within and surrounding the reservoir including natural gas that may be dissolved in the oil, natural gas present above the oil, and/or water below the oil (not realistic in shales), as well as gravity.
- Oils tends to span a large range of viscosities, with lower viscosity liquids tending to provide higher flow rates during production.

$$Q = \frac{k \times H \times \Delta P}{\mu}$$

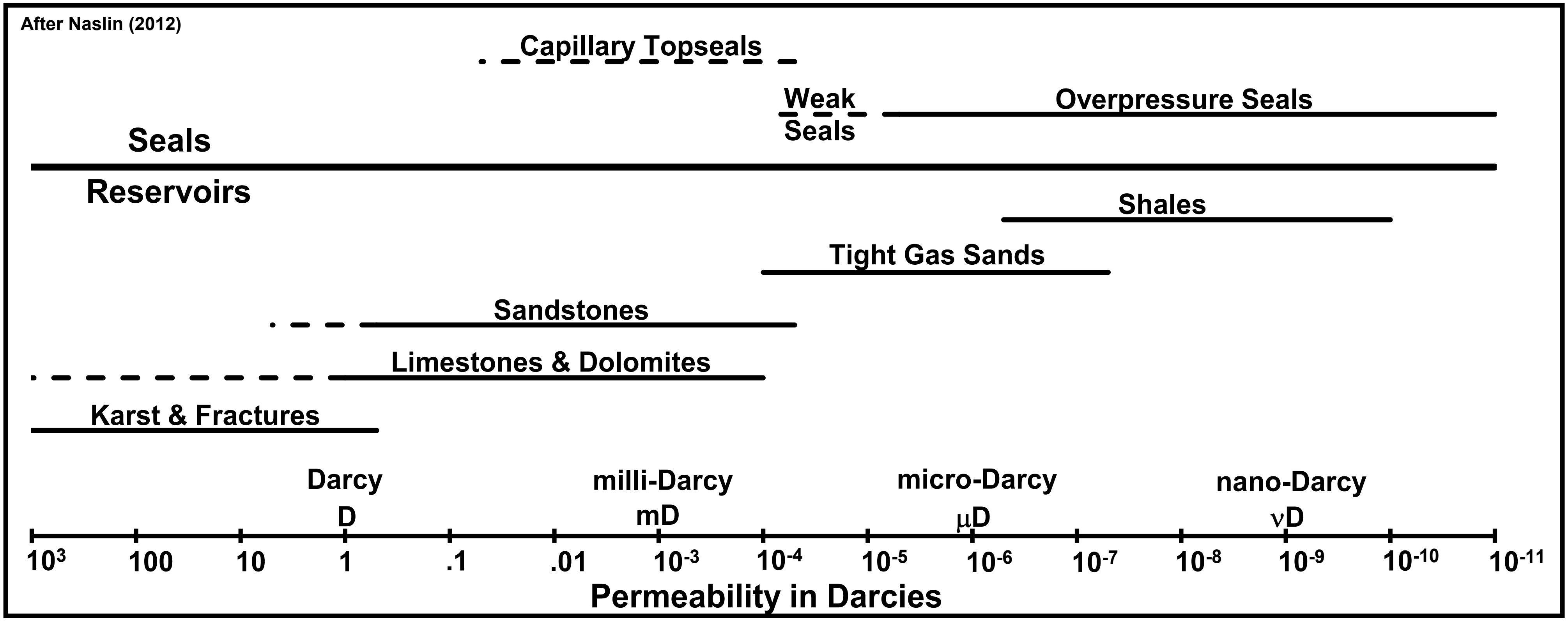
Q is the flow rate
k is the permeability
H is the thickness
ΔP is the pressure gradient
μ is the viscosity



(after Cander, 2012)

Conventional vs. Unconventional Permeability

1 Darcy = the passage of one cubic centimeter of fluid of 1 centipoise viscosity flowing in 1 second under a pressure of 1 atmosphere through a porous medium having a cross-section of 1 square centimeter and a length of 1 centimeter.



Shales are more similar to seals than they are to reservoirs. This is especial true for black oil.

Viscosity

- The internal friction due to molecular cohesion in fluids which results in the resistance of a fluid to flow.
  - *Measured in Poise (grams/cm/sec), usually expressed as centipoise.*
- Viscosity is dependent on
  - *Temperature*
    - Increase in temperature will lower the viscosity.
  - *Dissolved gas content (GOR)*
    - Increase in gas content will lower the viscosity of petroleum.
- API Gravity is not a direct indicator of fluid flow characteristics.

	Viscosity, poise
Air	1.8×10^{-4}
Water	1×10^{-3}
Gasoline	0.6×10^{-2}
Mercury	1.55×10^{-2}
Kerosene	2.0×10^{-2}
Lube Oils	8×10^{-2} to 1200×10^{-2}
Asphalts	10^{3} to 10^{7}

Hot Tea	~ 1 cp
Maple Syrup	1000 cp
Peanut Butter	10^{6} cp
Chocolate	10^{7} cp

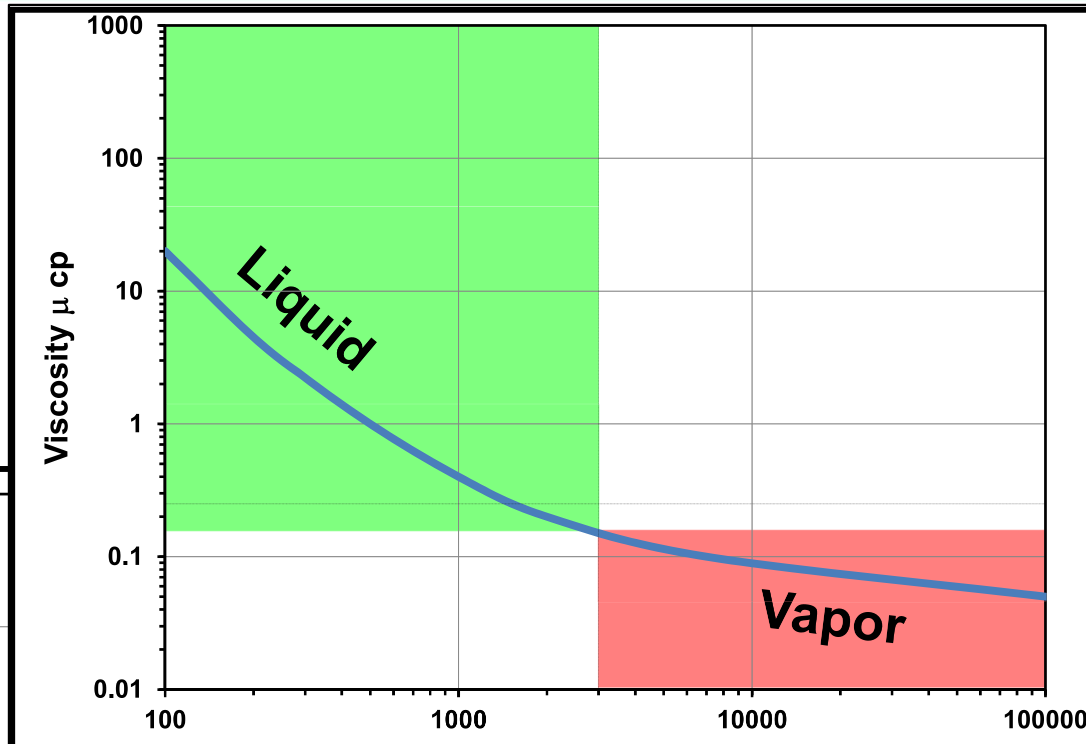
Viscosity in Centipoise (cp)	
Water	1
Bitumen	5,000-1,000,000
Heavy Oil	100-500
Black Oil	2-100
Volatile Oil	0.25-2
Natural Gas	<0.25

API Gravity: an expression of the specific gravity* of crude oils and condensates measured at 60°F (16°C), where API Gravity = (141.5/Specific Gravity)-131.5

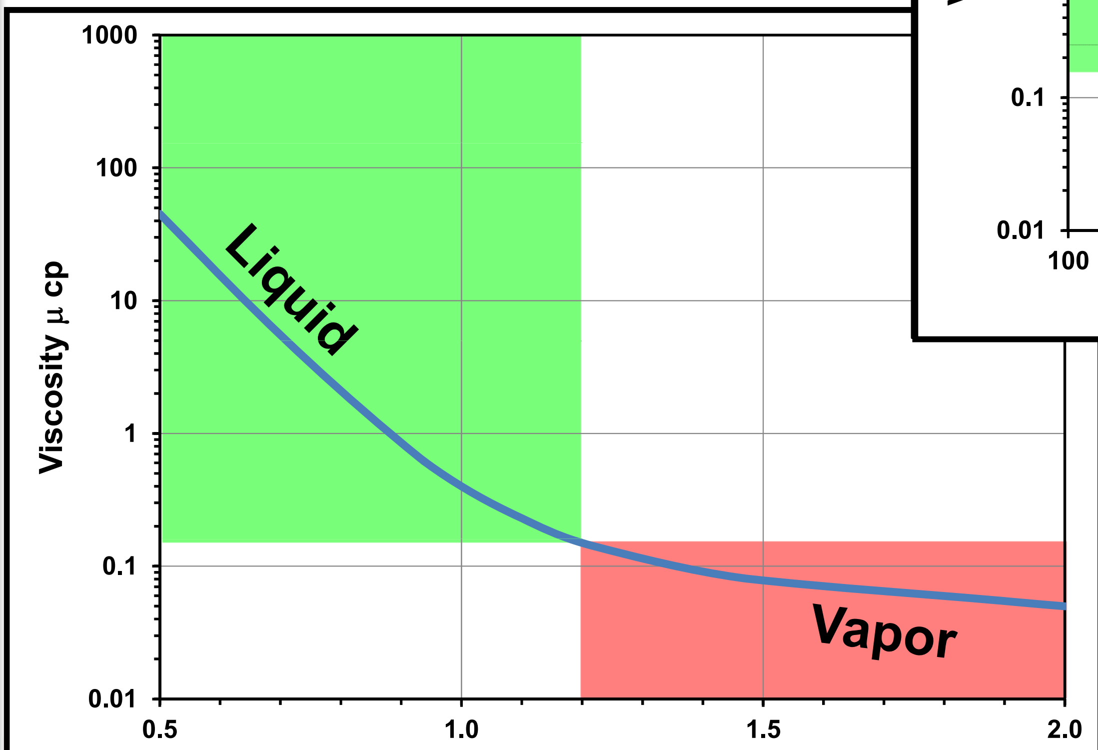
* Specific gravity – ratio of the mass of a body to the mass of an equal volume of water at a specified temperature (a proxy for density).

Viscosity, GOR, And Maturity

With increasing gas content, the viscosity of the oil in the source rock will decrease.



(after Cander, 2012)

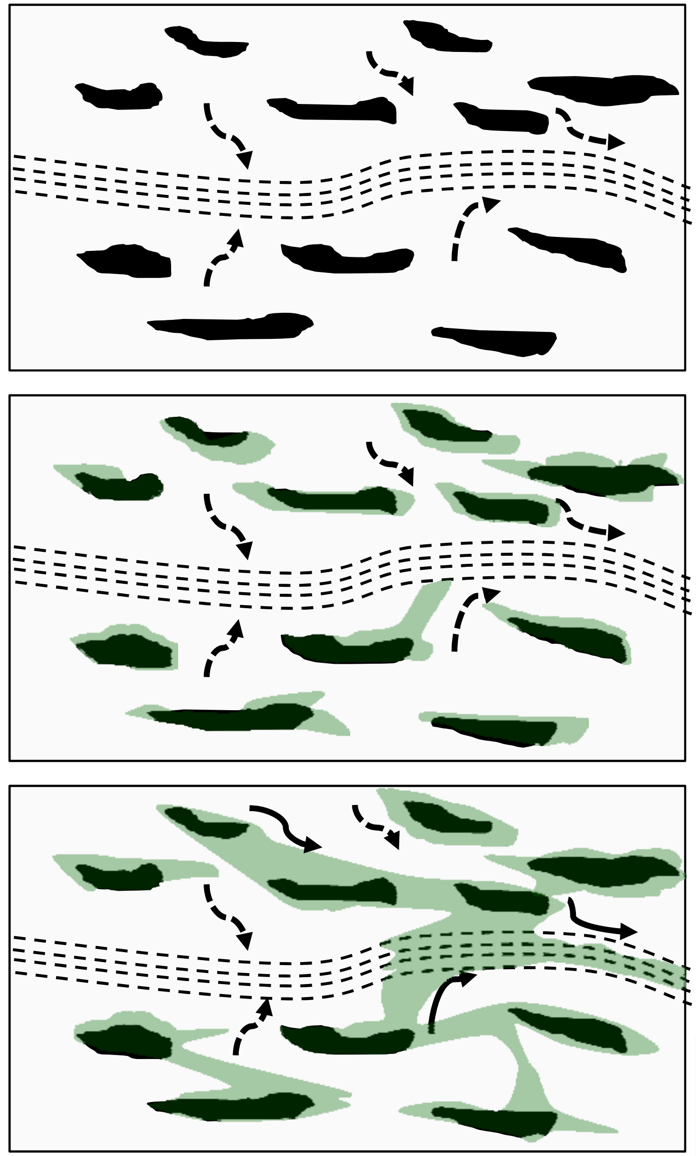


(after Cander, 2012)

With increasing maturity, the viscosity of the oil in the source rock decreases with changes in the composition of the oil due cracking, generation of smaller molecules, and increasing dissolved gas content.

Moving Oil Out Of A Source Rocks

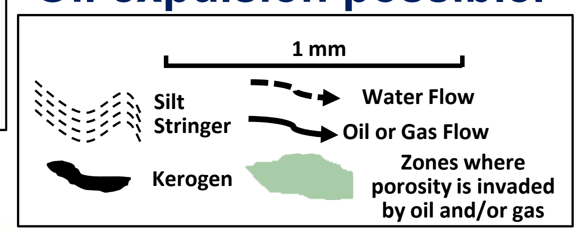
- Oil will flow from source rocks in the oil window - if it didn't we wouldn't have conventional oil accumulations.
- Typically, flow is initiated at ~0.7-0.9% Ro (vitrinite reflectance) and requires reaching a minimum hydrocarbon saturation and overcoming the adsorption of the oil on the kerogen and mineral matrix.
- Oil accumulations form by oil flowing/migrating out of source rocks over geologic time with flow rates that are very low relative to production.



Immature
VR < 0.6% Ro
ϕ = 15%
So = 0%
Water expulsion from compaction

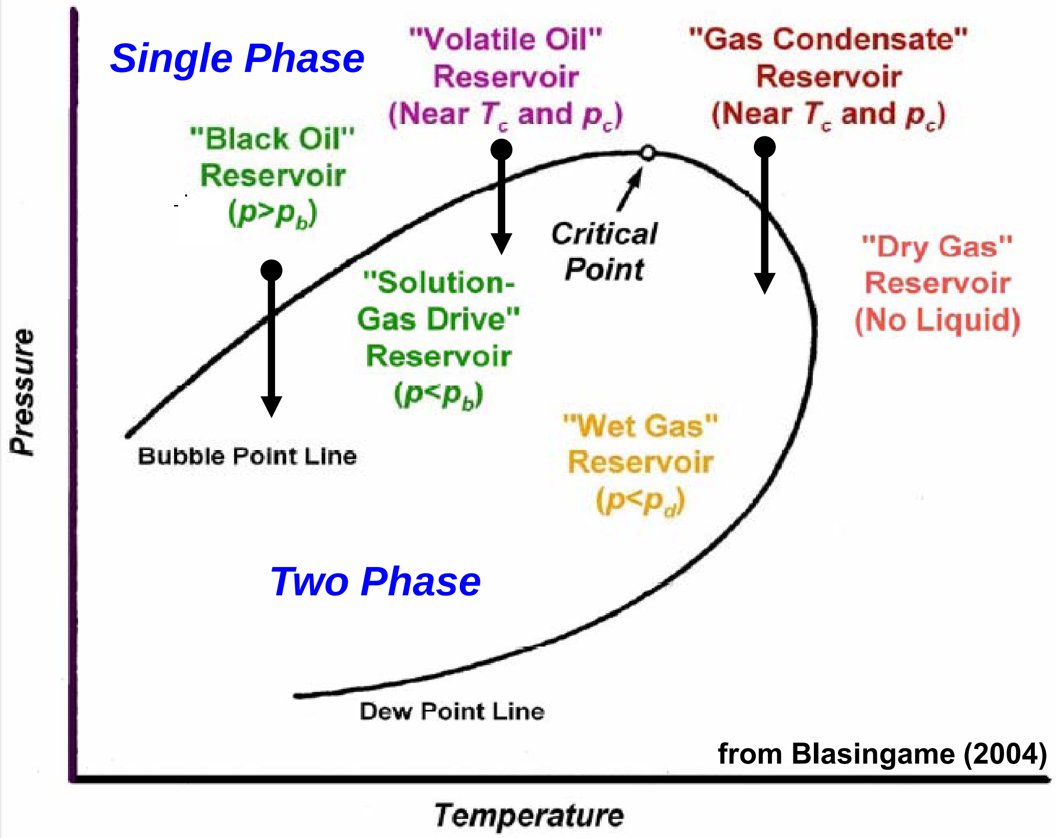
Onset Of Generation
VR ~ 0.6% Ro
ϕ = 10%
So = 5%
Hydrocarbons invade surrounding porosity, no oil expulsion

Peak Oil Generation
VR = 0.9-1.0% Ro
ϕ = 5%
So = 20%
Oil expulsion possible.



after Ungerer et al. (1984)

PVT Behavior Of Fluids During Production



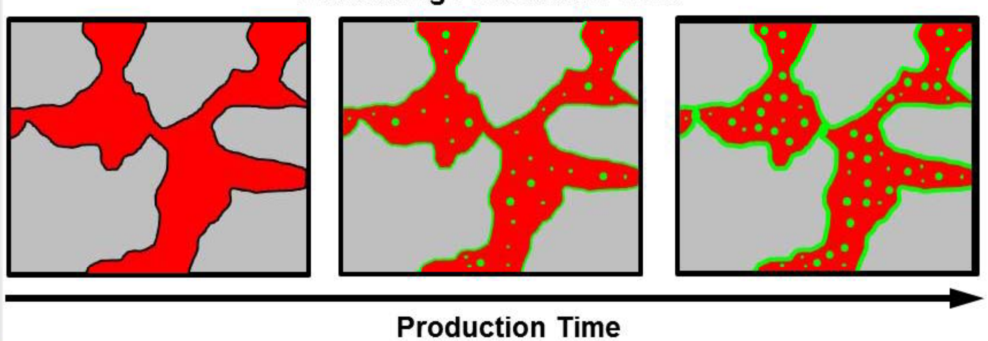
from Blasingame (2004)

In a liquids-rich shale gas play, as long as the condensate and wet gas are in a gas solution, liquid drop out obstructing flow will not occur. But as formation pressure drops this could become a critical issue.

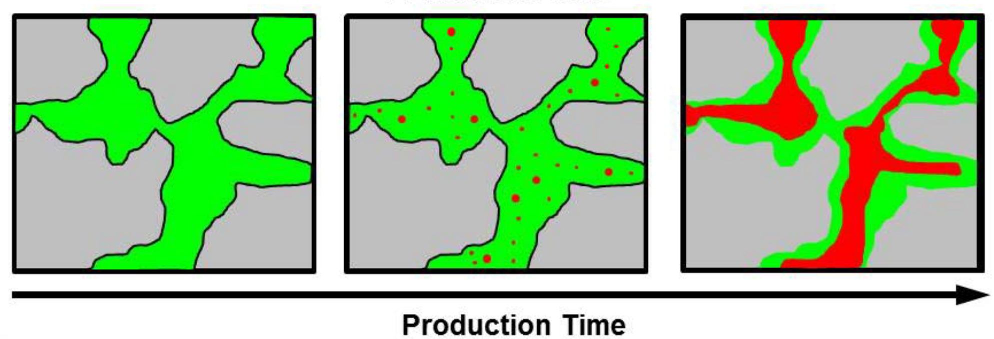
In a black oil or volatile oil shale play, as formation pressure drops to the bubble point curve, gas comes out of solution resulting in a decrease in GOR of the liquid phase and an increase in its viscosity, making it more difficult for the liquid to move out of the pore space.

In addition, the free gas phase can move more freely through the pore throats of the rock leaving behind the liquids.

Retrograde Condensation Impeding Flow As Pressures Drop With Increasing Production Time

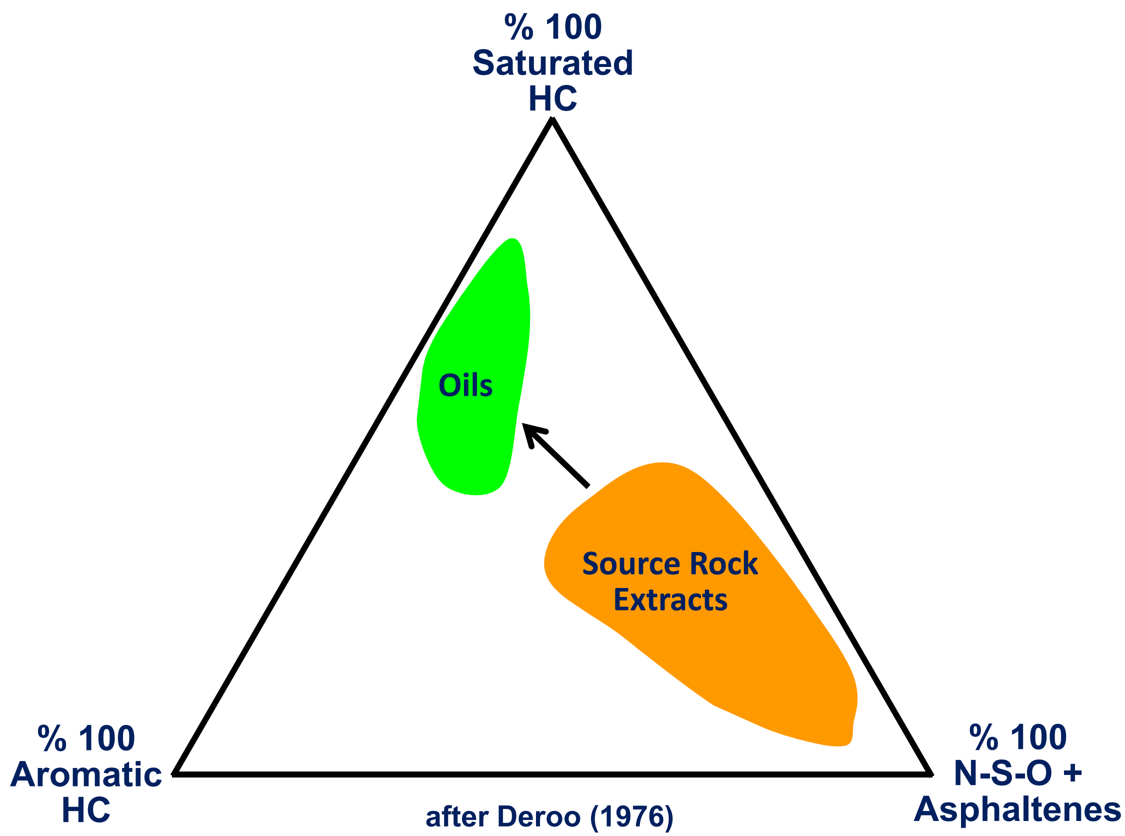


Gas Exsolution Impeding Flow As Pressures Drop With Increasing Production Time

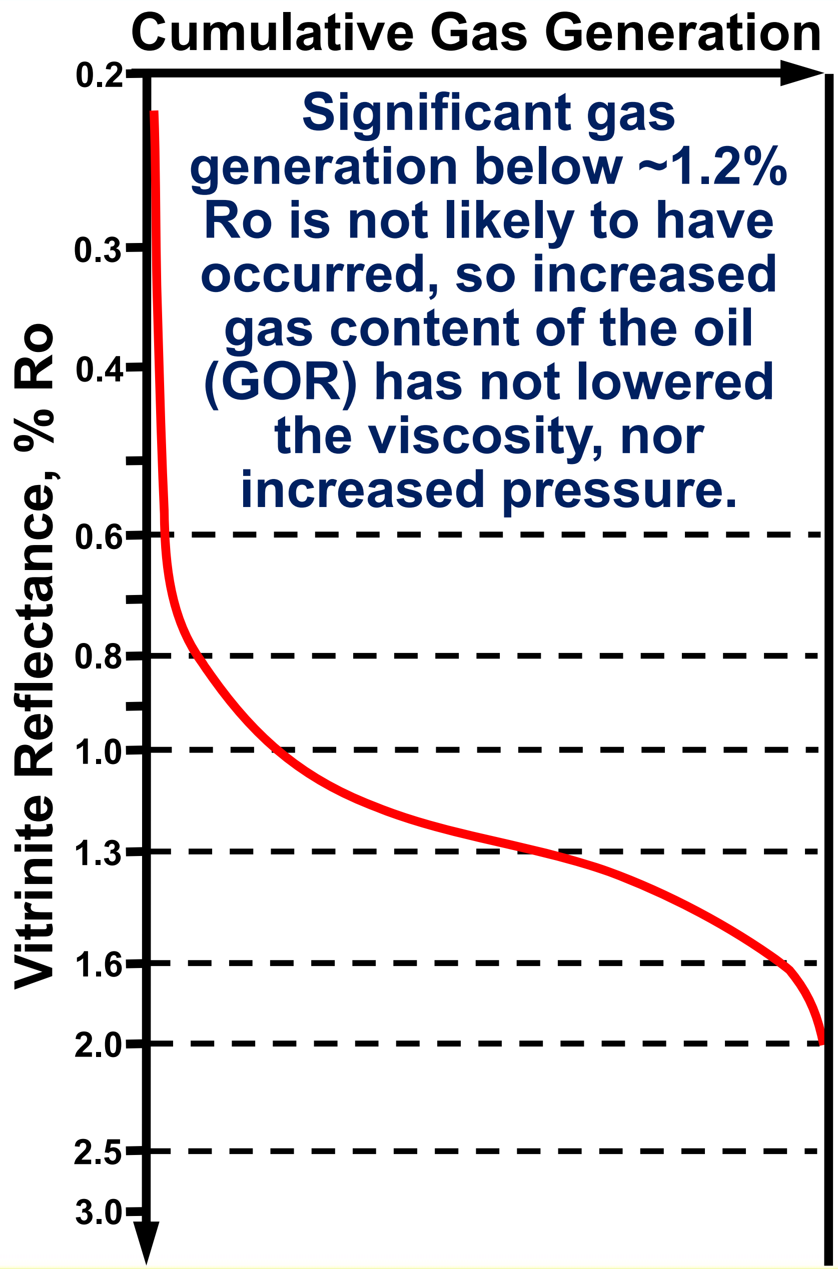


Obstacles To Oil Flow From Shale

Residual oil in the source rock is not as mobile as the migrating phase, and contains higher concentrations of high molecular weight compounds as well as more resins (N-S-O compounds) and asphaltenes.



after Deroo (1976)



The Findings

- *Can black oil escape from shales?*
  - Yes, expulsion and migration of black oil from shales is how conventional oil accumulations form.
- *Under what conditions does this occur?*
  - The source rock (shale) reaches a critical saturation and overcomes adsorption for oil to move out of the rock.
- *Are commercial flow rate possible/probable?*
  - Expulsion and migration are processes that operate over geological time (millions of years), not in real time.
- *What are the main obstacles to success?*
  - Low permeability in the shale, high viscosity of the oil, low gas content in the oil window, and lack of reservoir energy all contribute to the lack of success.

Conclusions

Can we get black oil to flow from a shale in the oil window at sustained commercial rates?

Not likely, the shale's permeability, the oil's viscosity, and the lack of reservoir energy all work against sustained commercial flow rates for black oil from a shale in the oil window.

What's the best chance for liquids in shale plays?

Shale gas plays rich in condensate and natural gas liquids where the maturities are in the range of about 1.2-1.3 to about 1.5 % Ro vitrinite reflectance.

Thank You For Your Attention.
Questions?

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"The greatest enemy of knowledge is not ignorance, it is the illusion of knowledge." **— Stephen Hawking**

Harry Dembicki, Jr.
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email: harry.dembicki@anadarko.com

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