[PS]Source Rock Reservoirs are a Unique Petroleum System*

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Search and Discovery Article #41138 (2013)**
Posted June 30, 2013

*Adapted from poster presentation given at AAPG 2013 Annual Convention and Exhibition, Pittsburgh, Pennsylvania, May 19-22, 2013

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Abstract

Three distinct types of petroleum systems can be defined based on the difference in the basic physics of hydrocarbon accumulation. Conventional petroleum systems (Type 1) have the traditional components of source, seal, reservoir, trap, and timing that must be evaluated and that must be favorable for an accumulation to be present. Hydrocarbons migrate from the source rock to the reservoir and trap based on the density difference between oil, gas, and water. Continuous basin-centered accumulations (Type 2) trap migrating hydrocarbons in tight rocks by relative-permeability conditions that develop between the hydrocarbons and interstitial water. Reservoir conditions, therefore, also define the seal and the trap. Source rock reservoirs (SRRs, Type 3) have a much lower permeability and much smaller pore throats than even continuous accumulations. The remaining unexpelled and unmigrated hydrocarbons that remain in the porosity of the SRR are available to be produced if sufficient fracture conductivity is induced by hydraulic fracturing. Coal-bed methane, oil sands, and oil SRRs are variations on, and composites of, the three basic petroleum systems end members.

The physics of gas flow in SRRs are different from the other petroleum systems at the small pore throat sizes that are present in the secondary, oil, or gas-wet pores within the kerogens and their associated microfractures, from in the water-wet portions of the SRR, or in the migration pathways. In the absence of water within the nanopores, gas is present in a number of diffuse systems. Adsorbed gas is present as a diffuse layer on the surface of the organic porosity. If there is a gradient along that surface, diffusion occurs in a linear fashion. The free gas in the pore space moves from high concentration to low concentration by slippage flow, as described by Knudsen diffusion. There is free interchange between the free and adsorbed gas molecules by "hopping" from one diffuse system to the other. Gas is absorbed within the kerogen matrix and diffuses out to become adsorbed. The relative contribution and rates of flux in these various systems are an active research topic, but the high deliverability of gas from SRRs is a result of the different physics of gas flow.

Source Rock Reservoirs are a Unique Petroleum System

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Abstract

Three distinct types of petroleum systems can be defined based on the difference in the basic physics of hydrocarbon accumulation. Conventional petroleum systems (PetSys 1) have the traditional components of source, seal, reservoir, trap and timing that must be evaluated and that must be favorable for an accumulation to be present. Hydrocarbons migrate from the source rock to the reservoir and trap based on the density difference between oil, gas and water. Continuous basin-centered accumulations (PetSys 2) trap migrating hydrocarbons in tight rocks by relative permeability conditions that develop between the hydrocarbons and interstitial water. Reservoir conditions therefore also define the seal and the trap. Source Rock Reservoirs (SRRs, PetSys 3) have a much lower permeability and much smaller pore throats than even continuous accumulations. The remaining unexpelled and unmigrated hydrocarbons that remain in the porosity of the SRR are available to be produced if sufficient fracture conductivity is induced by hydraulic fracturing. Coal bed methane, oil sands, and oil SRRs are variations on and composites of the three basic petroleum systems end-members.

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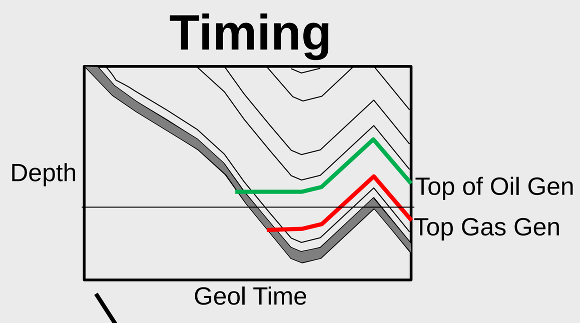
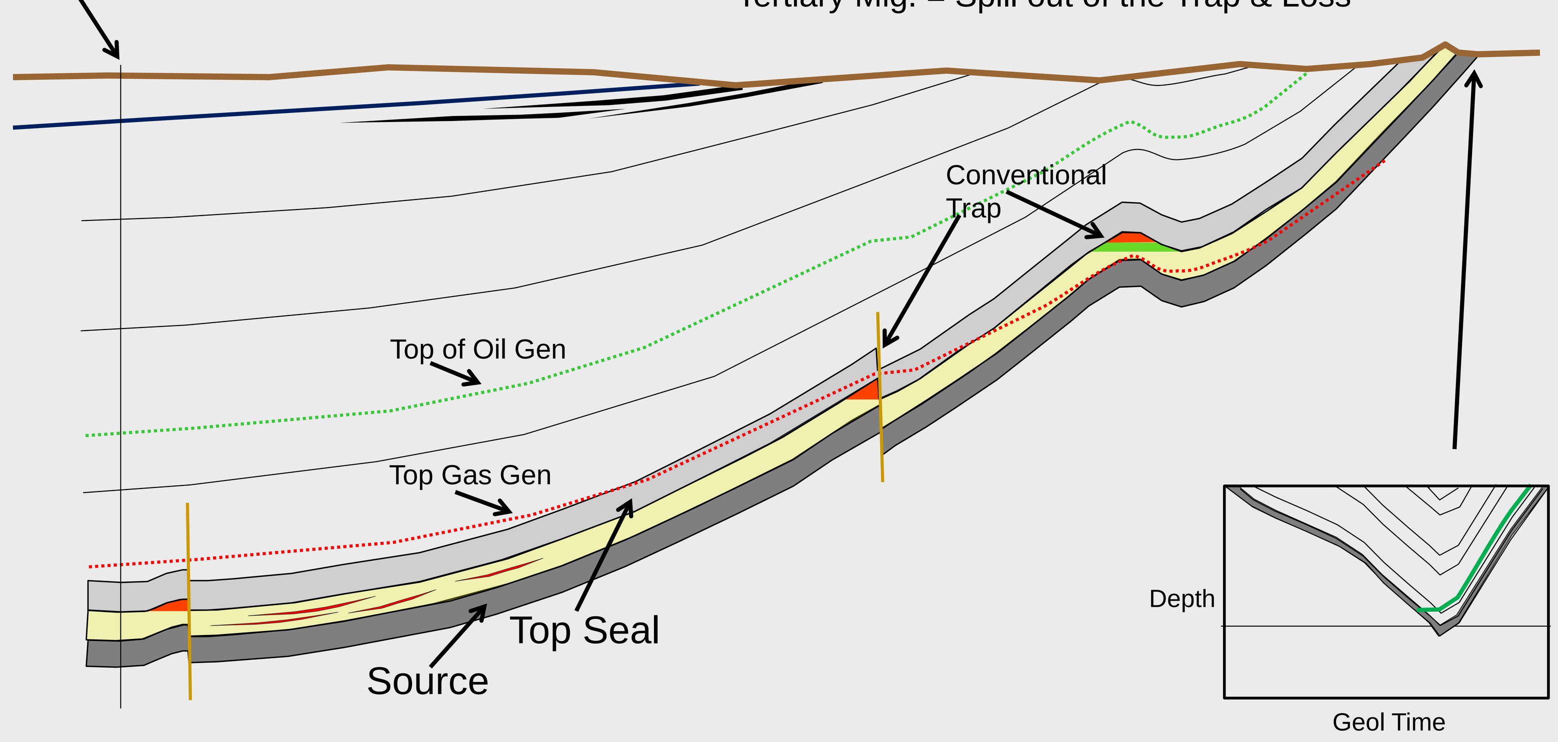
End-Member Petroleum Systems



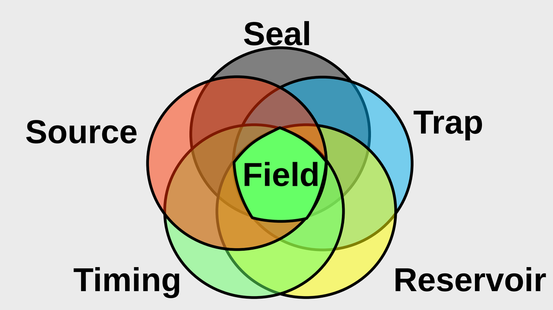
Conventional Petroleum System (1)

Gravity (Density) Dominates

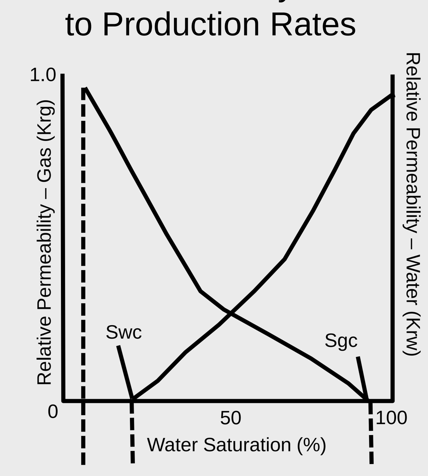
Primary Migration = Oil out of the Source Rock
Secondary Mig. = Movement to Trap
Tertiary Mig. = Spill out of the Trap & Loss



All System Components Must Work



Relative Permeability is Critical to Production Rates



Characteristics of Tight Gas (PetSys 2):

after Cumella (2008), Law (2002), Shanley (2004) and others

- [ ] Low permeability (<0.1md) reservoirs
- [ ] Abnormally pressured
  - overpressured = accumulating
  - underpressured = dissipating
- [ ] Regionally pervasive gas saturation (extensive gas shows while drilling)

- [ ] Little produced water
- [ ] Lack a downdip water contact (rare or no gas-water contacts seen on logs)
- [ ] Hydraulic fracturing is required
- [ ] May grade updip into wet zones
- [ ] Sweet spots are very important
- [ ] Structure is often synclinal (poorly defined traps and seals)
- [ ] Often the largest gas field in the basin

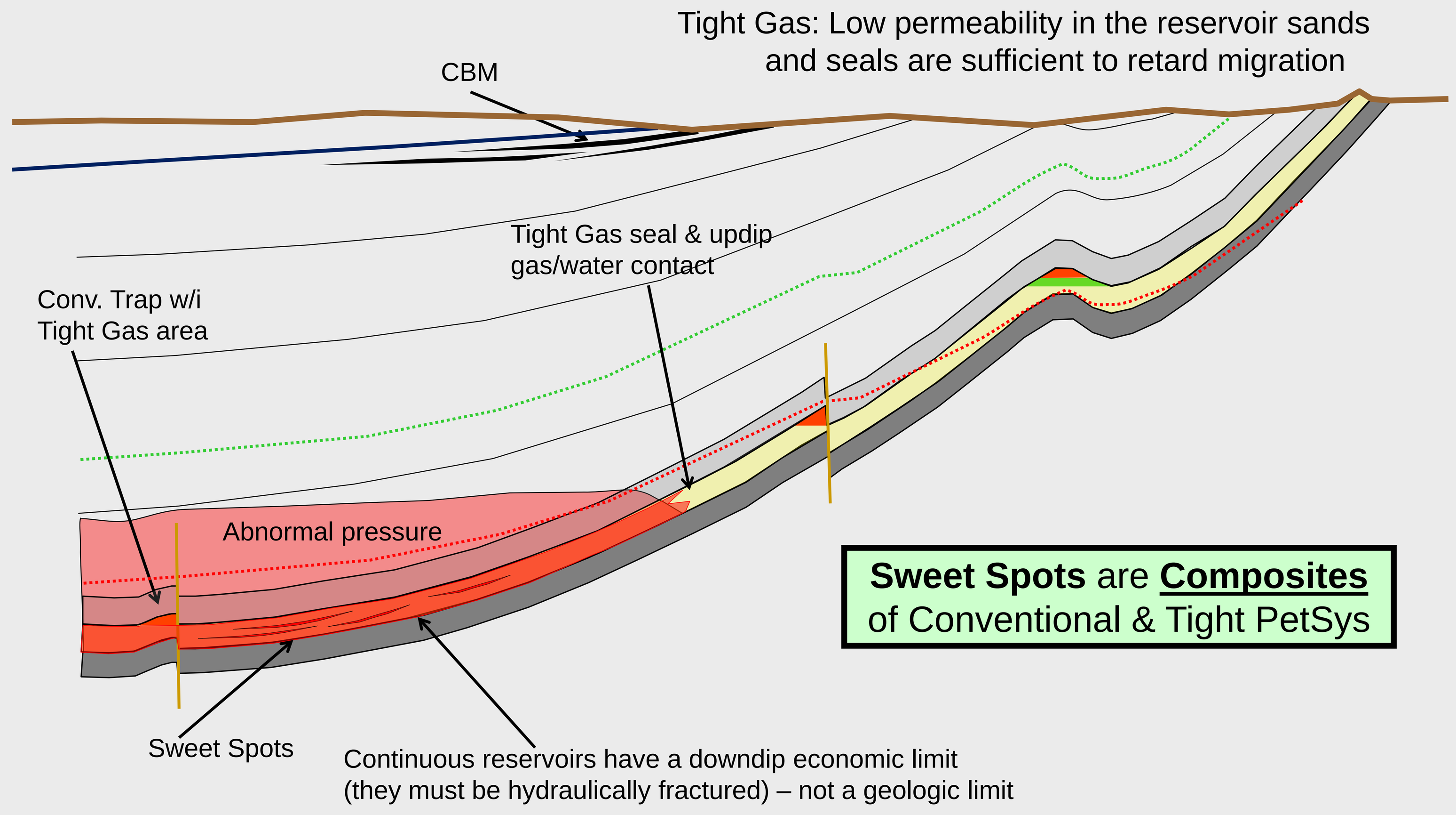
Three Things are Required for a Tight Gas Sands PetSys 2

[1] Preexisting tight rock (compaction, diagenesis, etc.)
[2] A gas source (thermogenic, biogenic, coal, etc.)
[3] Leaky seals (to get large volumes of water out of the basin)

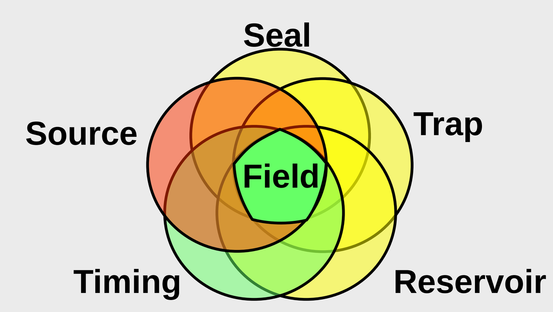
Tight Gas Sands: (Continuous) Petroleum System (2)

Relative Permeability Dominates

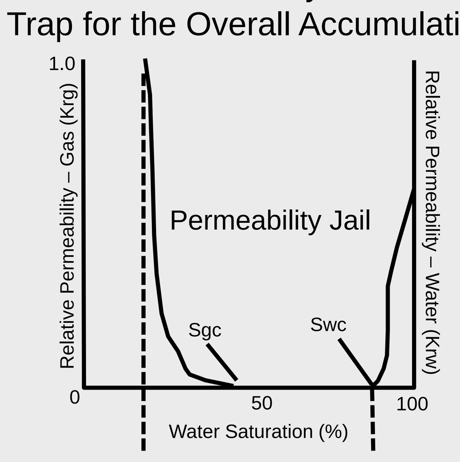
Tight Gas: Low permeability in the reservoir sands and seals are sufficient to retard migration



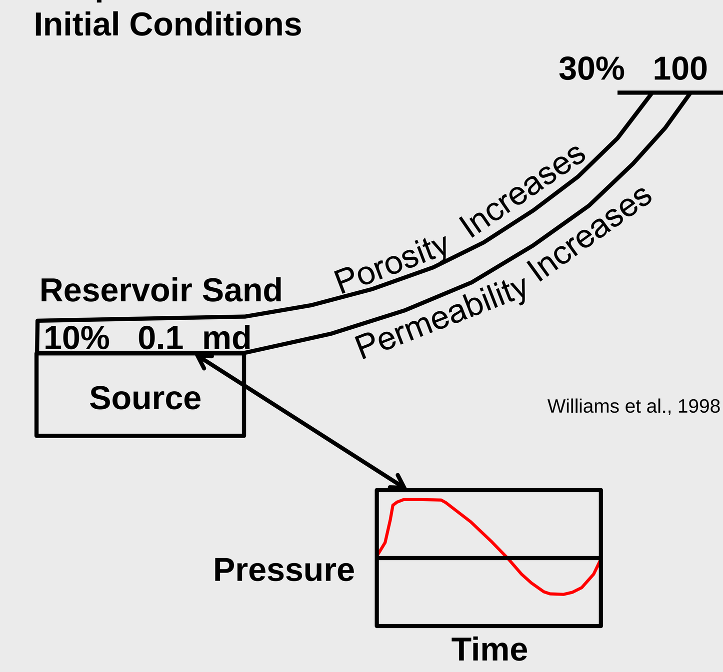
Trap, Seal & Reservoir may be the same tight rock



Relative Permeability defines the Trap for the Overall Accumulation



Simplified Reservoir Simulation Model Initial Conditions

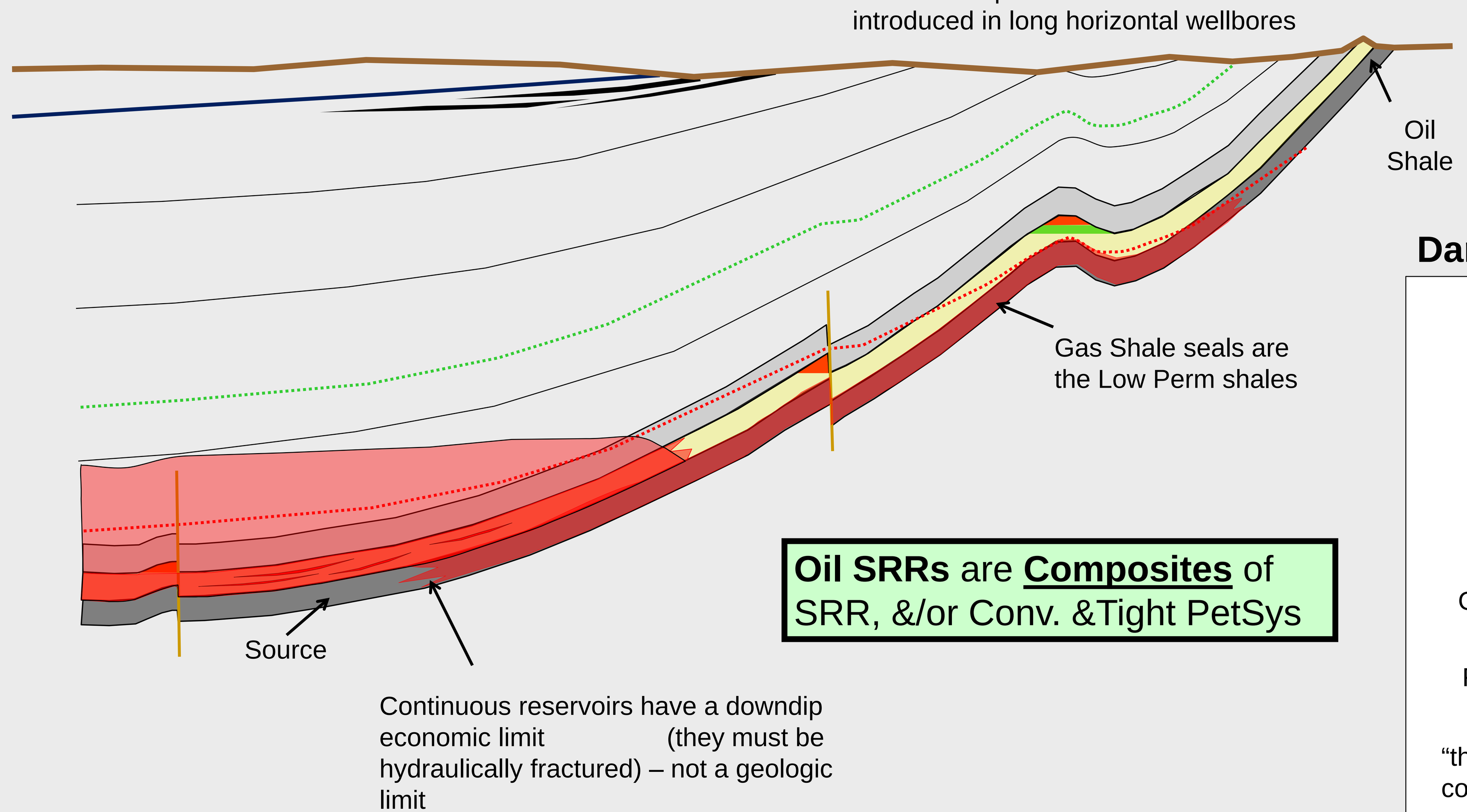


Abnormal Pressure Evolution

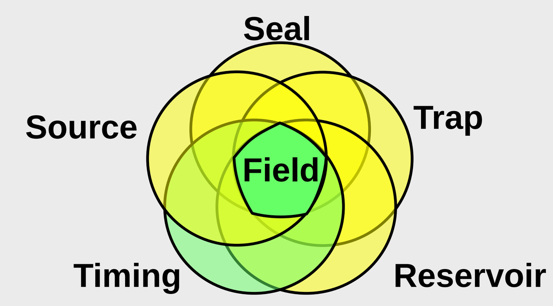
Gas Source Rock Reservoir Petroleum System (3)

Electromagnetic (Molecular) Forces Dominate

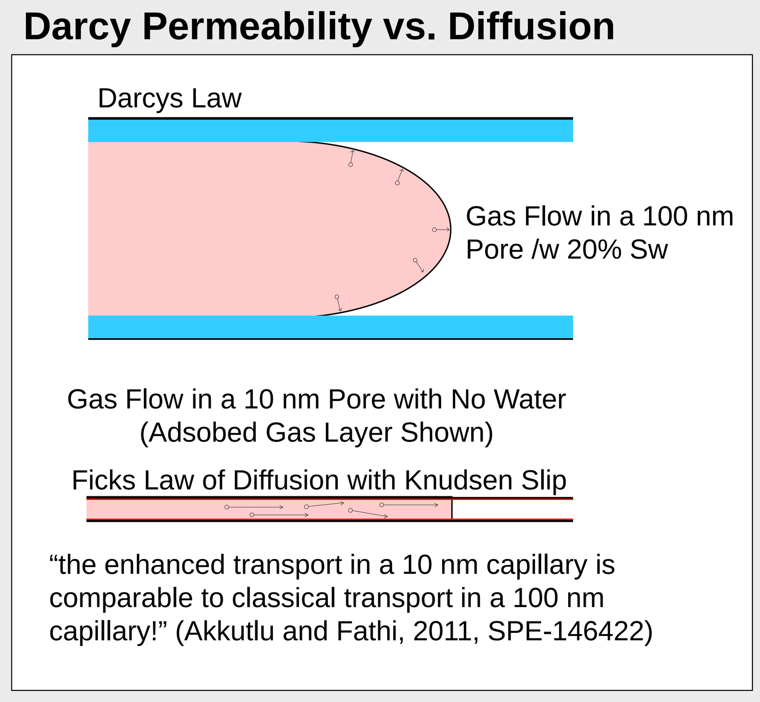
SRRs (Gas Shales): Unexpelled gas in the source rock can be produced if sufficient fractures are introduced in long horizontal wellbores



Source, Seal. Reservoir, and Trap may be the same rock Timing is critical



Darcy Permeability vs. Diffusion



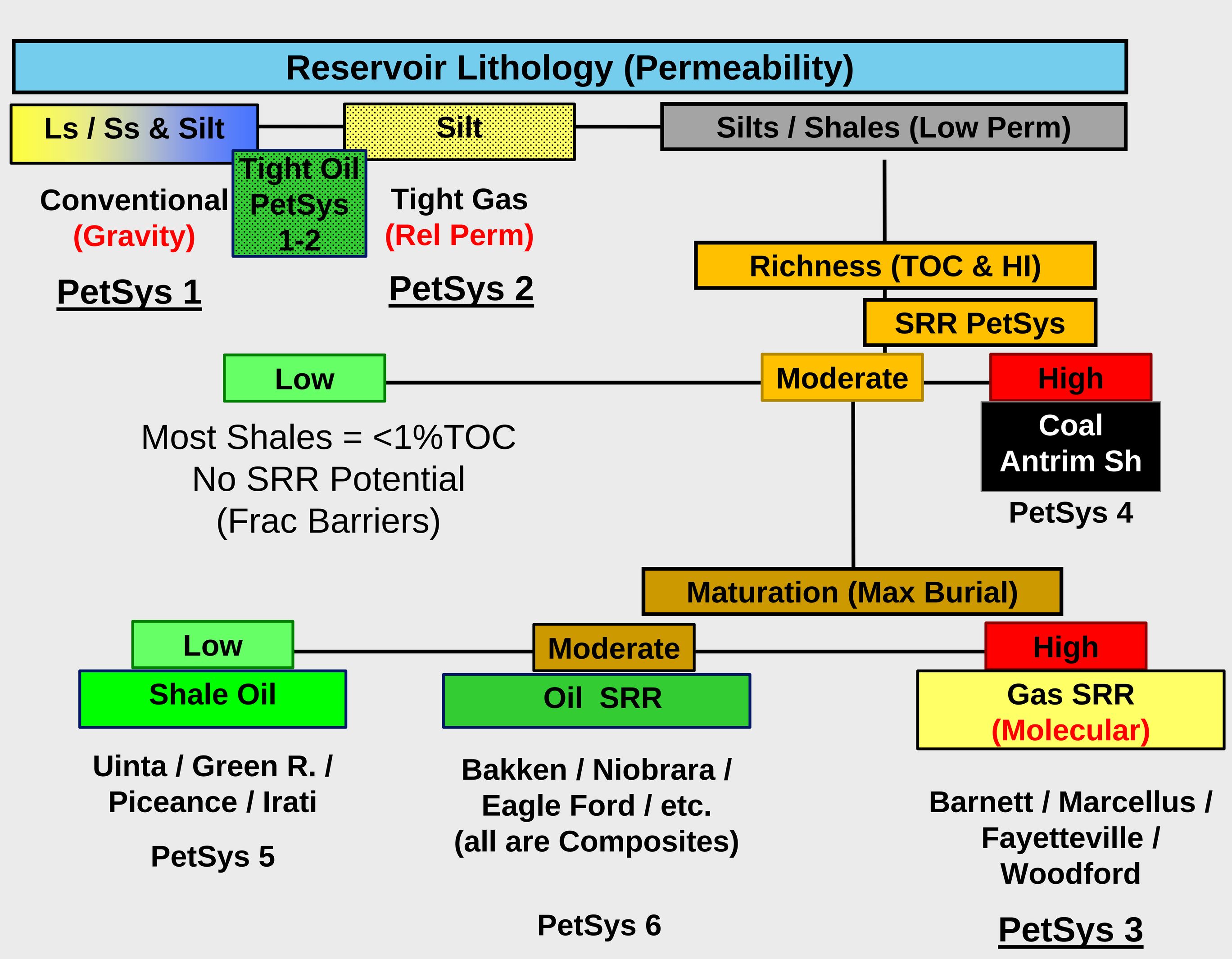
Notes on Source Rock Reservoirs (SRRs)

- [ ] Most shales are *NOT* source rocks
- [ ] SRRs are oil or gas-wet *NOT* water-wet rocks
- [ ] Por in SRRs is *NOT* the same as in conventional rocks

- [ ] Kerogen contains both free & adsorbed gas
- [ ] Flow by diffusion slip gives high deliverability
- [ ] Oil molecules may be nearly the same size as SRR pore throats => oil window oil blockage
- [ ] Oil SRRs are composites of the SRR and other PetSys (conventional porosity is required)

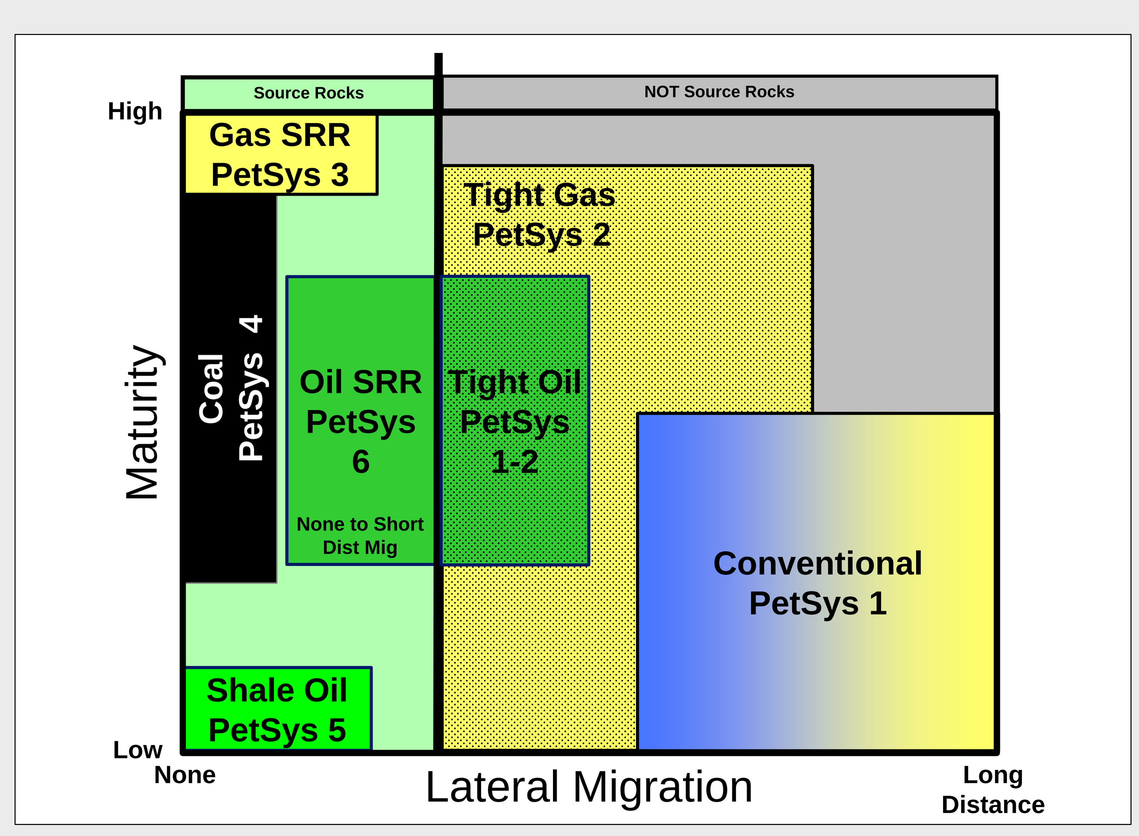
- [ ] SRRs require both horizontal wells & multiple fracs
- [ ] Maturity of the SRR can be modeled and calibrated
- [ ] Maturity informs oil vs. gas production & the clay reactivity

Comparison of Petroleum Systems Permeability / Richness / Maturation



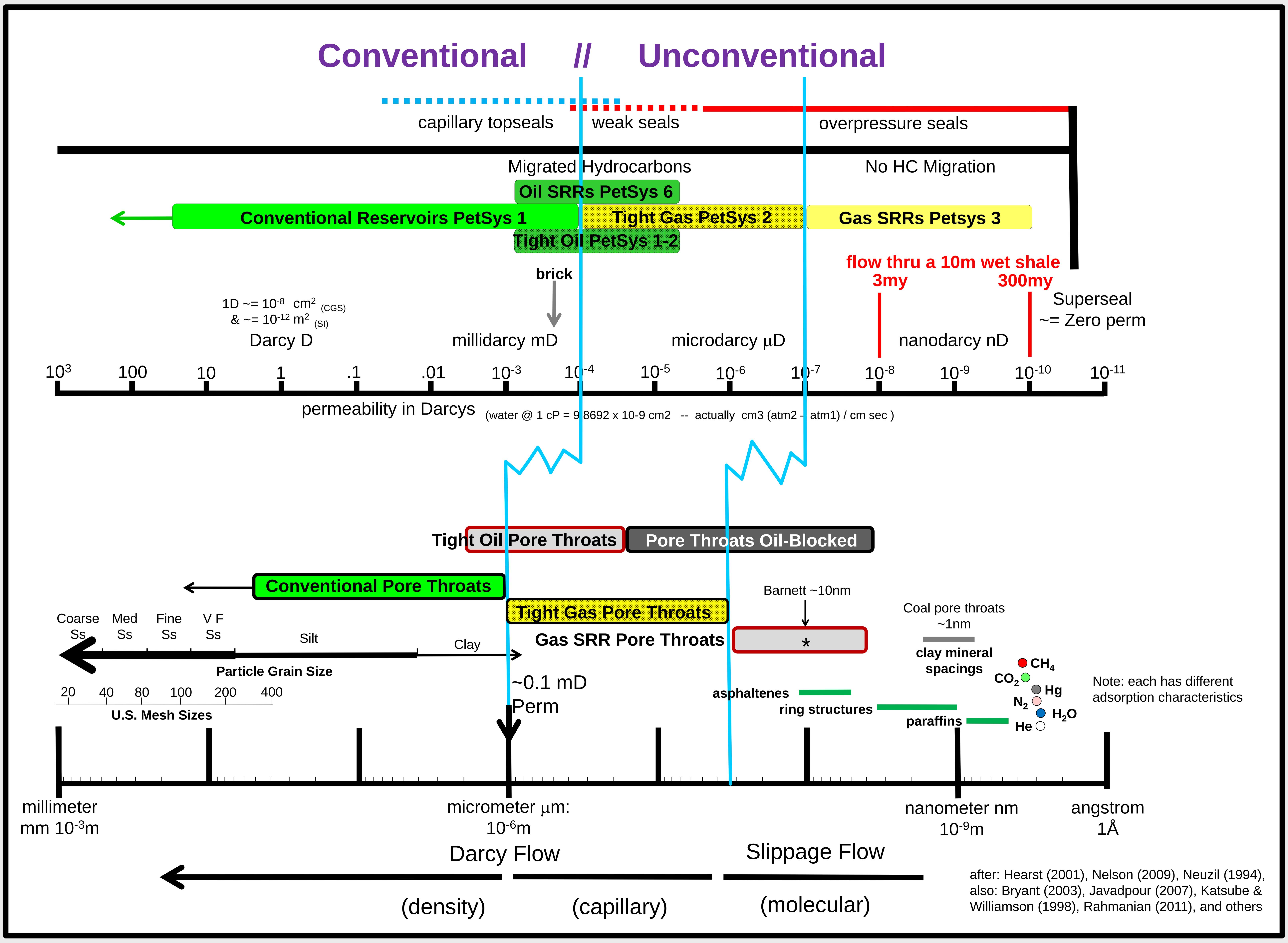
Oil SRR is a variation on the Gas SRR but with short-distance lateral migration. Carbonate SRRs appear to be preferred over Clastics

Some Gas and *ALL* Oil SRRs are Composites of SRR &/or Conventional &/or Tight Petroleum System Elements



Comparison of Petroleum Systems Maturity vs Lateral Migration

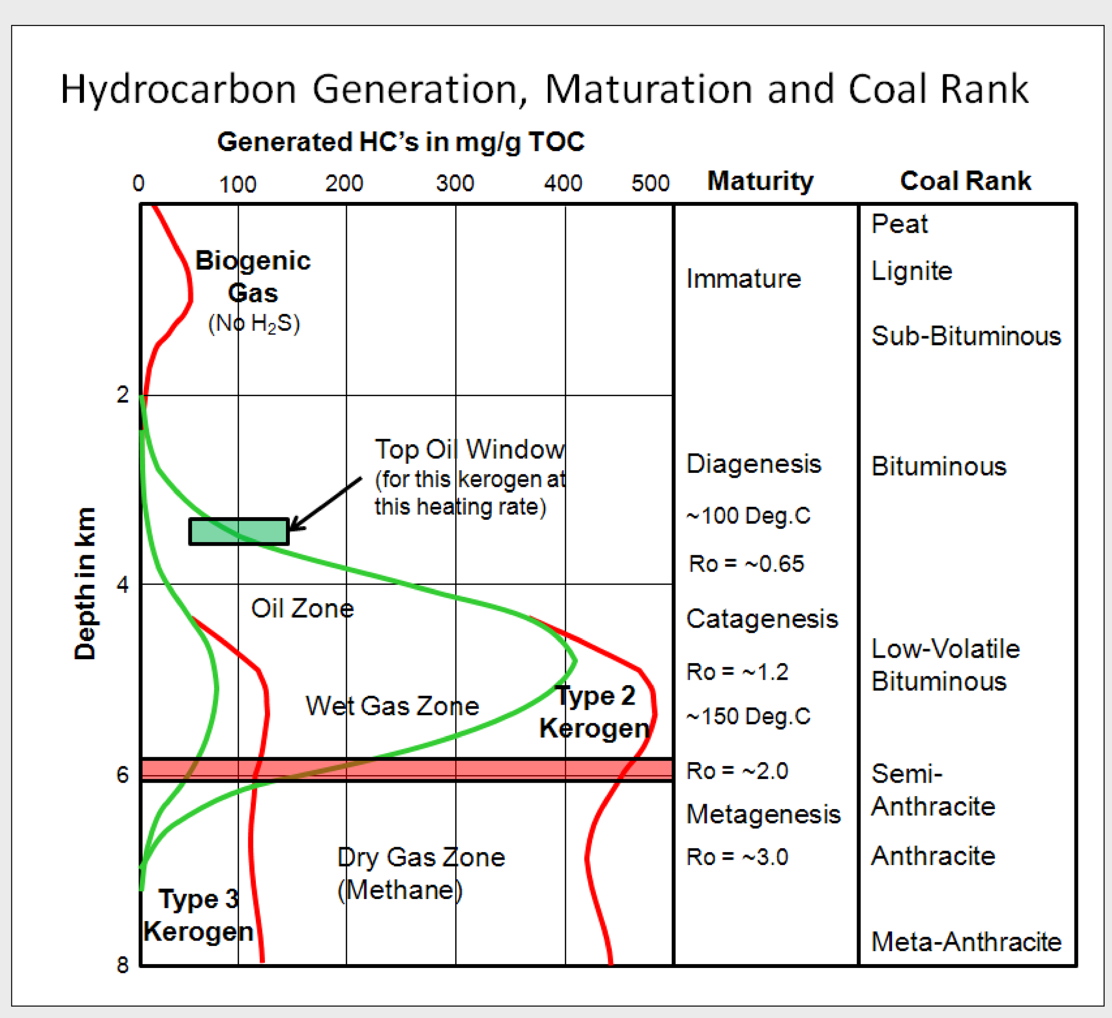
Permeability & Pore Throat Sizes

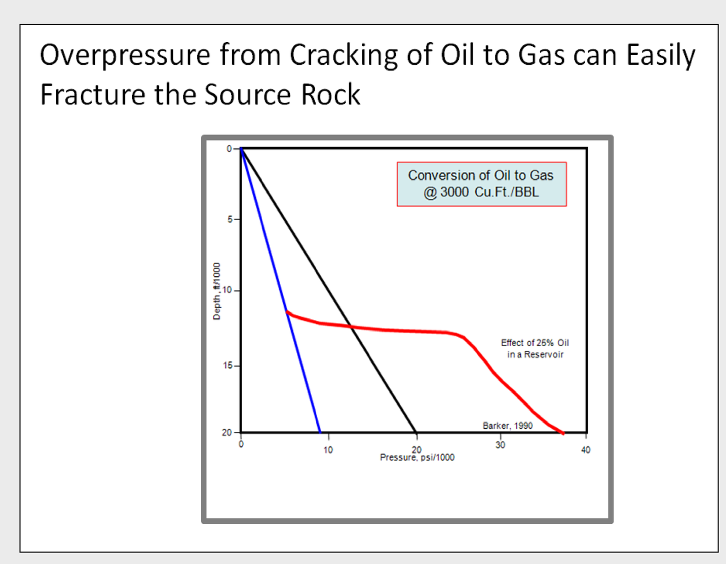


1D Geohistory Modeling of Hydrocarbon Generation and Migration Timing

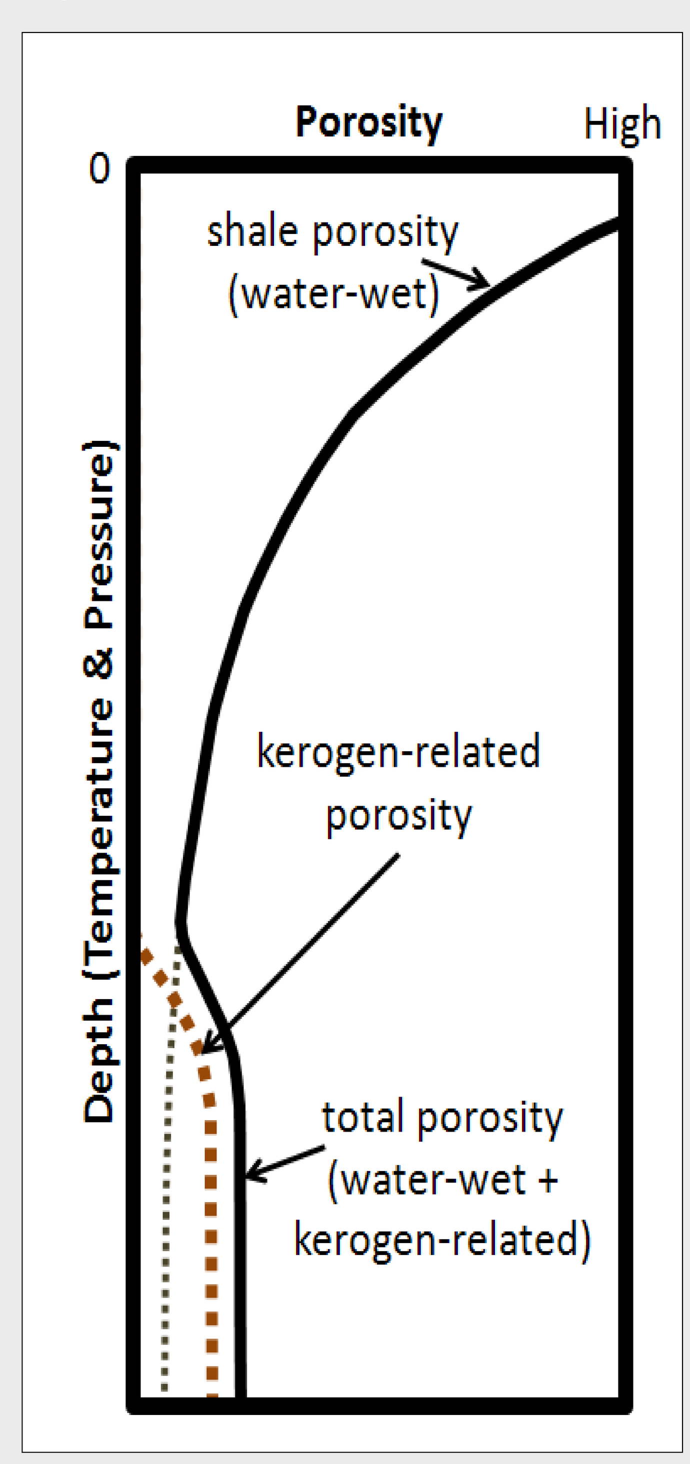
Burial, Paleo-Topography & Paleo-HF

Maturation, Expulsion & Pressure





Secondary Porosity due to generation & expulsion of hydrocarbons

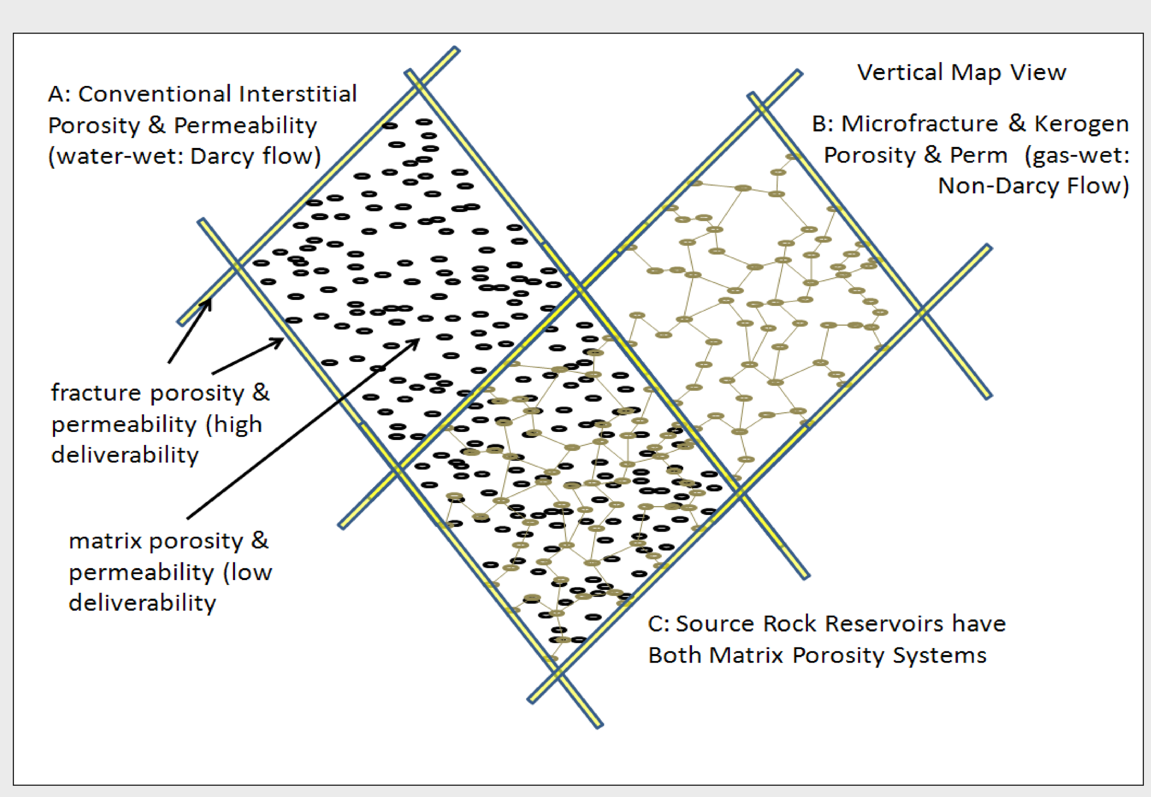


Gas & Oil SRRs: Key Points

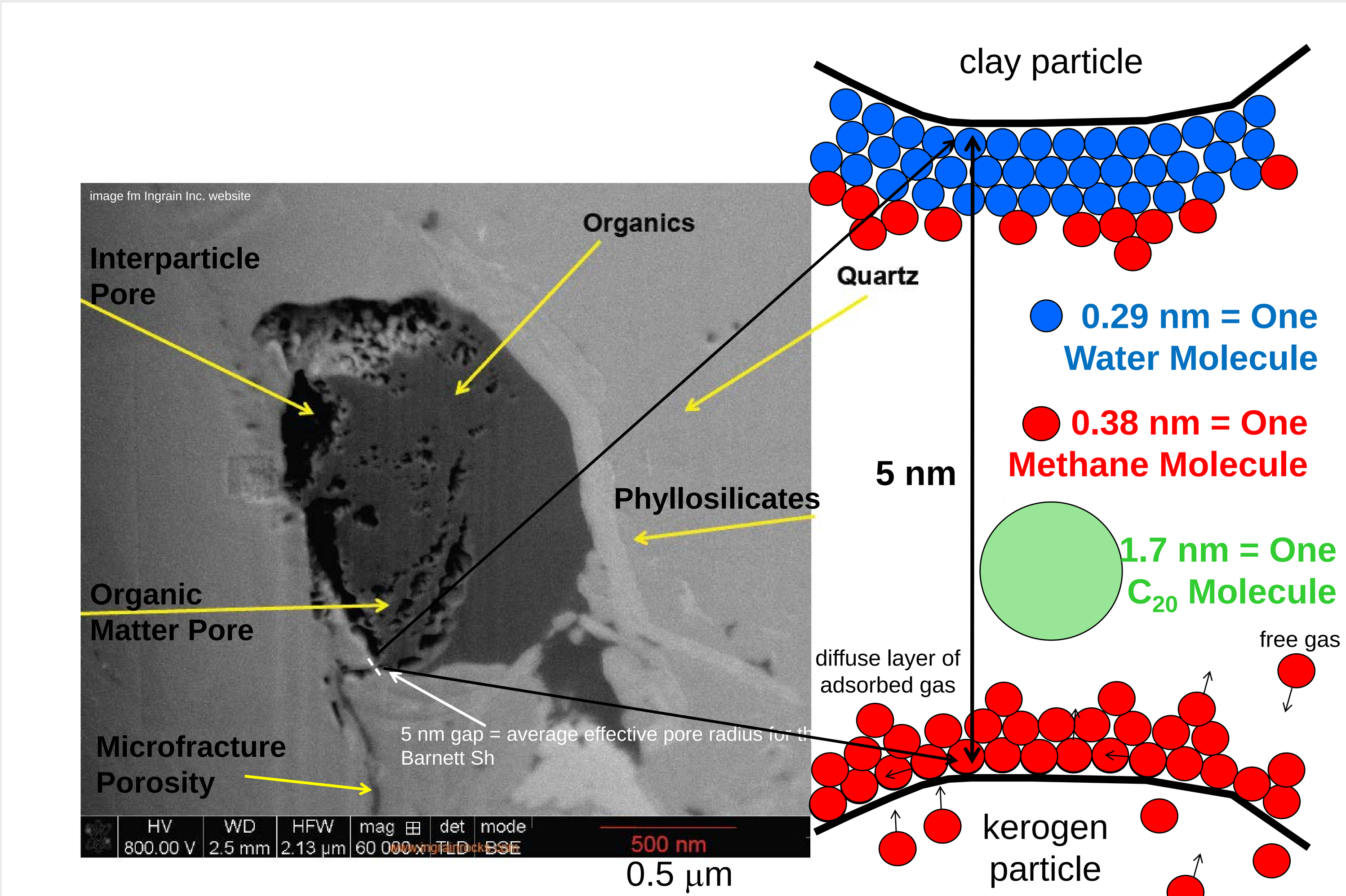
- [ ] Conventional, Tight Gas & SRRs are very different PetSys
- [ ] Neither porosity nor permeability is the dominant controlling factor in gas flow rate
- [ ] The physics of trap & flow is different in each PetSys
- [ ] Kerogen type, TOC, & Maturity (Geol Hist) all influence the porosity due to Gen > Expulsion
- [ ] Brittleness / ductility influences porosity preservation & frackability
- [ ] In Gas SRR organic porosity, there is free, adsorbed & adsorbed gas and there is also water-wet inorganic porosity
- [ ] The organic and inorganic pores may not be connected in the reservoir until hydraulic fracturing reconnects them

- [ ] SRRs are a combination of the two different storage & deliverability systems (water-wet & organic kerogen porosity)
- [ ] Oil SRRs must have a large component of conventional porosity due to oil blockage in small pore throats
- [ ] Oil SRRs appear to prefer carbonate reservoirs with secondary porosity enhancement related to hydrocarbon generation and short-distance lateral migration

Overlap of Organic and Inorganic Porosities in SRRs



Kerogen Porosity at the Nanometer Scale



Note: Two types of kerogen within the same particle (with and without porosity)

There are many different kinds of Diffusion. Several are depicted here:

[1] Diffuse layer on the kerogen particle surface
(high concentration near the surface & low at a distance).
Note: This gas is produced at a slower rate than the initially free gas since it becomes available for production only when it becomes free

[2] Free gas < = > adsorbed diffuse layer
Note: Free gas is produced first at a very high deliverability even in small pore throats.

[3] Linear diffusion along the adsorbed layer from high concentration to low
Note: May not be significant to production rates.

[4] Diffusion of the absorbed molecules within the kerogen to the adsorbed layer on its surface.
Note: this occurs at lower pressure and over a long time and results in kerogen shrinkage and increased porosity and permeability. This contributes to the very long production times (decades) for gas SRRs

Why are the Successful (so far) Oil SRR plays in Carbonates?

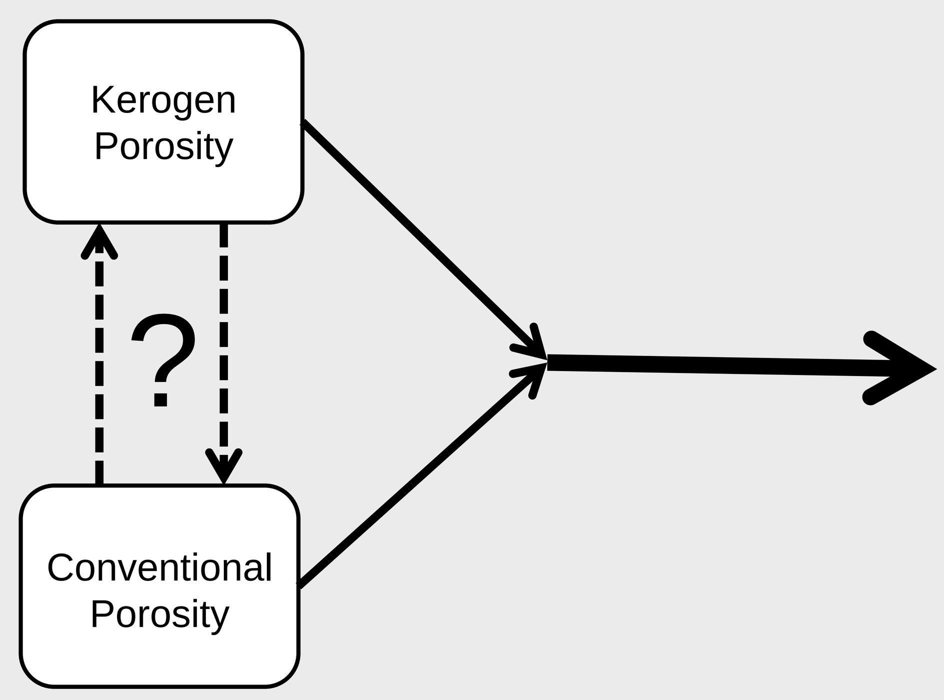
[ ] Hydrocarbon generation & expulsion is accompanied by many compounds:
  [ ] Organic acids
  [ ] CO_2 > becomes the weak carbonic acid in water
  [ ] H_2S > becomes the weak hydrosulfuric acid in water

[ ] These acids can contribute to secondary porosity development by carbonate dissolution

[ ] The secondary porosity should occur close to the source rock that expelled the acids and be depleted before long-distance migration occurs

A Possible Reservoir Modeling Strategy

Contribution to Total Production During Depletion



Oil vs. Gas SRR Matrix Characteristics < in > Organic Porosity and Inorganic Porosity

Organic Porosity: Nanoporosity and Nanofractures

Gas SRR:
+ No migration from source
+ Gas storage in kerogens
+ High deliverability fm NanoPor
+ Pressure depletion PLUS desorption

Oil SRR:
- No migration from source
- Low storage in kerogens
- Low deliverability fm NanoPor
- Pressure depletion PLUS blockage

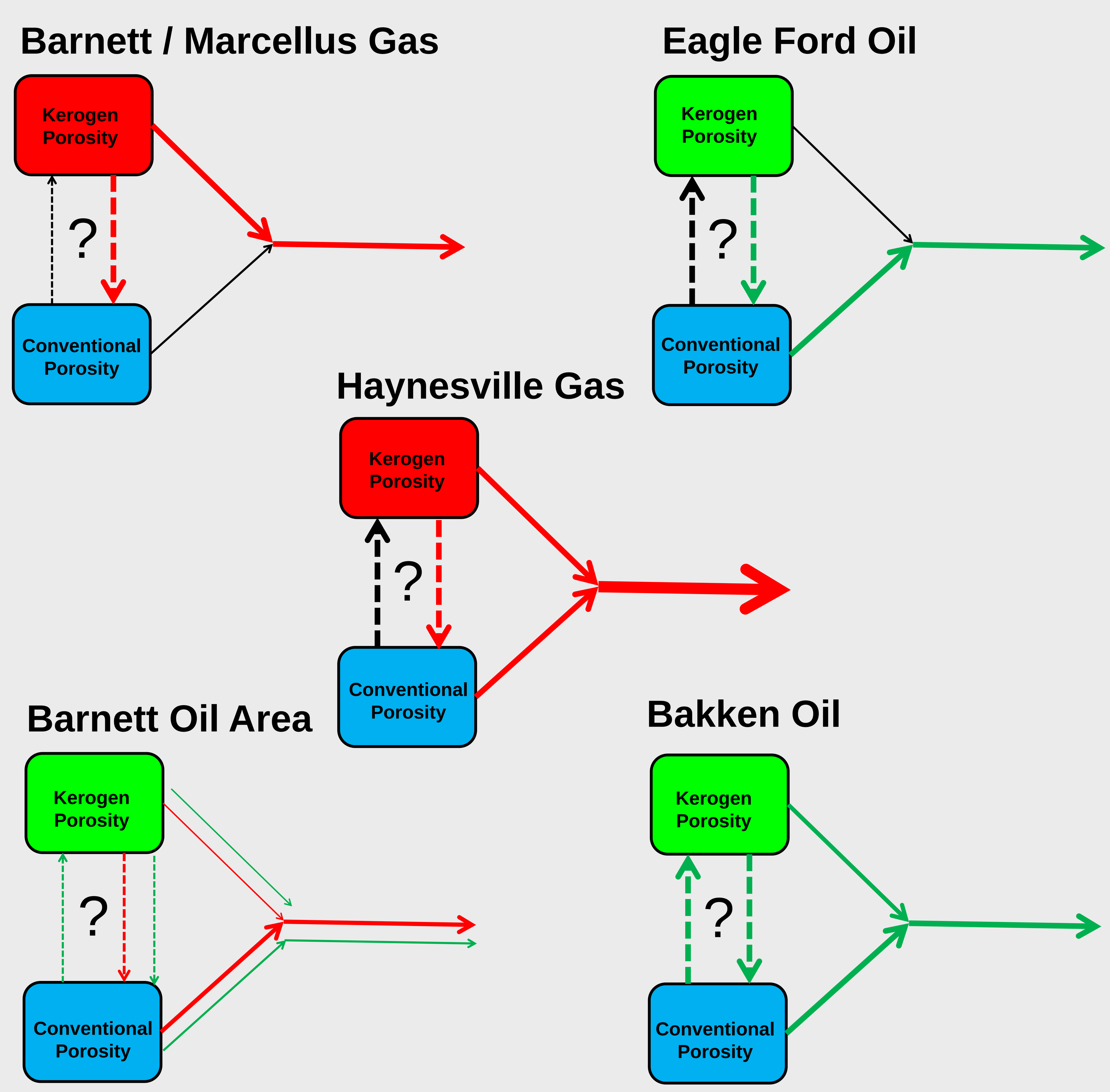
Best Target Porosity is *IN* the Kerogens

Inorganic Porosity: Conventional Water-wet Porosity & Microfractures (cemented?)

Gas SRR:
- Some migration from source
- Some to no gas storage
- Low deliverability
+ Pressure depletion

Oil SRR:
+ Short-dist migration fm source
+ Most of the movable oil storage
+ Most of the deliverability
- Pressure depletion PLUS liquid drop-out (blockage)

Best Target Porosity is Conventional: but close to the TOC



Conclusions:

[ ] Petroleum Systems come in a variety of types, some with very different physics of accumulation, entrapment and production
[ ] Conventional PetSys 1 is dominated by gravity segregation of migrated hydrocarbons
[ ] Continuous gas PetSys 2 is dominated by relative permeability capillary effects of migrated hydrocarbons
[ ] Gas SRRs PetSys 3 are dominated by diffusion effects in organic porosity and produce unmigrated gas from the source
[ ] Oil blockage occurs in small pore throats. Production from oil SRRs appears to occur in conventional porosity near the kerogens, possibly due to the effects of acids that accompany hydrocarbon generation / expulsion
[ ] Carbonate SRRs appear to be preferred for oil production (so far)
[ ] Interactions between the organic and inorganic porosities may need to be considered in developing a successful modeling strategy for SRRs

Acknowledgements:
Thanks to Halliburton C&P Digital Solutions and the Consulting and Tech Team members for their assistance and for many enlightening discussions.