PS The Permeability of Overpressure Shale Seals and of Source Rock Reservoirs is the Same*

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Abstract

Permeability of rocks in the subsurface varies over many orders of magnitude from too high to be a useful concept to too low to be measurable. The division between conventional petroleum systems and continuous accumulations is approximately 0.1 millidarcy. At that point, relative permeability and capillary pressures create the trapping seal. Weak barostratigraphic seals become common in the microdarcy range. Good overpressure seals are modeled to be in the 10 to 100 nanodarcy range. The flow of water is slow enough at these permeabilities so that the interstitial water bears a portion of the overburden load and is overpressured (undercompaction disequilibrium).

Source rock reservoirs (SRR) are present in 'shales' with permeabilities that are also in the 10 to 100 nanodarcy range and are capable of producing gas at commercial flow rates. This apparent paradox is addressed by examination of the geologic history of the SRR. Generation, maturation (including the cracking of oil to gas) and the expulsion of hydrocarbons creates high internal overpressures sufficient to fracture the host rock, so that the hydrocarbons can be expelled through a microfracture network. The generation of hydrocarbons also creates pore space within the kerogen grains themselves. After expulsion ceases, cementation and diagenesis occludes the larger fractures and primary migration routes in the SRR, and isolates the kerogen and microfracture system. Hydraulic fracturing reopens the natural fractures and connects to the oil-wet, gas filled porosity in the SRR kerogens. The remaining unexpelled free and adsorbed gas is then available to be produced.

Due to the expulsion of hydrocarbons and associated water, SRRs may not be water-wet, but may be hydrophobic. Furthermore, the laminated nature of many source rock shales and the presence of oil and gas in the pore space creates a relative permeability reduction to the flow of water and also facilitates the formation of capillary seals. SRRs may be an effective pressure seal. The separate gas filled microporosity system is isolated within the matrix of the SRR and can be accessed through artificial fracturing. The conventional

interstitial and interparticle porosity is water-wet and may be gas-filled, and produces by Darcy flow. The kerogen and microporosity system is oil-wet and gas filled with an adsorbed gas component. It produces by diffusion flow. The combination of the two systems is what is seen at the wellbore.

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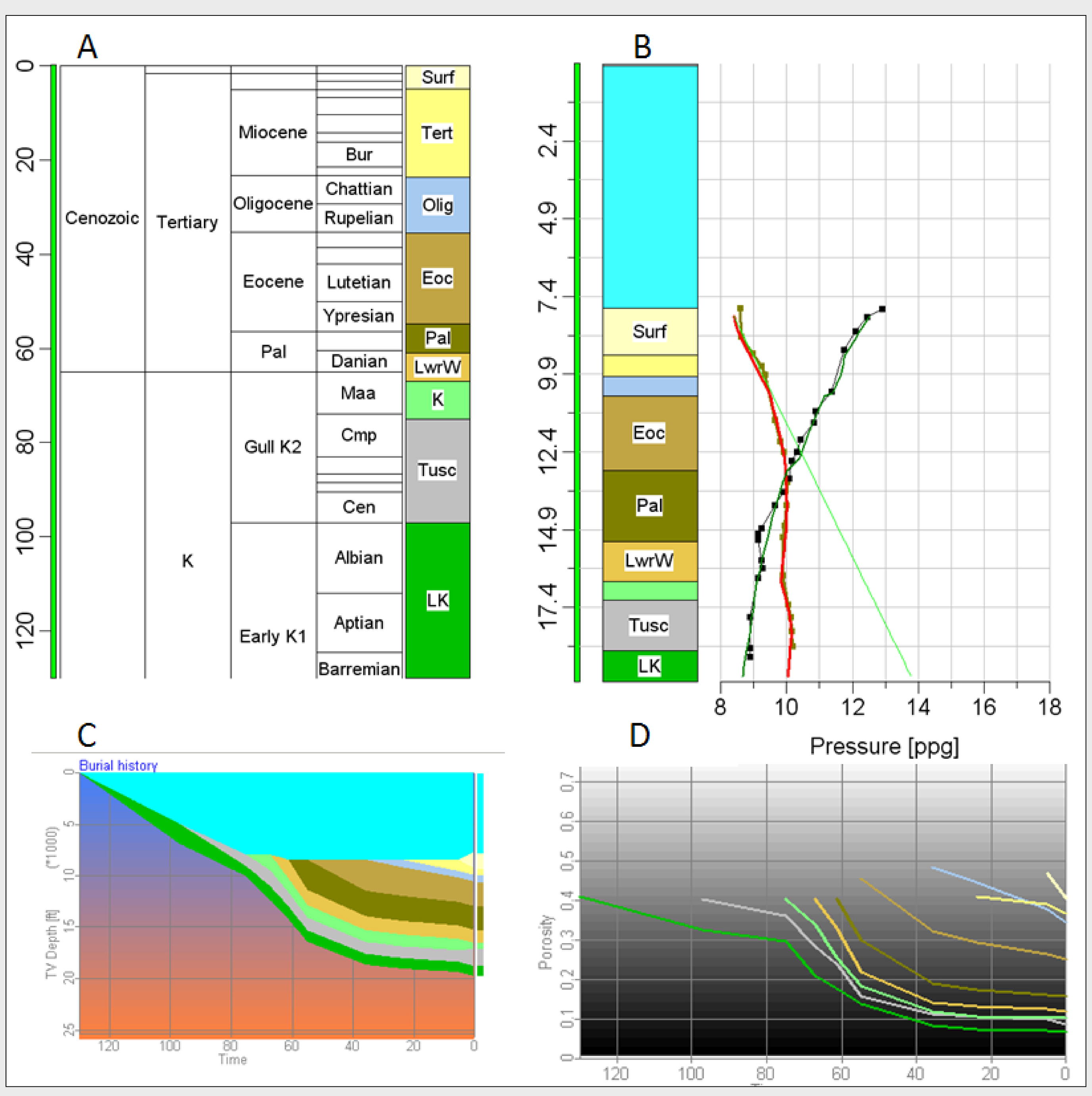
The Paradox: Seals for Overpressure and Source Rock Reservoirs both have Permeabilities in the same10-100 nanodarcy Range.

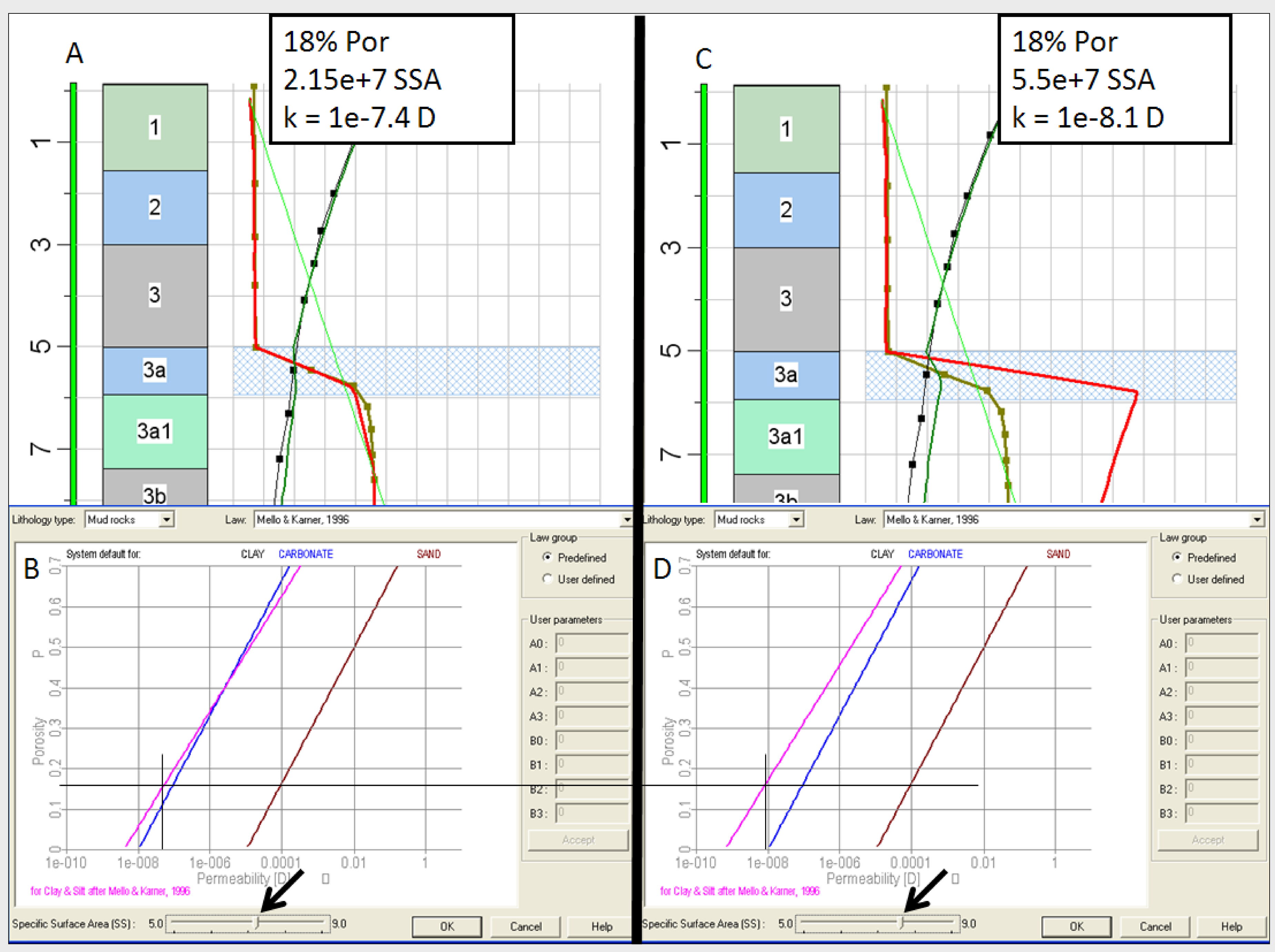
Pore Pressure and Permeability

1) Permeability and porosity both decrease with depth and compaction and are strongly related to lithology Athey exponential equation and many others: see Refs in Allen & Allen (2005)
2) Porosity is related to both permeability and effective stress see among others: Kozeny-Carman, Mello and Karner (1996), Madatov & Sereda (2005), Hantschell & Kauerauf, (2009)
3) Many commercial and proprietary programs since the mid-1980's commonly model and calibrate overpressures using these relationships
4) Good pore pressure seals are commonly modeled in shales or silty shales with permeabilities in the range of 10^{-7}-10^{-8} D (10-100 nD)

Overpressure Pressure Modeling (using Madatov & Sereda, 2005 software)



A) Stratigraphic Column for a Deepwater GoM Well
B) Lithologic Column & Pressure / Porosity Model
C) Burial History
D) Porosity Evolution

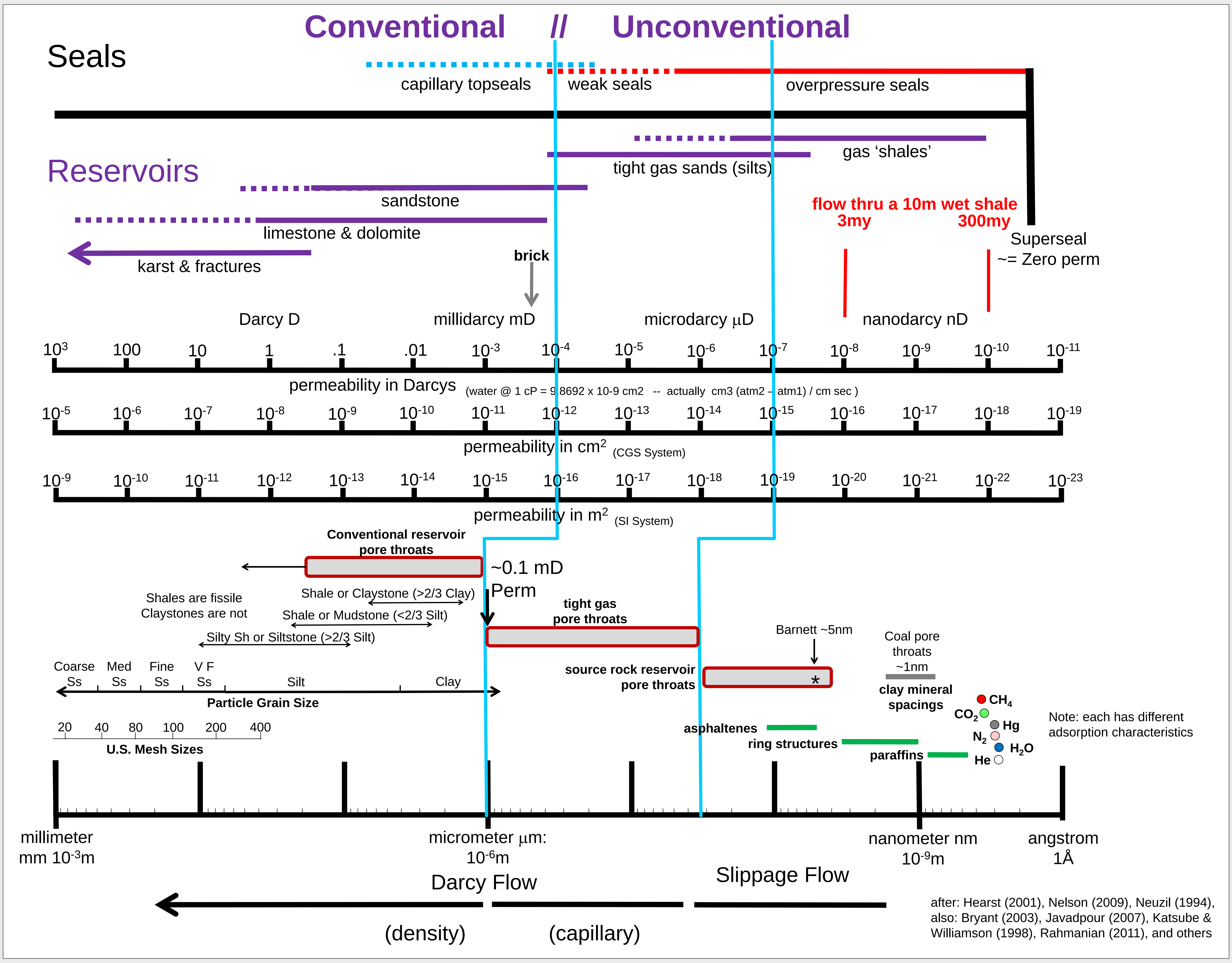


A) Calibrated Barostratigraphic Model for an Example Well
B) Porosity-Permeability for Shale /w Calibrated SSA
C) Uncalibrated test Example with a Higher SSA
D) Same Porosity + Lower SSA = Lower Permeability and Higher Overpressure

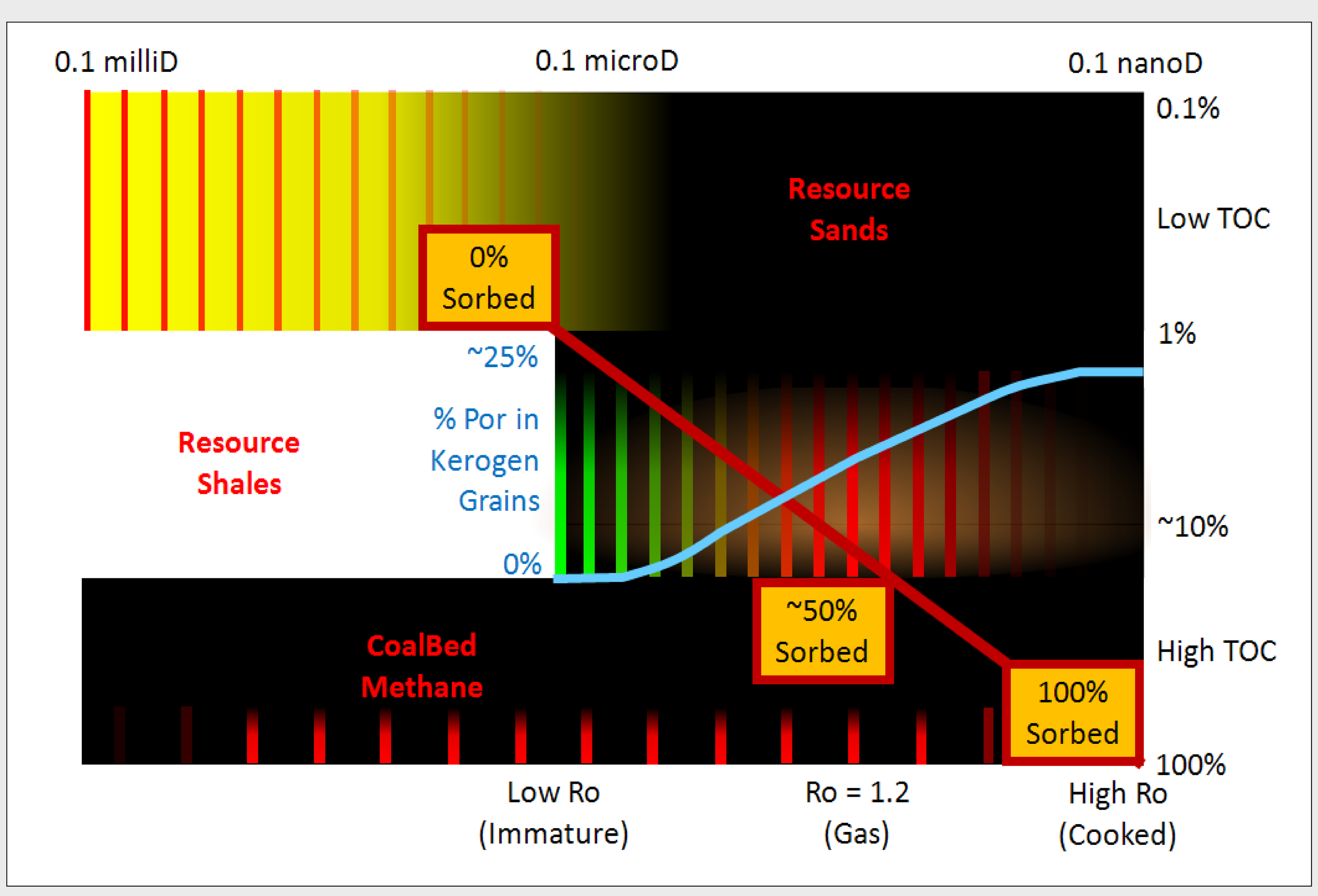
Permeability Measured from Rock Samples

1) SRR permeability is very hard to measure accurately at low values and there is high variability from lab to lab see Ambrose (2011), Cui (2009), Hartman (2011), Passey (2010), Sondergeld (2010)
2) Tests are usually not conducted at reservoir temp & pressure (adsorption & stress effects are often or usually not considered)
3) Tests are usually done on crushed samples & particle size is related to the determined permeability
4) Helium, N_2, etc. is used to measure Perm & is converted to water (intrinsic perm) by various algorithms.
5) Perm to water is less than the perm to gas
6) SRR perms are commonly measured to be in the range of 10-100 nD or lower (pressure-pulse tests on crushed samples) (see Bustin (2008), Civan (2010), Neuzil (1994))

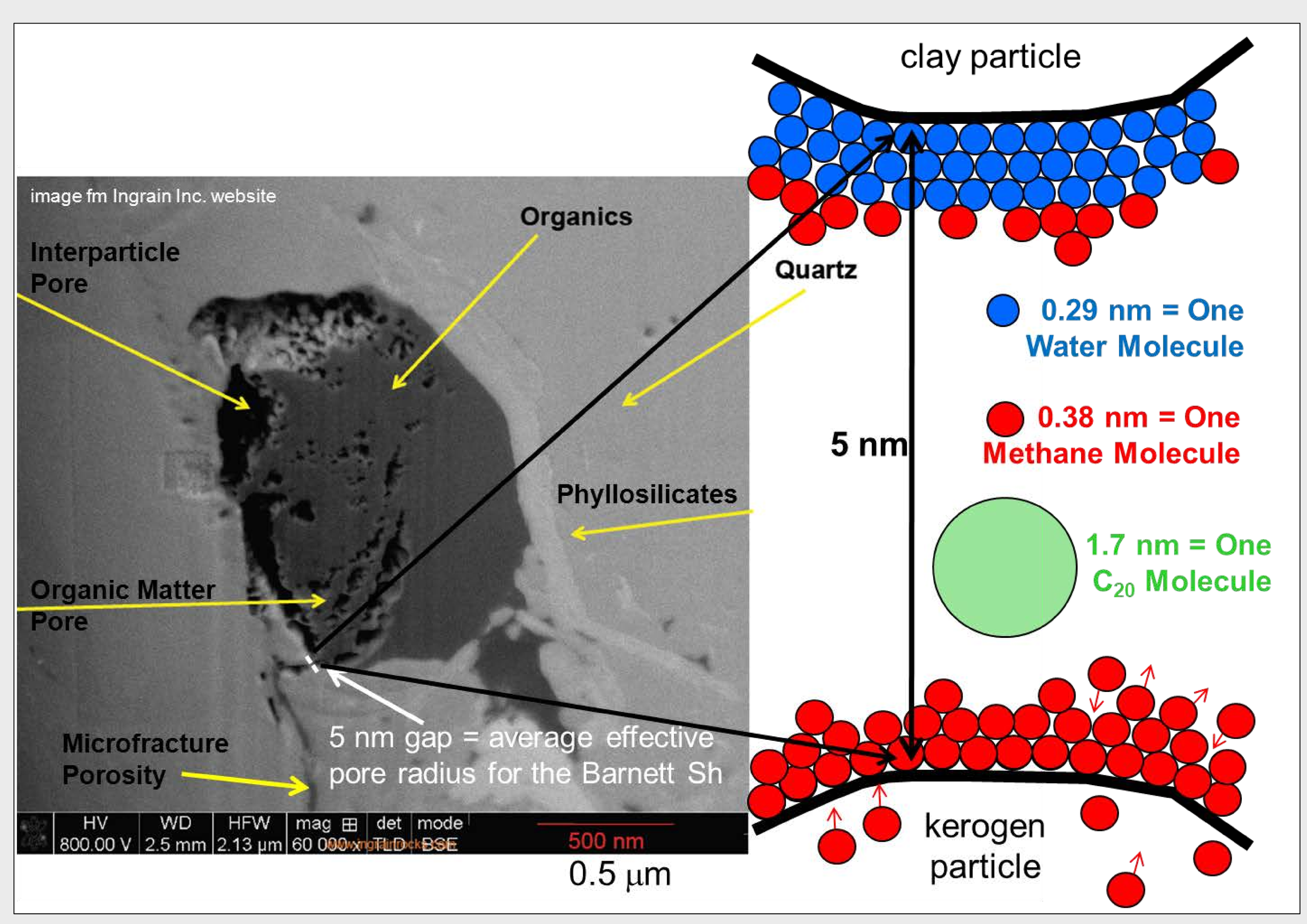
Permeability & Pore Throat Sizes



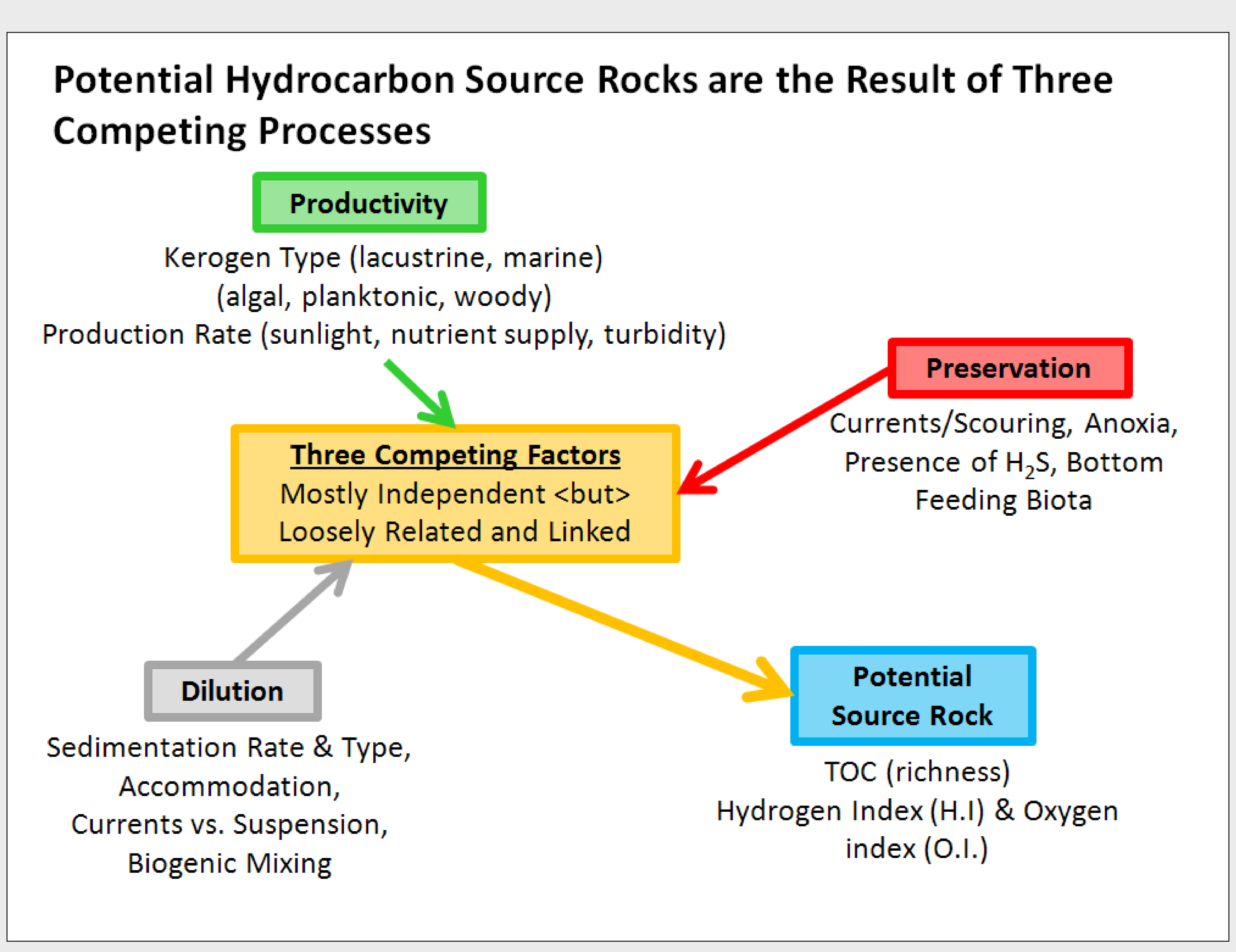
1) SRRs are very Different than Tight Gas



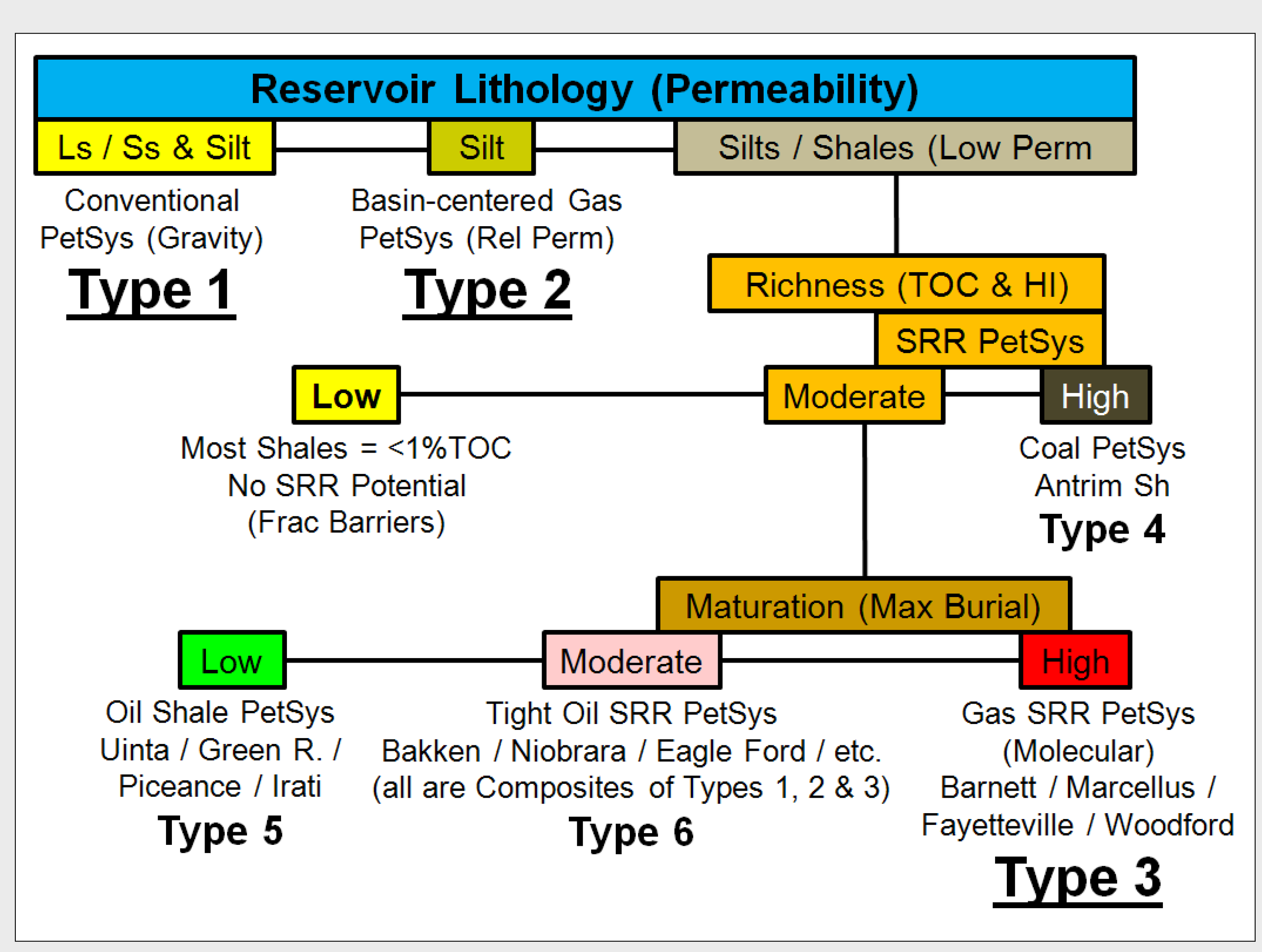
2) Pore throats are at molecular scale



3) Origin & Preservation of Organic Matter

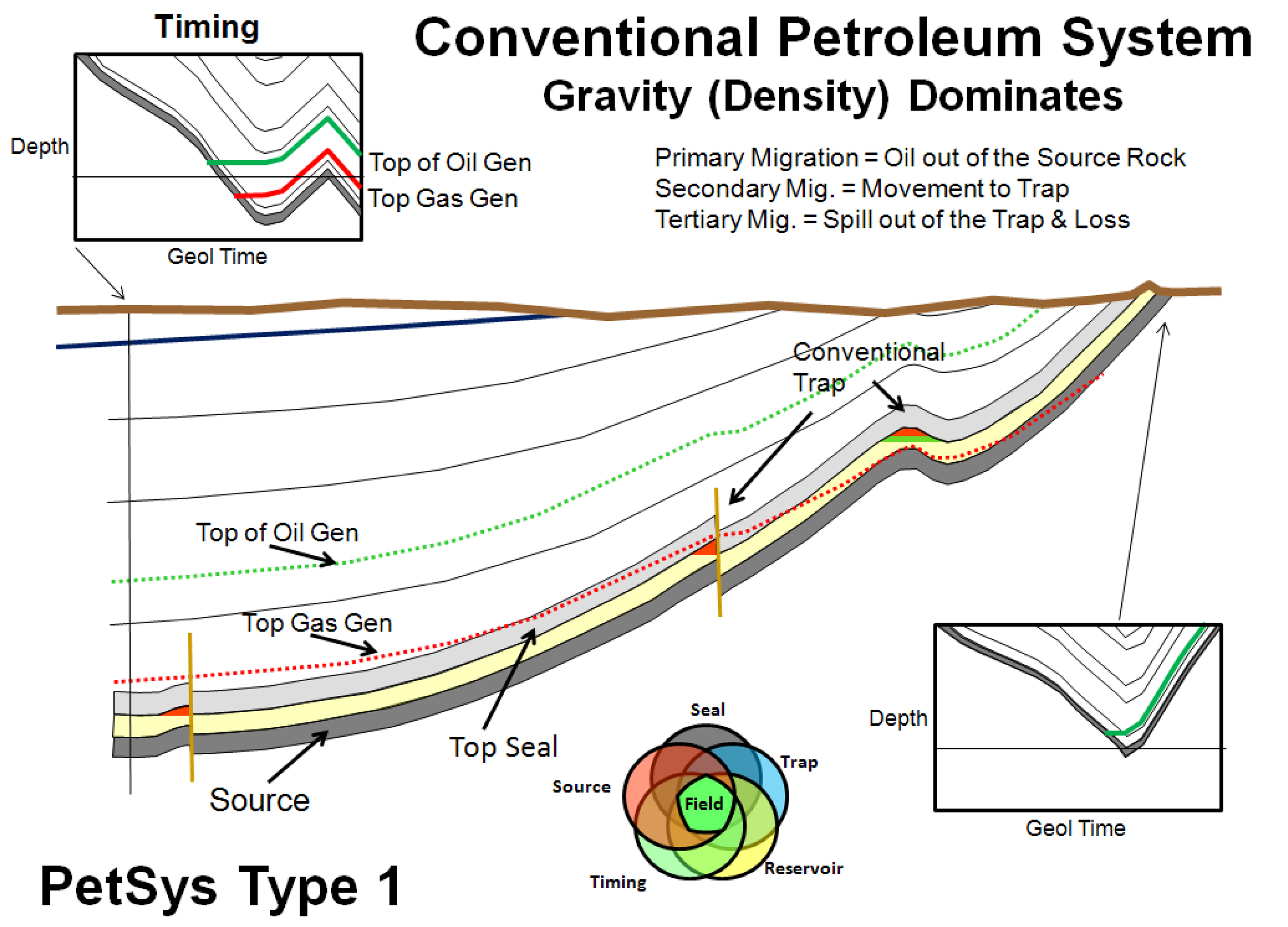


4) Gas SRRs are a Distinct PetSys



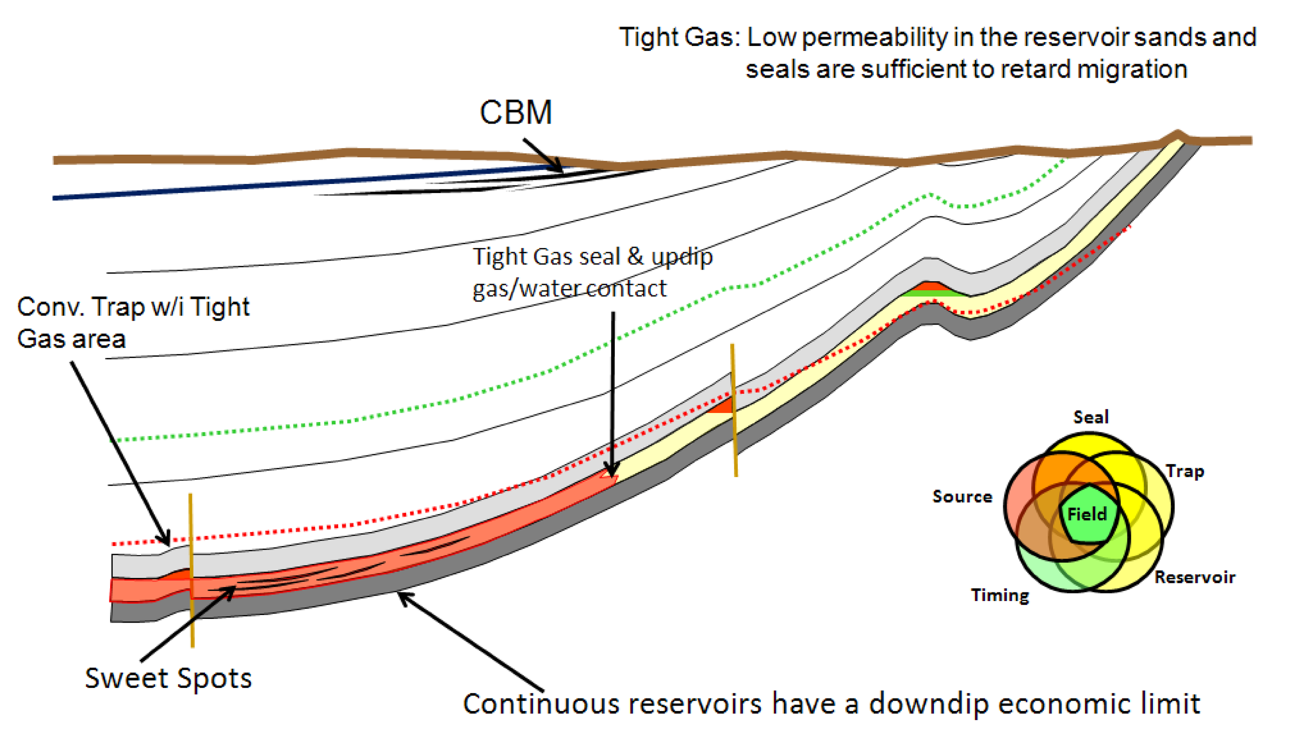
End-Member & Composite Petroleum Systems

Conventional Petroleum System
Gravity (Density) Dominates



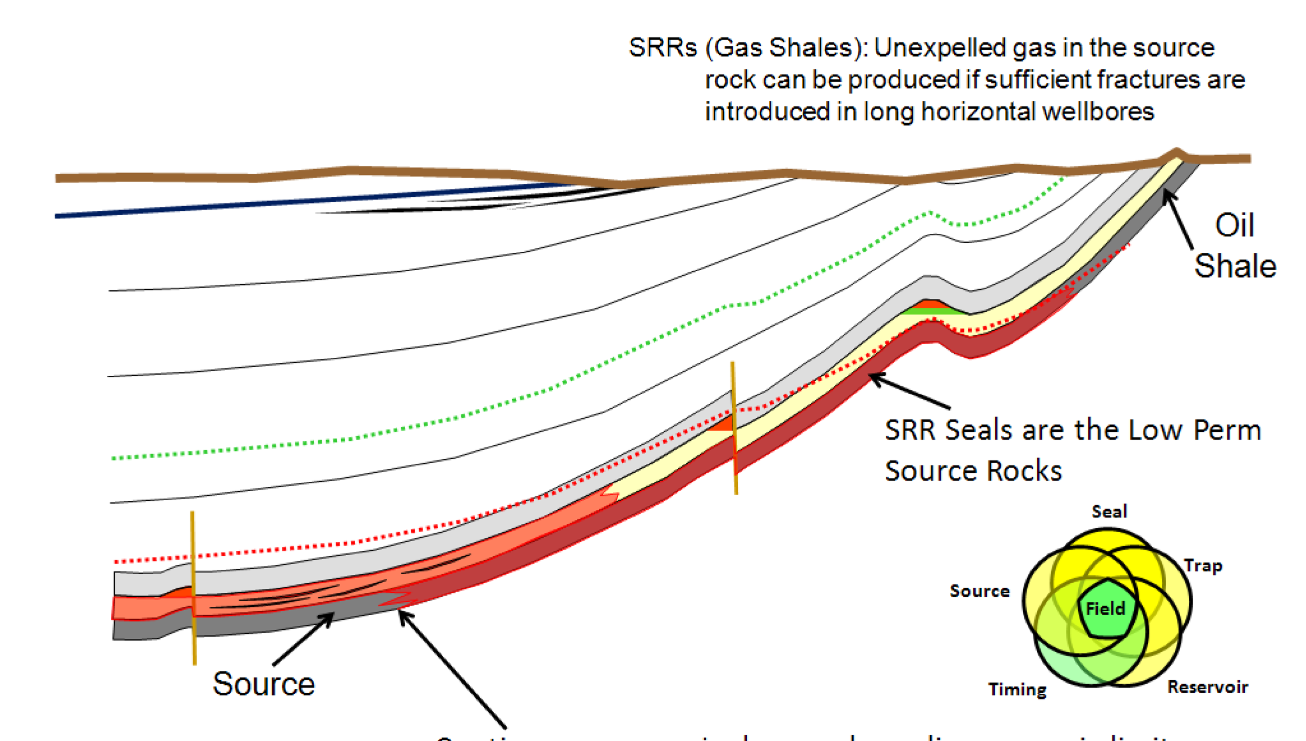
PetSys Type 1

Tight Gas Sands PetSys
(Relative Permeability Dominates)



PetSys Type 2

Gas Source Rock Reservoir PetSys
(Electromagnetic (Molecular) Forces Dominate)



PetSys Type 3

Characteristics of Tight Gas Sands:

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

1) Low permeability (<0.1md) reservoirs
2) Abnormally pressured
   overpressured = accumulating
   underpressured = dissipating
3) Regionally pervasive gas saturation
   (extensive gas shows while drilling)
4) Little produced water
5) Lack a downdip water contact (rare or no gas-water contacts seen on logs)
6) Hydraulic fracturing is required
7) May grade updip into wet zones
8) Sweet spots are very important
9) Structure is often synclinal (poorly defined traps and seals)
10) Often the largest gas field in the basin

Three Things are Required for a Tight Gas Sands PetSys
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)

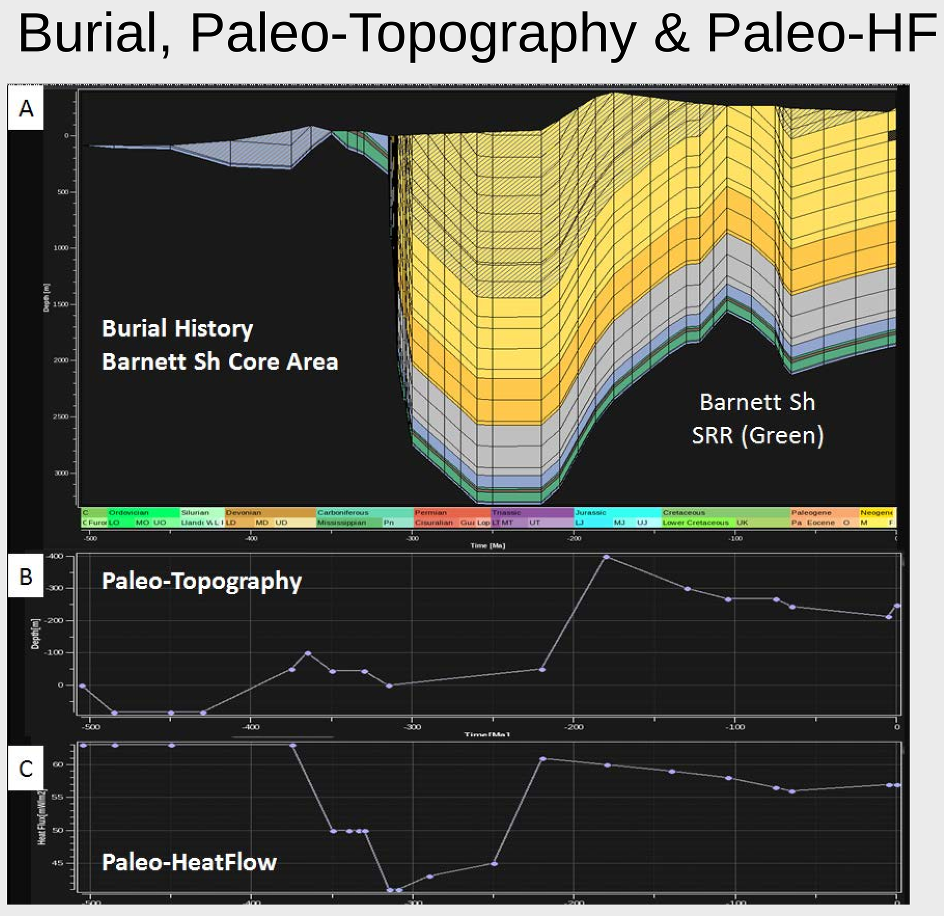
Sweet Spots are Composites of Conventional & Tight Gas Petroleum System Elements

Notes on Source Rock Reservoirs (SRRs)
1) Most shales are *NOT* source rocks
2) SRRs are oil or gas-wet *NOT* water-wet rocks
3) Por in SRRs is *NOT* the same as in conventional rocks
4) Free gas & adsorbed gas is in the kerogen porosity
5) Flow by Knudsen slip gives high deliverability
6) Oil molecules = same size as SRR pore throats
7) Oil SRRs are composites of the SRR and other PetSys
8) SRRs require both horizontal wells & multiple fracs
9) Maturity of the SRR can be modeled and calibrated
10) Maturity informs oil vs. gas production & the clay reactivity

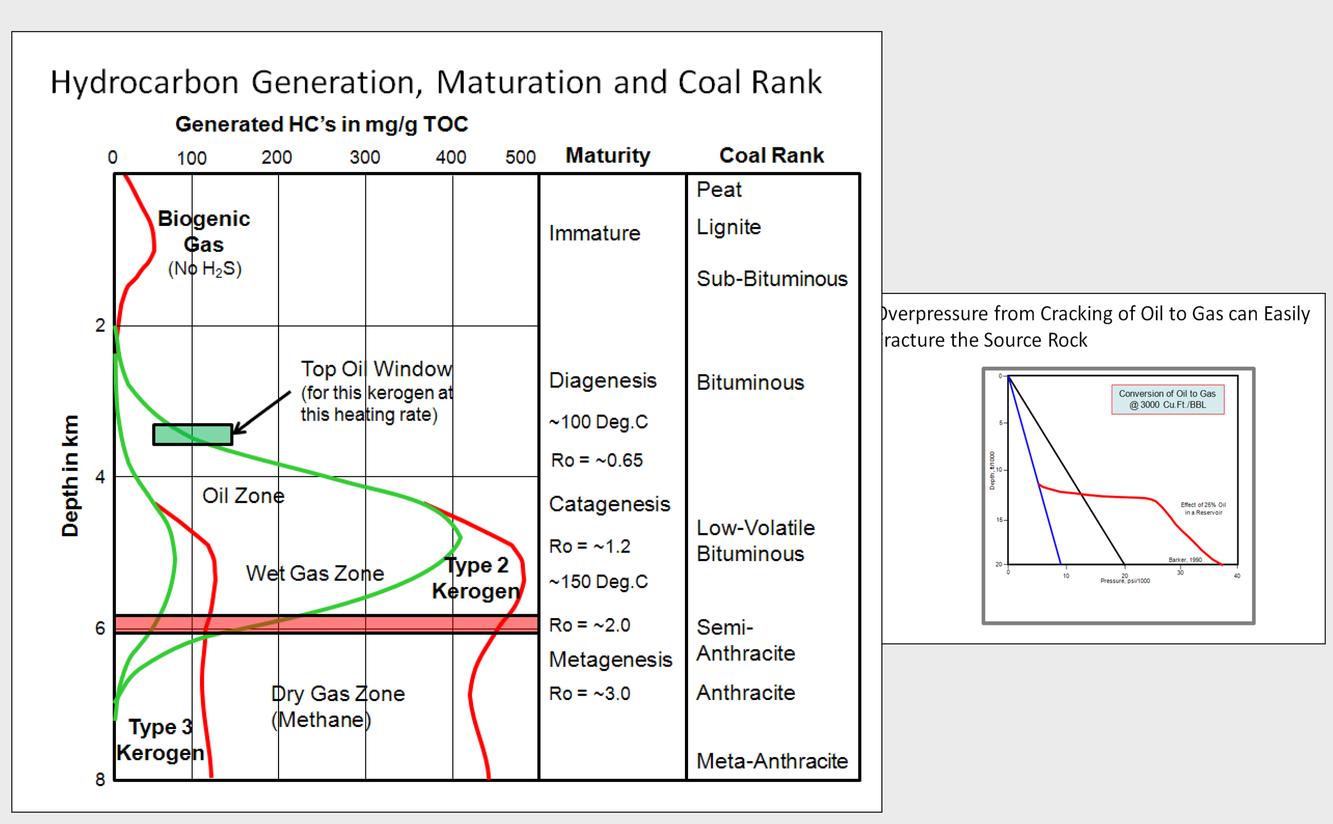
Some Gas and *ALL* Oil SRRs are Composites of SRR &/or Conventional &/or Tight Petroleum System Elements

SRRs are Hydrocarbon Source Rocks

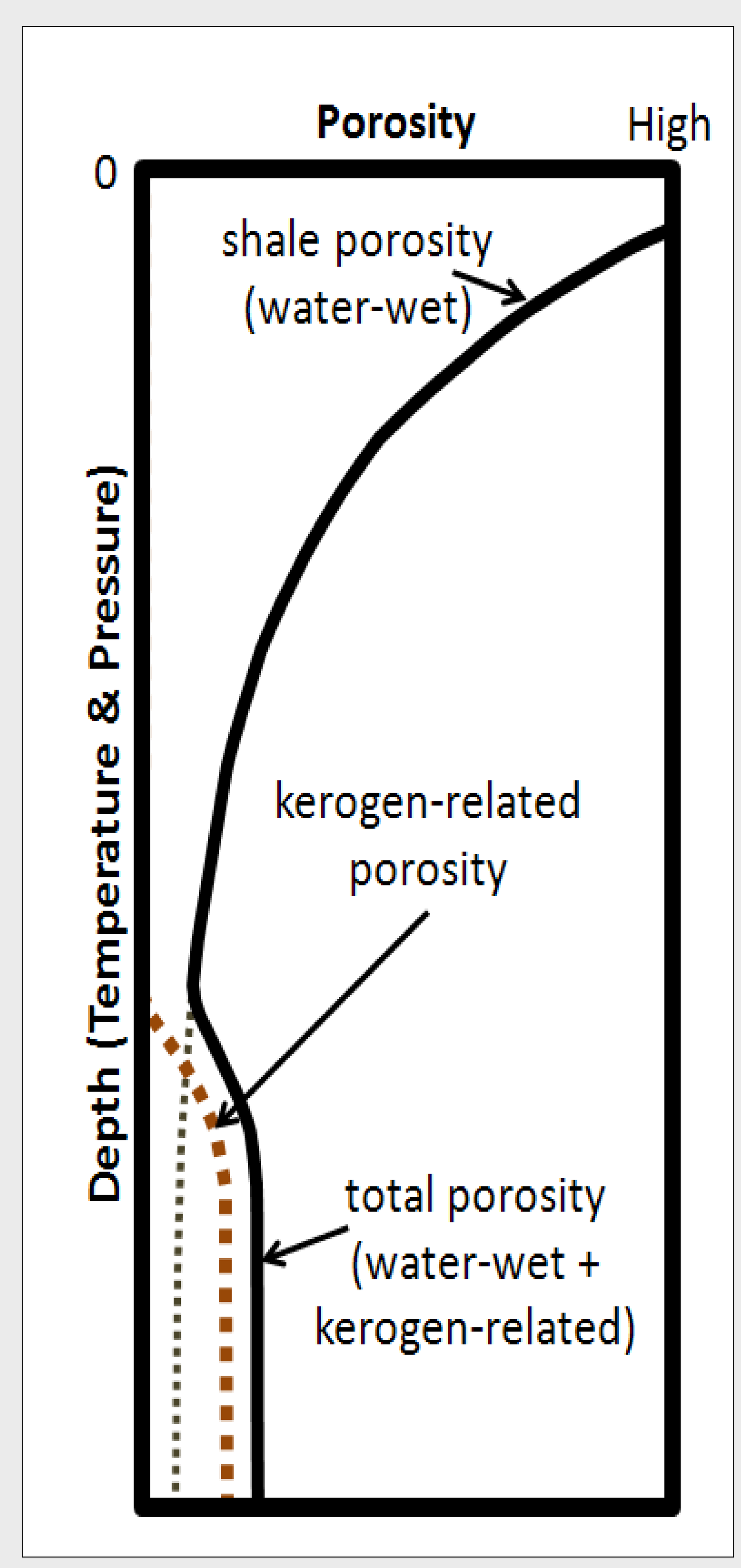
1) Burial, Paleo-Topography & Paleo-HF



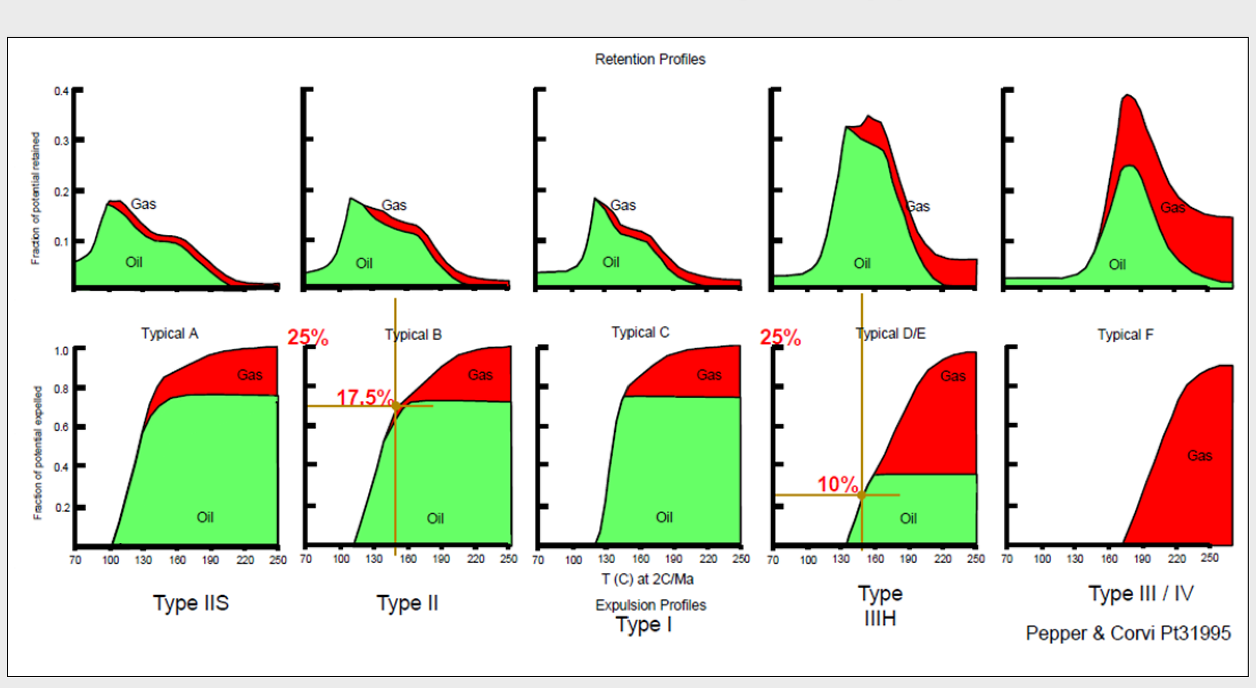
2) Maturation, Expulsion & Pressure



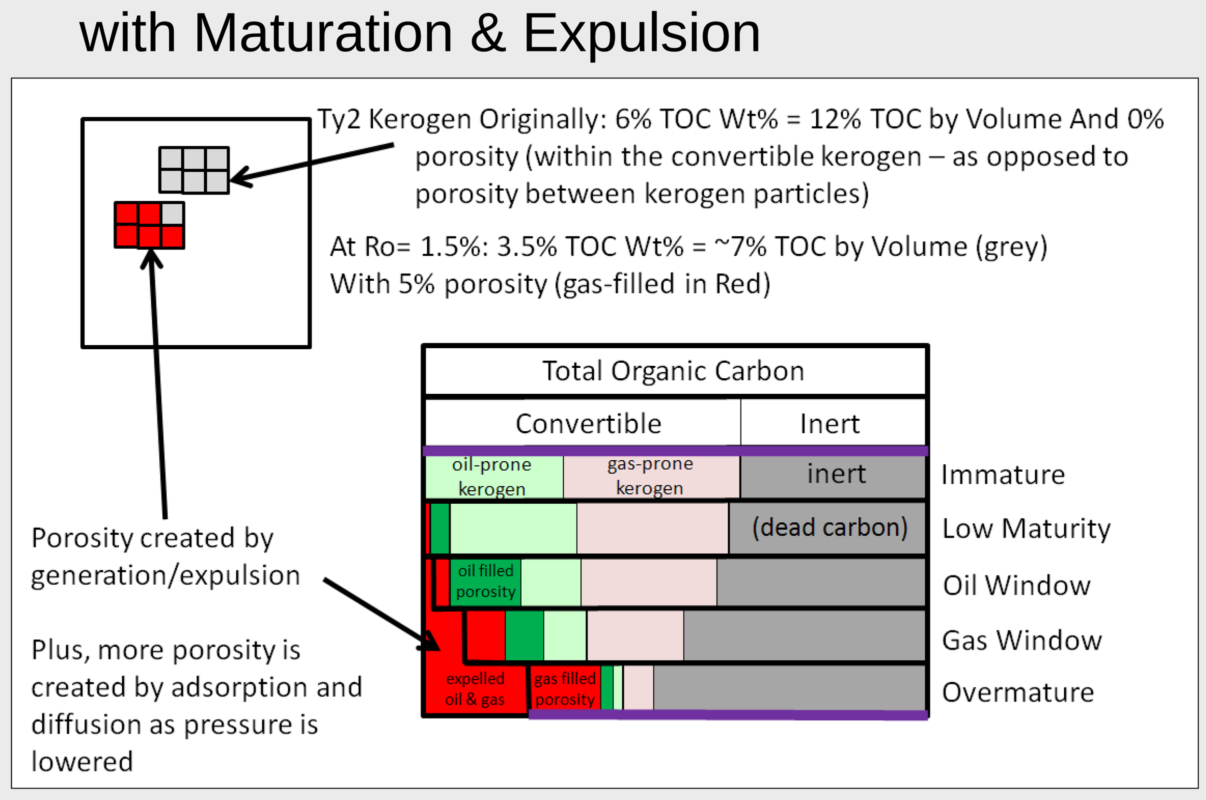
5) Porosity vs. Depth for SRRs and Normal Shales



3) Generation & Expulsion Rates are Different for Different Kerogen Types

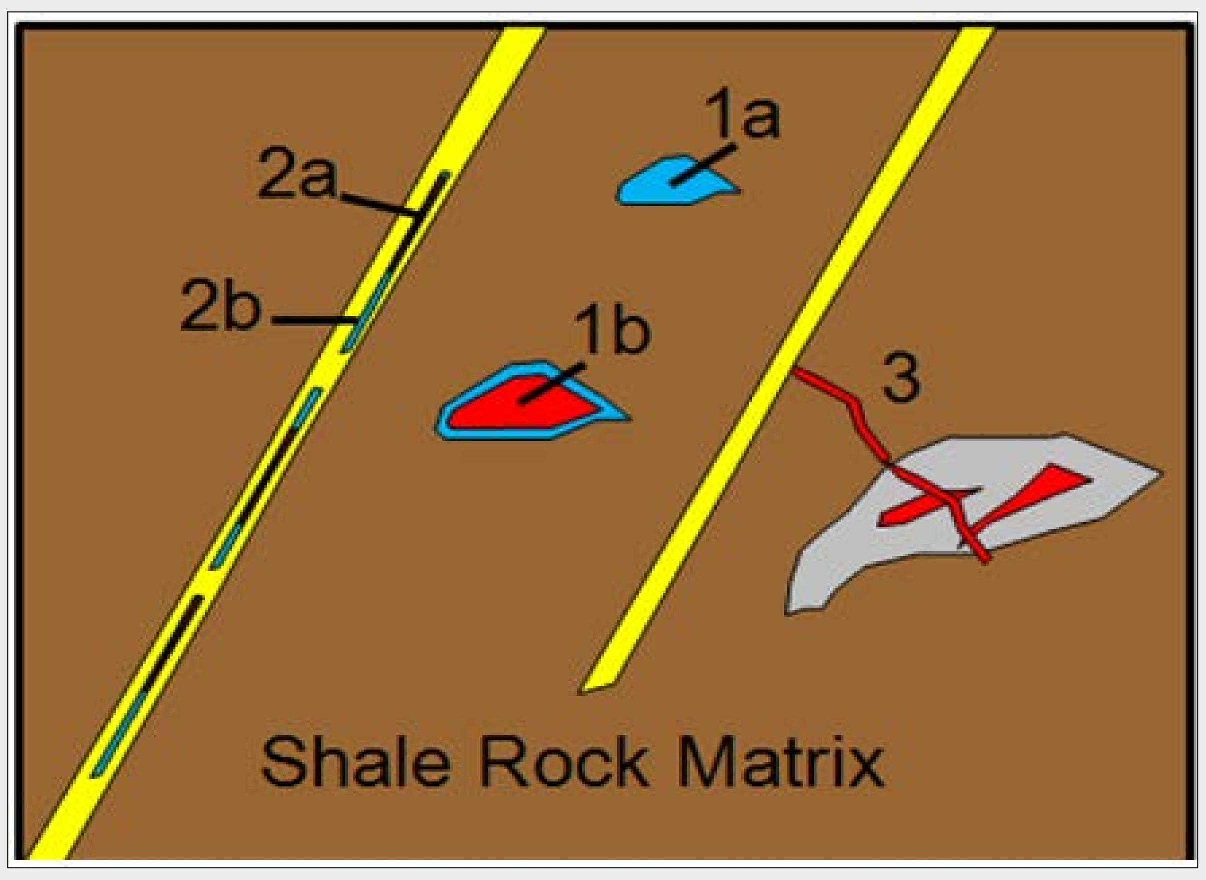


4) Internal Kerogen Porosity Develops with Maturation & Expulsion



The SRR Matrix has Both Water-wet (Darcy Flow) and Oil/Gas-wet (Slip Flow) Porosity

1) Porosity in SRRs is Complicated

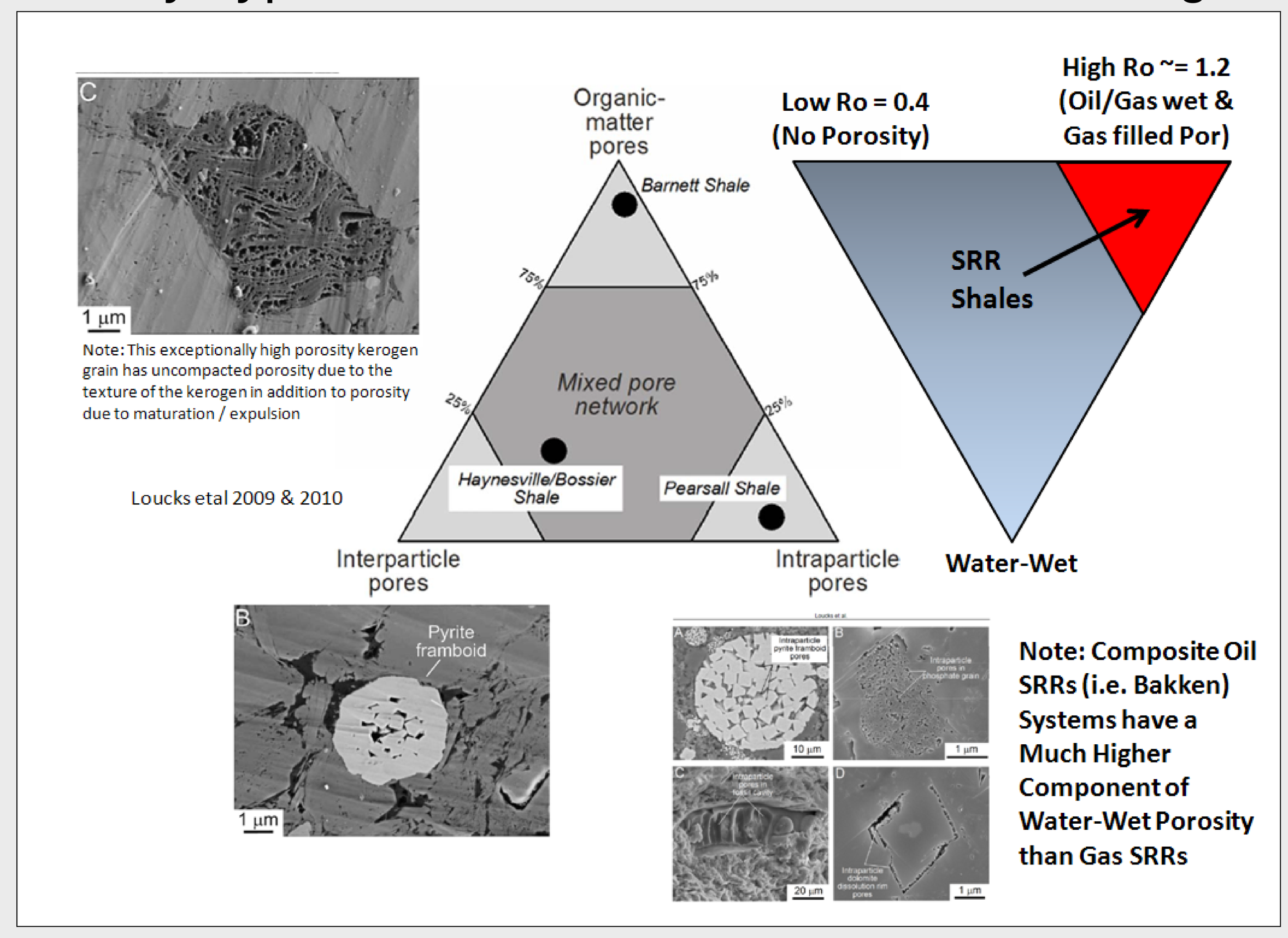


1a) Water-wet
1b) Water-wet & gas-filled

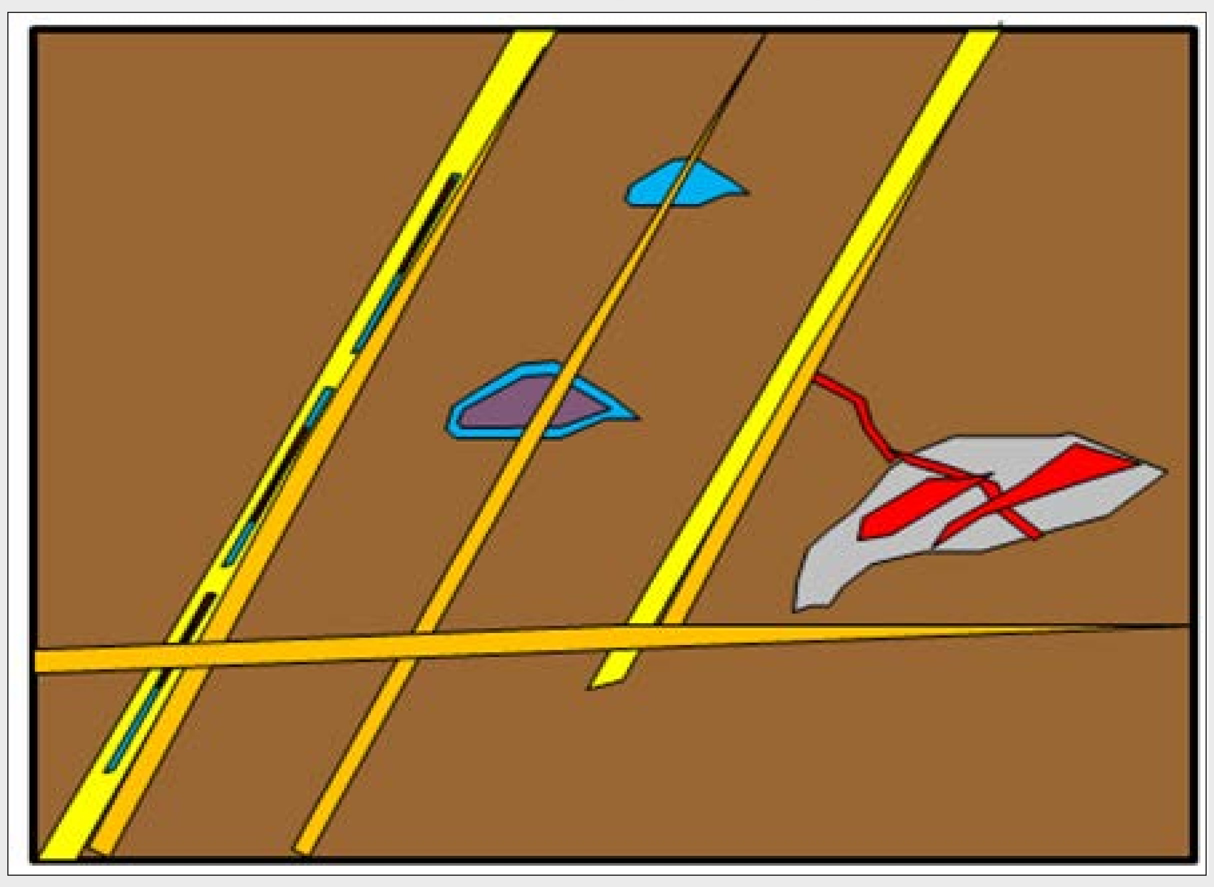
2a) Gas in fractures
2b) Water in fractures

3) Kerogen and microporosity oil/gas-wet and gas filled

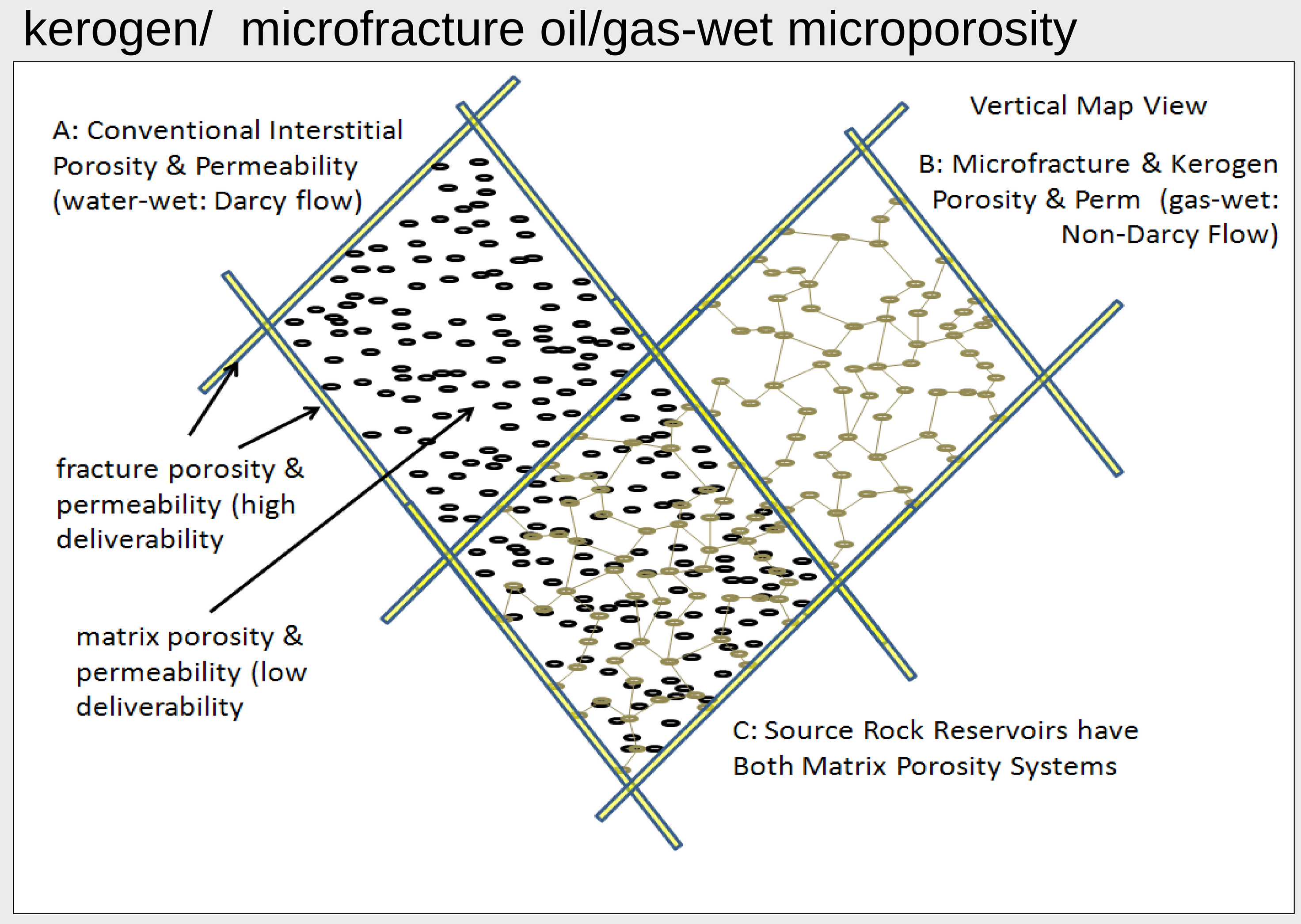
2) Porosity Types in SRRs are both water-wet & oil/gas-wet



3) Hydraulic fracturing reconnects to the kerogen porosity & microfractures created by HC expulsion



4) SRR porosity is a composite of conventional water-wet and kerogen/ microfracture oil/gas-wet microporosity



5) In a Gas SRR, the two main matrix porosity systems **overlap but do not connect:**

a) The microfracture system created by primary migration is very small (5 nm in the Barnett)
=> high capillary entry pressure

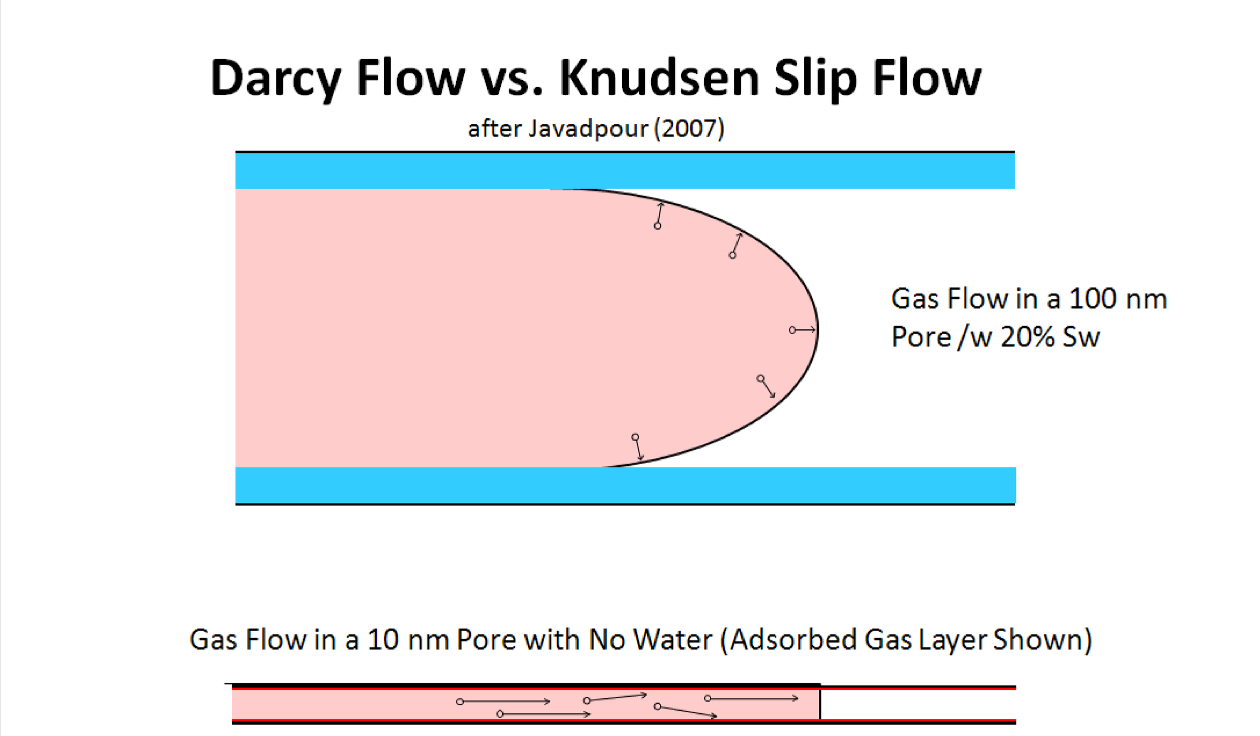
b) The kerogens & microfractures are oil or gas-wet
=> entering water must overcome relative permeability

c) The kerogen system is overpressured relative to the water-wet system (it expelled hydrocarbons)

6) The Dominant Physics of Flow Changes with Changing Scales of Permeability

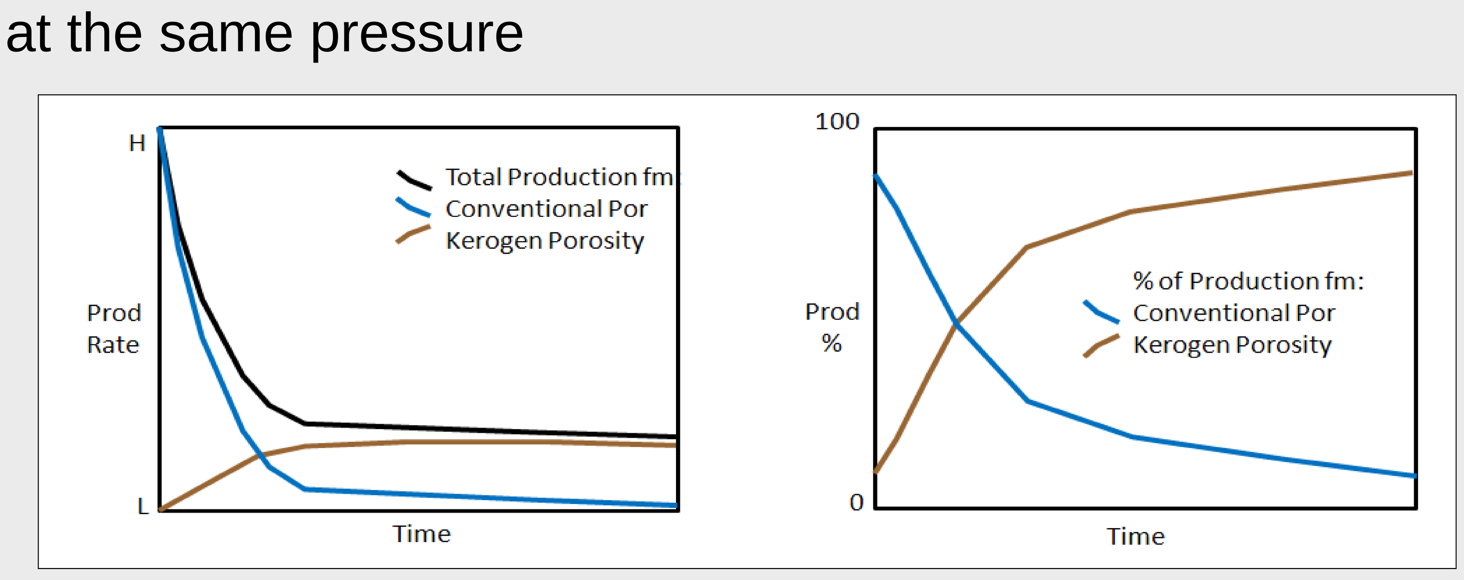
	Conventional Perm	Tight Gas Perm	SRR Perm
Matrix (water-wet)			Zero > Low in Composite SRR's
Kerogen (Oil or Gas-wet / Gas Filled)	Kerogen Not Present	Kerogen Not Present	High Flow Rates Due to Slippage (Sw Not Relevant)
Hydraulic Fractures (propped & water-wet)	Not Needed		

after Shanley, 2004



"the enhanced transport in a 10 nm capillary is comparable to classical transport in a 100 nm capillary!" Akkutlu and Fathi (2011)

7) The two porosity systems will flow at different rates at the same pressure



Conclusions:

- Conventional, Tight Gas & SRRs are different PetSys
- The permeability in overpressure seal units is the same as permeability in SRRs
- Permeability is not the controlling factor in SRR production
- The physics of flow changes with changing scales of permeability and pore throats
- Knudsen diffusion dominates in nanometer pore throats in gas systems and provides high deliverability where Darcy flow would be low enough to be a pressure seal
- TOC and maturation (geologic history) are important
- Kerogen porosity develops as oil/gas are expelled
- Gas is adsorbed onto the kerogen surface and free gas is present in the porosity
- The kerogen system is oil or gas-wet and gas-filled
- SRRs are a composite of the two different storage/delivery systems (water-wet <and> kerogen system)
- Hydraulic fracturing reconnects to the kerogen system
- Oil SRRs are composites of several PetSys

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