Our Current Working Model for Unconventional Tight Petroleum Systems: Oil and Gas*

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Search and Discovery Article #41968 (2016)**
Posted December 26, 2016

*Adapted from oral presentation given at AAPG Pacific Section and Rocky Mountain Section Joint Meeting, Las Vegas, Nevada, October 2-5, 2016

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Abstract

The driving forces for conventional accumulations (structural or stratigraphic traps) are Forces of Buoyancy which are due to differences in densities of hydrocarbons and water. In contrast, the driving forces for unconventional tight accumulations are Forces of Expulsion which are produced by high pressures. That is an enormous difference and creates unconventional petroleum systems that are characterized by very different and distinctive characteristics. The Force of Expulsion pressures are created by the significant increase in volume when any of the three main kerogen types are converted to hydrocarbons. At those conversion times in the burial history, the rocks are already sufficiently tight so the large volumes of generated hydrocarbons cannot efficiently escape through the existing tight pore system, thus creating a permeability bottleneck that produces an overpressured compartment over a large area corresponding to the proper thermal oil and gas maturities for that basin. The forces initially created in these source rocks can only go limited distances into adjacent tight reservoirs (clastics or carbonates) above or below the source. The exact distance will vary depending on the pressure increase, matrix permeability, and fractures of that specific tight reservoir system. In general, the distances are small, in the orders of 10s to 100s of feet for oil and larger for more mobile gas systems. Those exact distance numbers are subject to ongoing investigations.

A plot of the pressure data versus elevation for a given formation is critical in determining whether an accumulation is conventional or unconventional. Conventional accumulations will have hydrocarbon columns of 10s to 100s of feet with the pressure in the hydrocarbons and that in the water equal at the bottom of the accumulation (at the HC-water contact). In contrast, the unconventional accumulations will show HC column heights of 1000s of feet with the pressure in the hydrocarbon phase and the water phase being the same at the top of the accumulation (at the updip transition zone). Those significant differences are critical for understanding and differentiating these two play types. Because the system is a pore throat bottleneck with very little or minimum lateral migration, the type of hydrocarbons are closely tied to the thermal maturity required to generate those hydrocarbons. Thus the play concept begins with two important geochemical considerations: (1) where are the source rocks and what are the kerogen types and organic richness (TOC), and (2) where are they mature in the basin for oil, condensate, and gas in the basin. These parameters will very quickly define the fairway for the play. Then one has to add the critical information on the reservoirs themselves: composition (brittleness), thickness, and reservoir quality (matrix porosity and permeability). In

summary, these tight unconventional petroleum systems (1) are dynamic, and (2) create a regionally inverted petroleum system with water over oil over condensate over gas for source rocks with Type I or II kerogen types.

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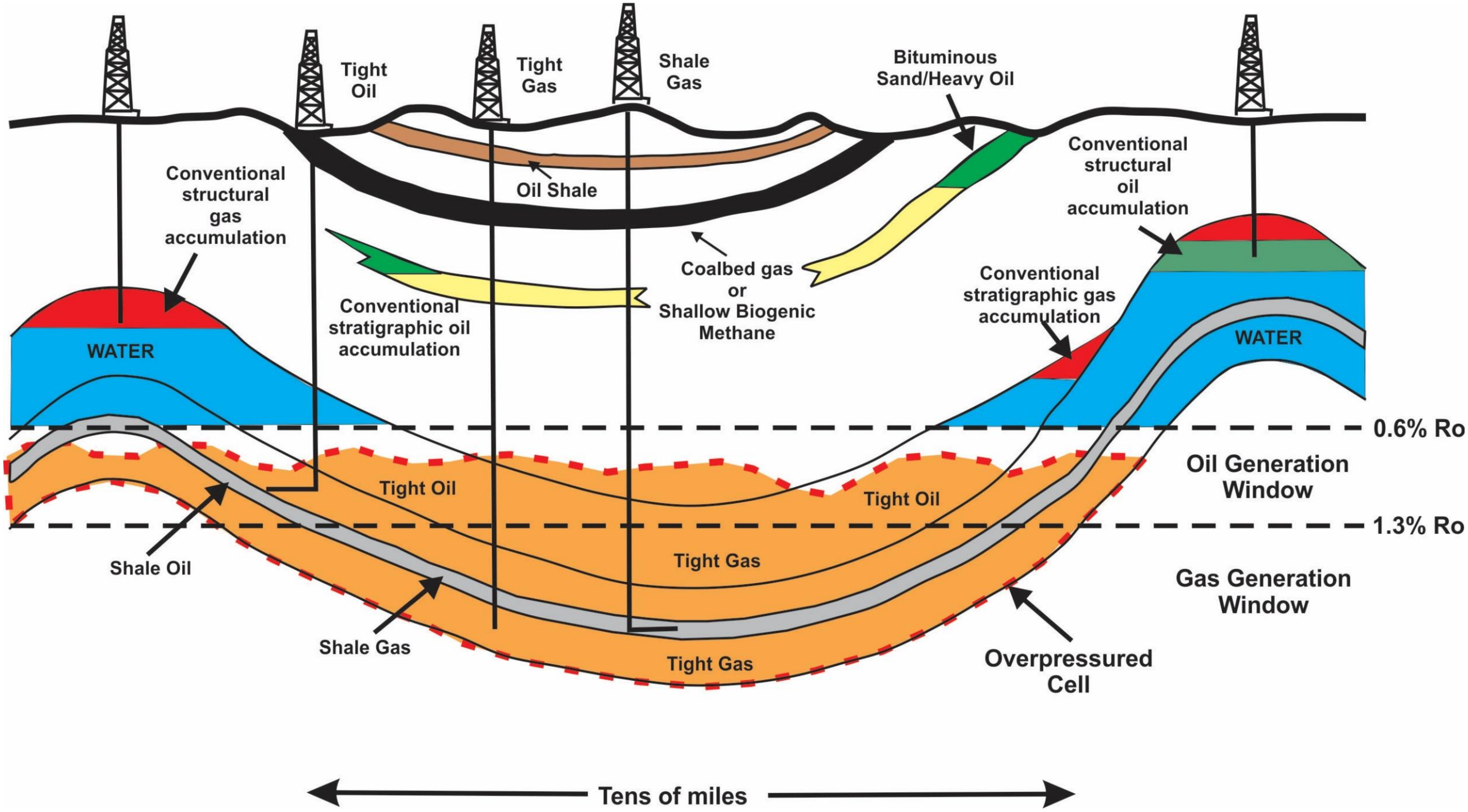
OUR CURRENT WORKING MODEL FOR UNCONVENTIONAL TIGHT PETROLEUM SYSTEMS: OIL AND GAS

Stephen A. Sonnenberg

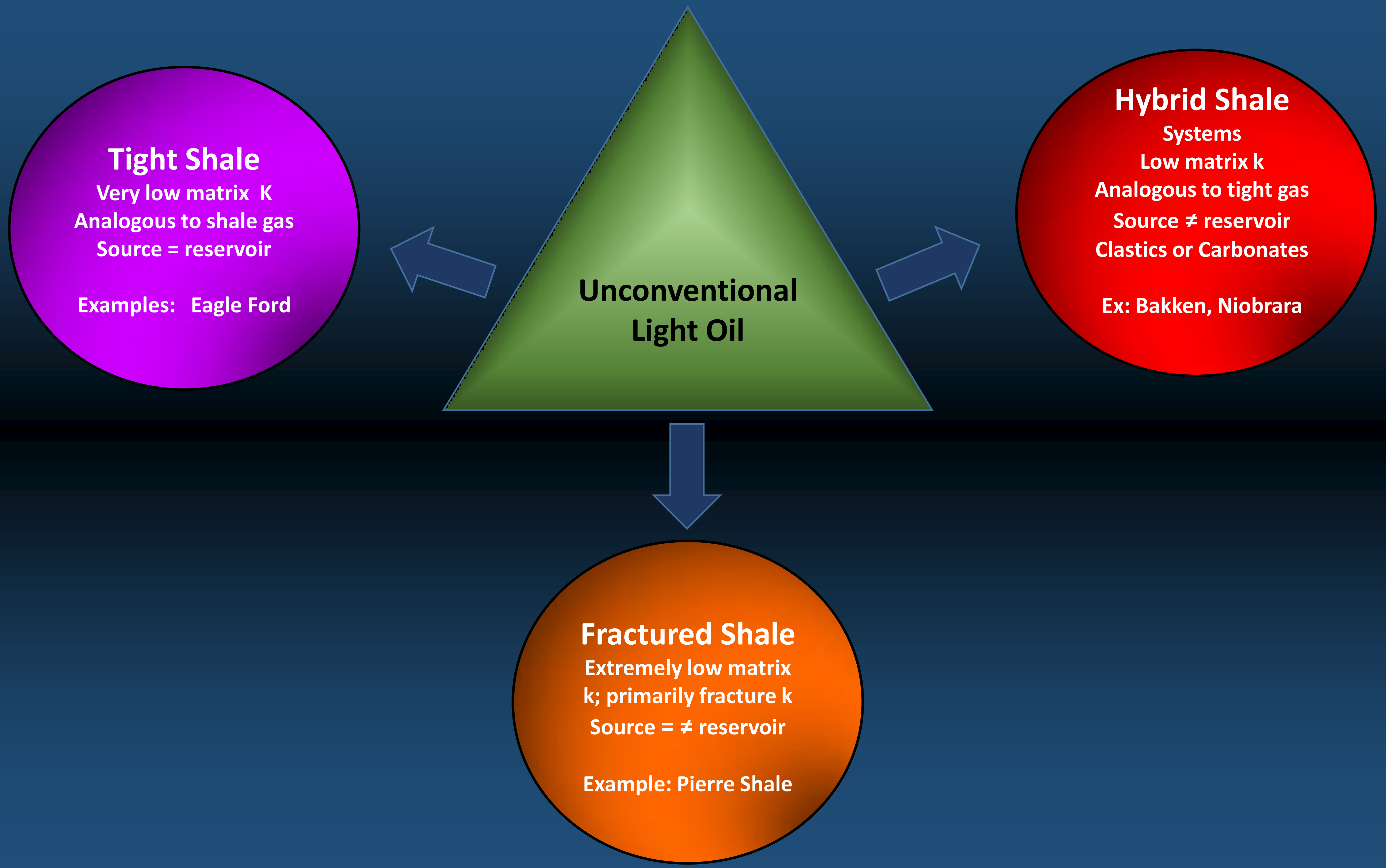
Larry Meckel

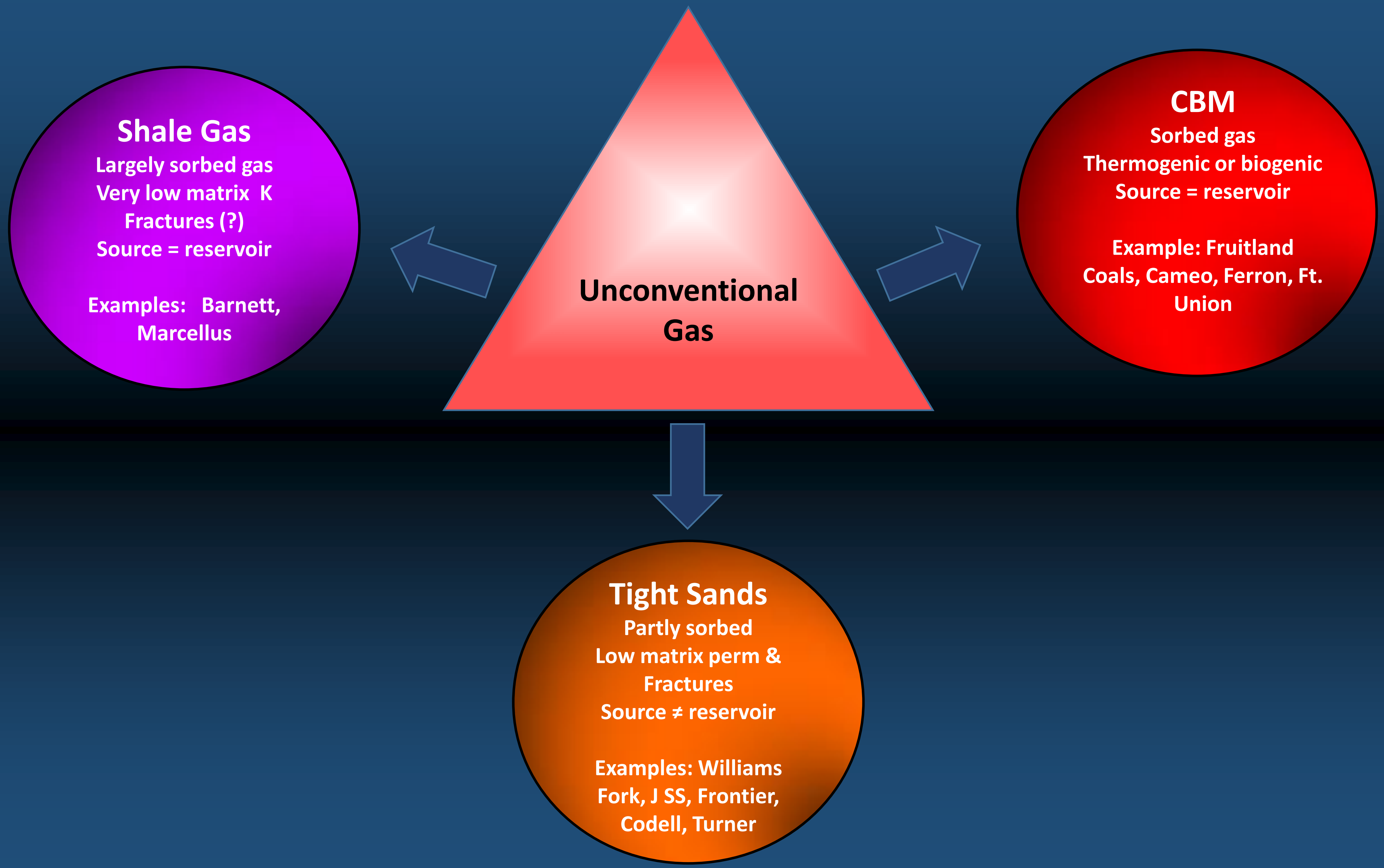
Outline

- Continuous (unconventional) versus discrete (conventional) traps
- Oil expulsion and accumulation
- Forces of expulsion versus buoyancy
- Abnormal pressure systems
- Microfractures
- Pressure compartments through time
- Residual oil and water saturations
- Inverted petroleum systems
- Check list for finding continuous accumulations
- Summary



Tight Oil
Tight Gas
Shale Gas
Bituminous Sand/Heavy Oil
Conventional structural gas accumulation
Oil Shale
Conventional structural oil accumulation
Coalbed gas or Shallow Biogenic Methane
Conventional stratigraphic gas accumulation
Conventional stratigraphic oil accumulation
WATER
WATER
0.6% Ro
Oil Generation Window
Tight Oil
Tight Oil
1.3% Ro
Tight Gas
Shale Oil
Gas Generation Window
Shale Gas
Tight Gas
Overpressured Cell
Tens of miles


Tight Shale
Very low matrix K
Analogous to shale gas
Source = reservoir
Examples: Eagle Ford
Unconventional
Light Oil
Hybrid Shale
Systems
Low matrix k
Analogous to tight gas
Source ≠ reservoir
Clastics or Carbonates
Ex: Bakken, Niobrara
Fractured Shale
Extremely low matrix
k; primarily fracture k
Source = ≠ reservoir
Example: Pierre Shale


Unconventional Gas
Shale Gas
Largely sorbed gas
Very low matrix K
Fractures (?)
Source = reservoir
Examples: Barnett, Marcellus
CBM
Sorbed gas
Thermogenic or biogenic
Source = reservoir
Example: Fruitland Coals, Cameo, Ferron, Ft. Union
Tight Sands
Partly sorbed
Low matrix perm & Fractures
Source ≠ reservoir
Examples: Williams Fork, J SS, Frontier, Codell, Turner

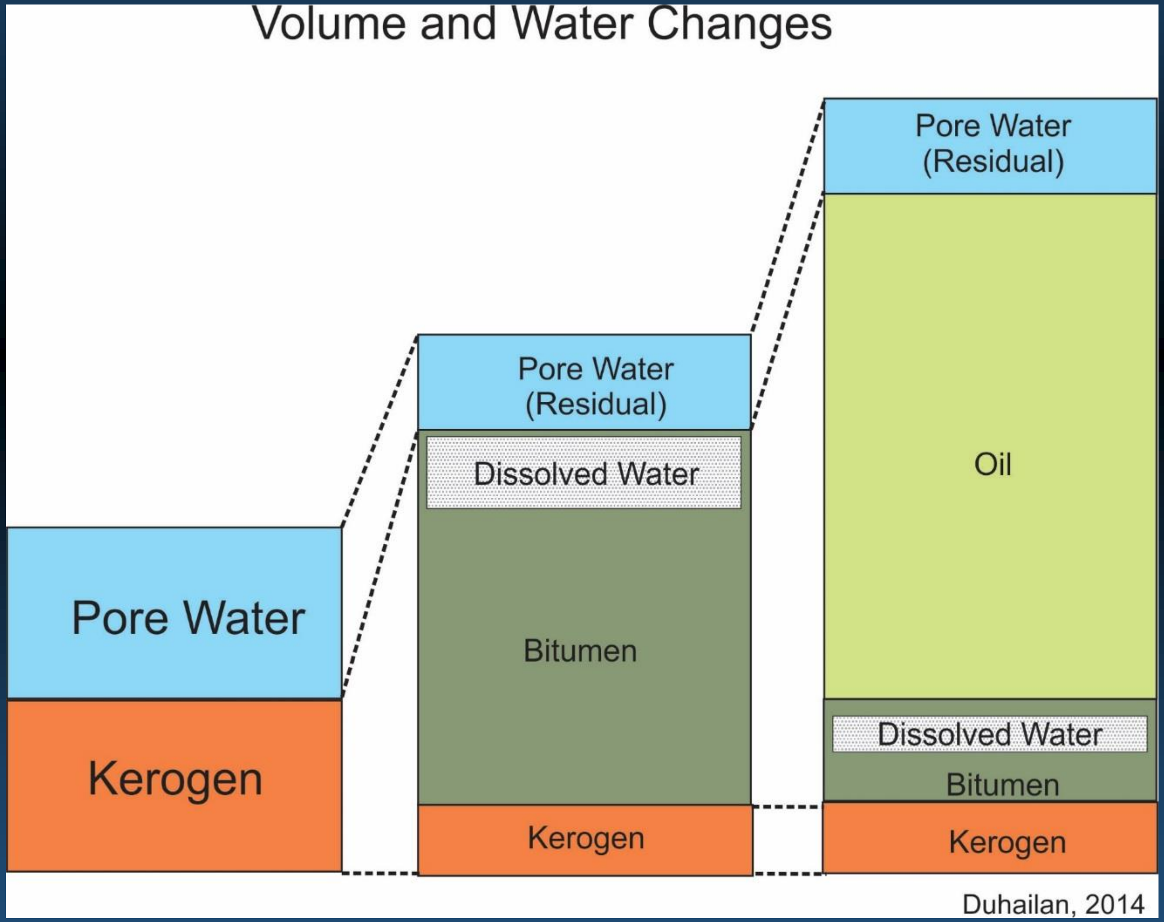
Oil Expulsion and Accumulation (Price, 2000)

- Deep parts of sedimentary basins are closed-fluid systems, where fluid movement is difficult
- Oil expulsion from source rock systems is inefficient
- Unless source rocks are physically disrupted by intense structural activity, faulting or good fluid conduits (sandstones), oil expulsion does not occur
- Most oil remains in or adjacent to its source rock

Kerogen to Bitumen to Hydrocarbons

Step 1.
- Conversion of kerogen to bitumen
- Reduction of kerogen volume
- Creation of kerogen nanopores
- Expansion of bitumen into pore spaces
- Increase in pressure
- Bitumen absorbs water

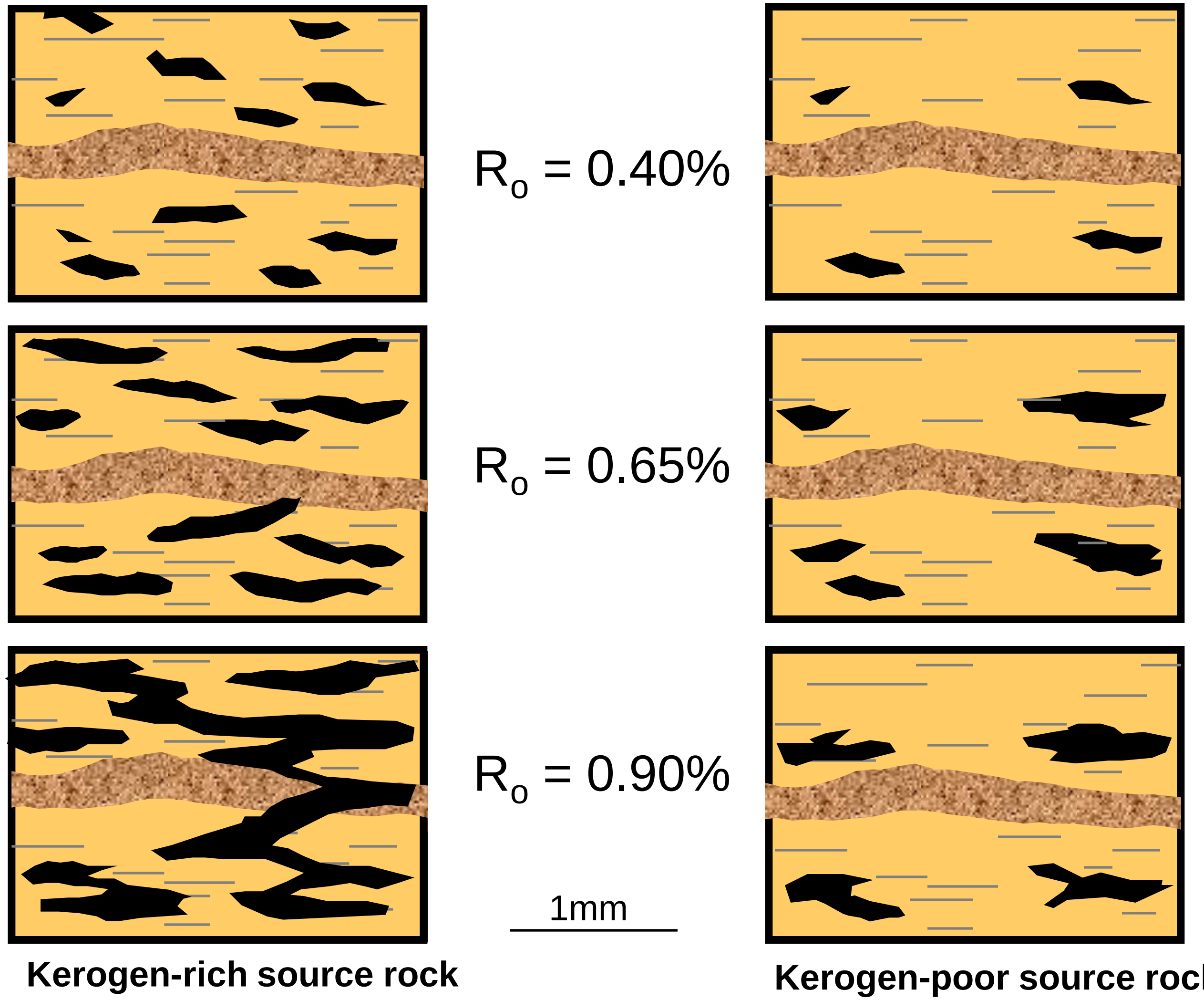
Step 2.
- Conversion of bitumen to oil
- Significant increase in volume
- Significant increase in pressure
- Drives remaining water out of system
- Exceeds rock tensile strength
- Creates microfractures



This large volume change in tight rock creates
FORCES OF EXPULSION
(Pressure Driven)

Very different from the FORCES OF BOUYANCY (Density Driven)
we used to for Conventional Systems

Impact of Organic Richness on Development of a Continuous Oil-Saturated Network



Kerogen-rich source rock

IMMATURE ZONE
Φ=15%
So=0
Water expulsion (compaction)

ONSET OF OIL FORM. ZONE
HC Generated invade Surrounding porosity
Φ=10%
So=20%
No oil expulsion

MIDDLE OR END OF OIL FORMATION ZONE
Φ=8%
So=20%
Primary migration is possible

Kerogen-poor source rock

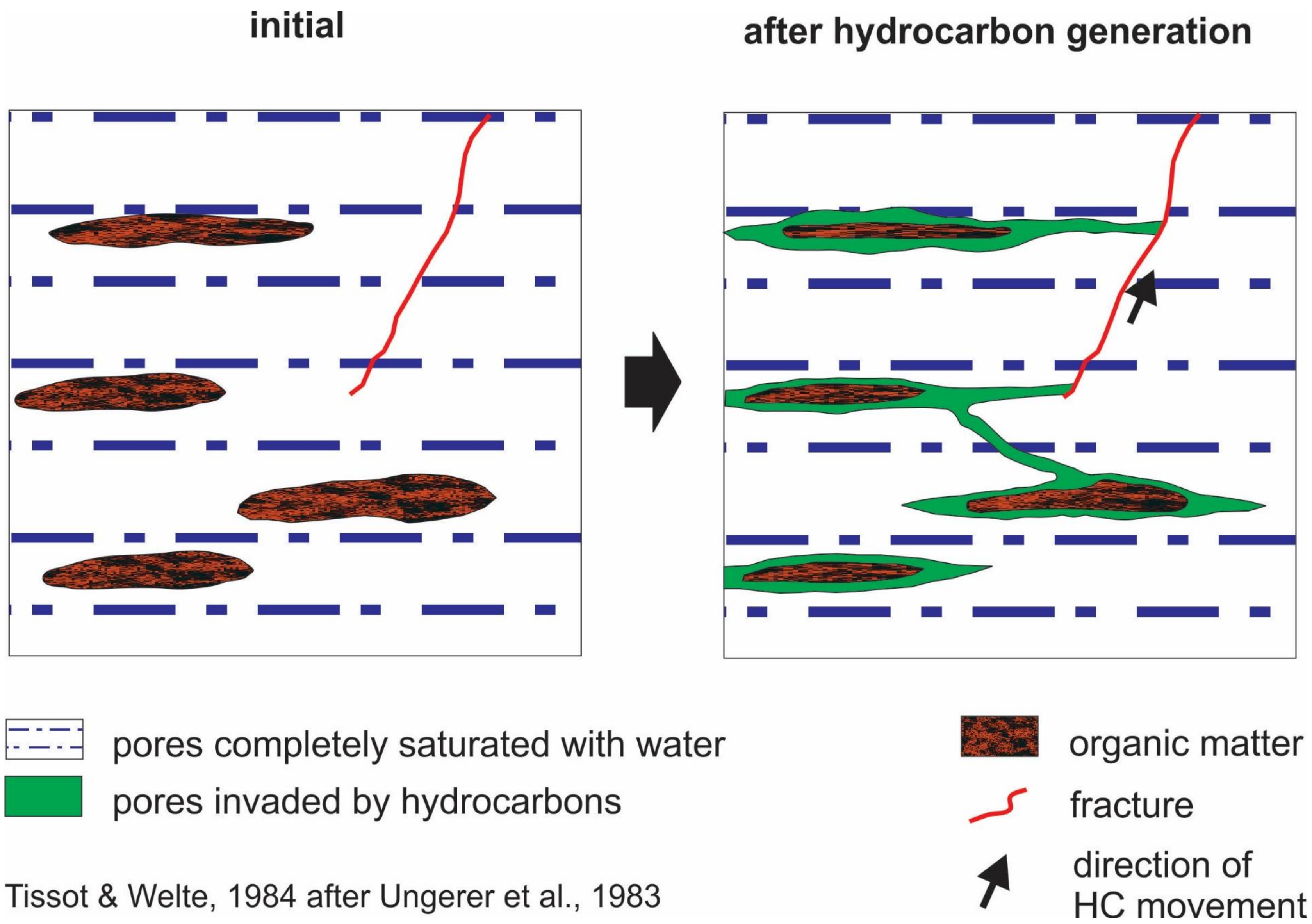
IMMATURE ZONE
Φ=15%
So=0
Water expulsion (compaction)

ONSET OF OIL FORM. ZONE
HC Generated invade Surrounding porosity
Φ=10%
So=20%
No oil expulsion

MIDDLE OR END OF OIL FORMATION ZONE
Φ=8%
So=20%
Primary migration is still not possible

after Katz, 2012 after Durand, 1988

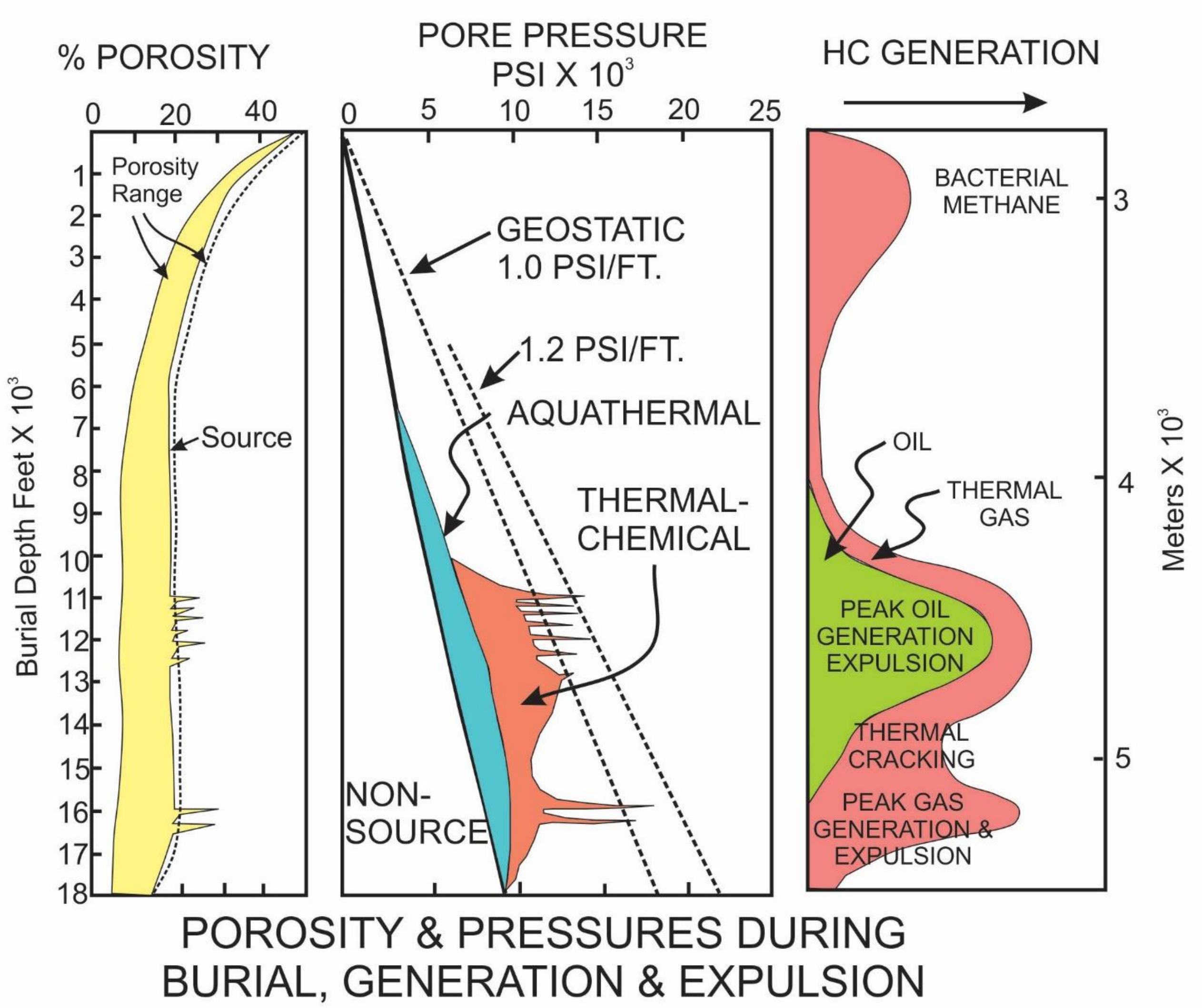
MICROFRACTURES



Forces of Expulsion Does Four Important Things

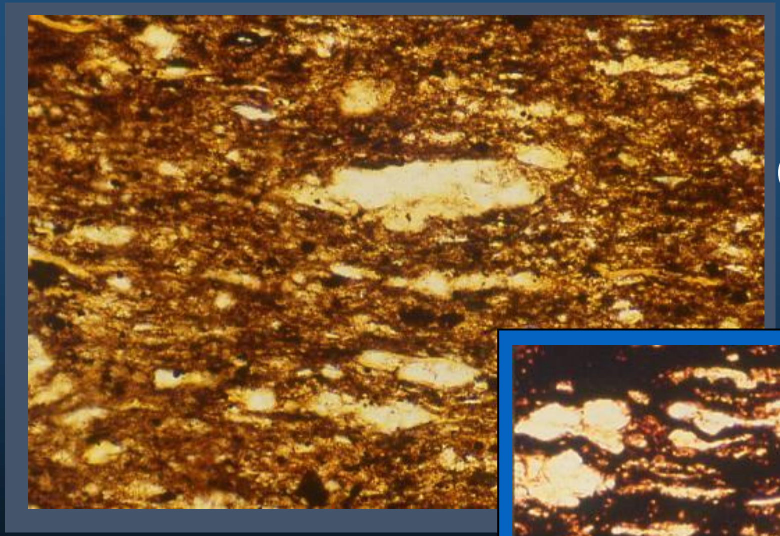
- Initially creates an over-pressured compartment
- Drives remaining water out of system (dehydrates the system)
- Forces oil and condensate into very tight pore space resulting in low water saturations
- Creates extensional fractures

Conceptual Burial History of Unit – Volume of Oil - Source

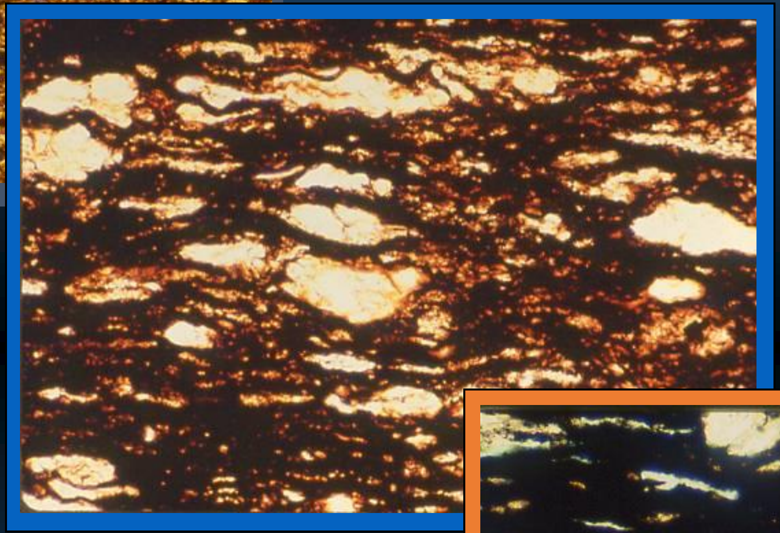


Modified from Momper, 1981

Petrographic Test for Onset of Oil Generation



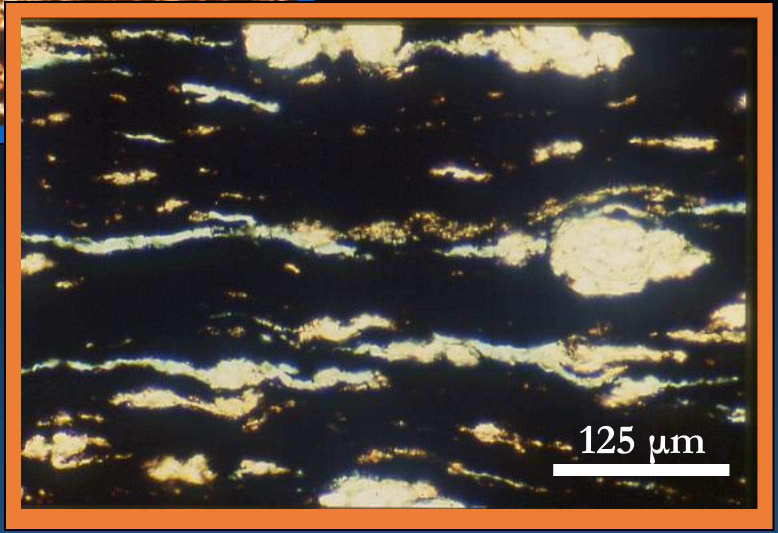
immature unheated
(20µm thick)



Onset

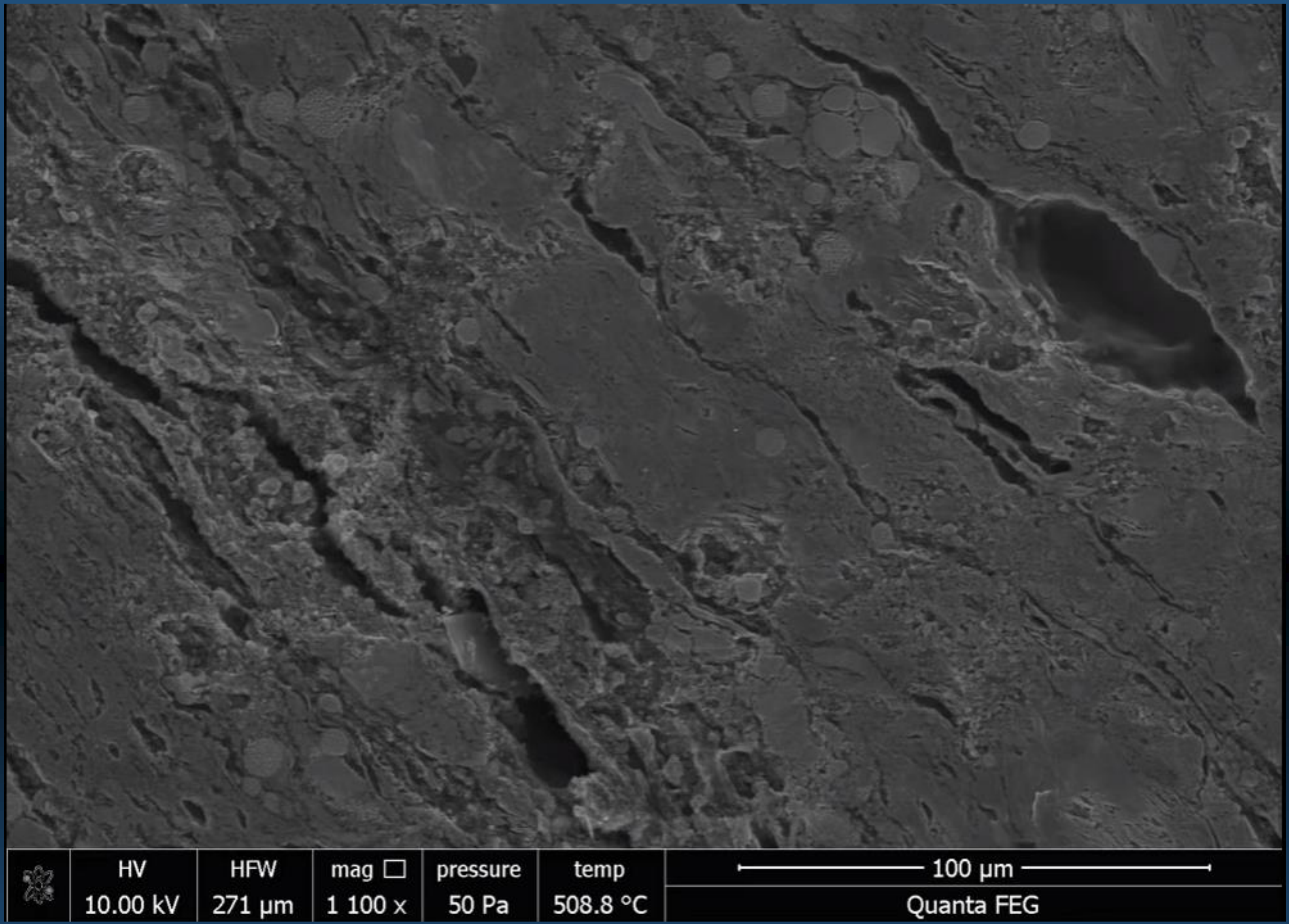
kerogen-bitumen
300°C/72h

Hydrous Pyrolysis of Woodford Shale Cores



bitumen-oil 352°C/72h

Lewan (1987)



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Making Movies of Oil Generation

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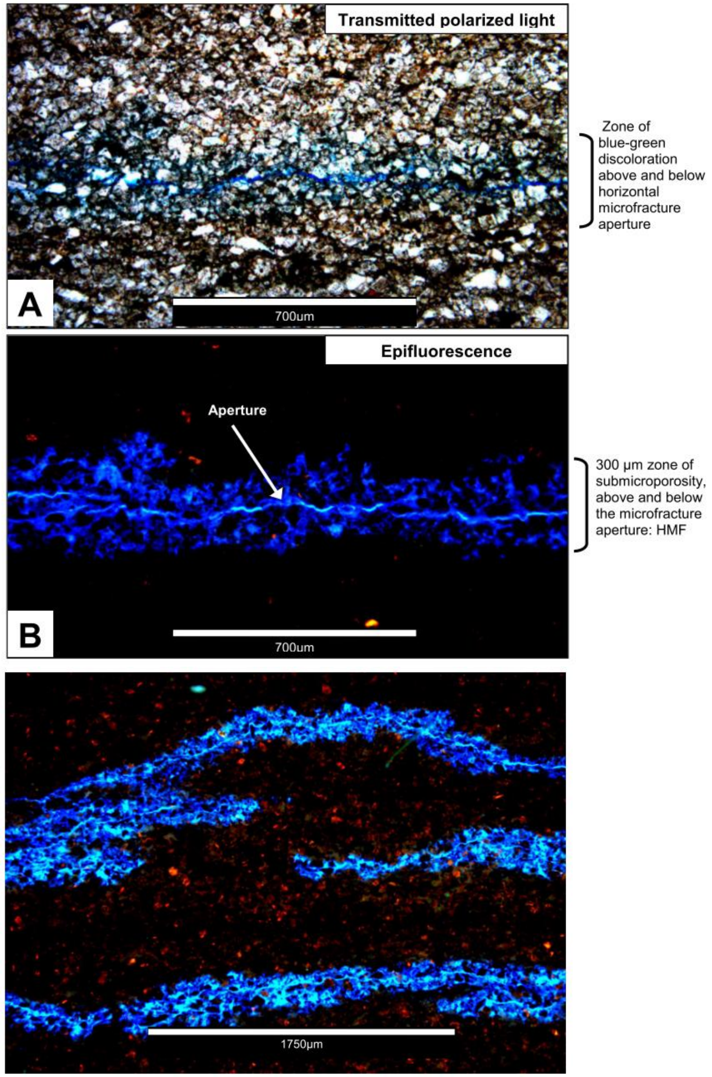
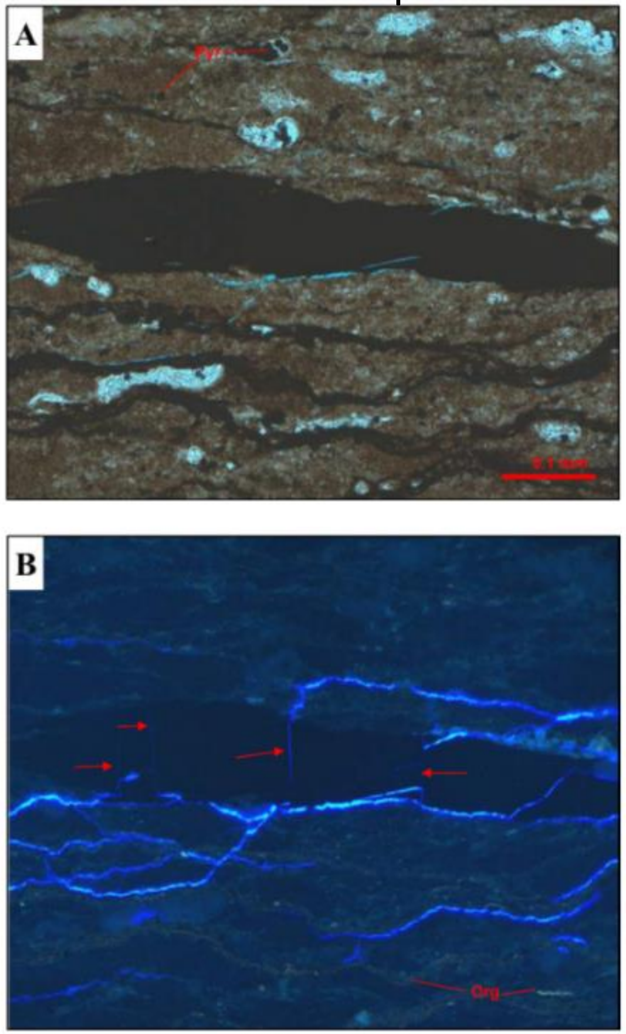
Microfractures Access Adjacent Porosity

Bakken Examples



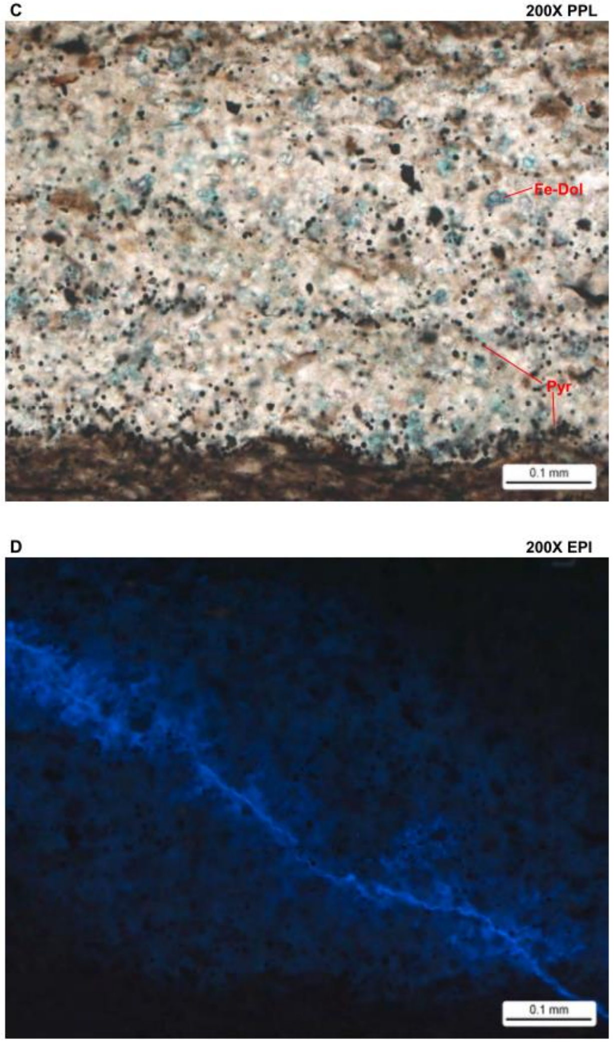
Figures modified from Warner, 2011

Niobrara Examples

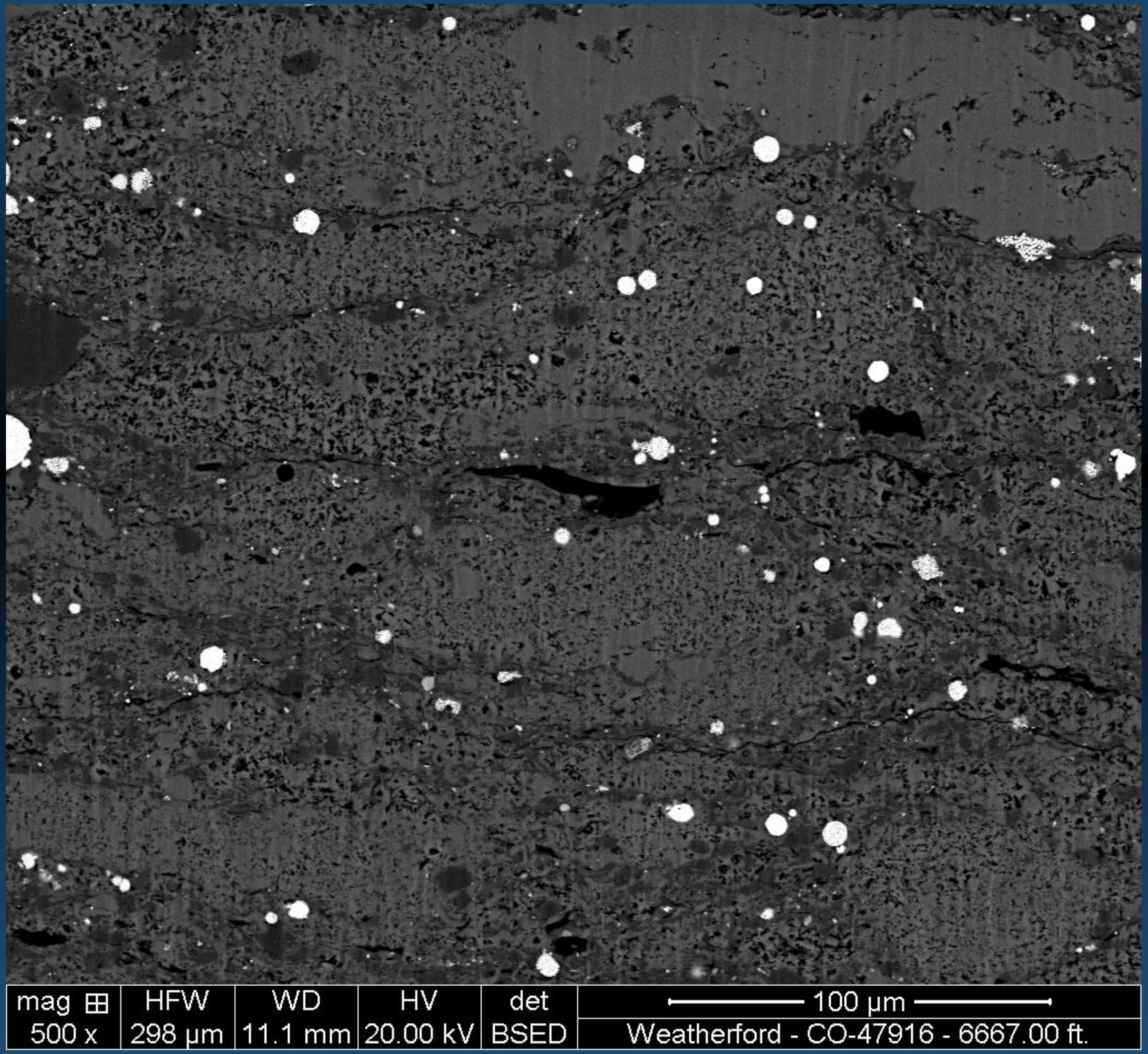


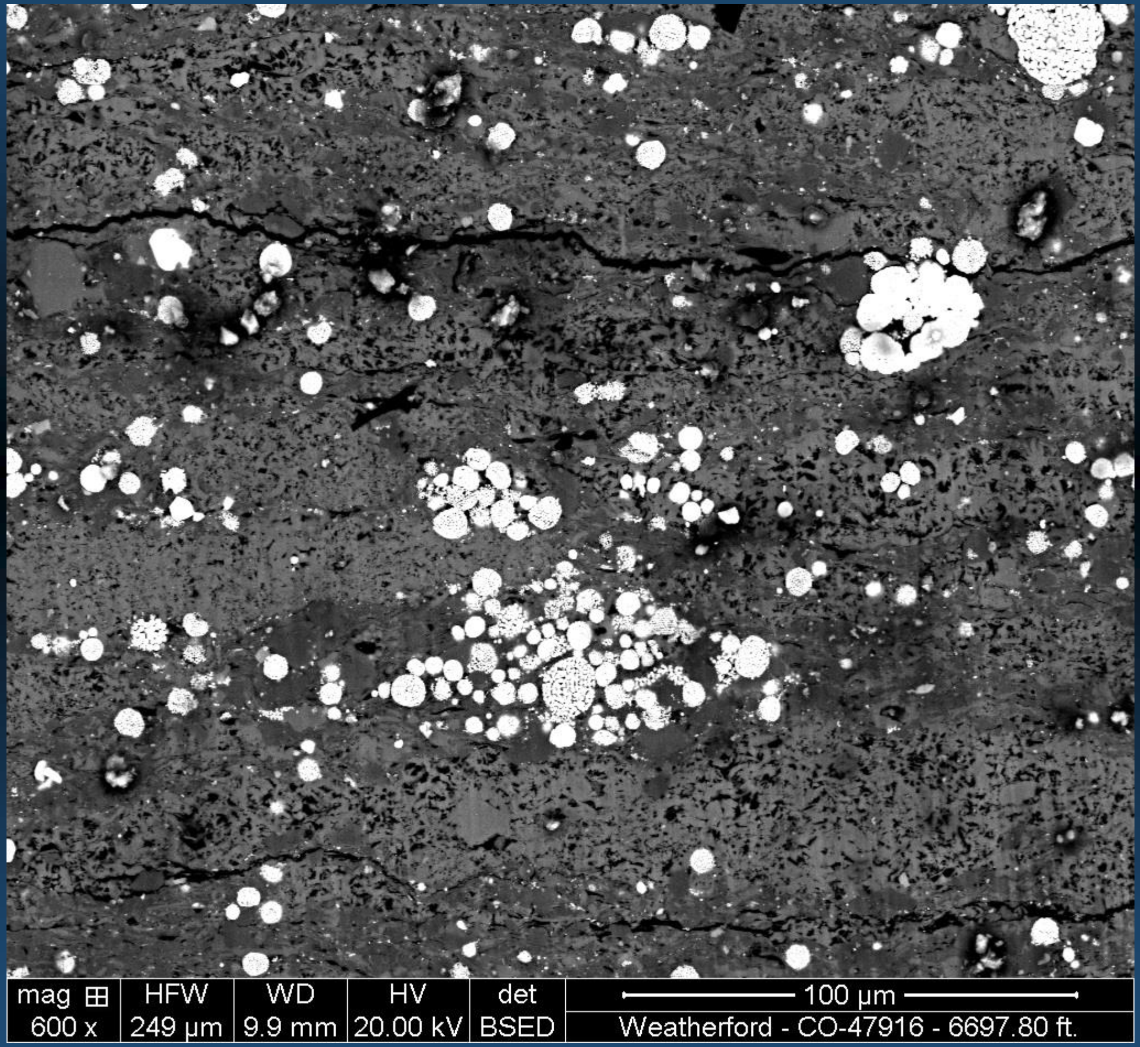
Figures modified from Duhailan, 2014

Mowry Shale Examples

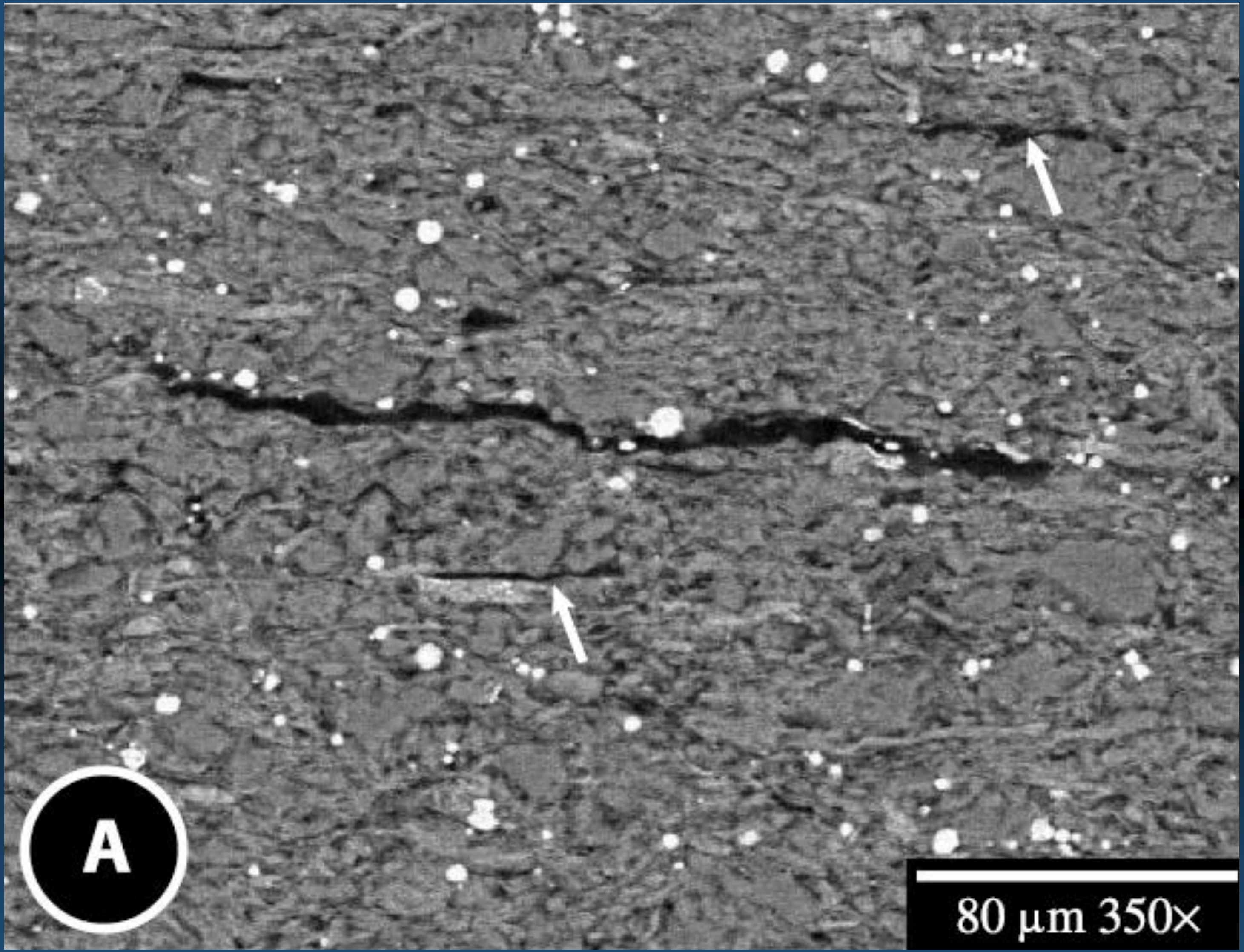


Gill # 2 Niobrara Formation





Pellets and microfractures



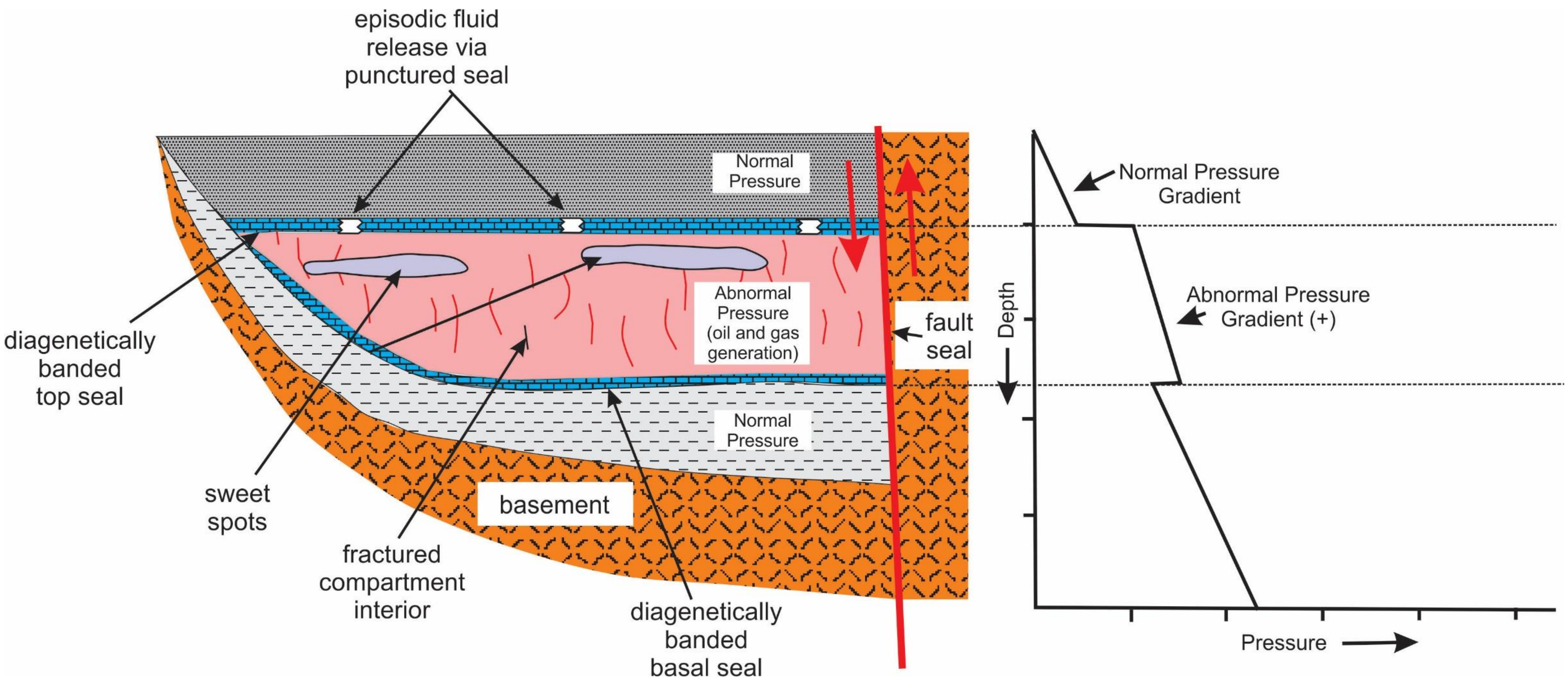
Dunkirk Shale

A. Backscattered electron micrograph of a polished sample showing an isolated large microcrack and two small ones (arrows)

Lash and Engelder, 2005

Microfracture Summary

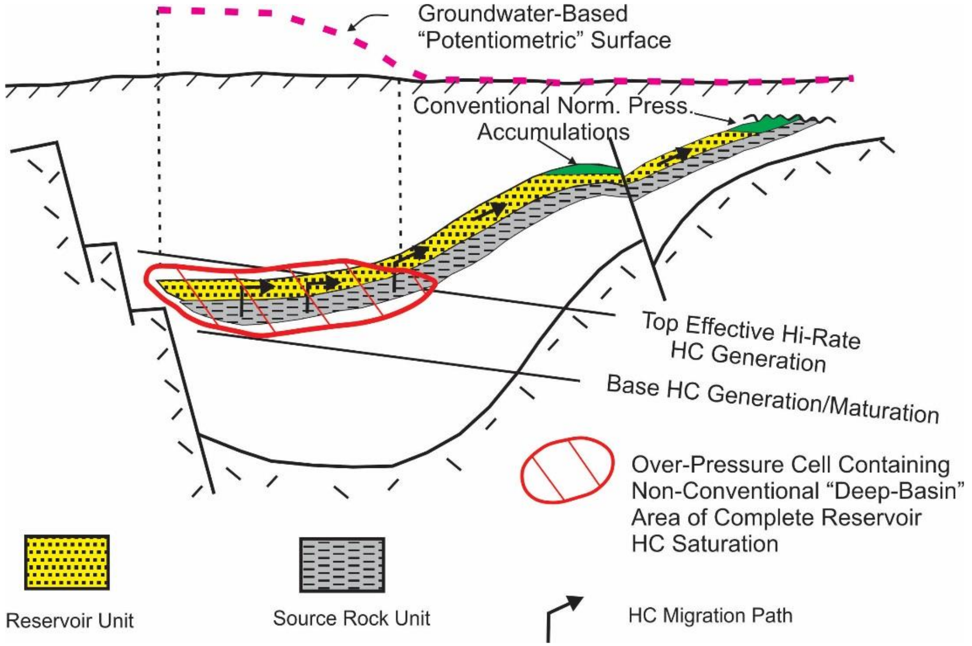
- Very common in organic-rich source rocks
- Dilate when we frack the well with high pressures
- Resulting in really good IPs
- But collapse (?) when pressure is drawn down
- Resulting in 50-80% first year declines
- Challenge: how to keep them open for years not months

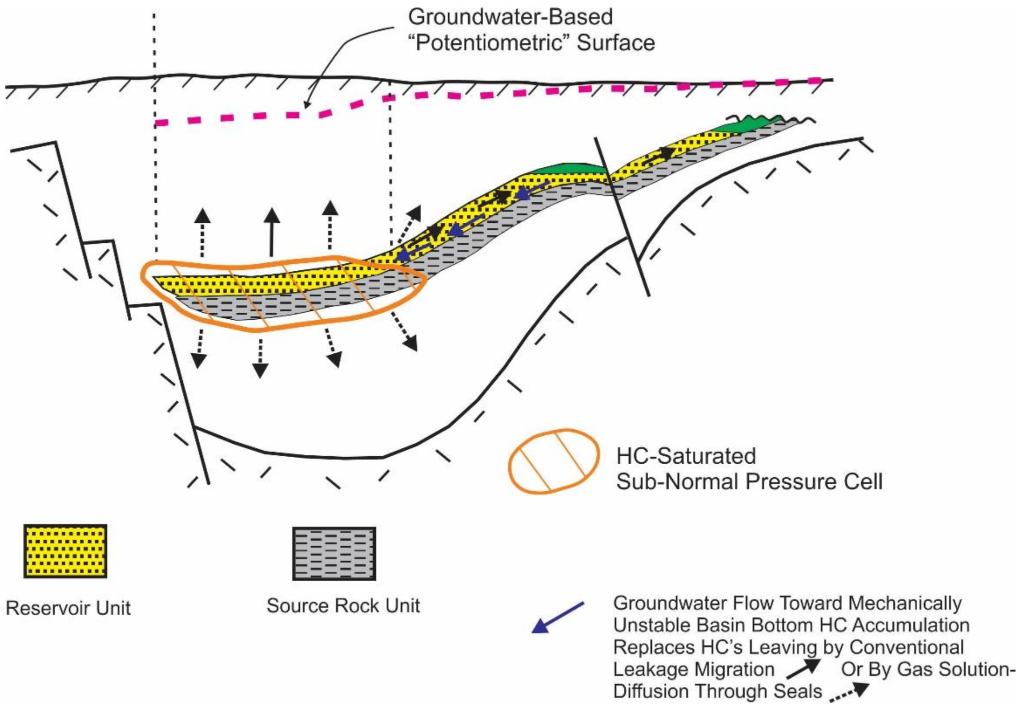


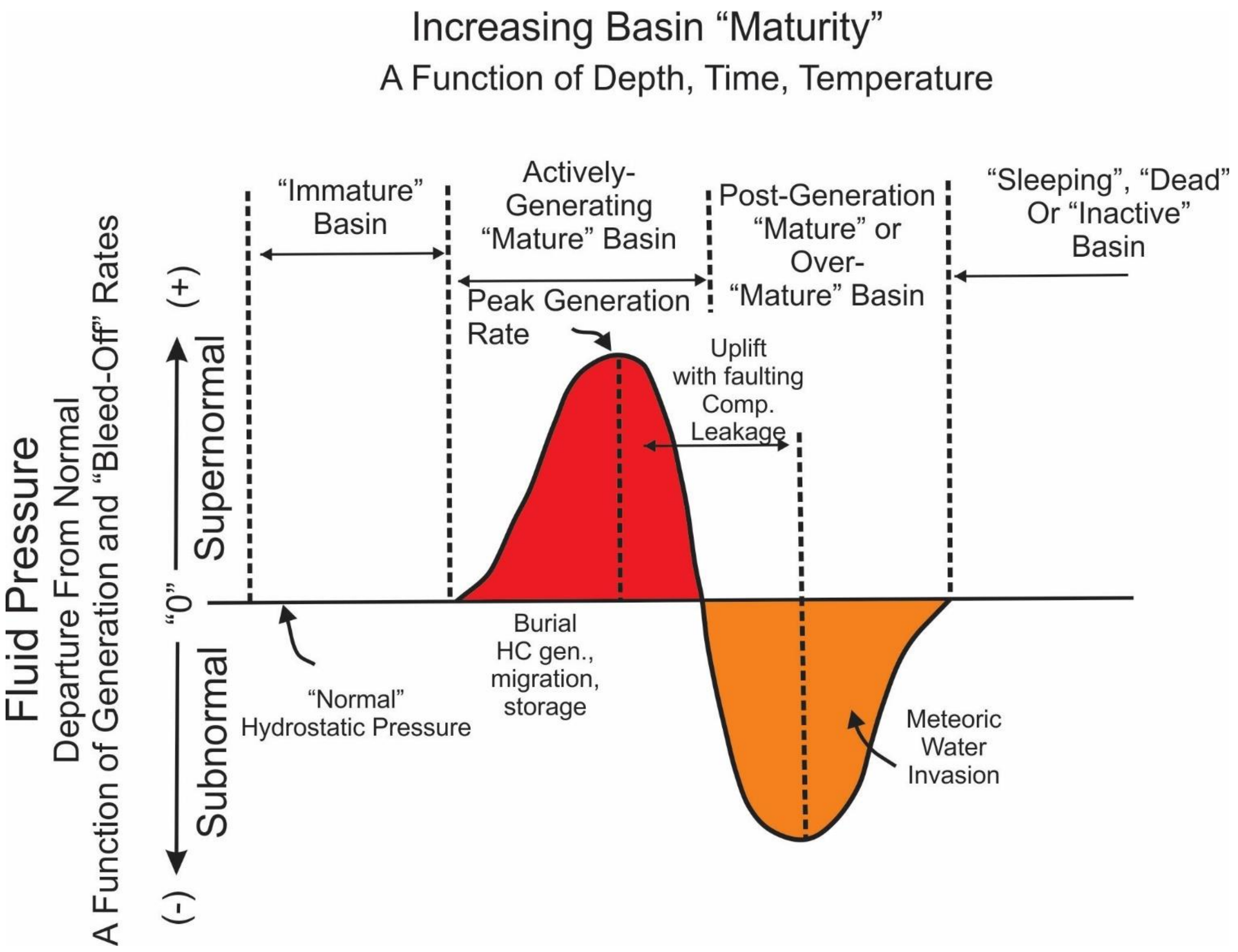
Modified from Ortoleva, 1994

The systems are dynamic and not static as in Conventional Traps

- The hydrocarbons are trying to escape
- But there is a bottleneck due to the very low matrix permeability, so the process is very slow resulting in overpressuring of the system
- The produces an exploration target where:
  - The lateral extent crosses stratigraphy and relates to maturity in the basin
  - The top and bottom will relate to the source rock package itself







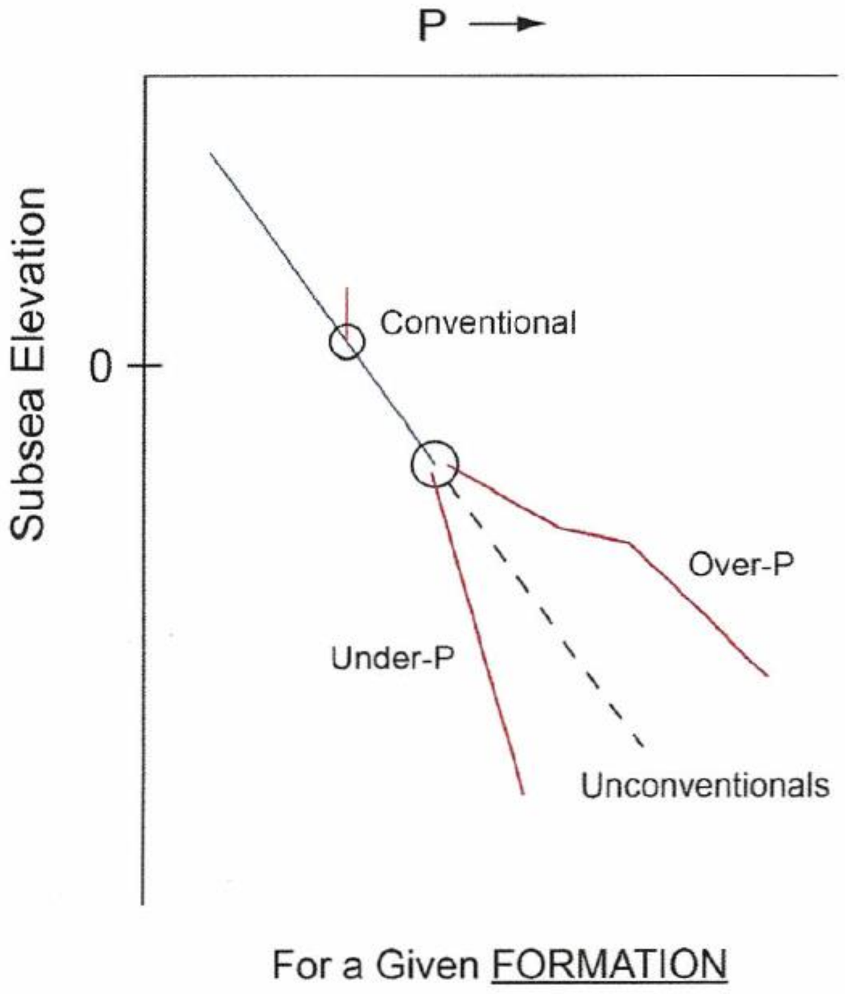
Meissner, 1997

Typical Pressure Plots

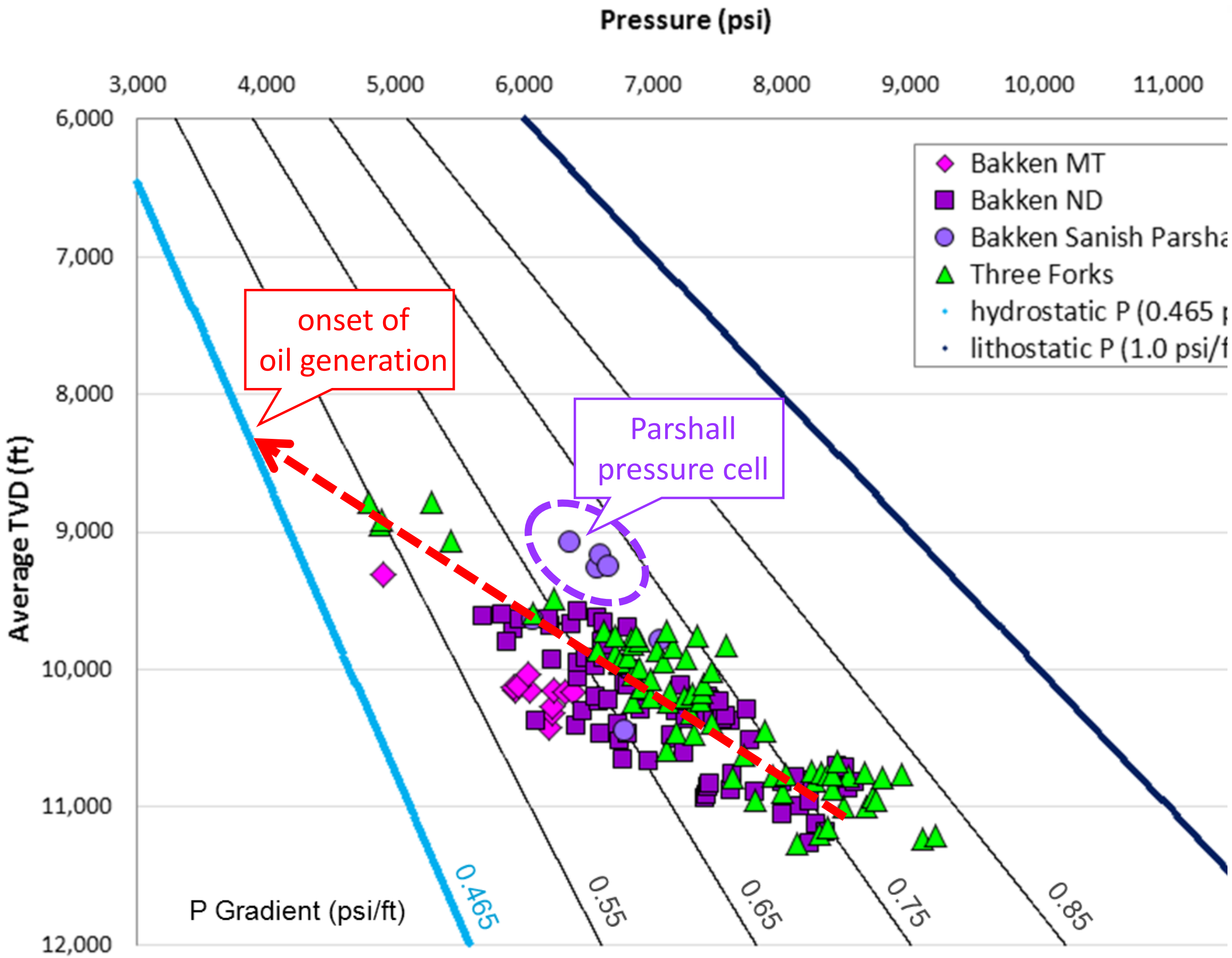
- UNCONVENTIONAL ACCUMUL
  100s to 1000s of feet
  Pw = Phc at TOP accumulation
  (see lower circle)

- CONVENTIONAL ACCUMUL
  Typically 10s of feet
  Pw = Phc at BOTTOM accumul
  (see upper circle)

Going upward: slanted into water line or slanted away.

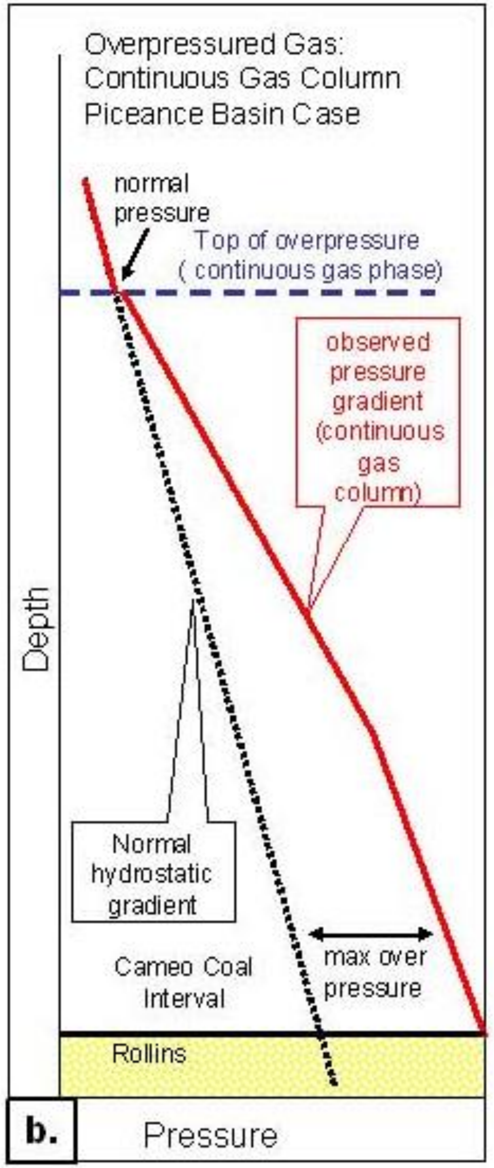


Pressure - Depth Trend



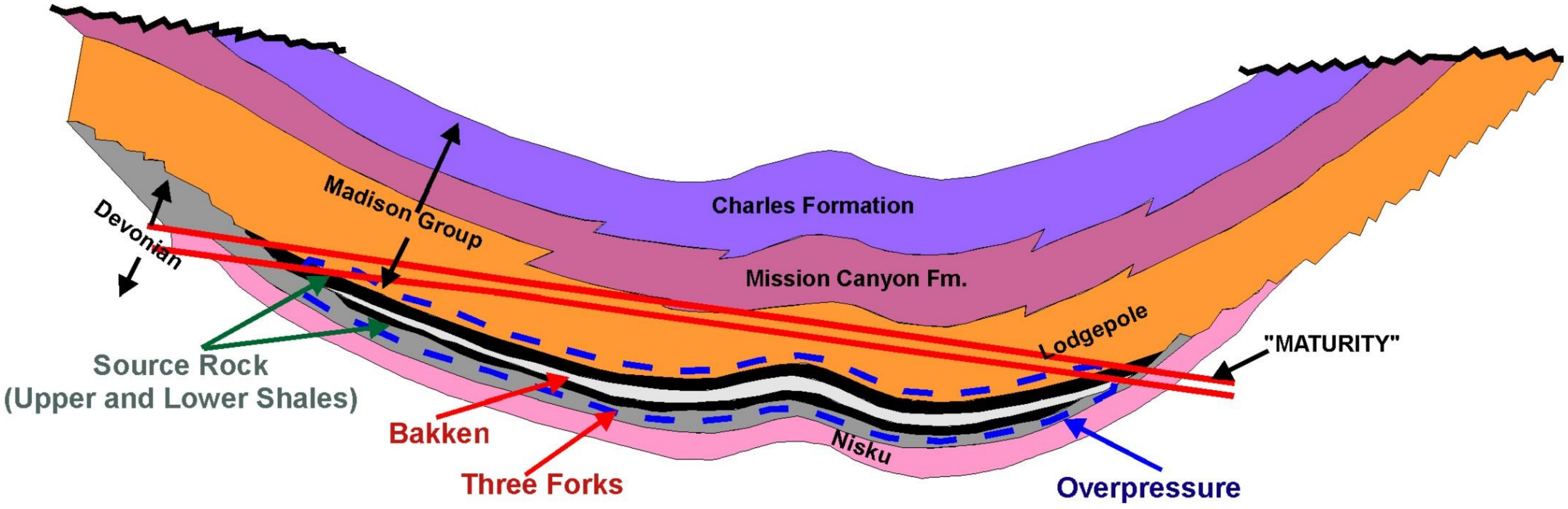
Indicative plot for **inverted continuous system**, leaking pressure at top

Theloy, 2012



Cumella and Scheevel (2005)

Bakken Petroleum System



Reservoirs:
Middle Bakken & Three Forks

Source Beds:
Upper & Lower Bakken Shales

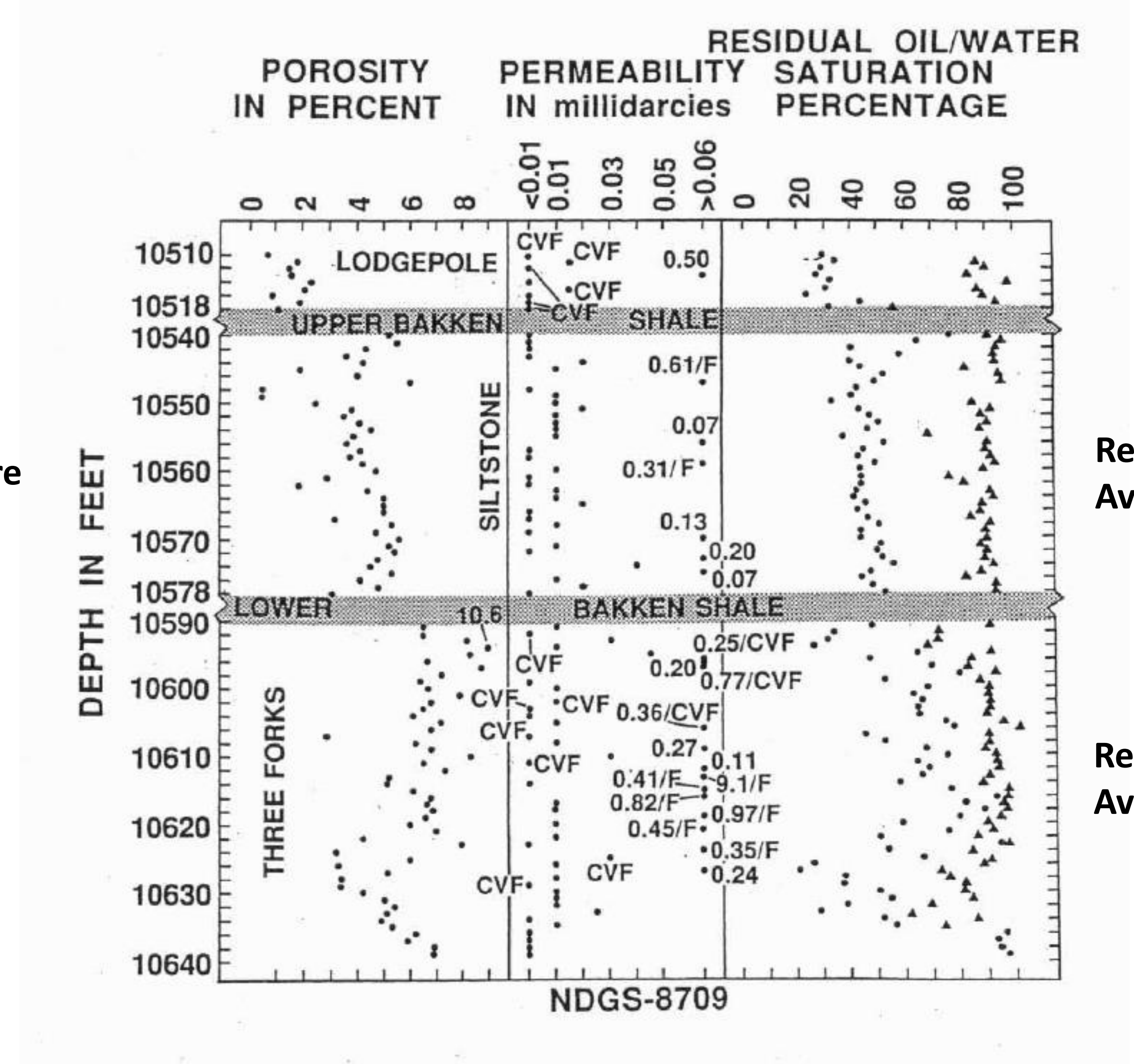
“what was made in the Bakken, stayed in the Bakken PS”

Burbank BIA #23-8
NESW sec. 8 T147N R93W

CVF=closed vertical fracture
F= undesignated fracture

Residual water saturations circles

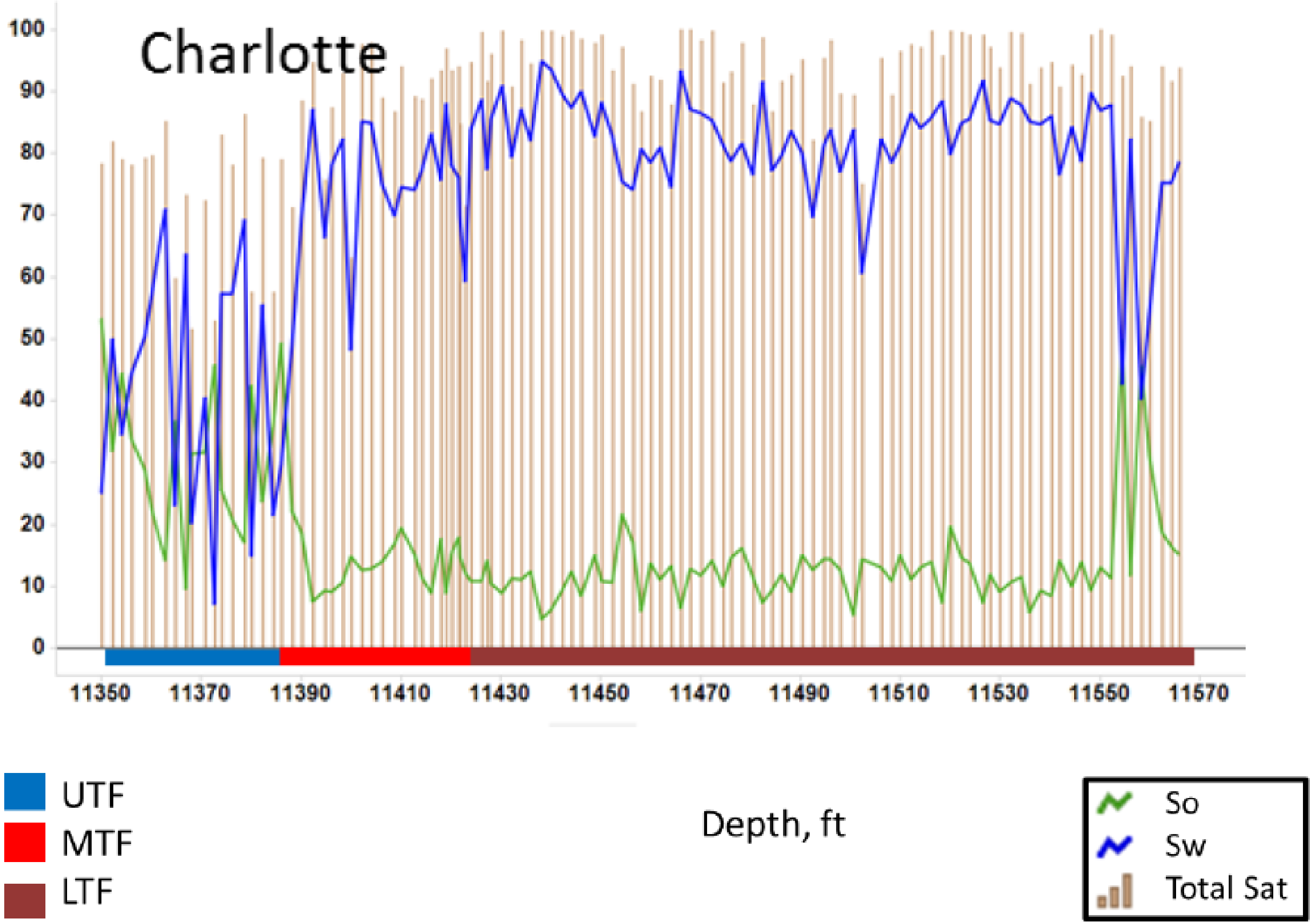
Residual oil saturations triangles



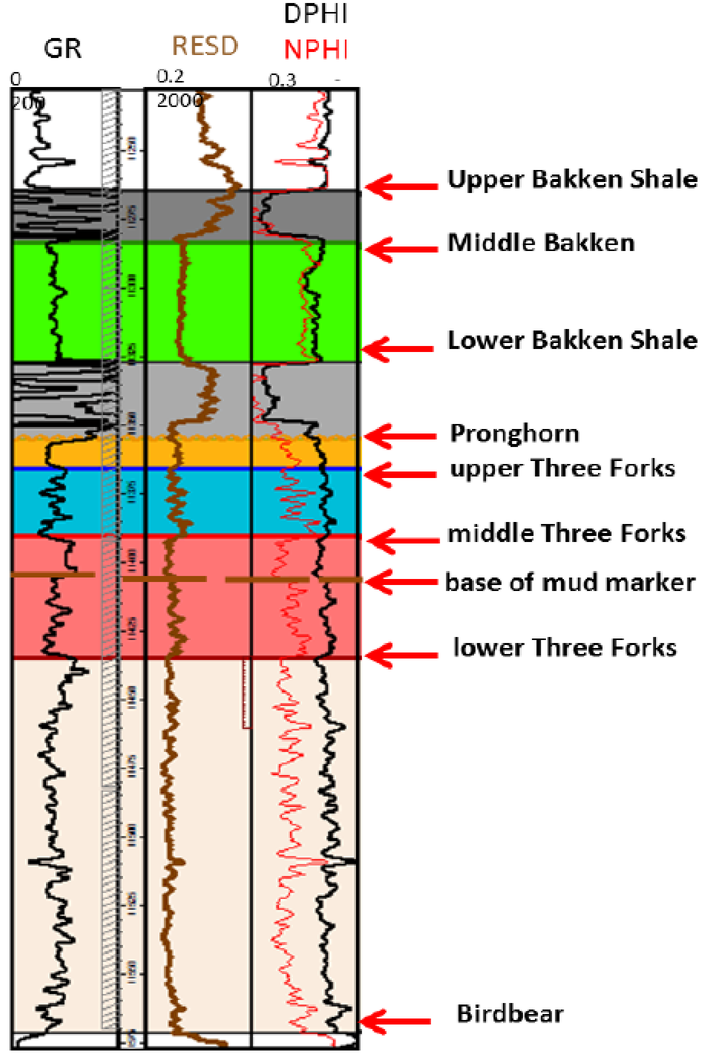
Res oil: 22-60%
Ave. 48%

Res oil: 20-100%
Ave. 65%

Price, 2000

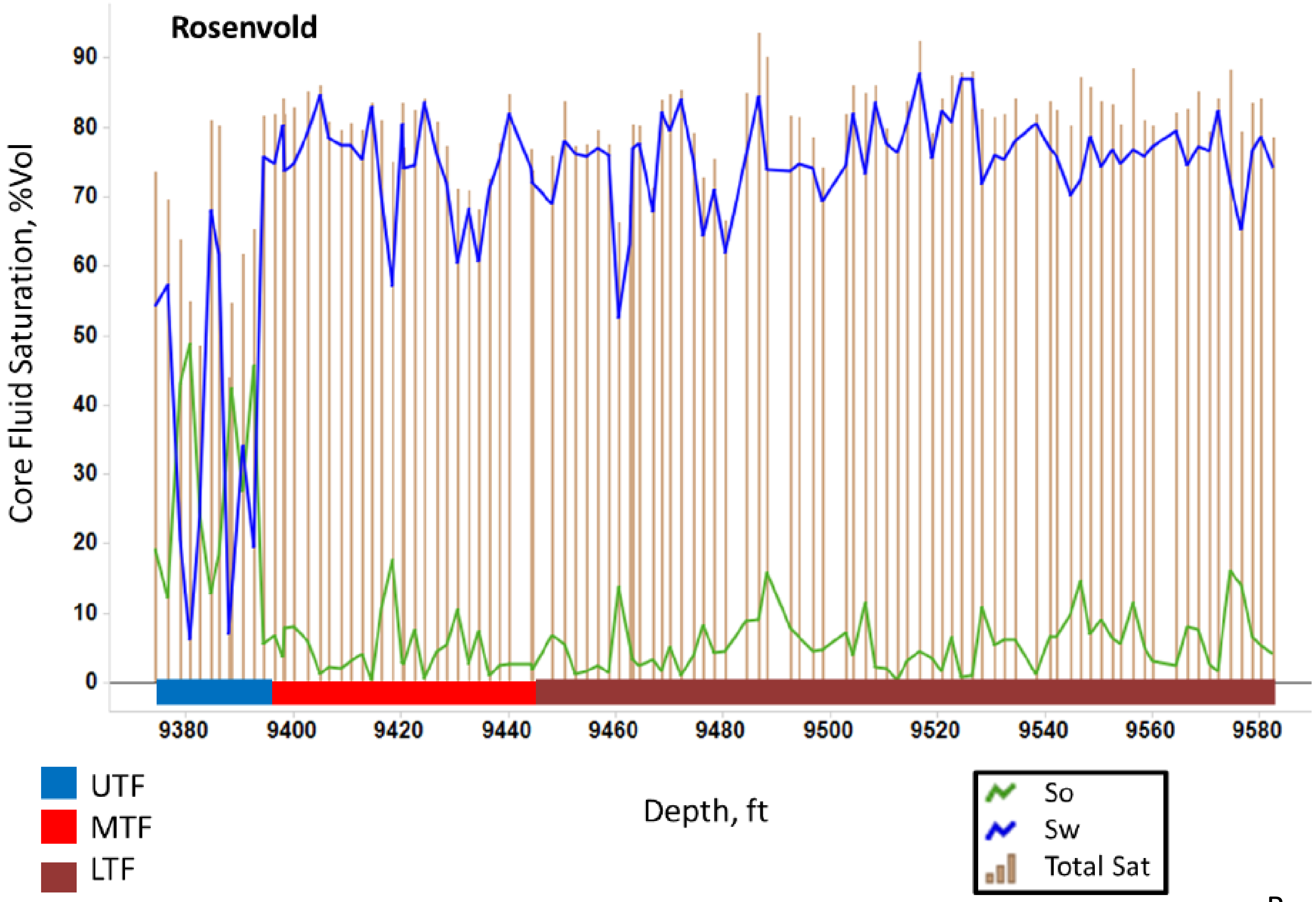


Charlotte 1-22H



Bazzell, 2014

Fluid Saturations Three Forks



Bazzell, 2014

Look At Some Typical Sws

- Most of the units are at irreducible water saturation which for these tight rocks requires those enormous forces of explusion pressures.

- Some typical Sw values:

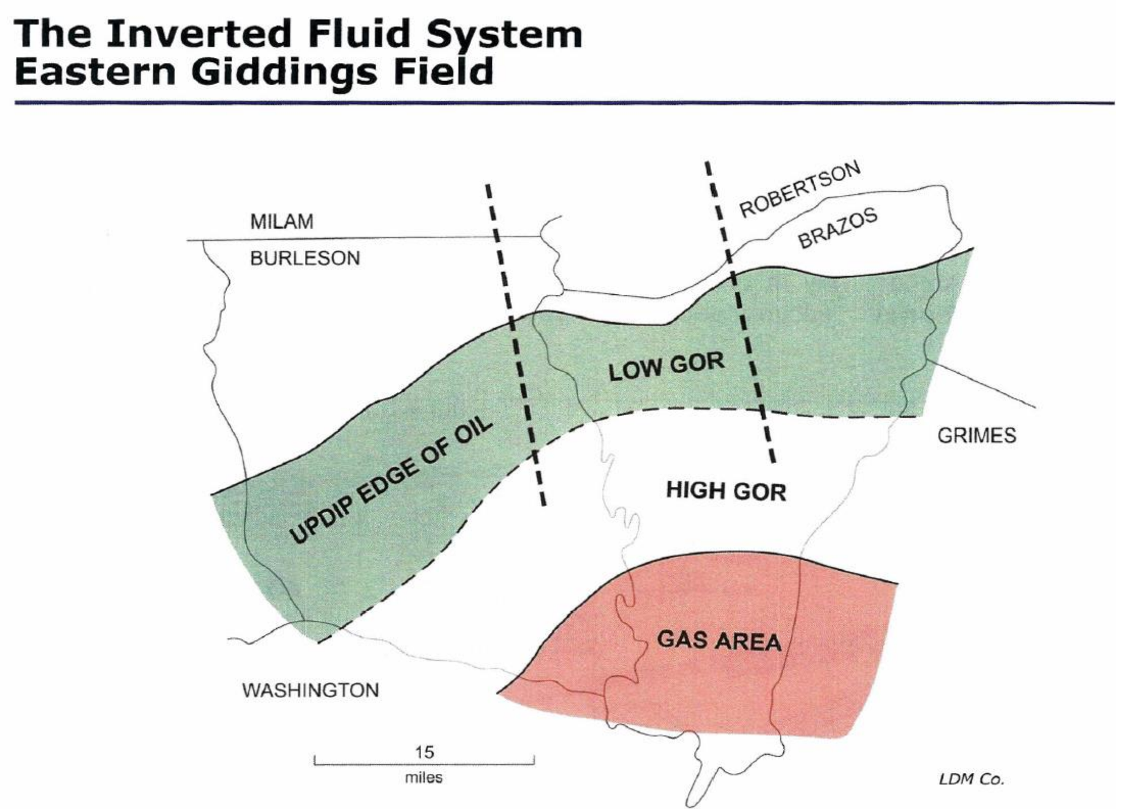
  - Wasatch at Altamont: < 10%

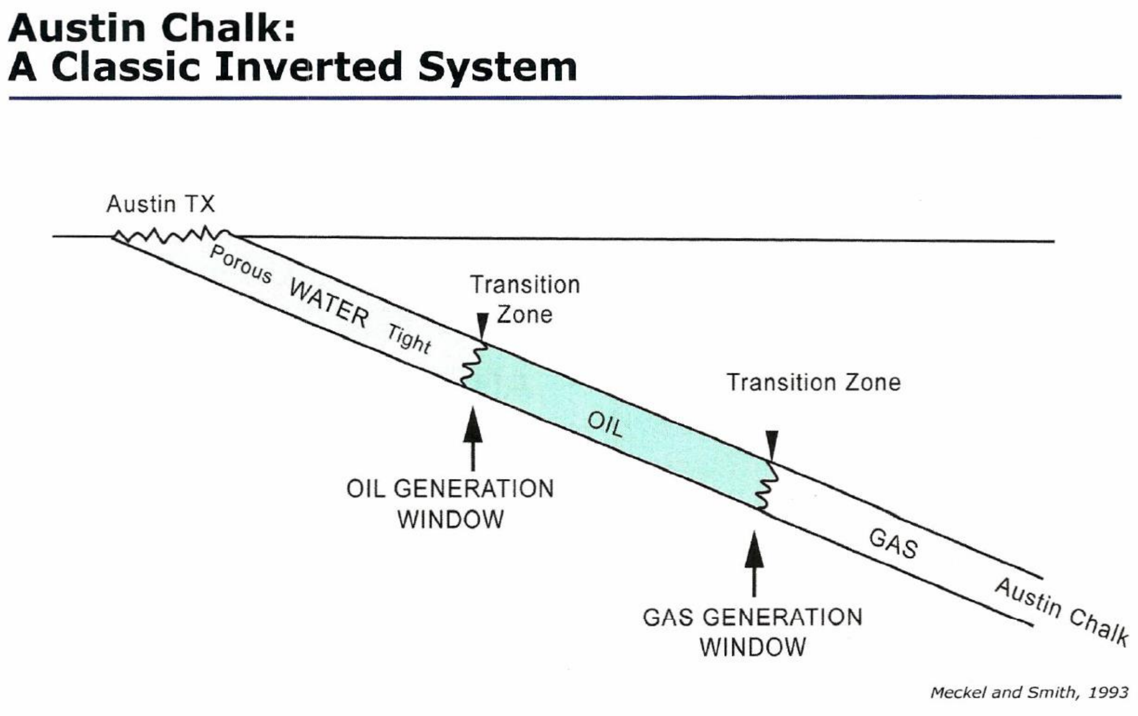
  - Cardium at Pembina: < 20%

  - Austin Chalk in Texas: < 20%

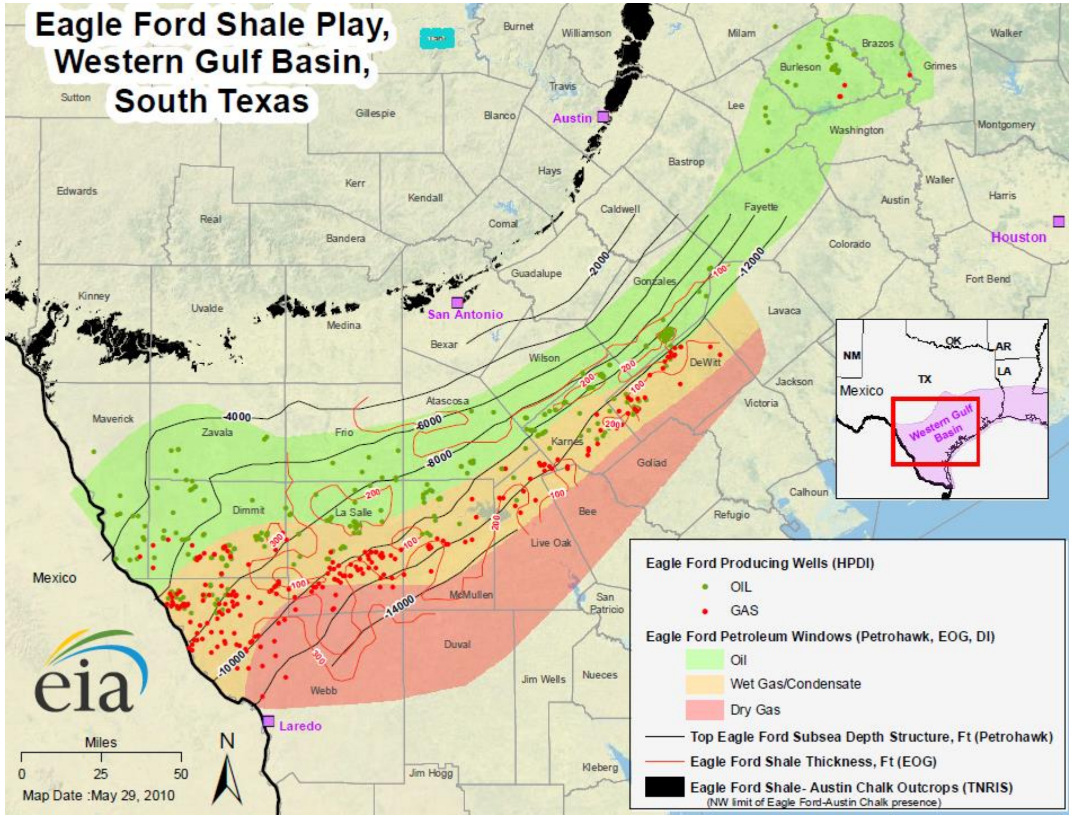
  - Spraberry in W. Texas: 20 – 30 %

The Inverted Fluid System

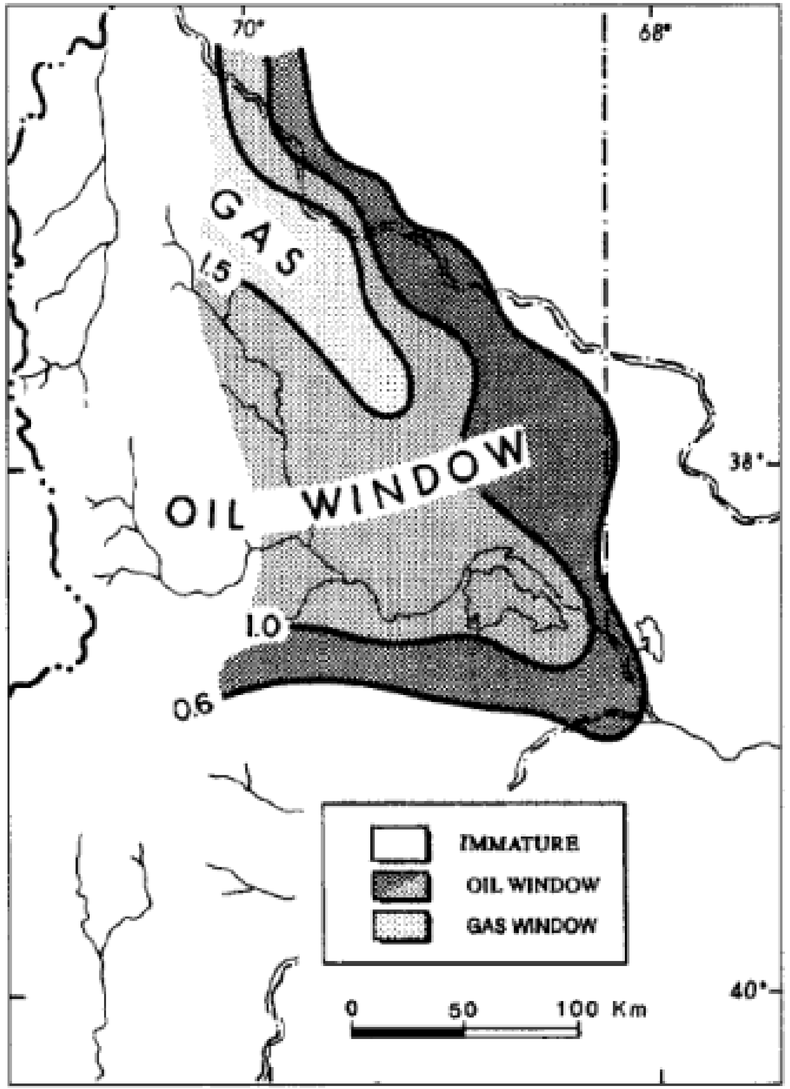




The Inverted Fluid System



Eagle Ford, Gulf Coast



Vaca Muerta, Neuquén Basin, Argentina

The Unconventional Check List

- Continuous type of accumulation
- Areally or vertically pervasive
- Hydrocarbon saturated (O or G)
- Abnormally pressured
- Lack of down-dip water
- Low ϕ and k
- Lack of obvious seal or trap
- Oil or gas generation window; large “kitchen”
- Updip transition to wet
- Enhanced sweet spots
- Large OOIP or OGIP
- TOC > 2.5 wt.%
- Net thickness of source bed > 50 ft
- Type I or II kerogen
- **Lack of intense structural activity; lack of “thief” zones**

Summary

- Unconventional tight oil resource plays are ‘changing the game’
- It all starts with good to excellent source beds
- Source beds mature over large areal extent
- Natural fracturing enhances tight reservoirs
- Horizontal drilling and fracture stimulation technology important in tight oil plays

Acknowledgements

- Fred Meissner
- Mohammed Al Duhailan