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Key Factors for Success in Unconventionals: Characteristics, Key Plays, Typical Challenges*

Susan Smith Nash[1]

Search and Discovery Article #80352 (2014)**
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Abstract

This presentation provides a review of key prospectivity and producibility considerations in unconventional petroleum resources, and develops a "need to know" checklist of factors and implementable technologies. Beginning with an expanded discussion of what makes a reservoir or play unconventional, and then covering characteristics of unconventionals along with important examples, the focus is on making it clear where we are today in terms of our knowledge and understanding of what constitutes a viable play, and perhaps more importantly, what conditions would completely rule out a play. The presentation reviews the published findings or "learnings" regarding major plays and compares / contrasts the "success determinants" for the Marcellus, Utica, Eagle Ford, Barnett, Haynesville, Niobrara, Woodford, Bakken, Monterey, and other formations. Once a formation has been determined to be prospective, can it be produced? In the second half of the presentation, published findings with respect to lithological properties are reviewed, along with emerging techniques and technologies, to identify the critical elements required for producibility in drilling, completions, and production (including water management).

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KEY FACTORS FOR SUCCESS IN UNCONVENTIONALS: Characteristics, Key Plays, Typical Challenges

Susan Smith Nash, Ph.D. / AAPG

What Makes a Play "Unconventional"?

Characteristics

Fine-grained Clastics: Gas / Oil / Liquids-Rich

Coalbed Methane

“Unconventionals”

Reservoir Quality

- *You must think of the end before you start at the beginning*
  - Why? The information you gather at the beginning is critical for producibility

Think of what the hydraulic fracturing and ongoing production will look like before you drill that very first test

- The formations were previously unproducible
- Very low permeability (below 0.1 millidarcies)
- May have low porosity as well
- Water issues
- Complex fractures / rock mechanics regime
- Low pressure gas, low gravity oil

“Unconventionals”

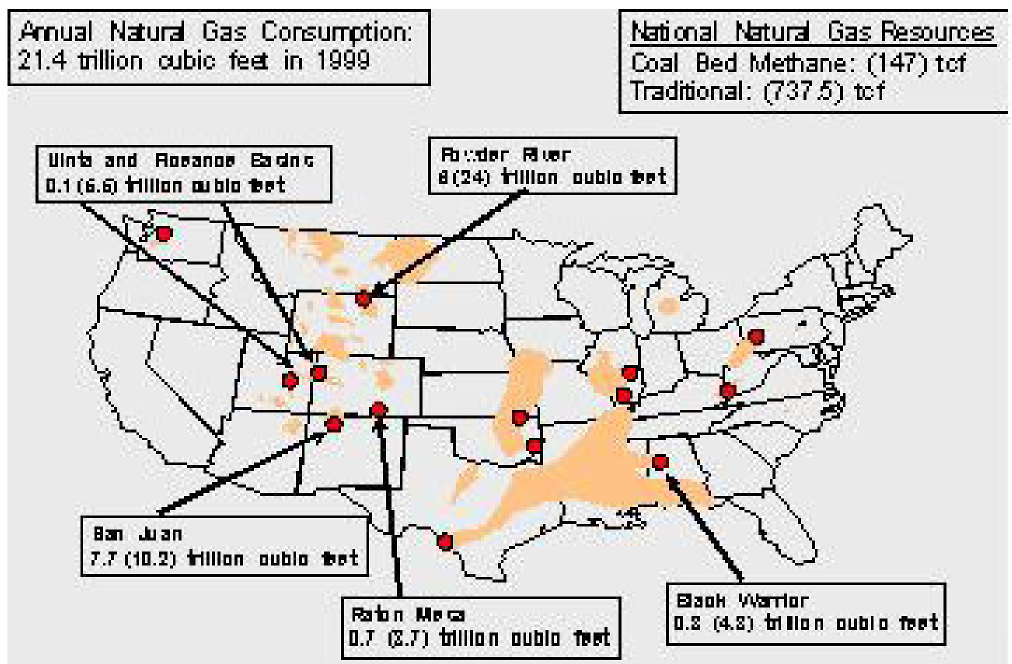
Fine-Grained Clastic: Gas / Oil / Liquids-Rich

- Unconventionals – fine-grained clastics
- Mudstones
- Very small pore throats
- Often a “liquids-rich” window
- Thermal maturity determinants
- Liquids-rich plays: Eagle Ford, Bakken, Woodford

“Unconventionals”

Coalbed Methane

- Methane found in coal seams
- Generated from biological processes (microbes)
- Generated from thermal maturation
- Often seam is saturated with water



"Unconventionals"

Other Types

- *All are challenging*
- Coalbed methane
- Tight gas
- Shale gas
- Shale oil
- Oil shales
- Methane hydrates

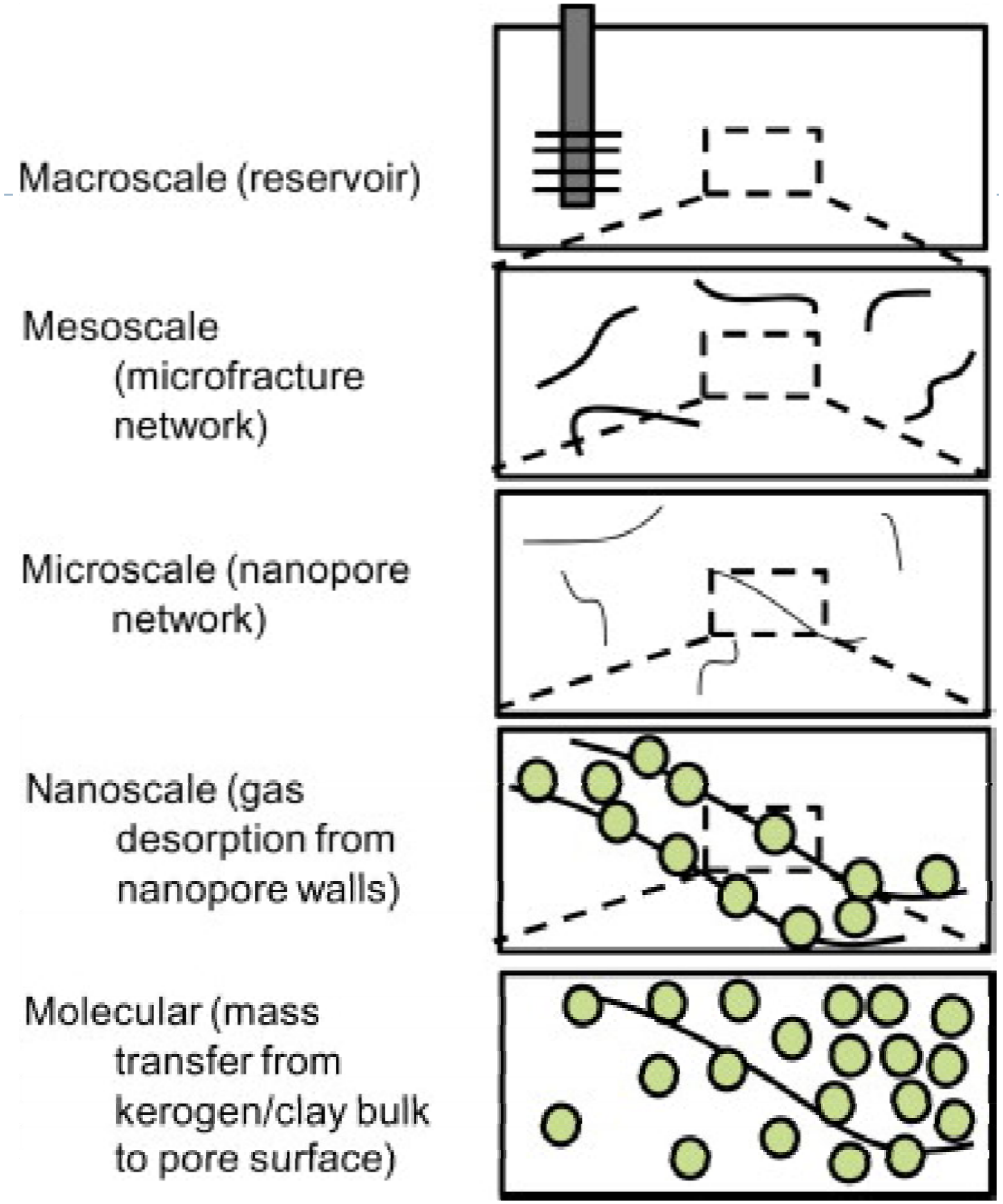


Illustration of the impact of scale on transport mechanisms in shale gas reservoirs. Flow to the wellbore is first initiated at the macro-scale, followed by flow at progressively finer scales, including molecular transport through nanoporosity in kerogen (Clarkson, et al., 2012).

Shale Play Roundup

Barnett

Marcellus

Bakken

Eagle Ford

Niobrara

Others

Shale Play Roundup

North America

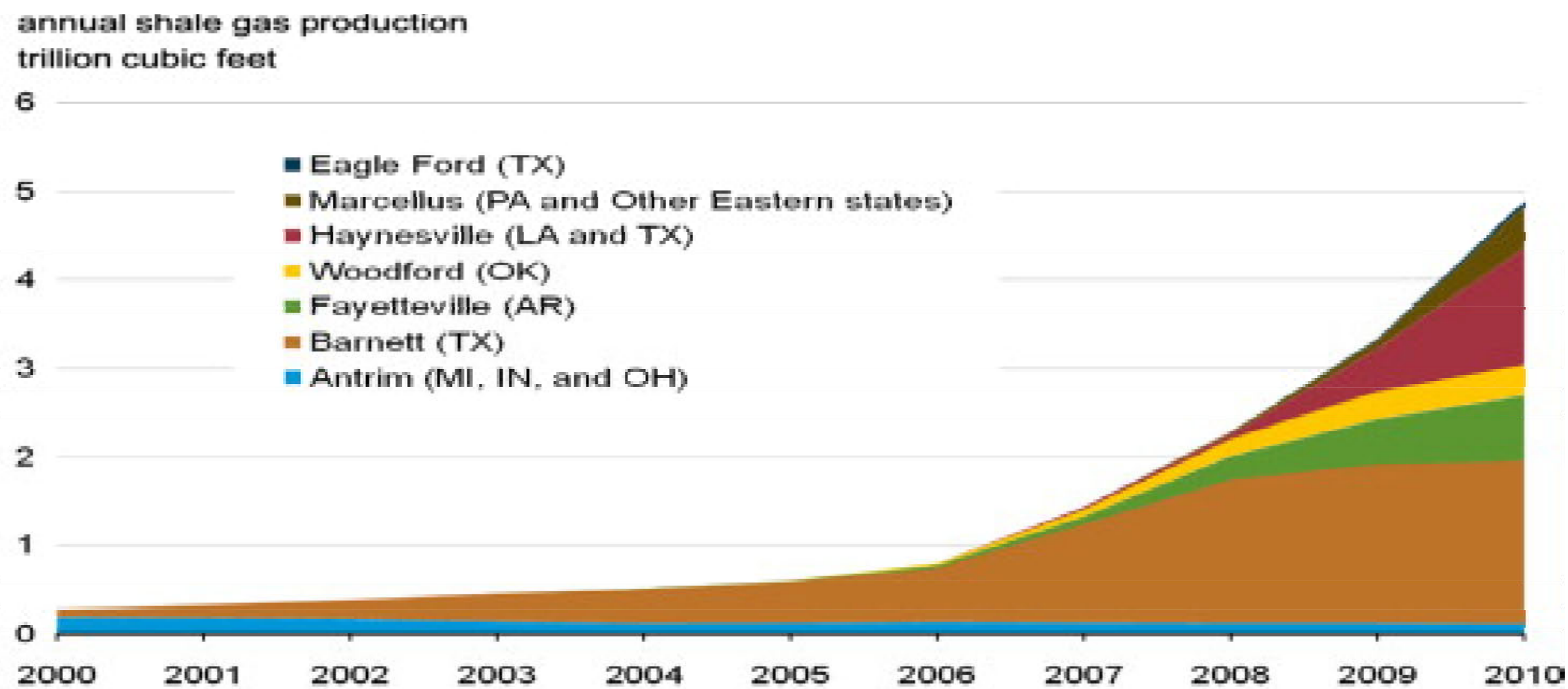
- EIA, 2011
- Since that time, some plays have expanded in their productive extent (Woodford, Cretaceous, Mancos, etc.)

Source: U.S. Energy Information Administration based on data from various published studies. Canada and Mexico plays from ARI.
Updated: May 9, 2011

Shale Play Roundup

North America

- U.S. shale gas production from 2000 - 2010

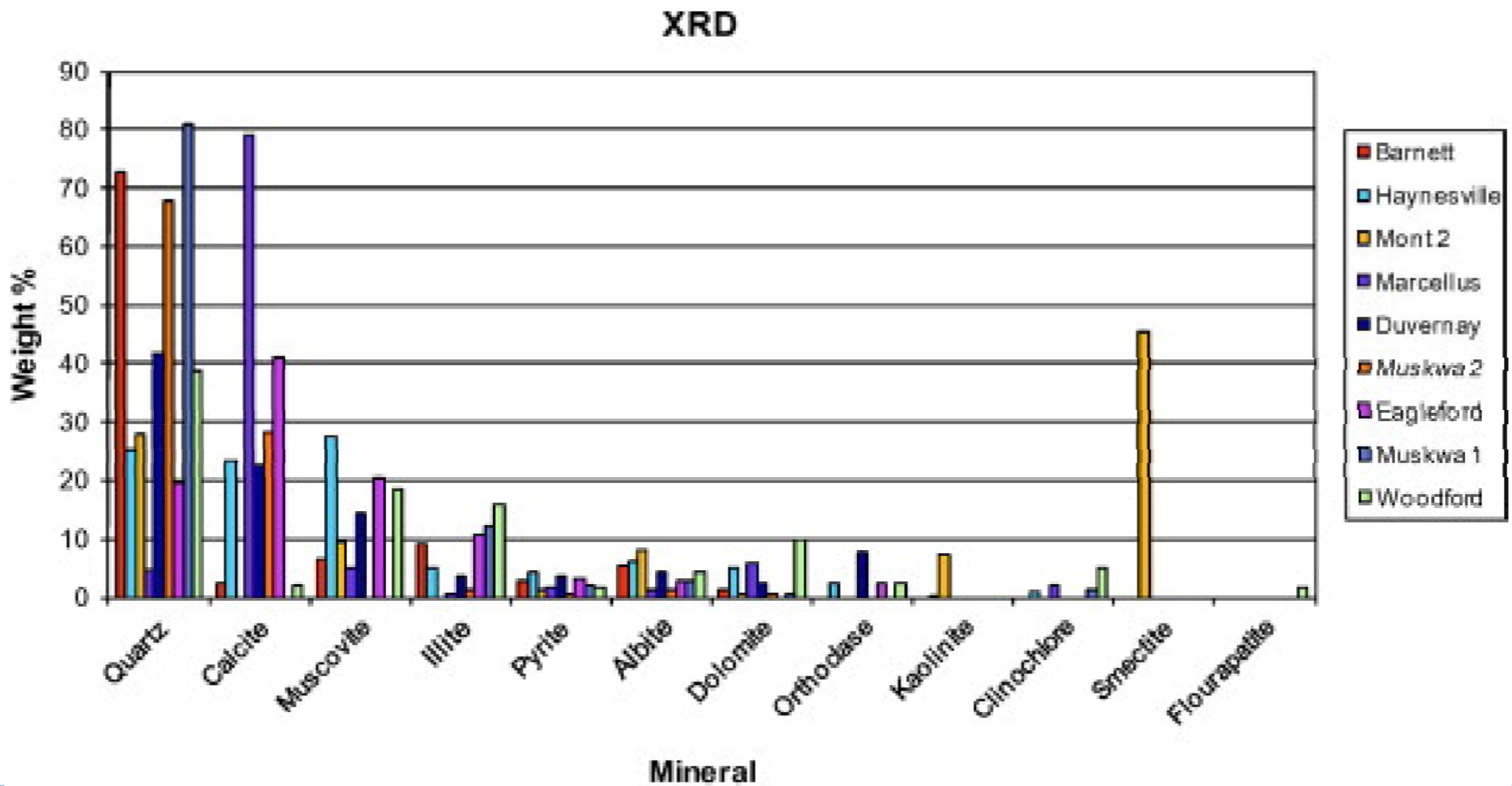


Sources: EIA and Lippman Consulting

Shale Play Roundup

Comparisons: XRD

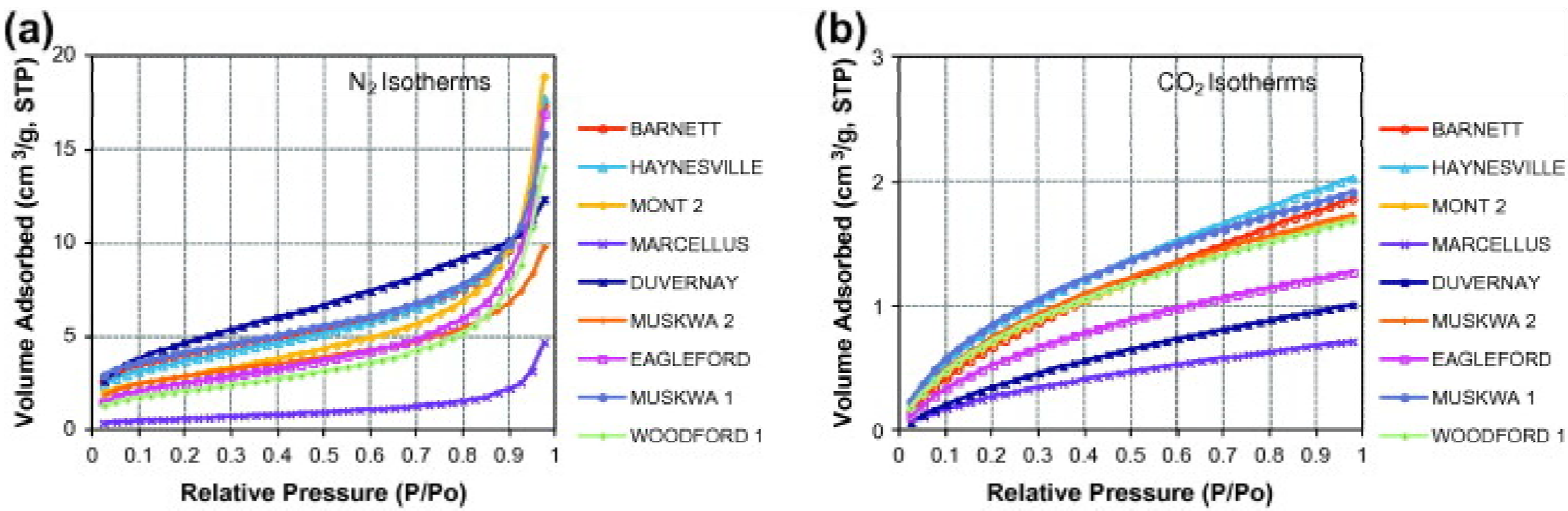
- From Clarkson et al. (2013)
- *Comparison of mineralogical composition of North American shale samples based on XRD analysis.*



Shale Play Roundup

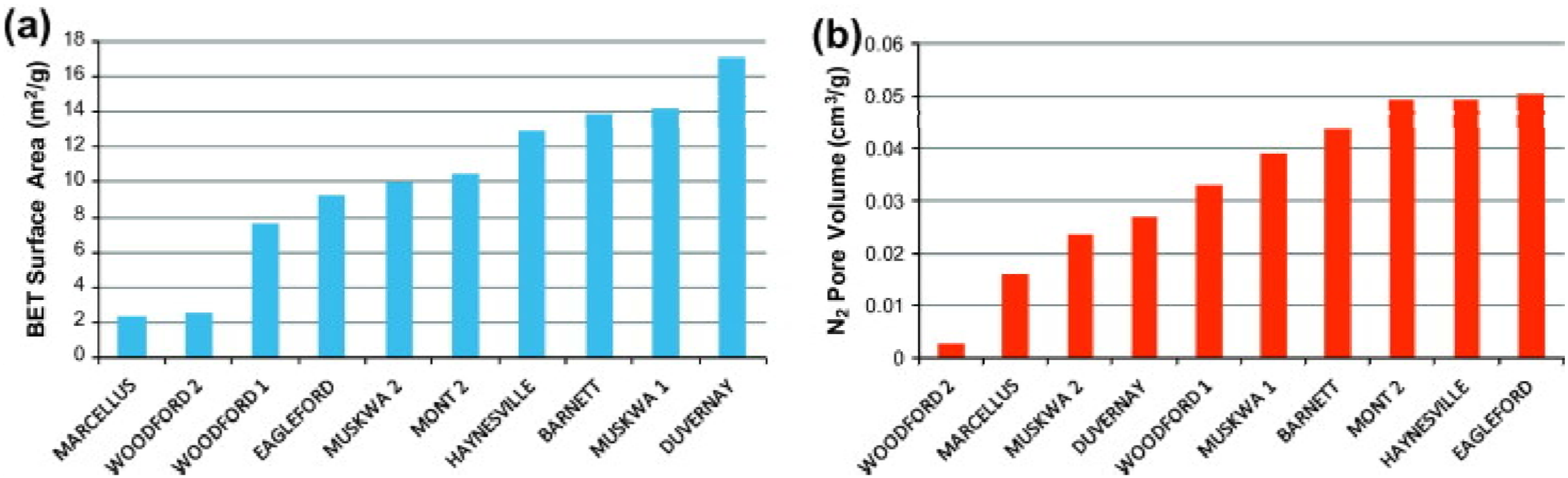
Comparisons: Adsorption

- From Clarkson et al. (2013)
- CO_2 adsorption isotherms are Type I, indicative of microporous solids. High amounts of adsorption suggest microporosity.



Comparisons: Surface Area / Pore Volume

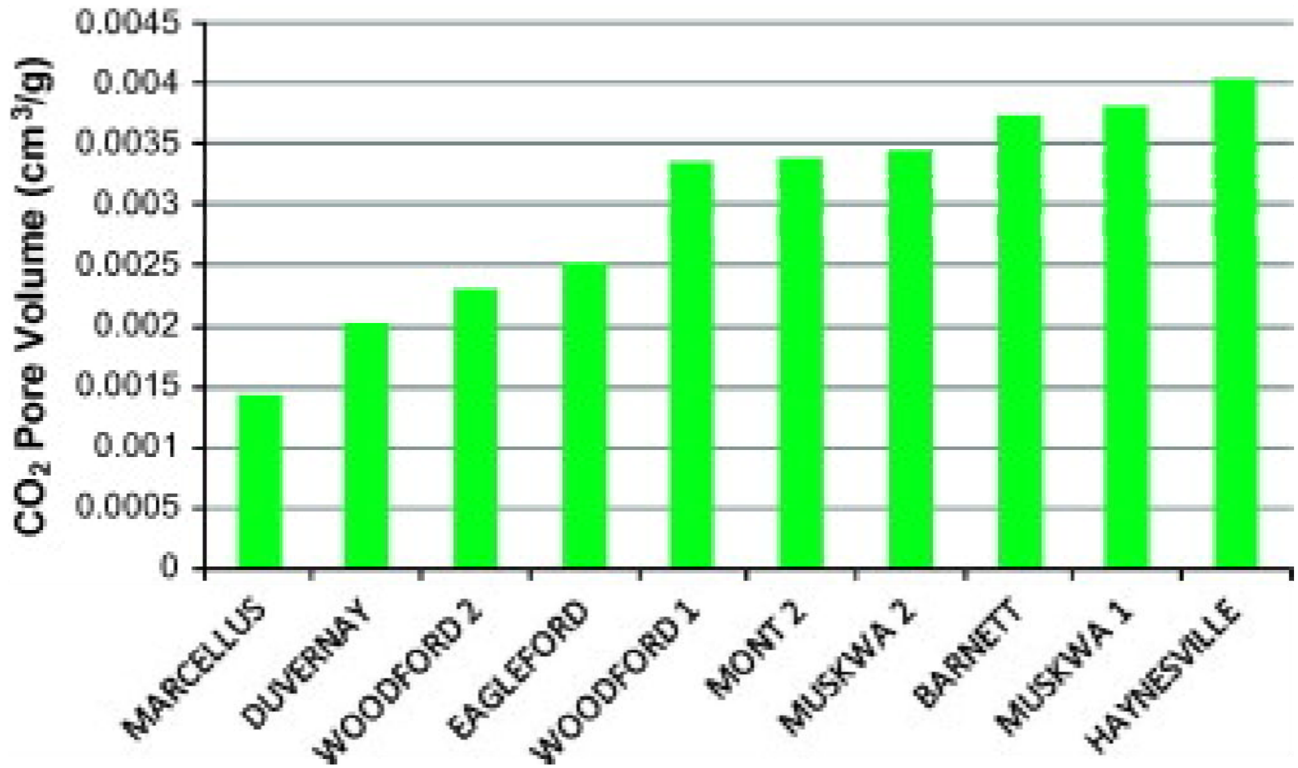
- From Clarkson et al. (2013)
- *Nitrogen Brunauer-Emmett-Telle (BET) surface areas (a) and pore volume (b) for the shale samples. Higher surface areas and pore volumes suggest higher porosity.*



Shale Play Roundup

Comparisons: adsorption

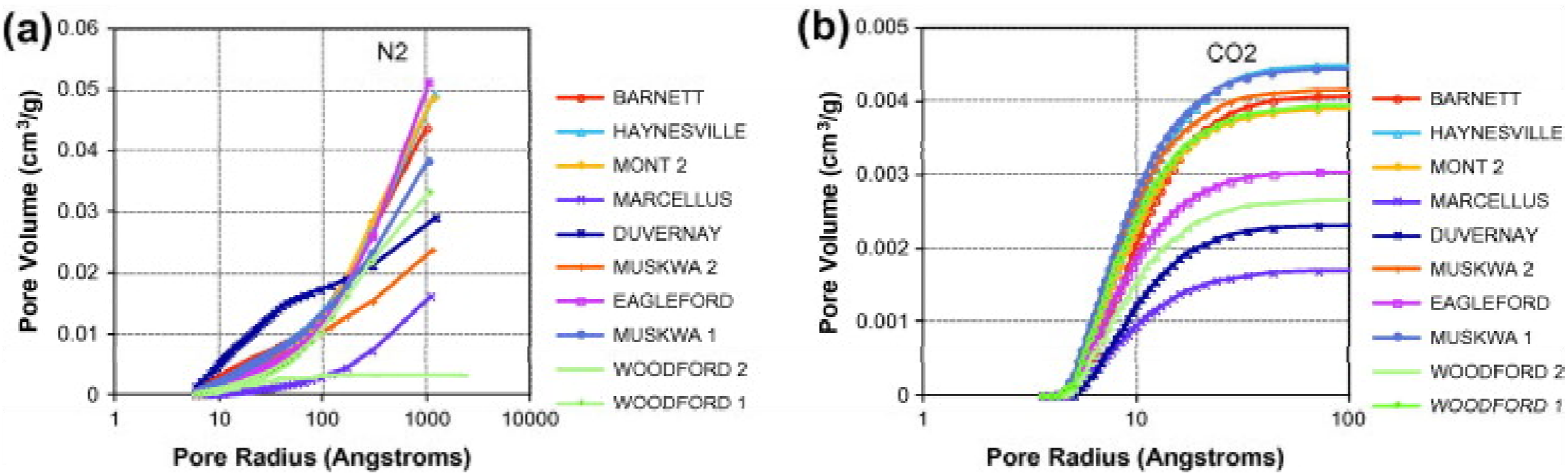
- From Clarkson et al. (2013)
- *Micropore volume of shale sample suite as determined by carbon dioxide adsorption.*



Shale Play Roundup

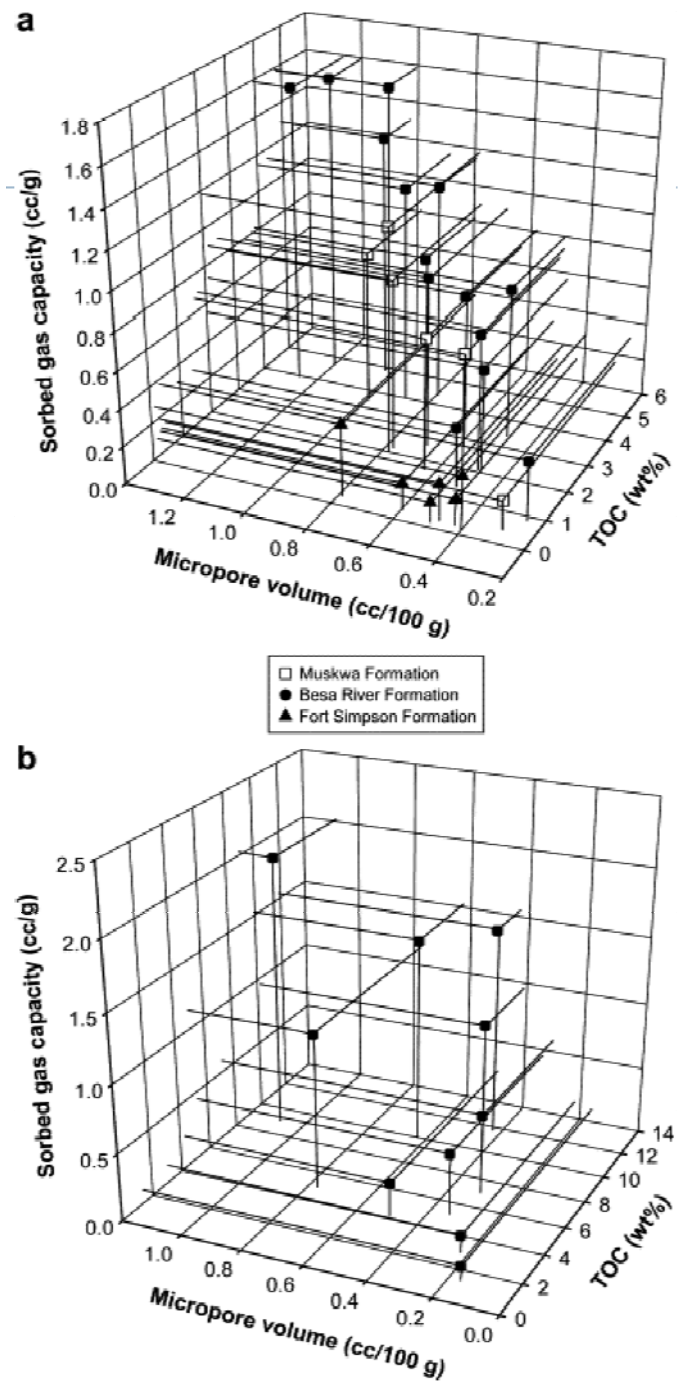
Comparative

- From Clarkson et al. (2013)
- *Cumulative adsorption pore volumes using (a) nitrogen and (b) carbon dioxide.*



Comparisons: Sorbed Gas

- From Ross & Bustin (2009)
- *Devonian–Mississippian shales show a positive correlation between TOC, micropore volume and sorbed CH_4 capacity, highlighting the microporous nature of the organic matter.*



Shale Play Roundup

Comparisons

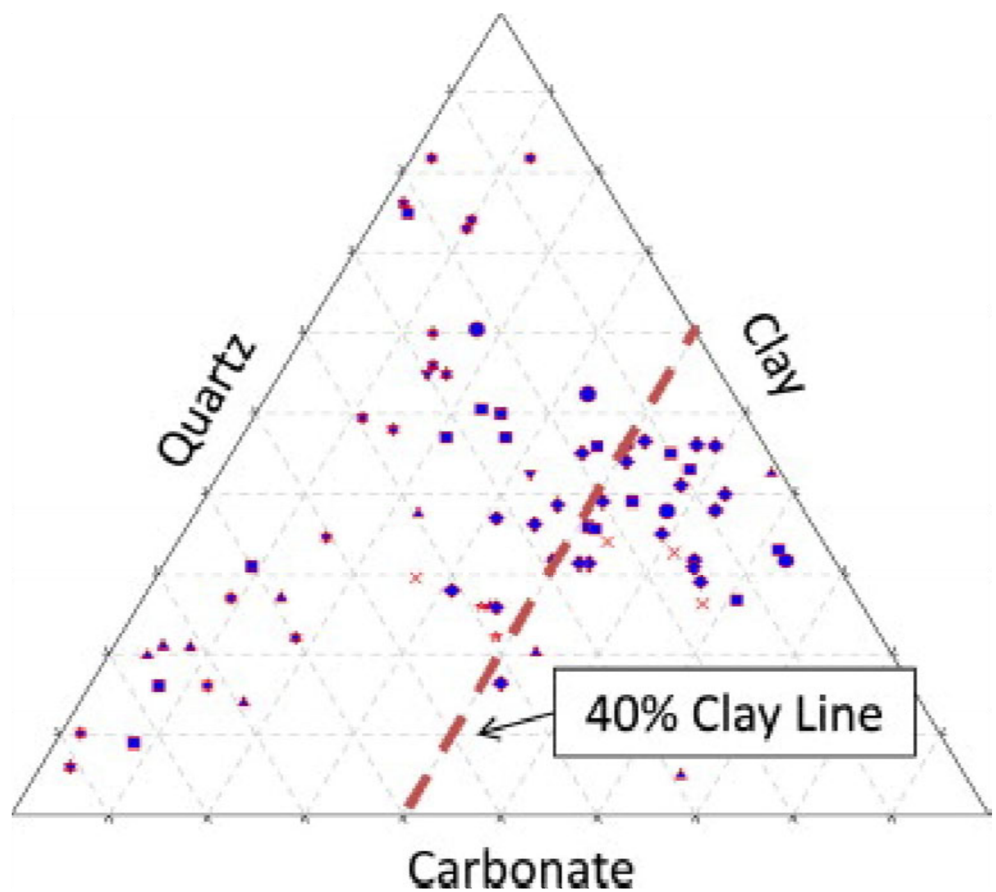
- From Ross & Bustin (2013)

Sample Group	Bamett-1	Haynesville-1	Eagle Ford-1	Eagle Ford-2	Fort St. John
Estimated In Situ	Sv: 65 Pp: 30	Sv: 85 Pp: 60␣70	Sv: 90 Pp: 65		Sv: 25␣30 Pp: 10␣12
Stress (MPa)	σeff: 35	σeff: 15␣25	σeff: 25	2.46␣2.54	σeff: 13␣20
Density (g/cc)	2.39␣2.47	2.49␣2.51	2.43␣2.46	11␣18	2.57␣2.60
QFP (%)	50␣52	32␣35	22␣29	63␣78	54␣60
Carbonate (%)	0␣3	20␣22	46␣54	6␣14	3␣5
Clay (%)	36␣39	36␣39	12␣21	4␣5	32␣39
Kerogen (%)	9␣11	8␣8	9␣11	3␣5	4␣5
Porosity (%)	4␣9	6␣6	0␣3		5␣6

Shale Play Roundup

Comparisons

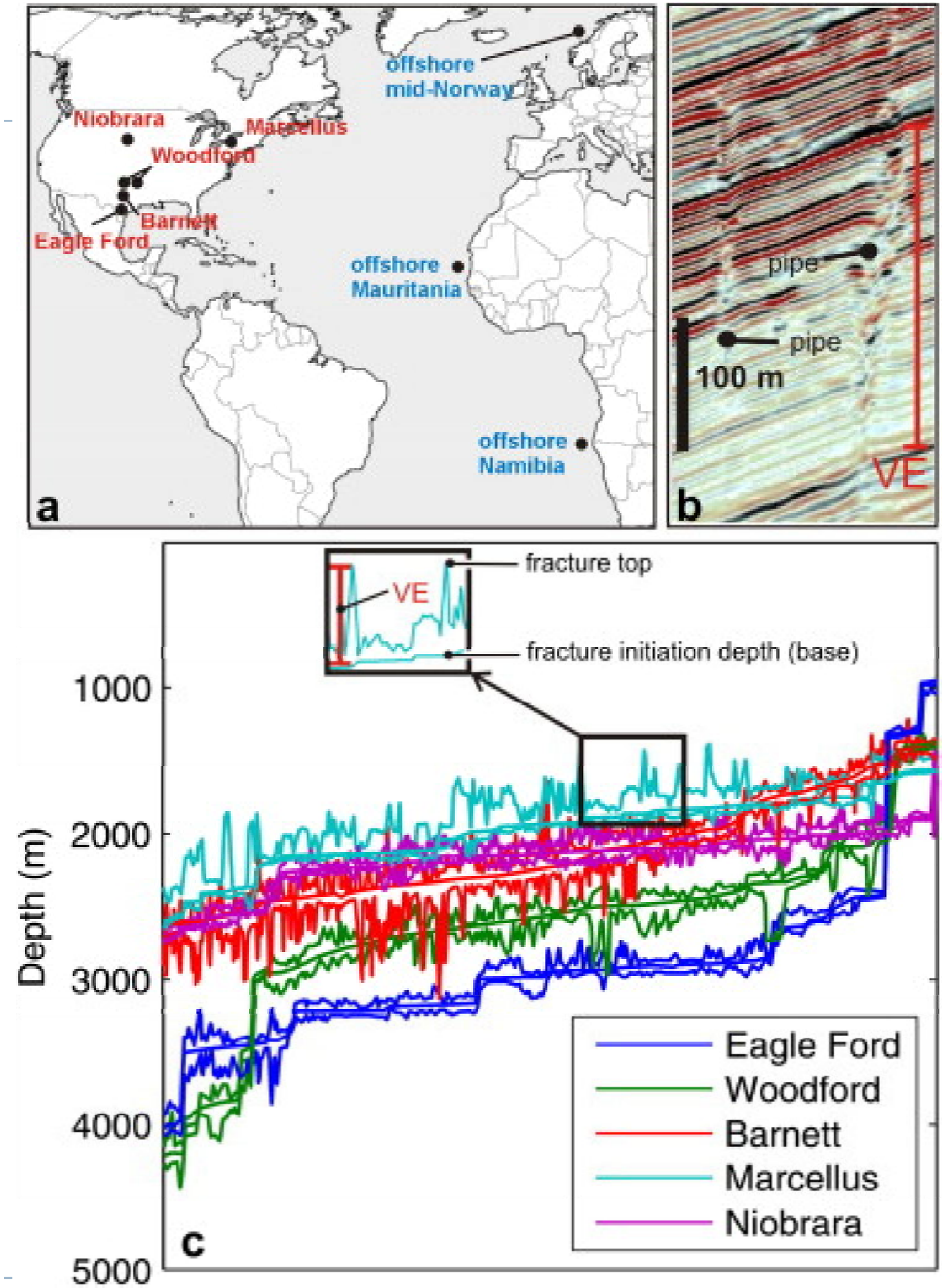
- Mineralogy of shales in North America (Britt, 2012)



Shale Play Roundup

Comparisons

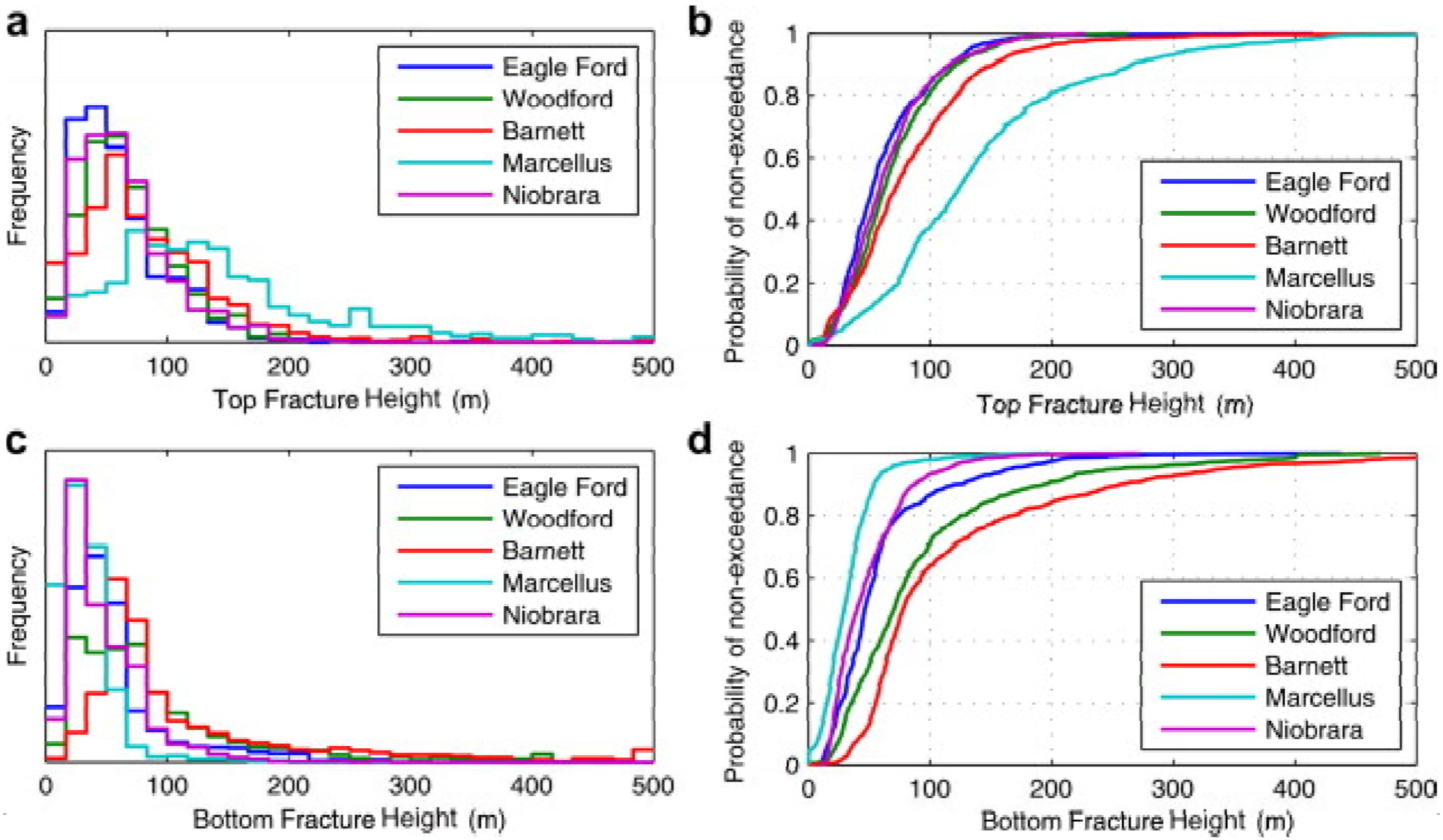
- Stimulated hydraulic fractures (Davies, 2012)



Shale Play Roundup

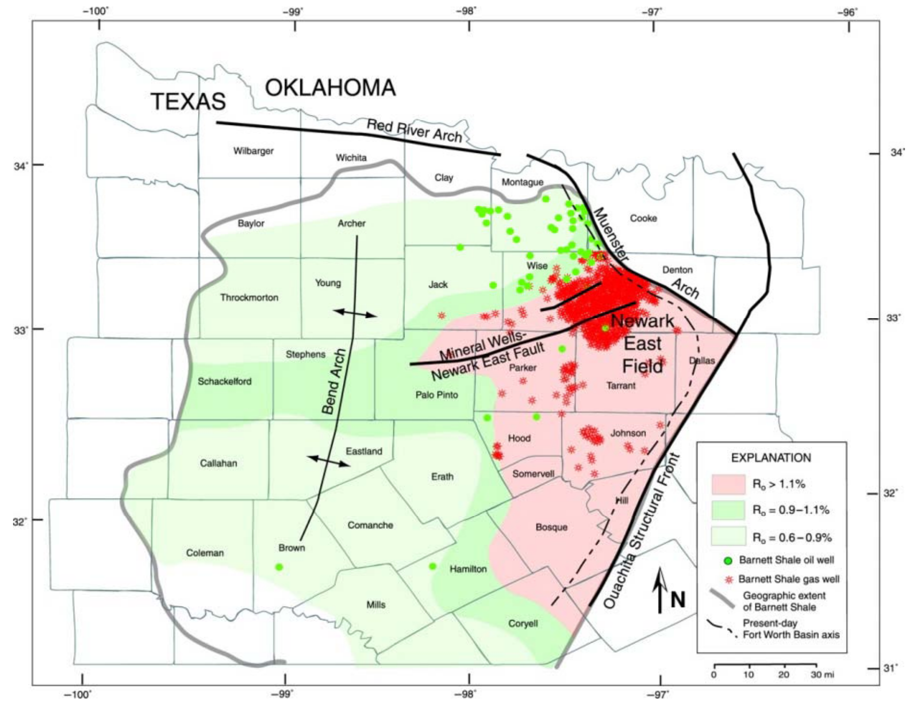
Comparisons

- Graphs of frequency against hydraulic fracture height for (a) upward and (b) downward propagating fractures in the Marcellus, Barnett, Woodford, Eagle Ford and Niobrara shales. (Davies, 2012)



Shale Play Roundup
Barnett

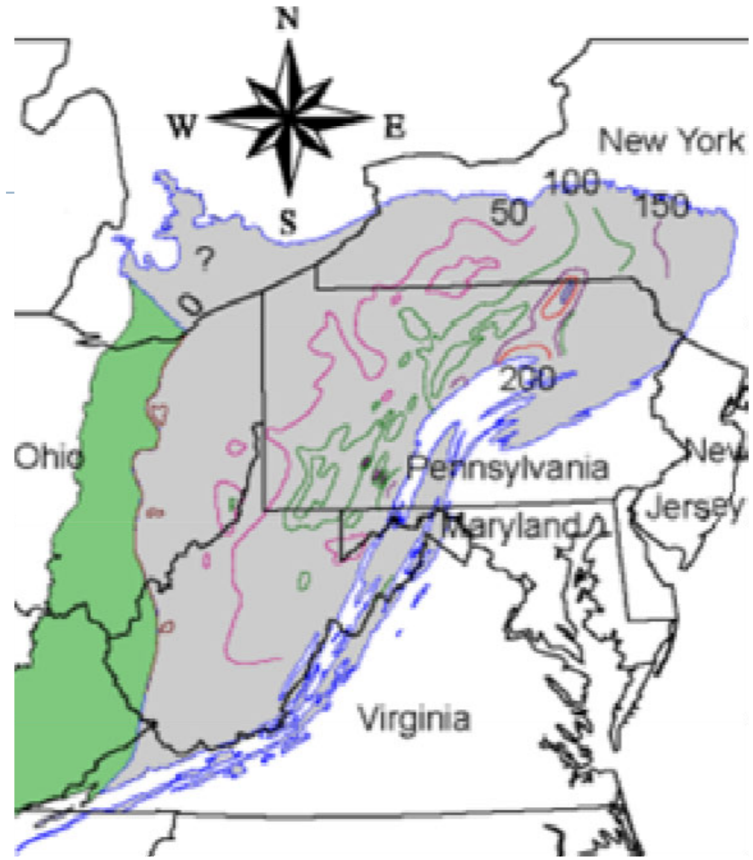
- First main shale gas
- Depth: 6,500 – 8,500 ft
- Thickness: 100 – 600 ft
- Average IPs: 4.0 MMcfd
- Laterals: 3,500 – 5,000 ft
- Sweet spots: Ro associated with depth of burial
- Problems: "learning curve" slickwater fracs; non-isolated multistage horizontals; declines / need to refract; can drill into wet lime (Ellenburger) and destroy well

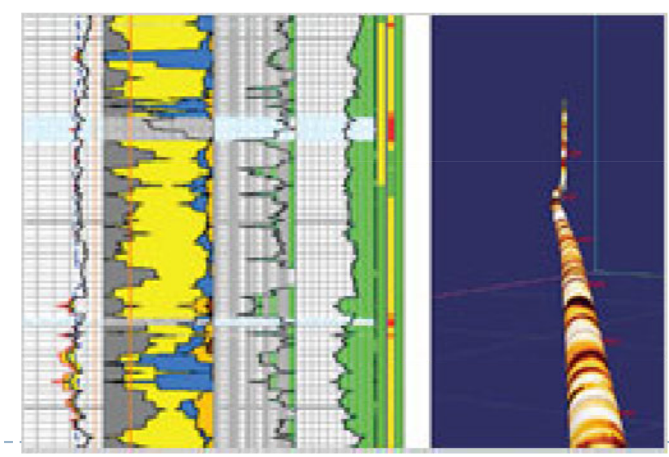


Shale Play Roundup

Marcellus

- Similar to Barnett monoclinal dip in a forearc setting
- "Sweet spots"
- Completion approaches (water frac / foam frac / N2 frac)
- Pressure gradient – low pressure -- must understand to successfully complete & produce
- TOC highly variable

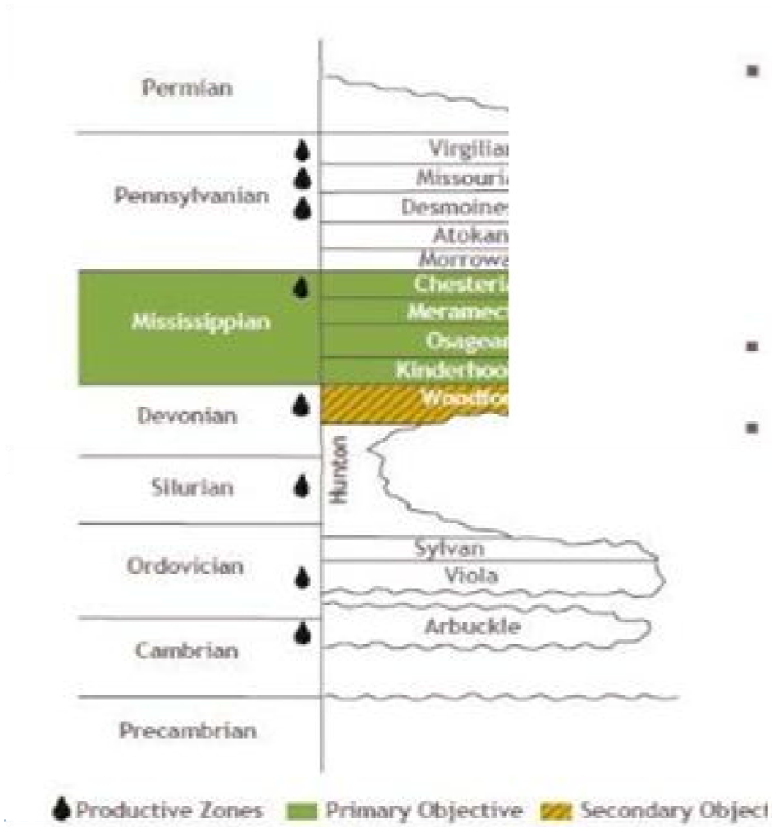


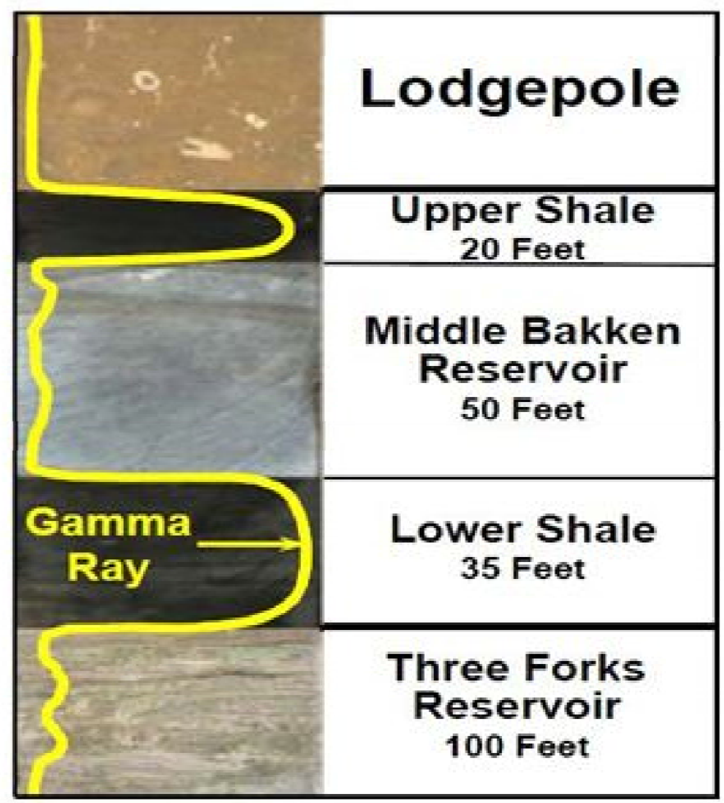


Shale Play Roundup

Bakken

- World Class Source Rocks
- Hard, siliceous, pyritic, fissile, organic-rich
- TOC.s as high as 40 wt% (average 11%)

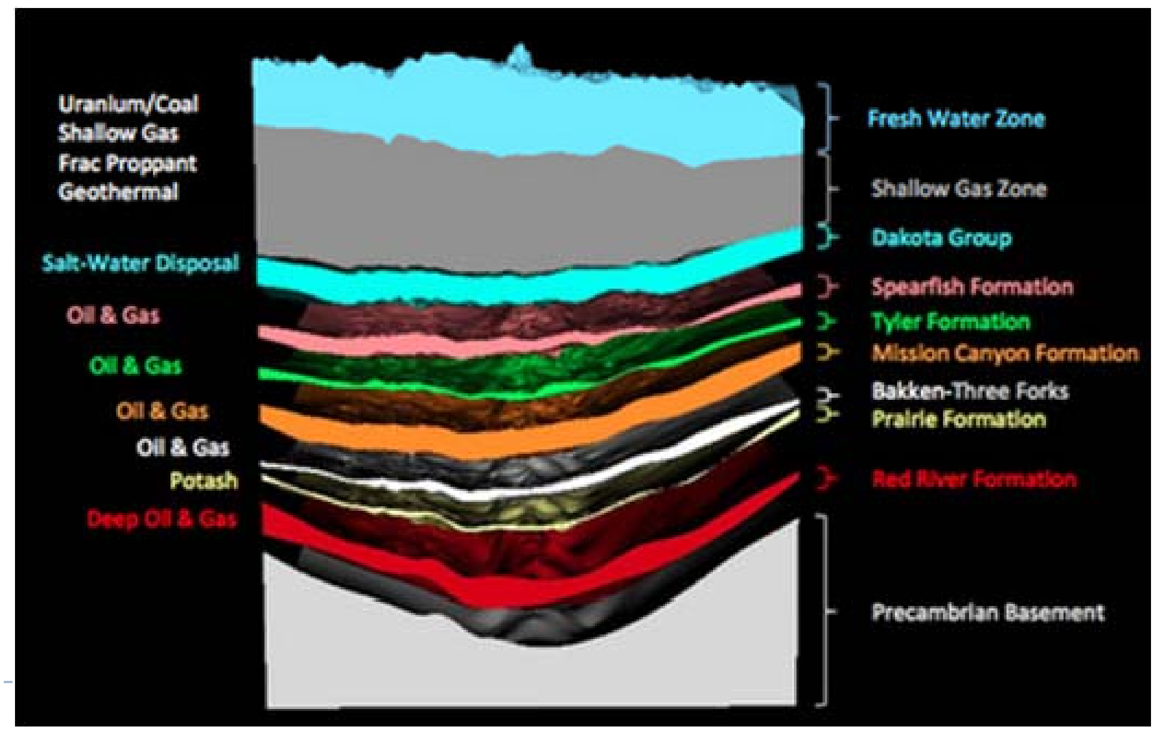




Shale Play Roundup

Bakken

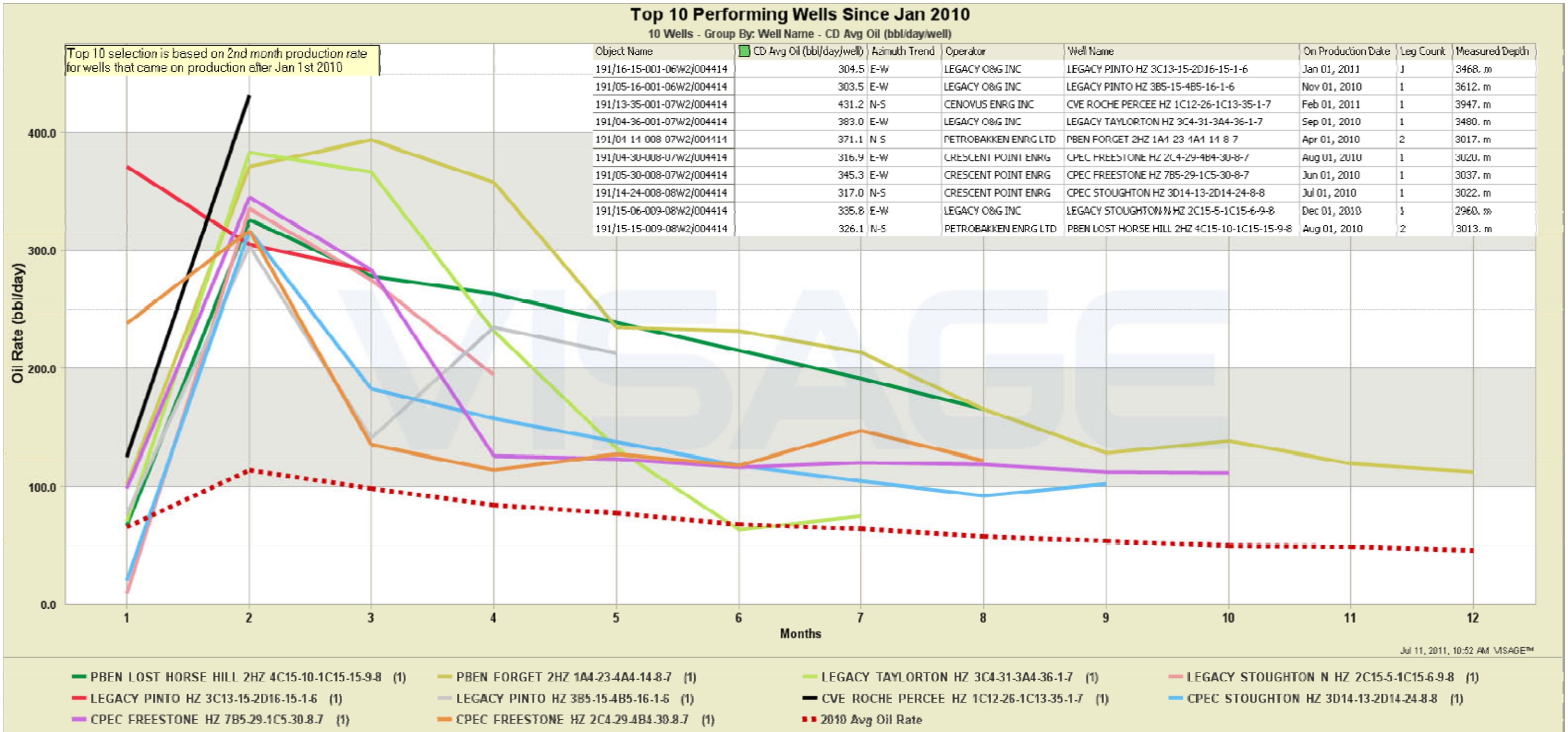
- High OM indicates anoxic conditions (amorphous-sapropelic OM)
- HC Generation: 10 to 400 B bbl oil
- Reservoir-favorable facies and diagenetic history (matrix permeability)
- Mature source rocks form continuous oil column (pervasive saturation)
- Favorable history of fracture development: folds, faults, solution of evaporites, high fluid pressures, regional stress field (fracture permeability)



Shale Play Roundup

Bakken

- Performance

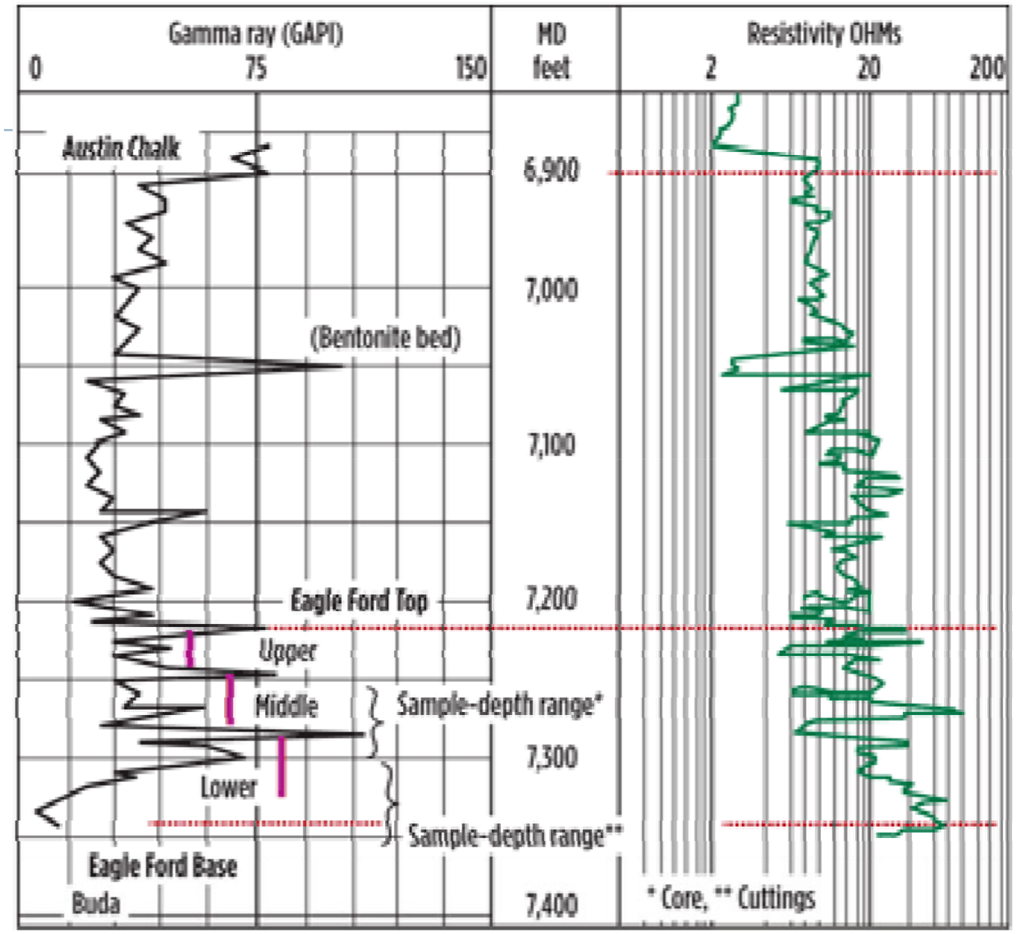


Object Name	CD Avg Oil (bbl/day/well)	Azimuth Trend	Operator	Well Name	On Production Date	Leg Count	Measured Depth
191/16-15-001-06W2/004414	304.5	E-W	LEGACY O&G INC	LEGACY PINTO HZ 3C13-15-2D16-15-1-6	Jan 01, 2011	1	3468. m
191/05-16-001-06W2/004414	303.5	E-W	LEGACY O&G INC	LEGACY PINTO HZ 3B5-15-4B5-16-1-6	Nov 01, 2010	1	3612. m
191/13-35-001-07W2/004414	431.2	N-S	CENOVUS ENRG INC	CVE ROCHE PERCEE HZ 1C12-26-1C13-35-1-7	Feb 01, 2011	1	3947. m
191/04-36-001-07W2/004414	383.0	E-W	LEGACY O&G INC	LEGACY TAYLORTON HZ 3C4-31-3A4-36-1-7	Sep 01, 2010	1	3480. m
191/01-14-008-07W2/004414	371.1	N-S	PETROBAKKEN ENRG LTD	PBEN FORGET 2HZ 1A4-23-4A4-14-8-7	Apr 01, 2010	2	3017. m
191/04-30-008-07W2/004414	316.9	E-W	CRESCENT POINT ENRG	CPEC FREESTONE HZ 2C4-29-4B4-30-8-7	Aug 01, 2010	1	3020. m
191/05-30-008-07W2/004414	345.3	E-W	CRESCENT POINT ENRG	CPEC FREESTONE HZ 7B5-29-1C5-30-8-7	Jun 01, 2010	1	3037. m
191/14-24-008-08W2/004414	317.0	N-S	CRESCENT POINT ENRG	CPEC STOUGHTON HZ 3D14-13-2D14-24-8-8	Jul 01, 2010	1	3022. m
191/15-06-009-08W2/004414	335.8	E-W	LEGACY O&G INC	LEGACY STOUGHTON N HZ 2C15-5-1C15-6-9-8	Dec 01, 2010	1	2960. m
191/15-15-009-08W2/004414	326.1	N-S	PETROBAKKEN ENRG LTD	PBEN LOST HORSE HILL 2HZ 4C15-10-1C15-15-9-8	Aug 01, 2010	2	3013. m

Shale Play Roundup

Eagle Ford

- Lower Cretaceous
- Depth: 4,000 – 12,000 ft
- Thickness: 100 – 475 ft
- TOC: 3 – 5 %
- Vitrinite Reflectance: 1.0 – 1.27% Ro
- Porosity = 9-12%
- Permeability = nanodarcies
- Pressure Gradient: 0.43-0.70 psi/ft
- Gas / liquids-rich production line: “oil window”

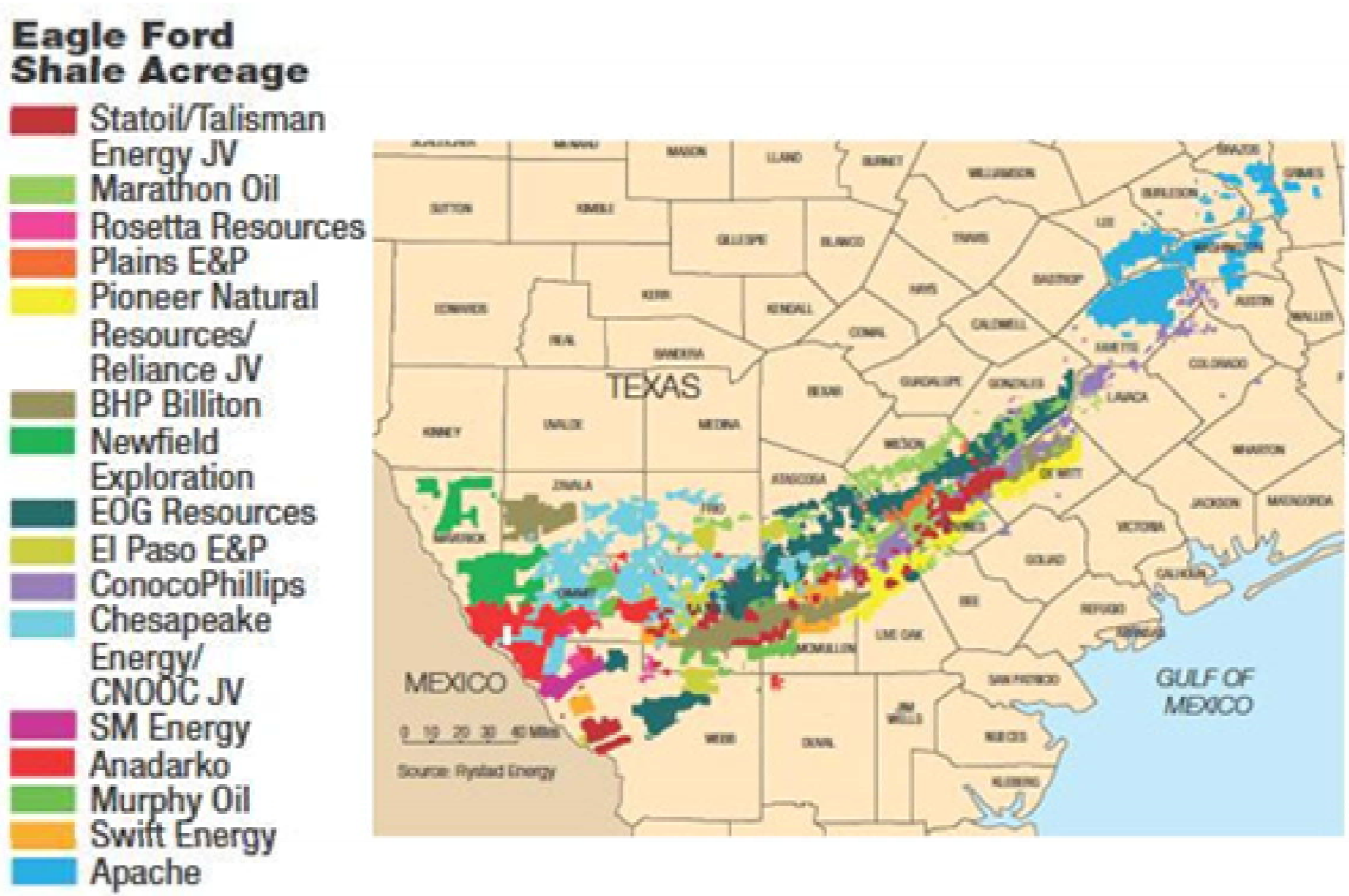


Source: Texas Railroad Commission, Well Completion Report; www.rrc.state.tx.us

Shale Play Roundup

Eagle Ford

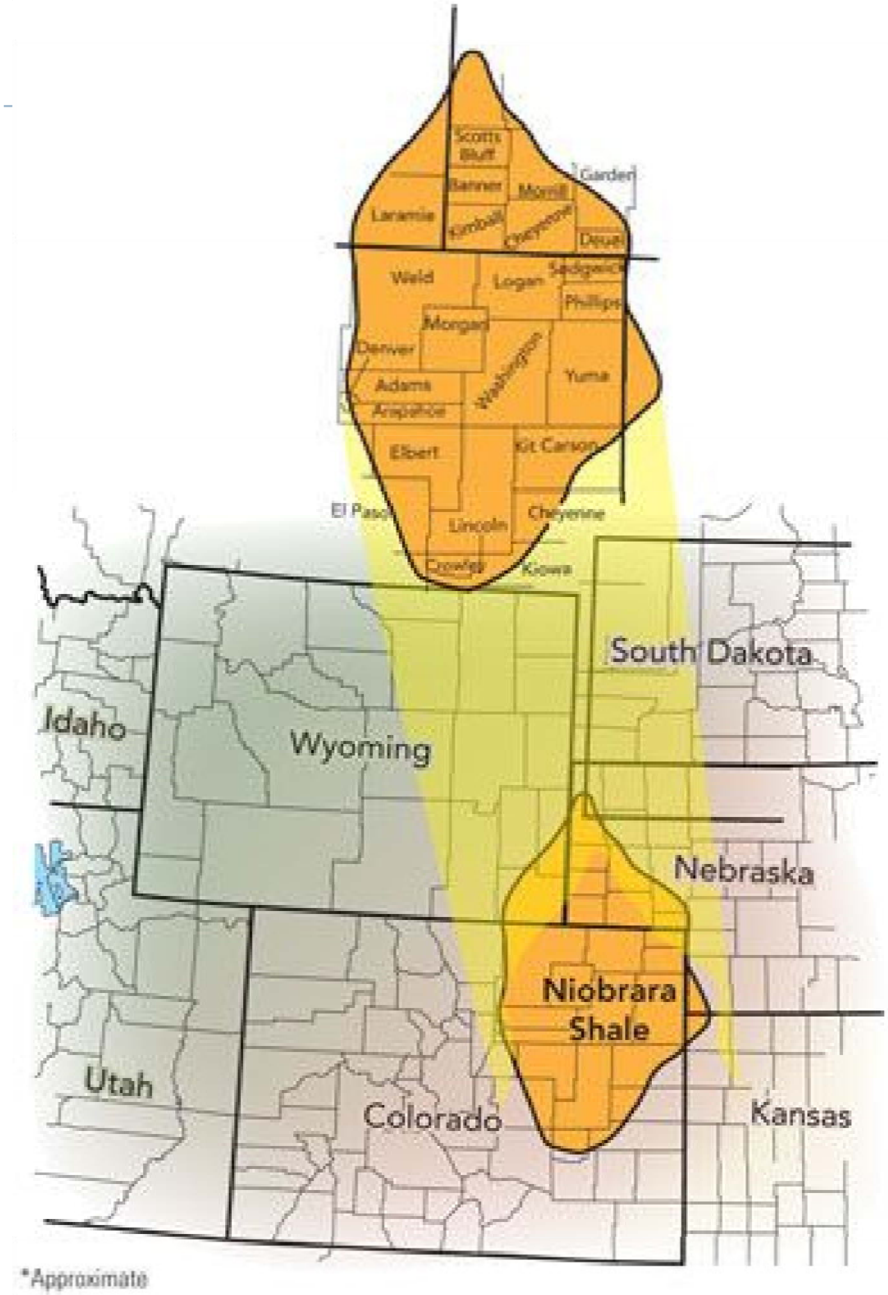
- Very active play; many operators, lots of turnover



Shale Play Roundup

Niobrara

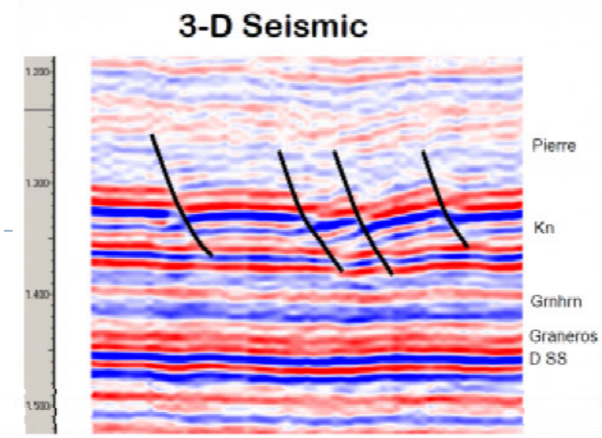
- Chalk: High petroleum saturation
- Mature source rocks
- Abnormally pressured
- Generally lacks downdip water / updip water saturation
- Low porosity and permeability reservoirs
- Fields enhanced by fracturing
- Folding and faulting / wrench faults

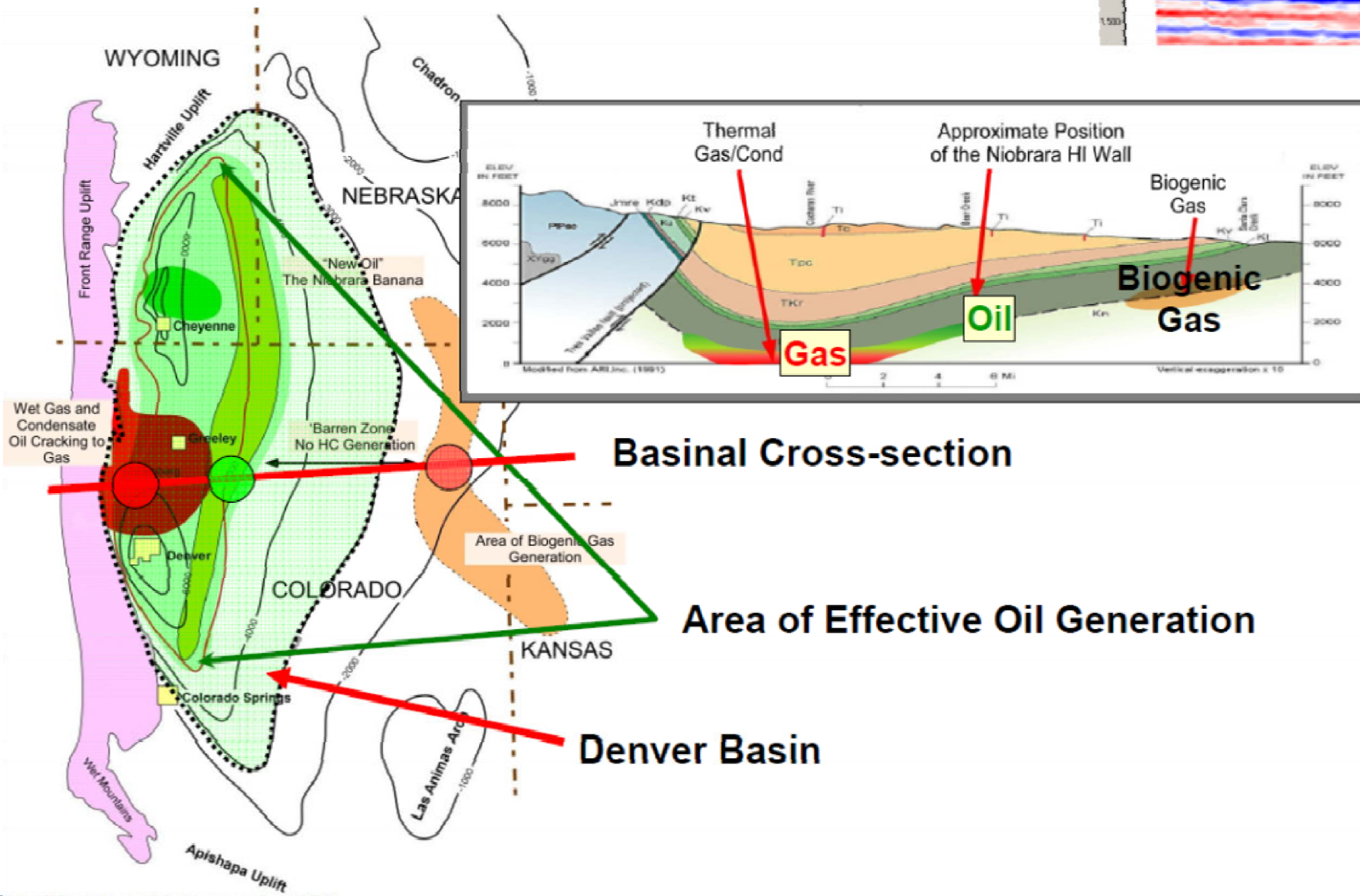


Shale Play Roundup

Niobrara

- Oil window & sweet spots



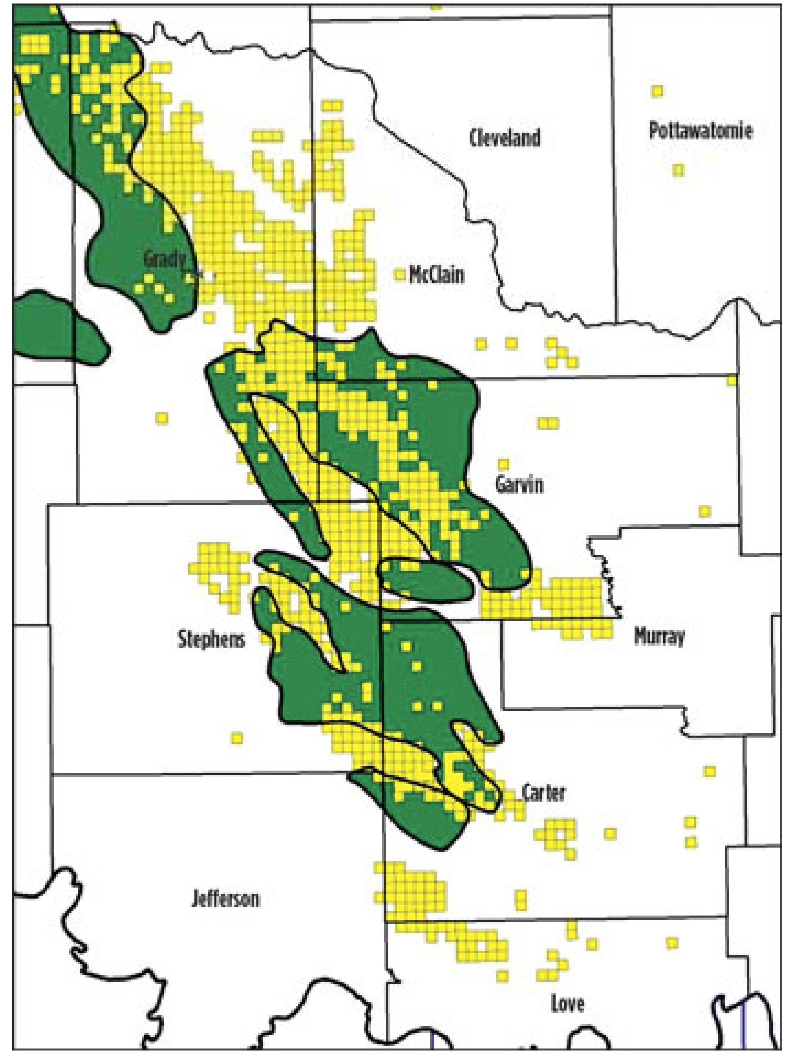


Modified from Matuszczak, 1973

Shale Play Roundup

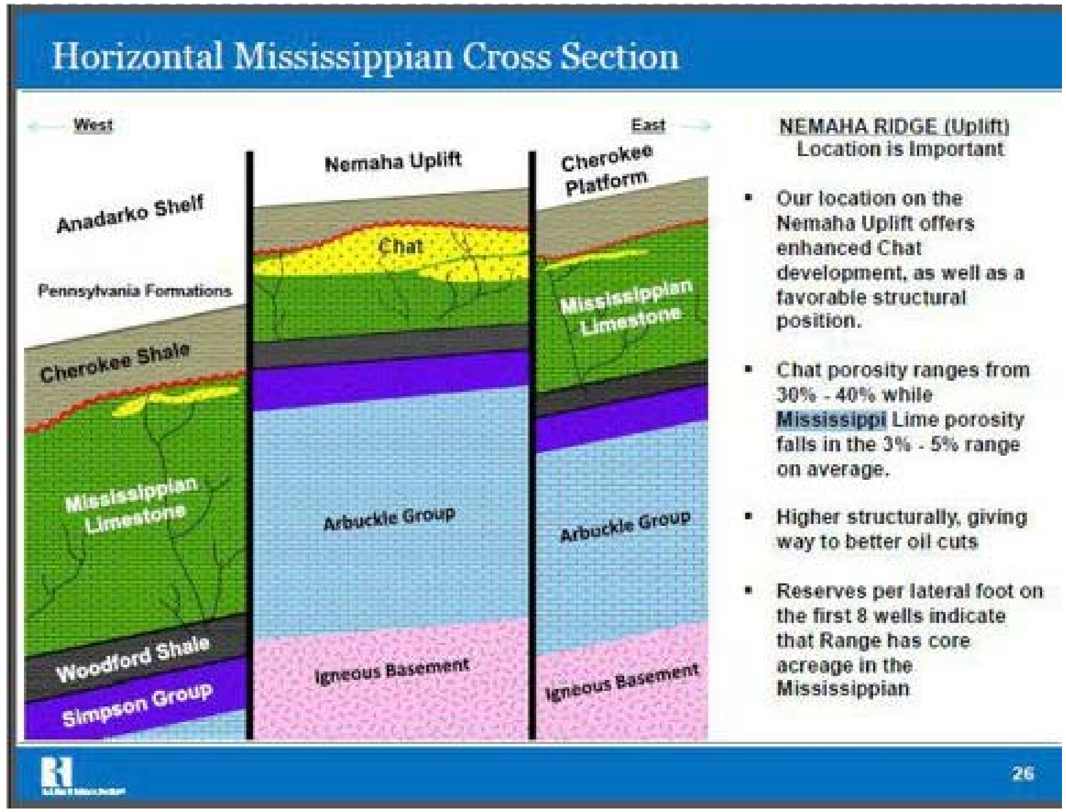
Woodford

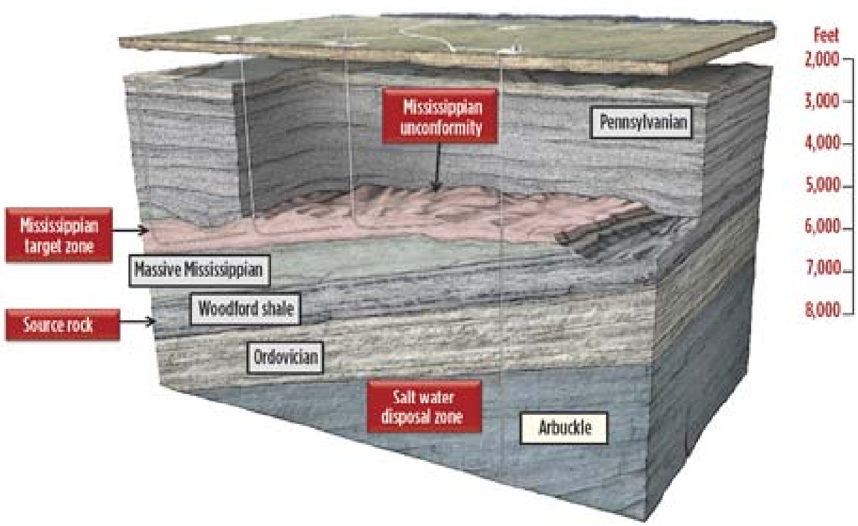
- Variable thermal maturity and kerogen type
- Highly variable structure
- Thermal flows are variable
- Structural regime extremely complicated
- Thickness varies
- Brittleness / Ductility factors



Mississippian Lime

- Tripolitic chert / "chat" zones
- Dolomitized
- Heat flows / alteration
- "New" carbonates
- Sweet spots

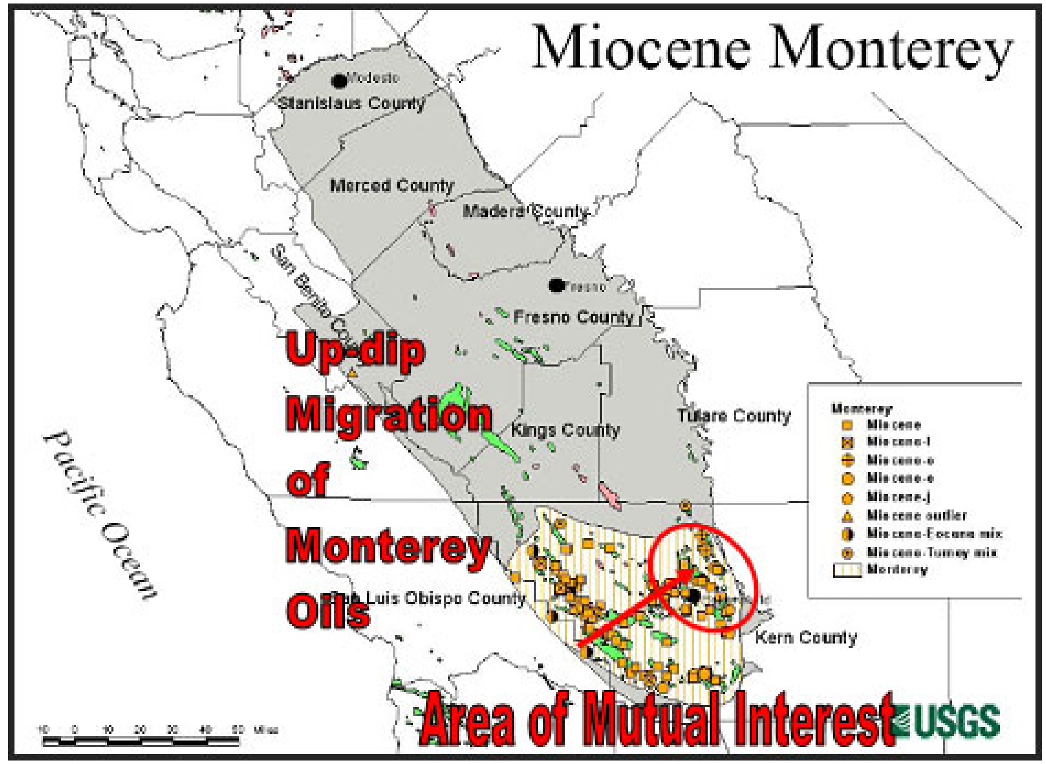




Shale Play Roundup

Monterey

- Lacustrine
- Diatomaceous
- Complex diagenesis
- Extremely low permeability



Shale Play Roundup

La Luna

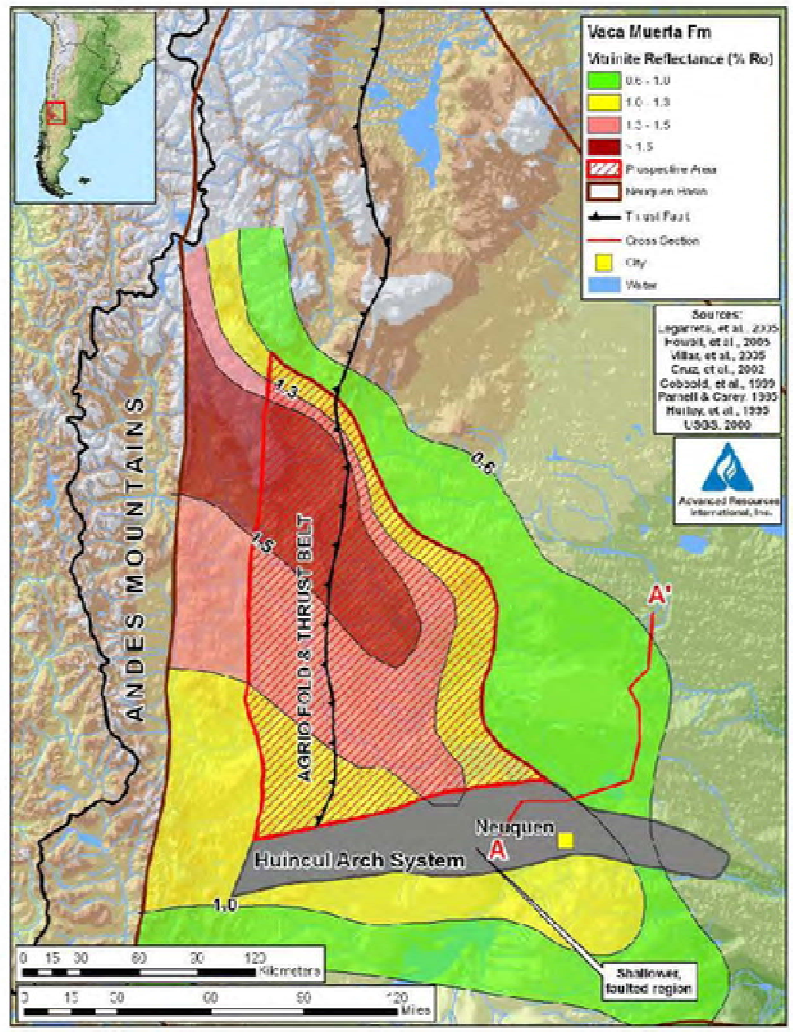
- Black shale
- High TOC
- Source rock for 90% of the Maracaibo Basin
- Fracable
- 3% natural porosity
- Thermal maturity (vitrinite reflectance – 1.26%)
- Low clay content
- 200 ft thickness for organically rich zone

Shale Play Roundup

Vaca Muerta

- Primarily marlstone
- Liquids-rich
- Excellent initial production rates possible
- 22.5 billion barrels EUR (Repsol, 2012)
- Highly variable TOC
- Brittleness varies

Figure IV-5. Vaca Muerta Fm, TOC, Thermal Maturity, and Prospective Area, Neuquen Basin



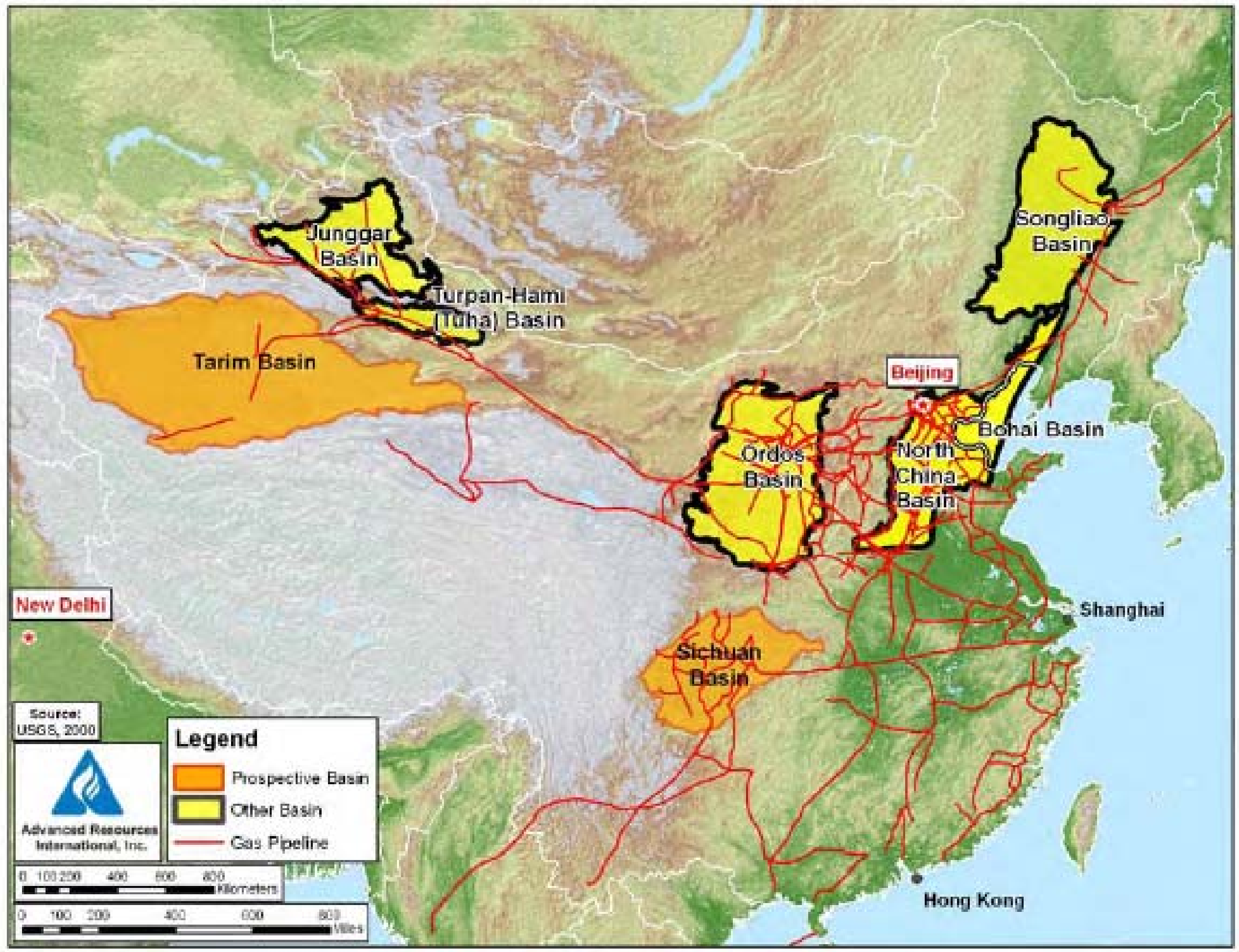
Shale Play Roundup

China's Shale Plays

- Lacustrine
- Very low permeability
- High heat flow
- Dry gas in some
- Extreme heterogeneity

FIGURE 2

China's key shale basins and natural gas pipeline system



Source: http://www.eia.gov/analysis/studies/worldshalegas/pdf/fullreport.pdf.

General Issues with Unconventionals

Heterogeneity

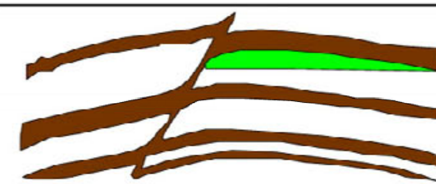
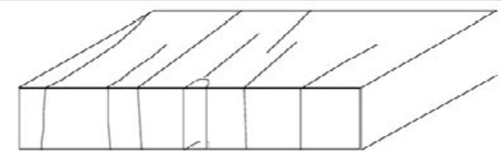
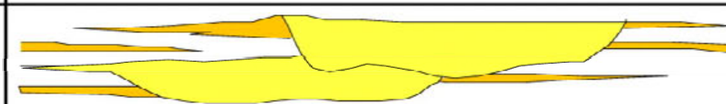
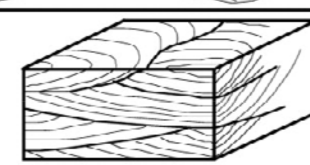
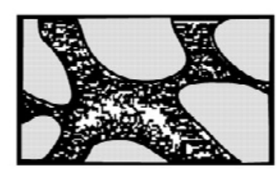
Typical Challenges

- Drilling
- Completions
- Production
- Water Sourcing, Treatment, & Disposal

Issues with Unconventionals

Heterogeneity

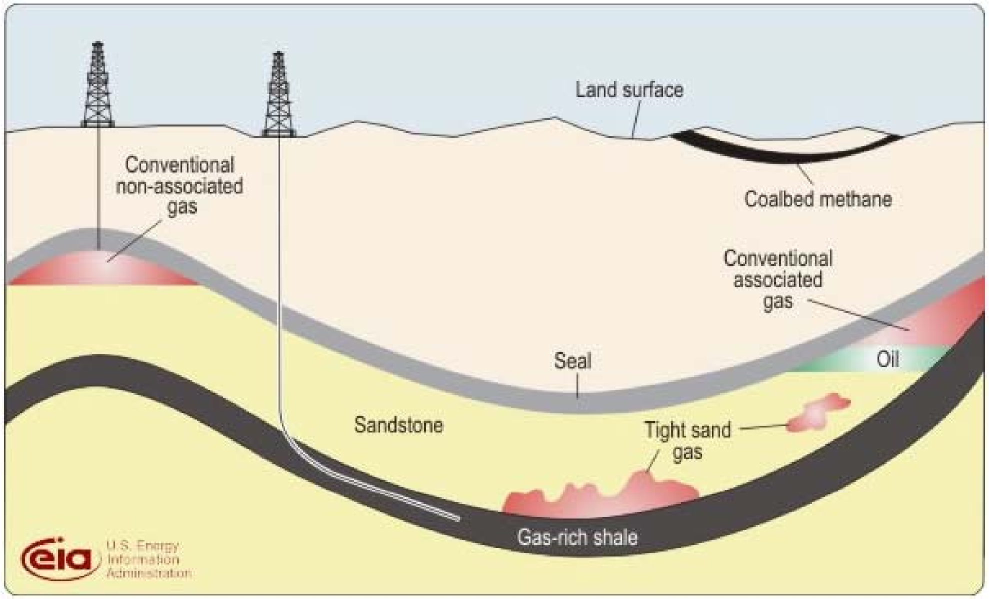
- Variable thicknesses
- Discontinuous sand / shale
- Lateral variability of lithology
- Fracture networks
- Variable pressure gradient
- TOC variability (3 – 5%)
- Vitrinite Reflectance: 1 – 2% Ro

Scale	Reservoir heterogeneity types	
Giga (>300 m)	*Sealing to nonsealing faults*	
	Fracturing	
Mega (10–100 m)	*Genetic unit boundaries*	
	Permeability zonation within genetic units	
Macro (in meters)	Baffles within genetic units	
	Sedimentary structures	
Micro (µm)	Microscopic heterogeneity	

Issues with Unconventionals

Drilling Challenges

- Staying in the zone
- Highly heterogeneous
- Brittleness varies
- Drilling fluid challenges
- Staying in the zone
- Drilling fluid
- Avoiding hazards (pressure / water zones)
- Some shales are high-pressure, high-temperature
- Unstable borehole
- Lost circulation challenges



Issues with Unconventionals

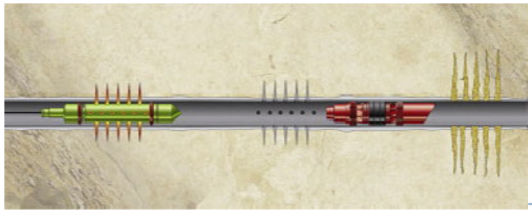
Completion & Stimulation Challenges

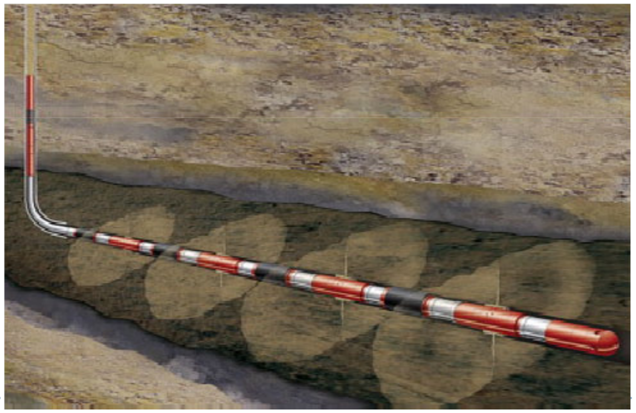
- Frac fluid selection
- Hydraulic fracturing challenges
- Proppant selection
- Understanding fractures / fracture networks
- Natural vs Induced fractures
- Geomechanics
- Understanding rock properties / fractures / geomechanics
- Placement of perforation clusters
- Zoned / isolated hydraulic fracturing
- Isolating the fracs

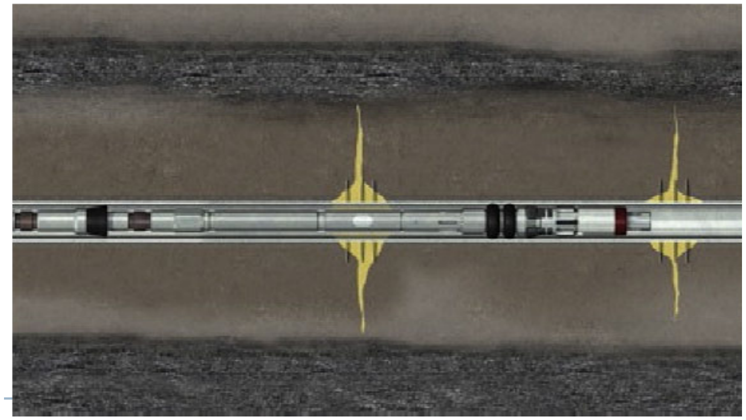
Issues with Unconventionals

Completion & Stimulation Challenges

- No plays are alike (King, 2010)
  - No two shale formations are alike. Shale formations vary spatially and vertically within a trend, even along the wellbore.
  - Shale “fabric” differences, combined with in-situ stresses and geologic changes are often sufficient to require stimulation changes within a single well to obtain best recovery.
  - Understanding and predicting shale well performance requires identification of a critical data set that must be collected to enable optimization of the completion and stimulation design.
  - There are no optimum, one-size-fits-all completion or stimulation designs for shale wells.



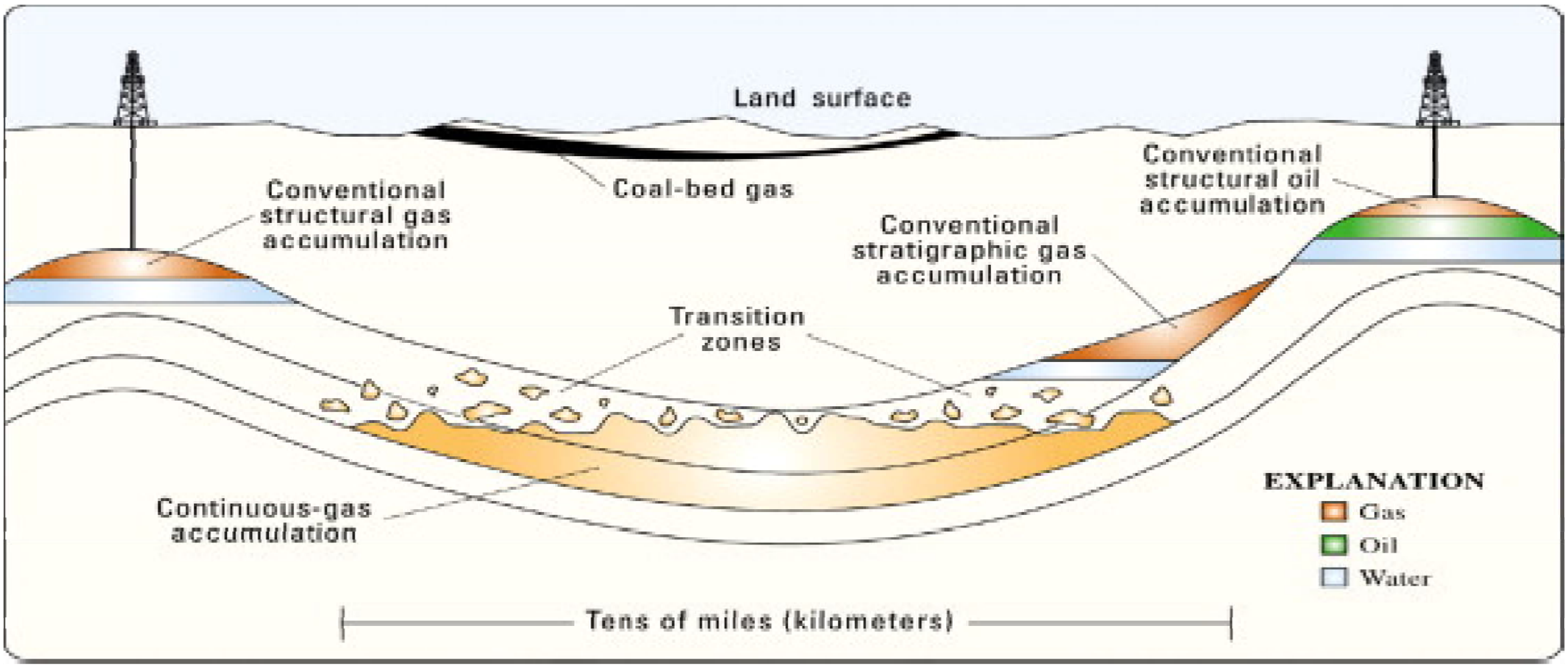




Issues with Unconventionals

Completion & Stimulation Challenges

- Transition zone discontinuities (Wang et al., 2014)
- *Schematic geology of shale gas compared to other types of gas deposits.*



Issues with Unconventionals

Completion & Stimulation Challenges

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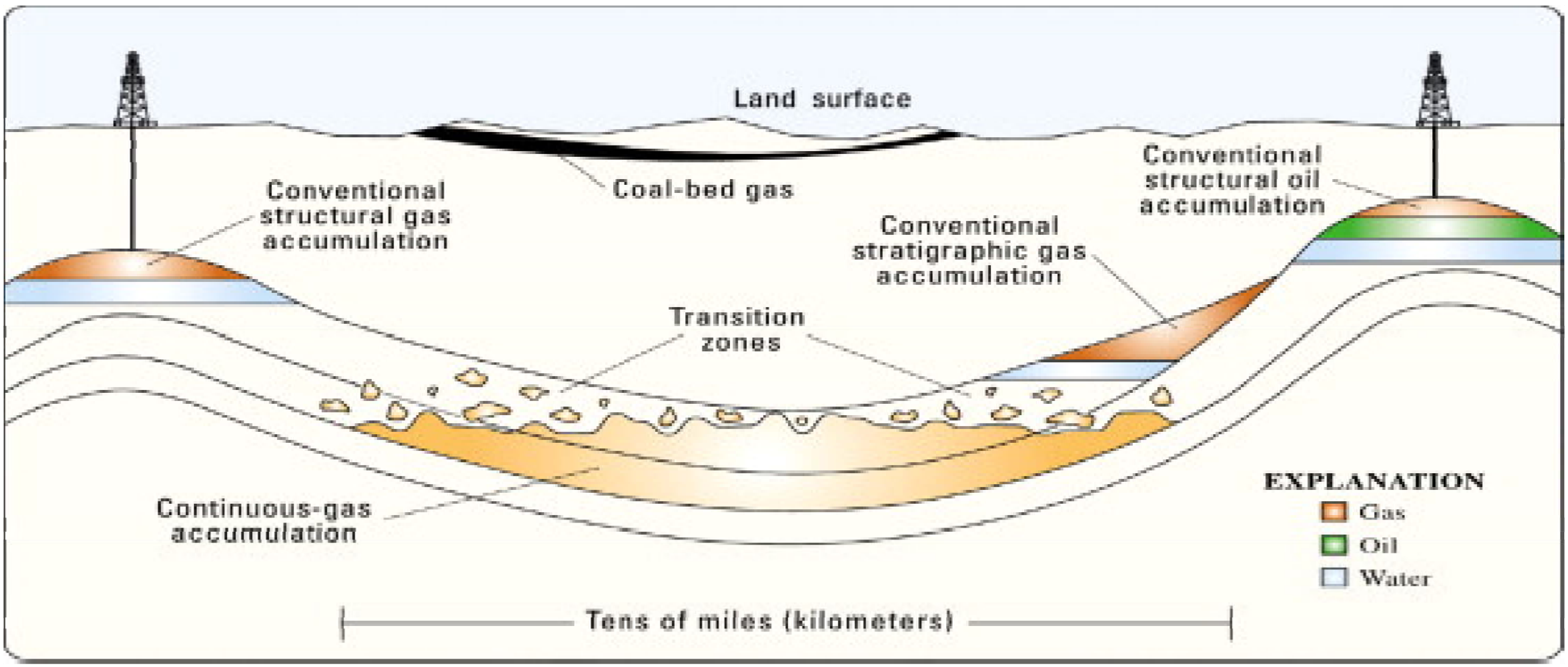
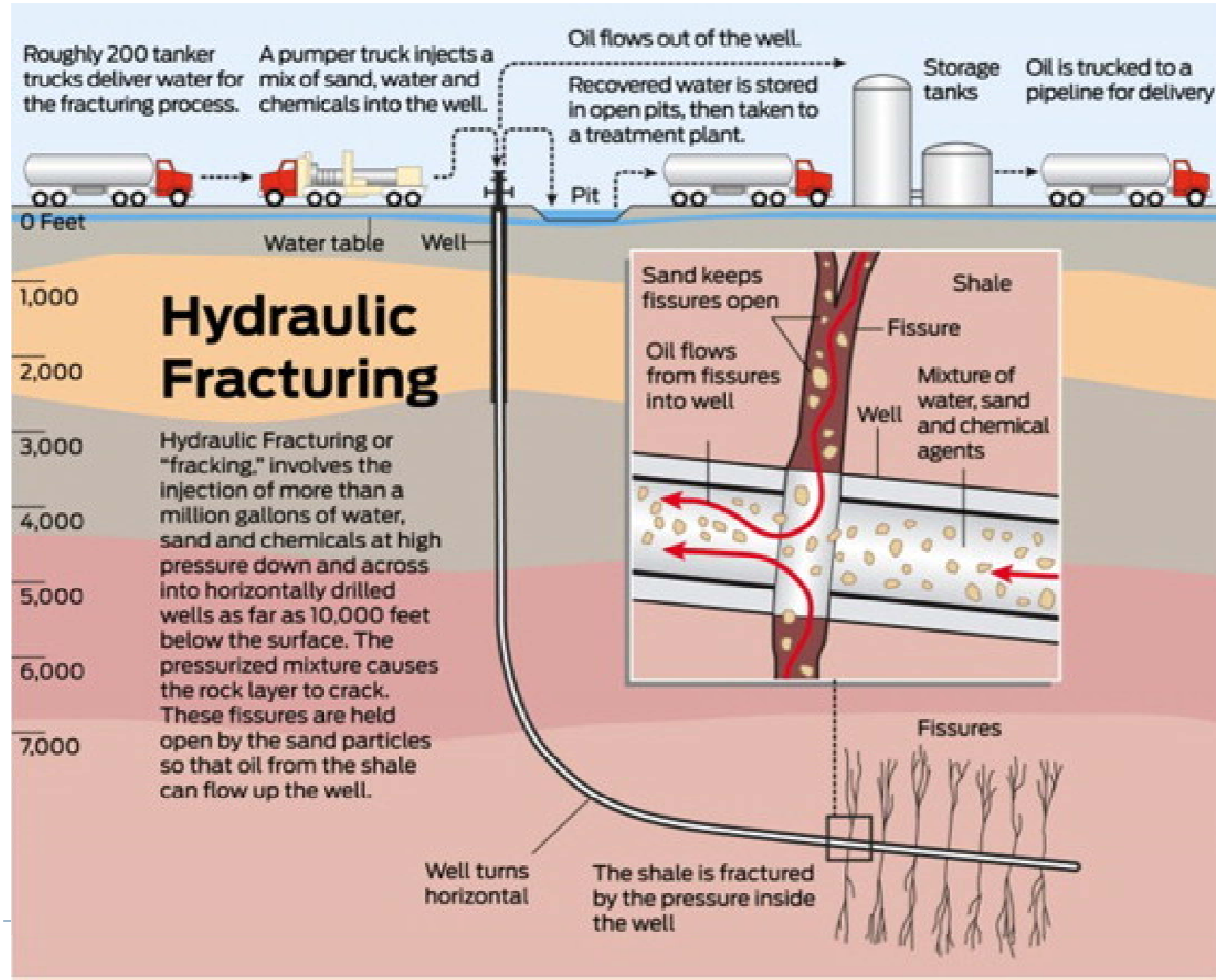


Issues with Unconventionals

Completion & Stimulation Challenges

- Hydraulic fracturing (Wang et al., 2014)



Completion & Stimulation Challenges

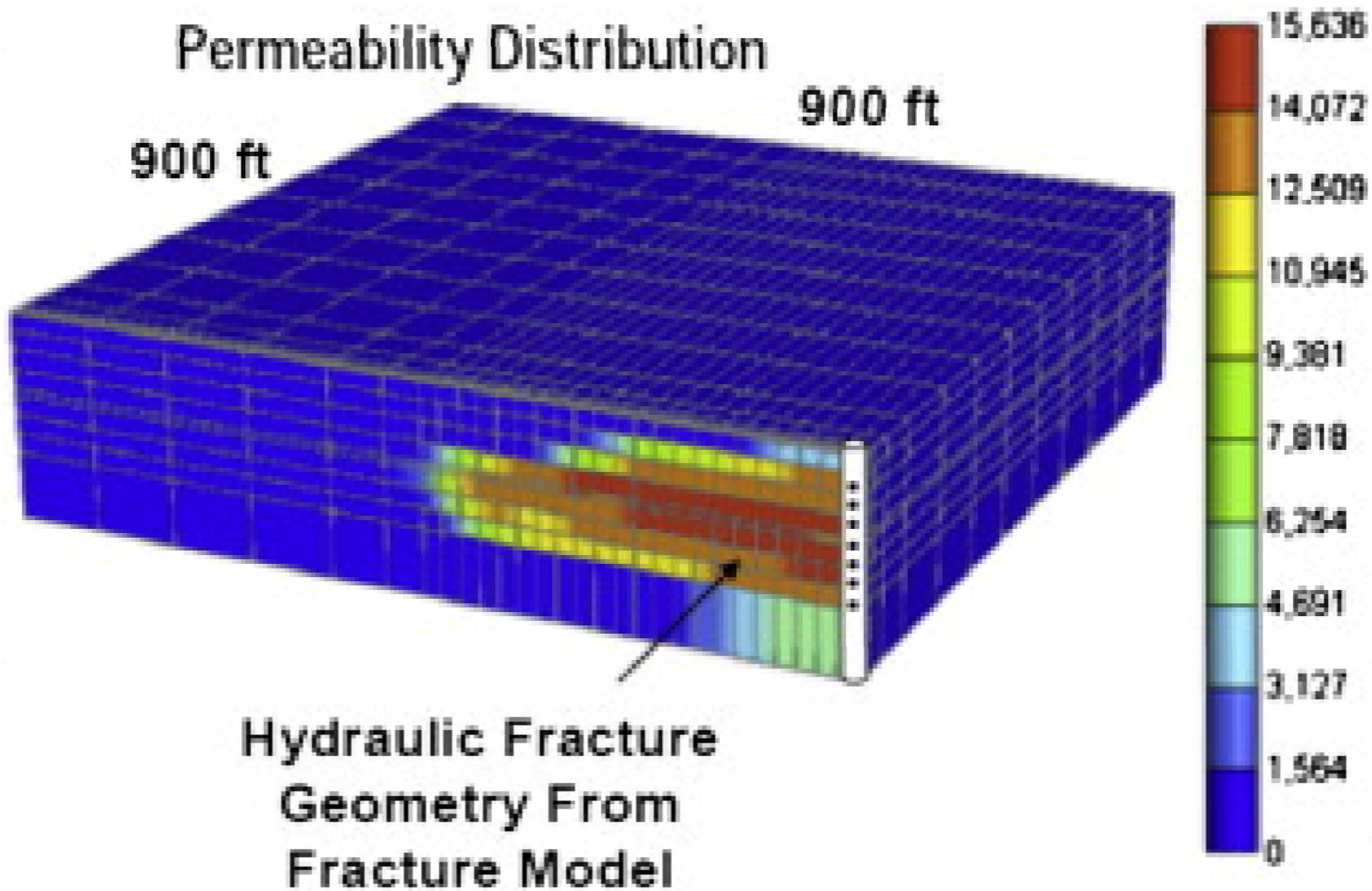
- What goes into a hydraulic frac? (Wang et al., 2014)

Chemicals	Function
Acids	To achieve greater injection ability or penetration and later to dissolve minerals and clays to reduce clogging, allowing gas to flow to the surface
Biocides	To prevent bacteria that can produce acids that erode pipes and fittings and breakdown gellants that ensure that fluid viscosity and proppant transport are maintained
Breakers	To allow the breakdown of gellants used to carry the proppant, added near the end of the fracking sequence to enhance flowback
Clay stabilizers	To create a fluid barrier to prevent mobilization of clays, which can plug fractures
Corrosion inhibitors	To reduce the potential for rusting in pipes and casings
Crosslinkers	To thicken fluids often with metallic salts in order to increase viscosity and proppant transport
Defoamers	To reduce foaming after it is no longer needed in order to lower surface tension and allow trapped gas to escape
Foamers	To increase carrying-capacity while transporting proppants and decreasing the overall volume of fluid needed
Friction reducers	To make water slick and minimize the friction created under high pressure and to increase the rate and efficiency of moving the fracking fluid
Gellants	To increase viscosity and suspend sand during proppant transport
pH control	To maintain the pH at various stages using buffers to ensure maximum effectiveness of various additives
Proppants	To hold fissures open, allowing gas to flow out of the cracked formation, usually composed of sand and occasionally glass beads
Scale control	To prevent build up of mineral scale that can block fluid and gas passage through the pipes
Surfactants	To decrease liquid surface tension and improve fluid passage through pipes in either direction

Issues with Unconventionals

Completion & Stimulation Challenges

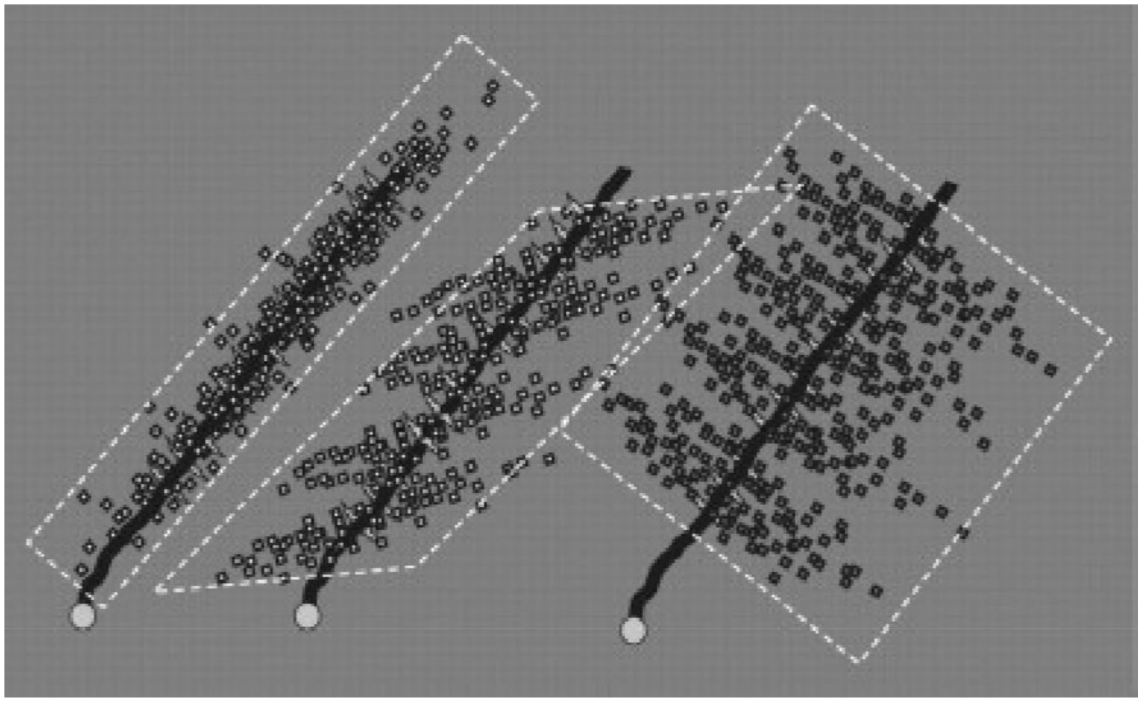
- Hydraulic fracturing modeling (Mohaghegh, 2013)



Issues with Unconventionals

Completion & Stimulation Challenges

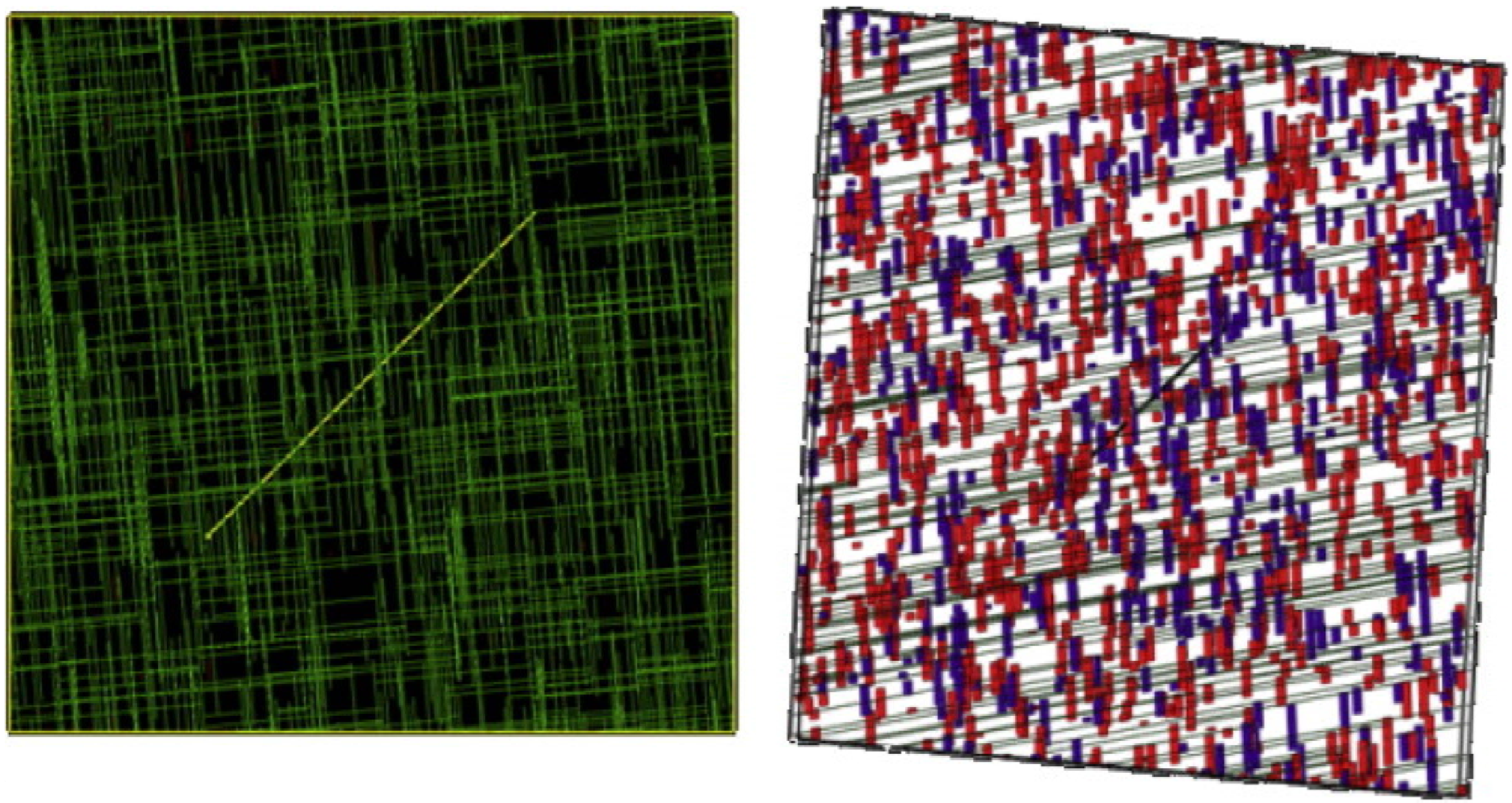
- Hydraulic fracturing modeling (Mohaghegh, 2013)
- Example of Stimulated Reservoir Volume



Issues with Unconventionals

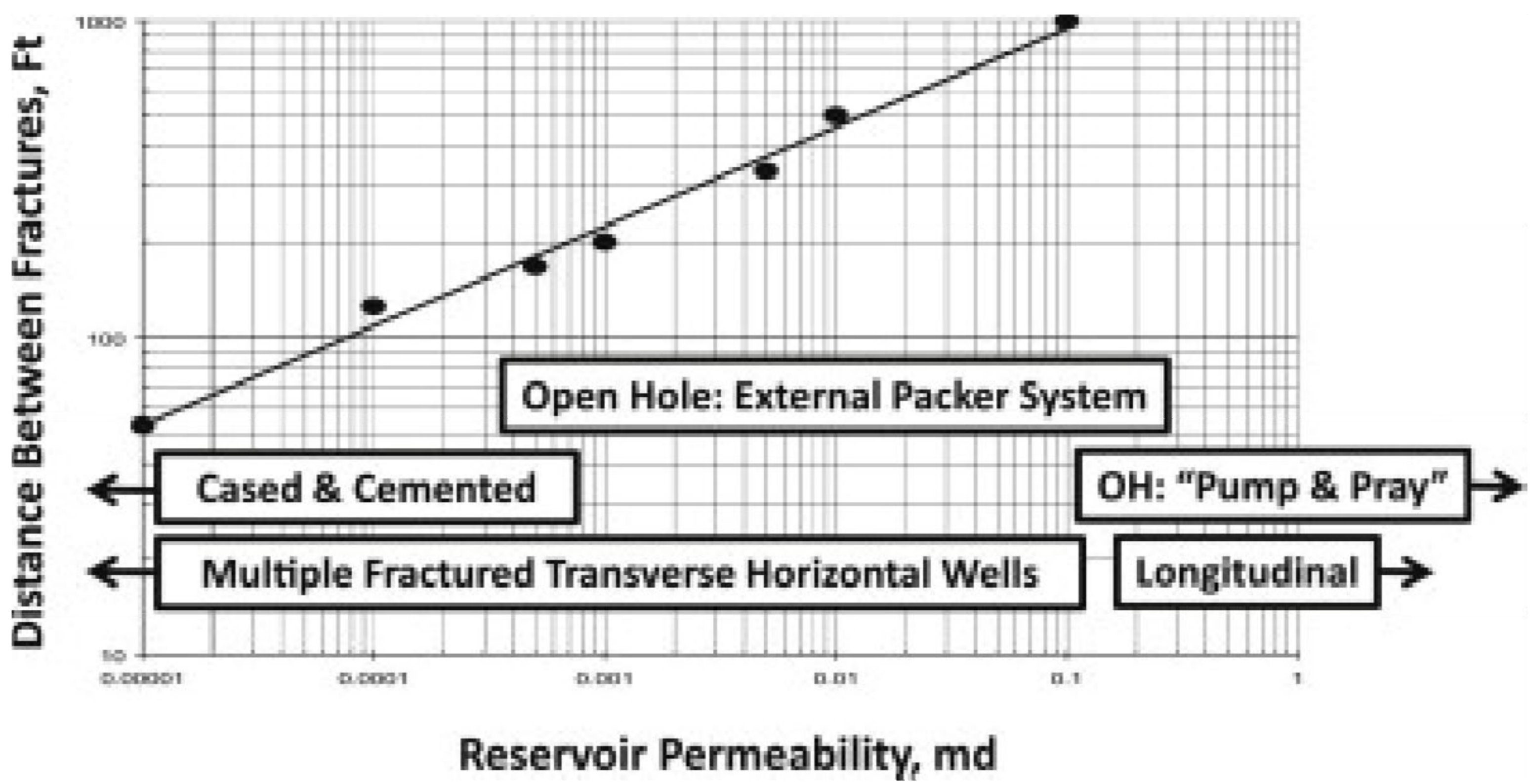
Completion & Stimulation Challenges

- Understand the natural fracture networks (after Mohaghegh, 2013)



Completion & Stimulation Challenges

- Optimal completion spacing versus permeability (Britt, 2012).



Issues with Unconventionals

Completion & Stimulation Challenges

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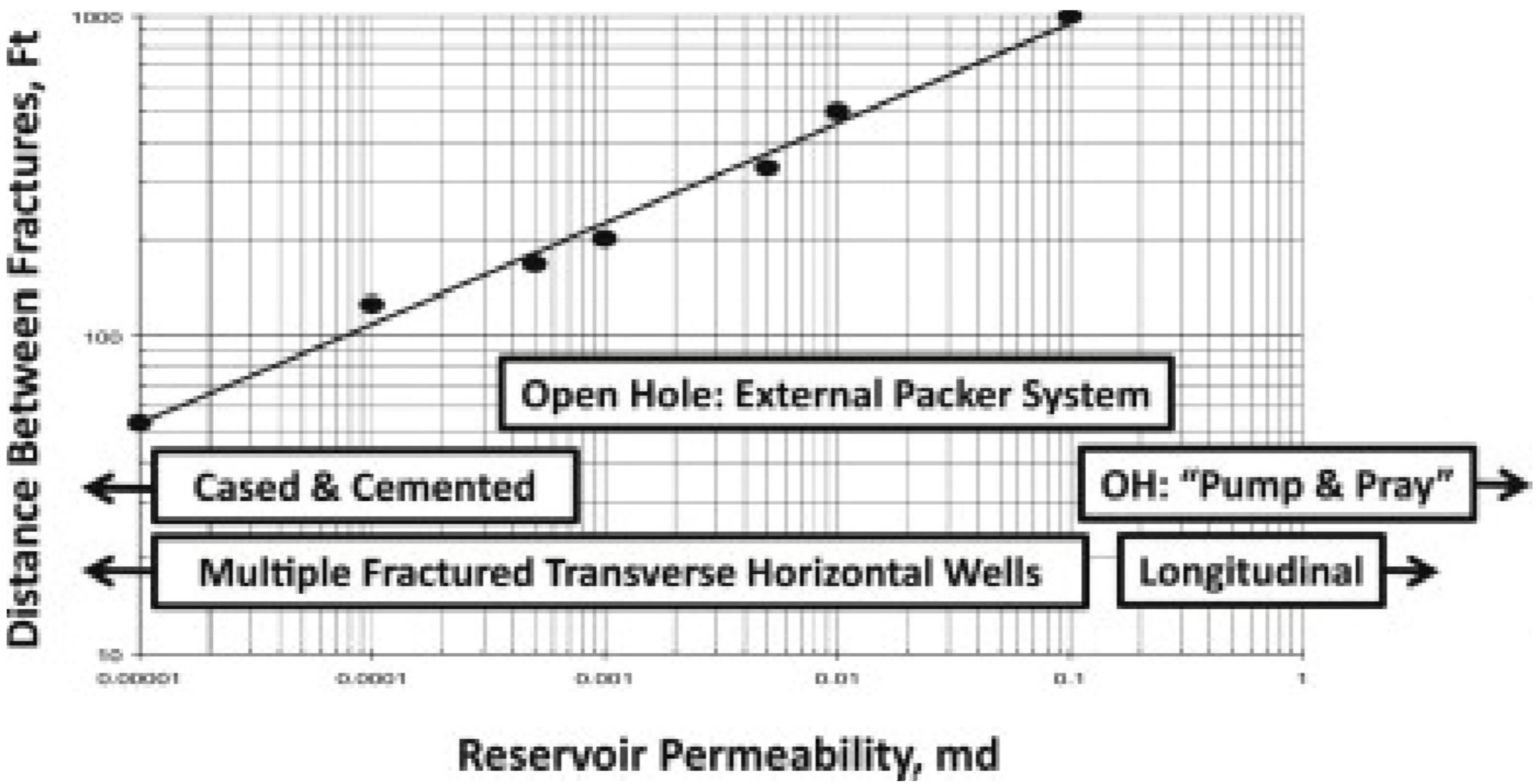
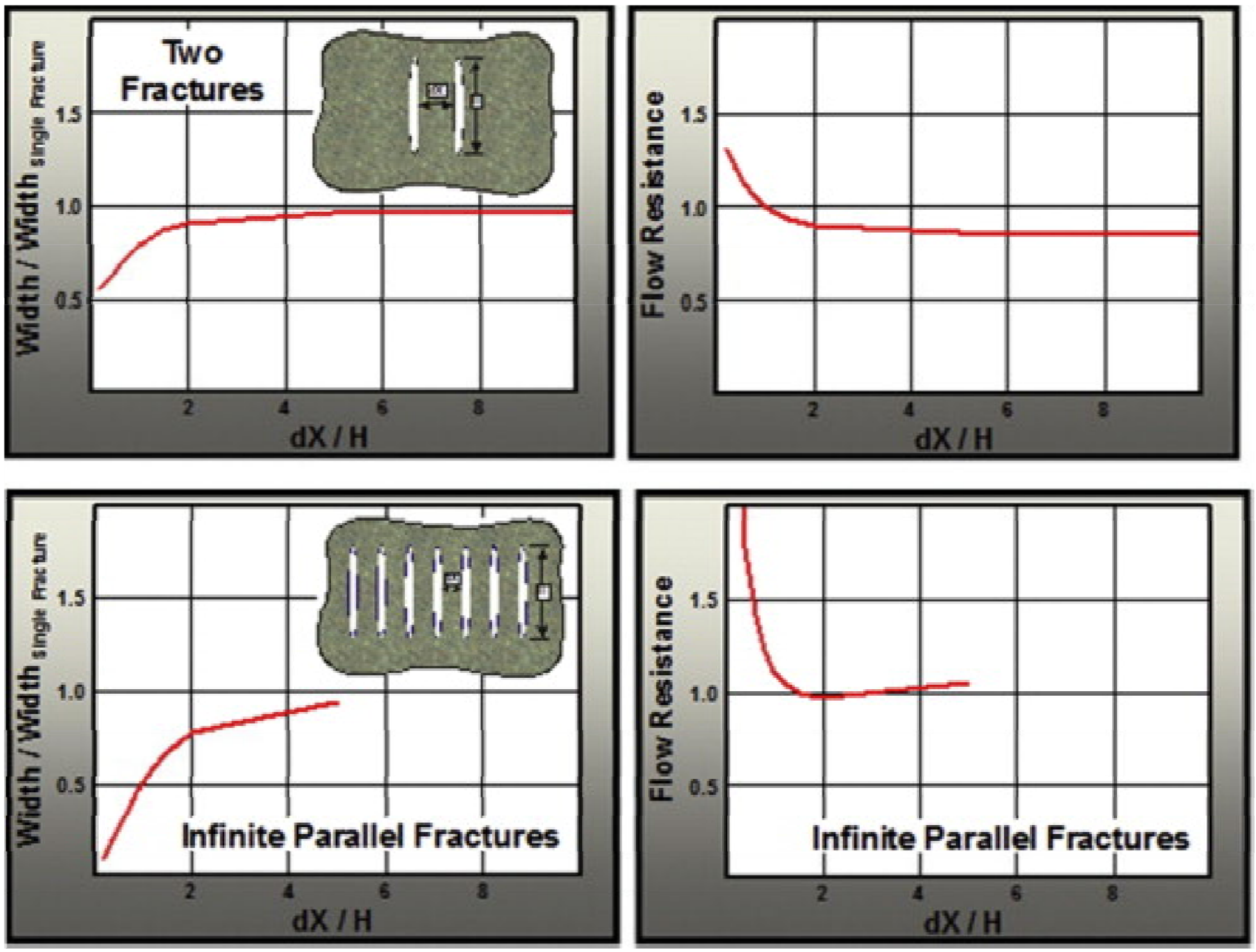


Issues with Unconventionals

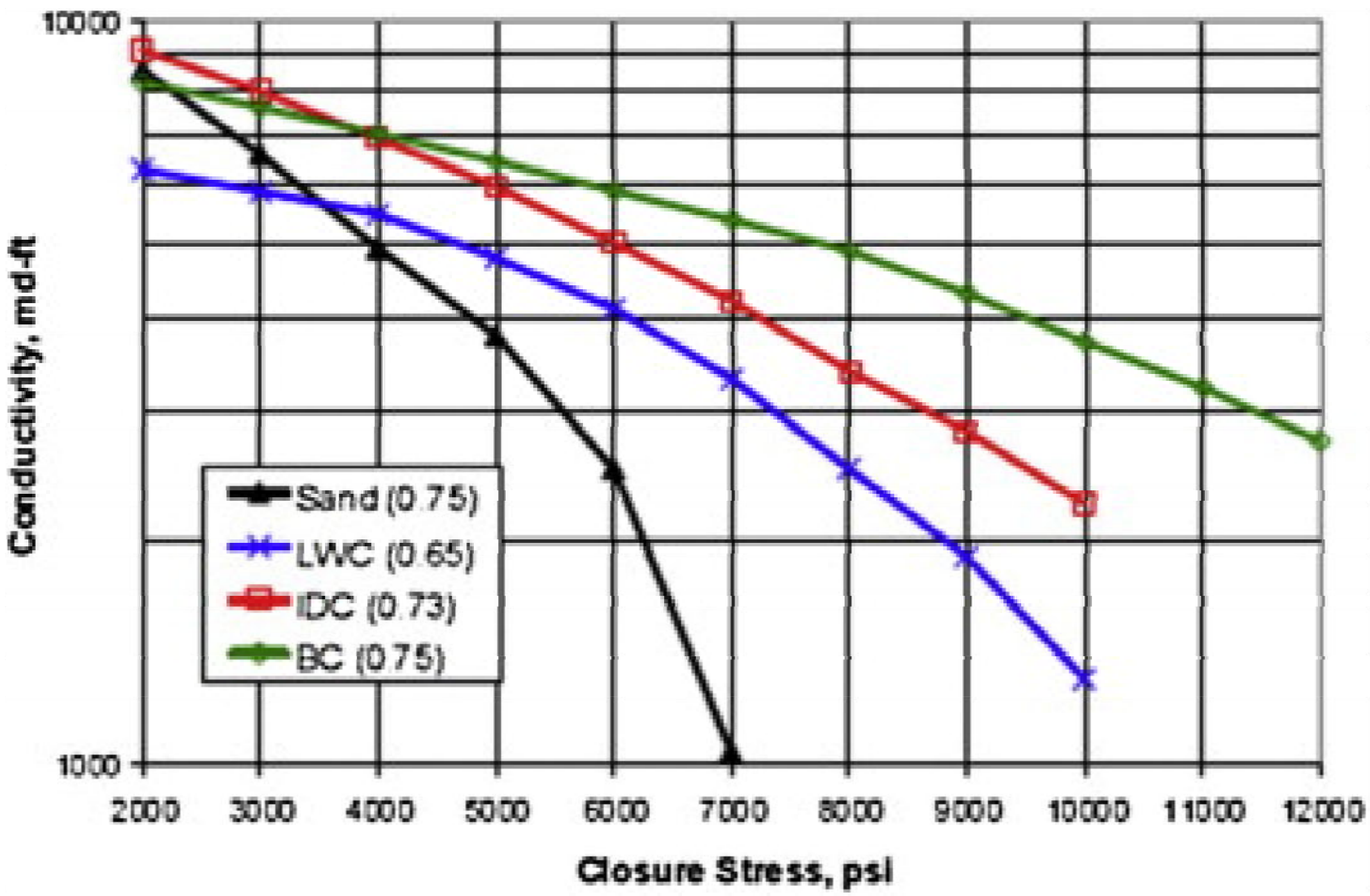
Completion & Stimulation Challenges

- The effects of competing fractures on width & pressure (Britt, 2012).



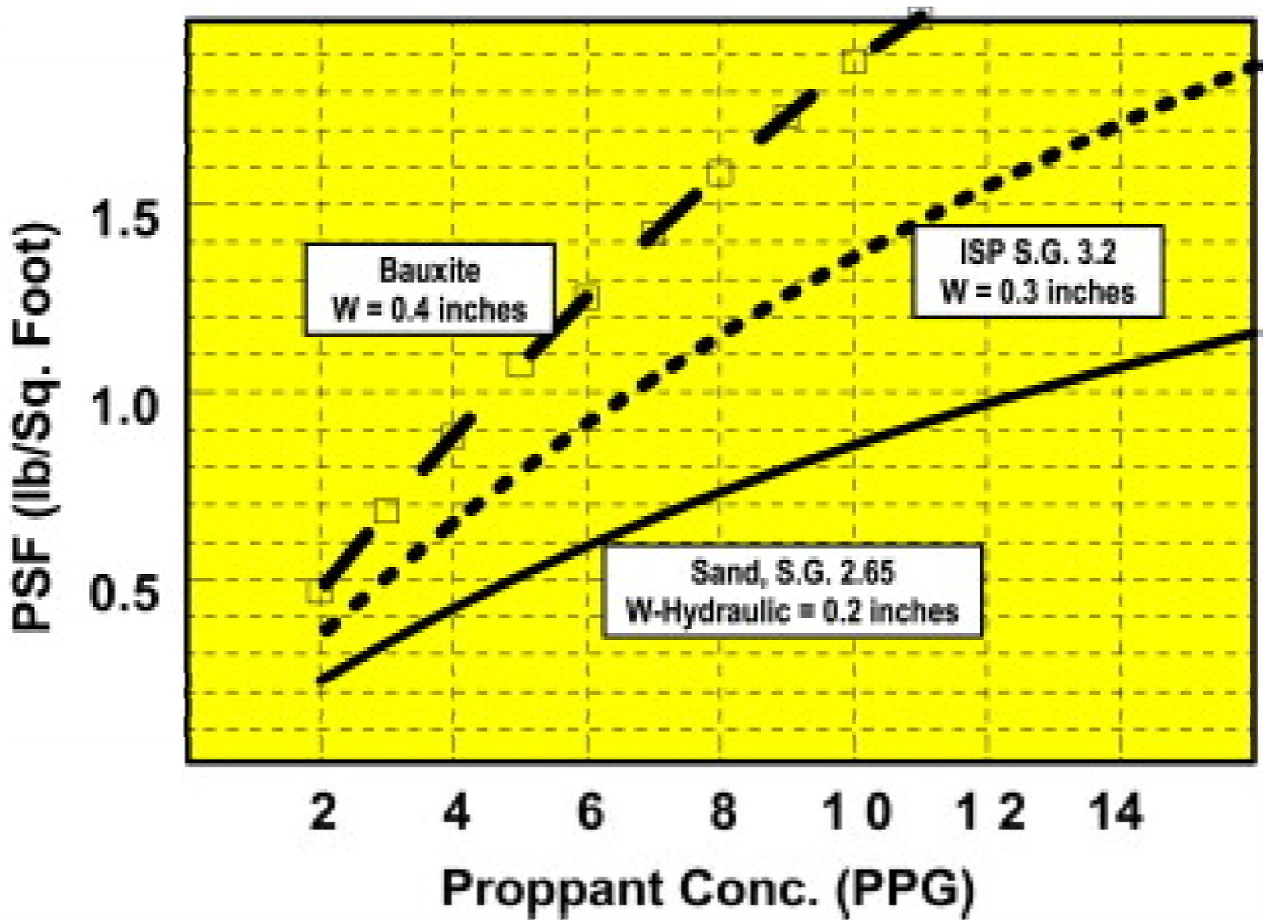
Completion & Stimulation Challenges

- Proppant selection (Britt, 2012).



Completion & Stimulation Challenges

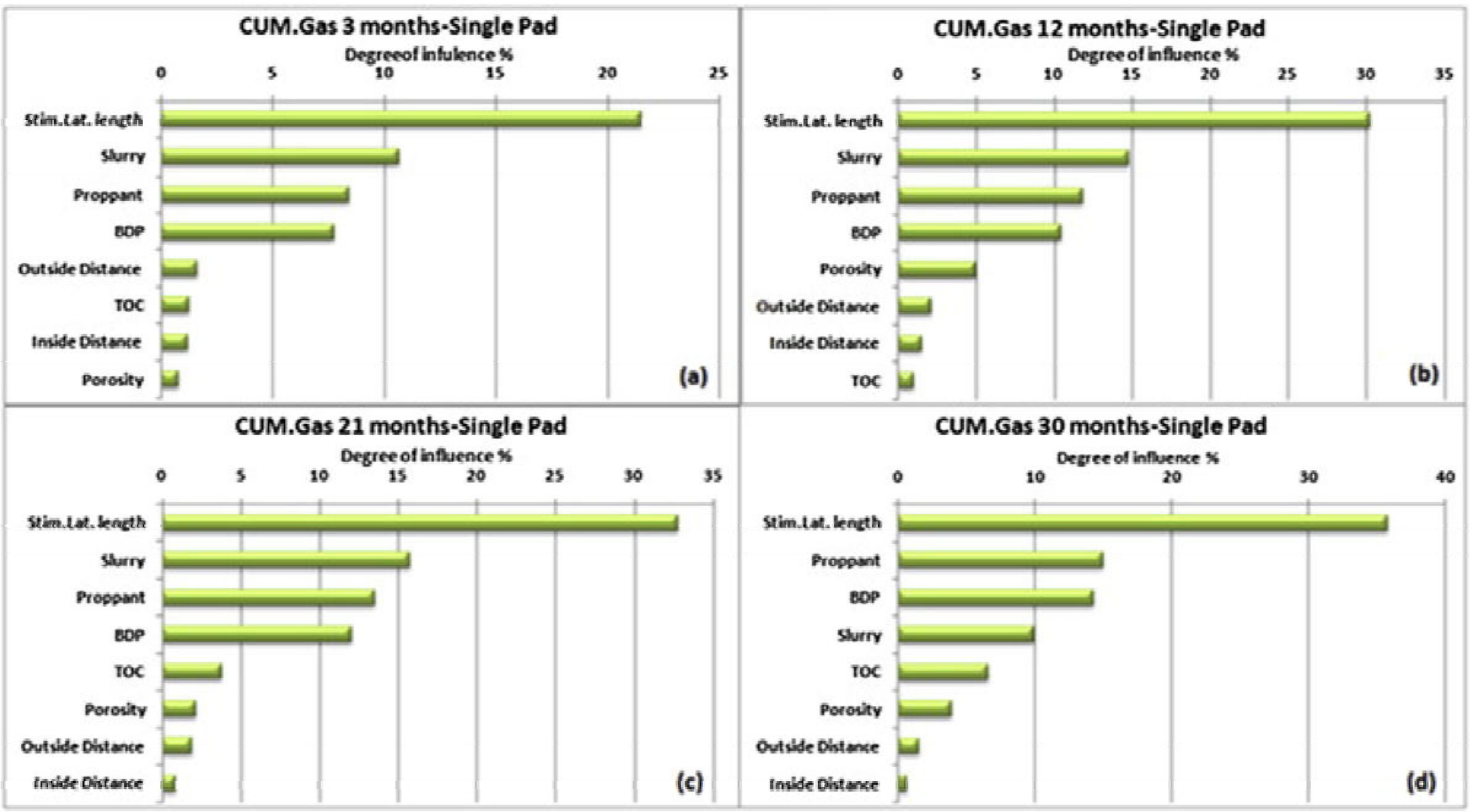
- Hydraulic width and propped width relationship (Britt, 2012).



Issues with Unconventionals

Completion & Stimulation Challenges

- What is impacting production? (after Mohaghegh, 2013)
- Tornado charts showing the impact of different parameters on production from a given pad. (a) After 3 months cum. production, (b) after 12 months cum. production, (c) after 21 months cum. production, (d) after 30 months cum. production



Issues with Unconventionals

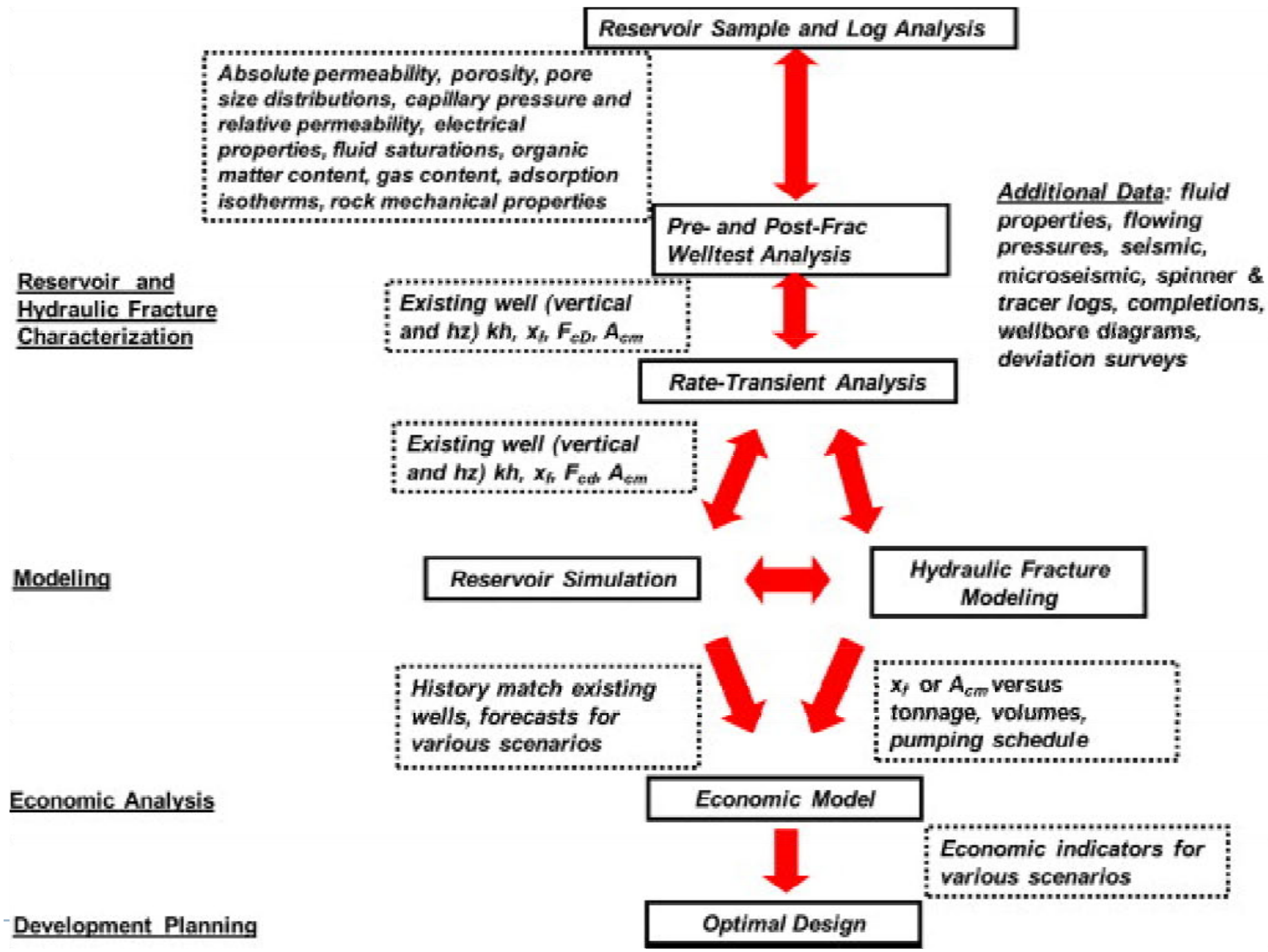
Production Challenges

- Using Mechanical Earth Modeling
- Production monitoring
- Induced fractures self-healing
- Artificial lift
- Proppant diagenesis
- Reservoir compartmentalization
- Temperature sensing and monitoring
- Refracturing
- Corrosion
- Bacteria / microbes

Issues with Unconventionals

Field Development Workflows

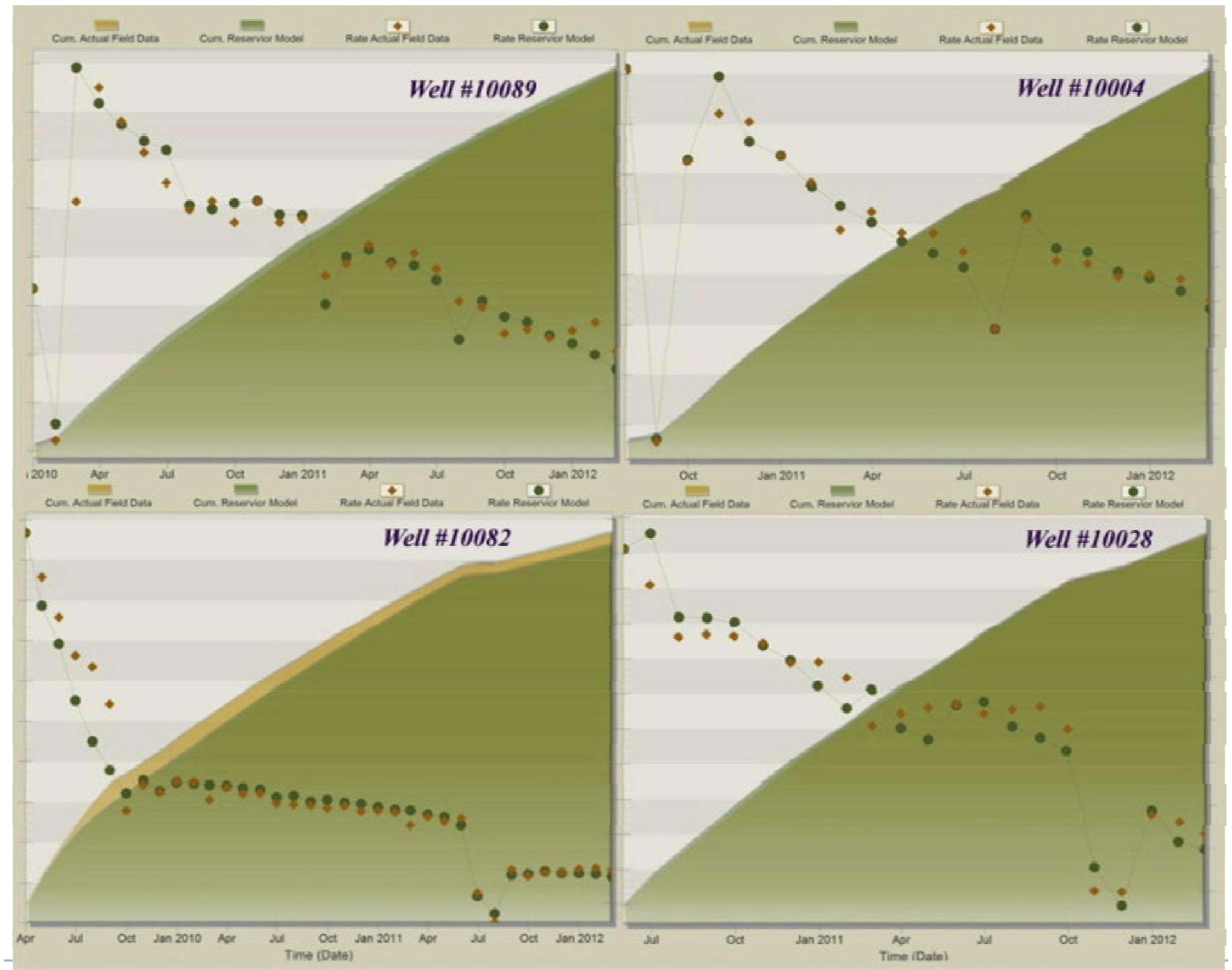
- Clarkson et al. (2012)
- Illustration of a workflow used to optimize field development in unconventional gas reservoirs.



Issues with Unconventionals

Production Challenges

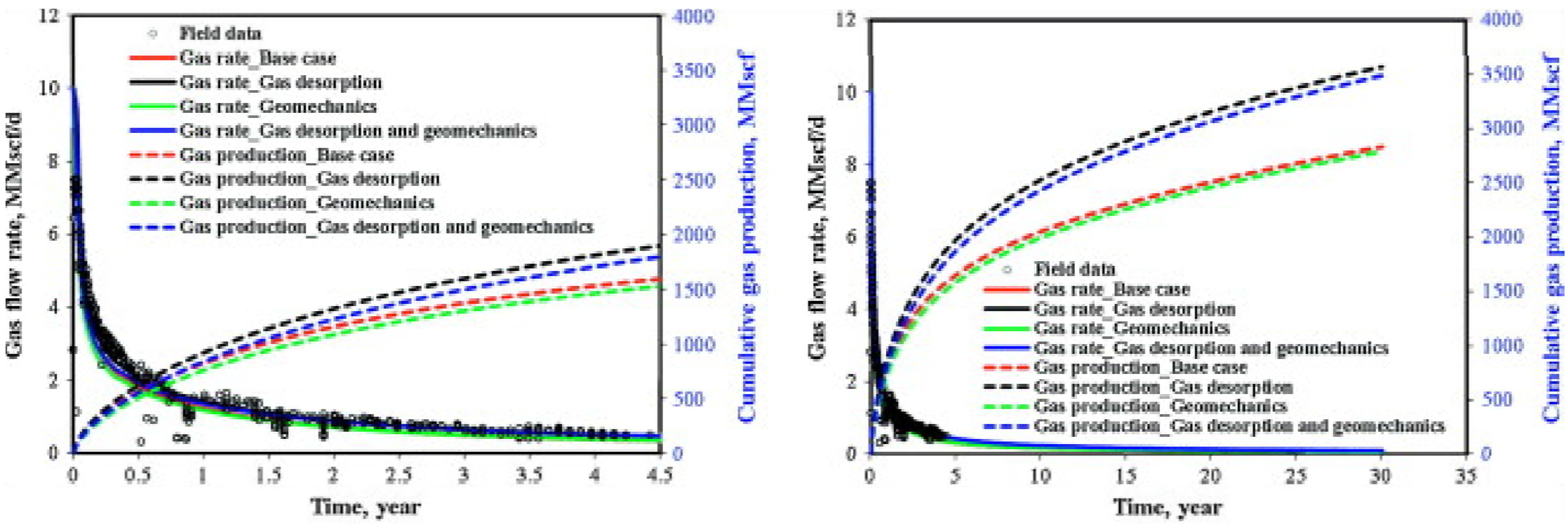
- History matching: performance of wells in the asset (Esmalli et al., 2012)



Issues with Unconventionals

Production Challenges

- Understanding the production history (Yu & Sepehrnoori, 2014)
- *History matching of Barnett Shale with gas desorption and geomechanics effects.*



(a) Gas production for a 4.5-year period

(b) Gas production for a 30-year period

Issues with Unconventionals

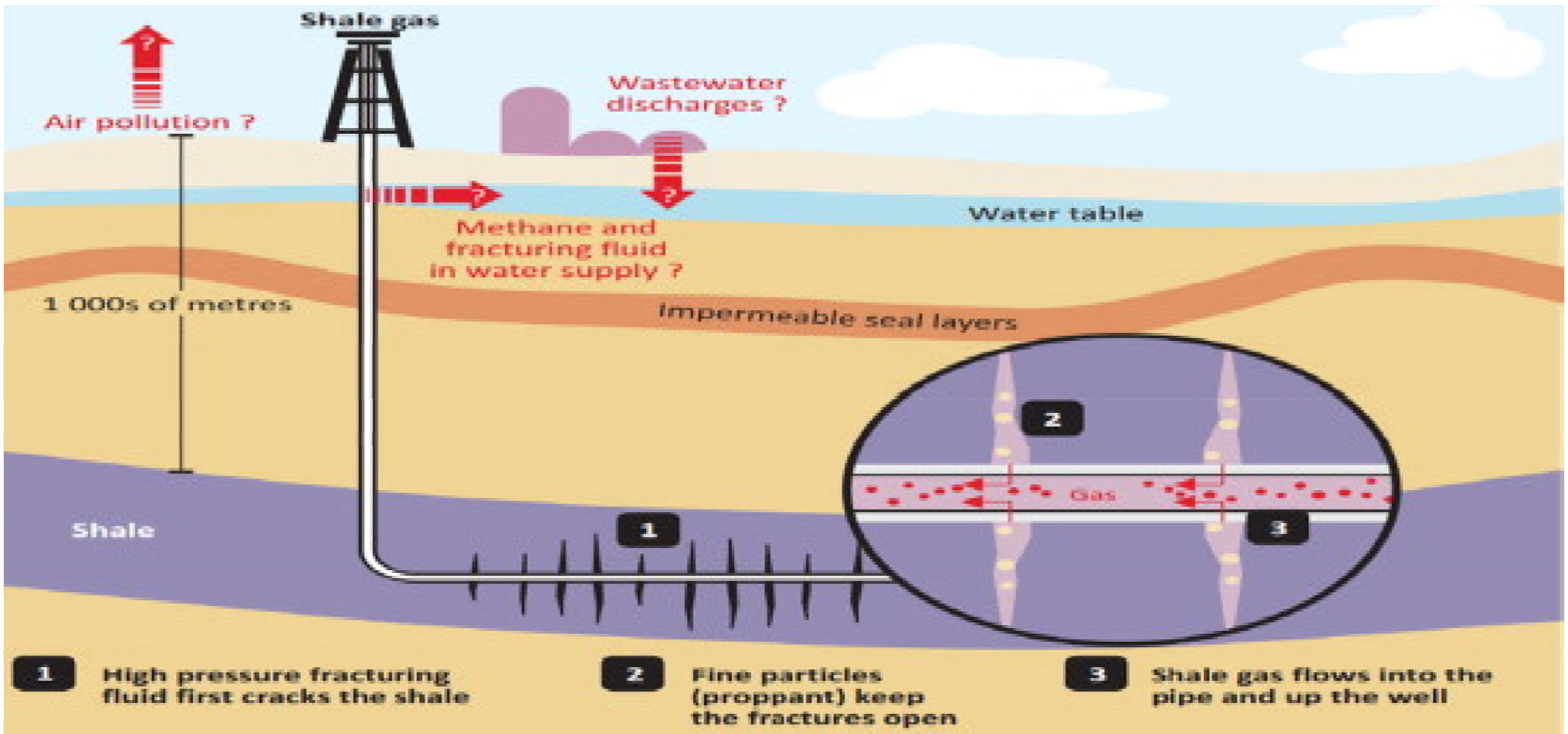
Water Sourcing, Treatment, & Disposal

- Surface water, produced / treated water, well water
- Treating / disposing of frac water
- Produced water: treatment / re-use
- Produced water: disposal
- Corrosion
- Water / stray gas

Issues with Unconventionals

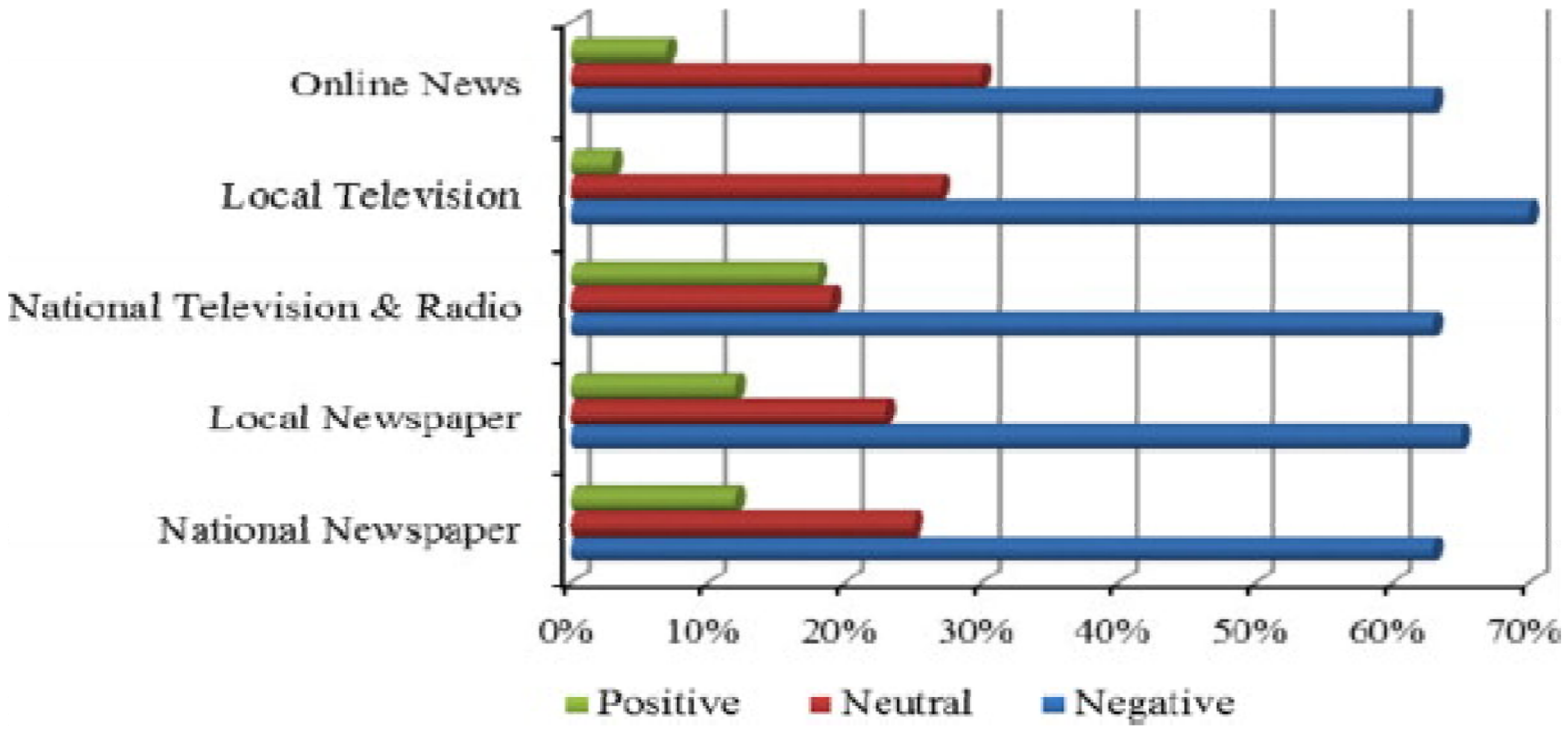
Environmental Concerns

- Potential problems: operations (Wang et al., 2014)



Environmental Concerns

- Potential problems: perception (Wang et al., 2014)



Issues with Unconventionals
Environmental Concerns

- Water
- *The water life cycle in hydraulic fracturing (Wang et al., 2014)*