Why Permeability and Geomechanics Drive the Completion And Stimulation Success In Multiple Fractured Horizontal Wells?

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(www.rocklaboratory.com)

Presentation Outline

- Why It Matters? The Keys To Success!
- Historical Perspective: Horizontal Wells
- Horizontal Well Characterization & Objectives
  - What We Want To Do?
- The Geomechanics Of Horizontal Wells
  - What We Can Do?
  - Complexity?
- Basis of Water Frac Designs – Ductility
- Permeability
- Summary

Why It Matters

- Where Do I Land the Horizontal Well?
- How Do I Complete The Well?
- Where Do I Complete The Well?
- How Many Completions Do I Need?
- How Do I Fracture Stimulate The Well?
- What Fracturing Fluid Do I Use?
- What Pump Rate Should I Use?

Why It Matters

- Where Do I Land the Horizontal Well?
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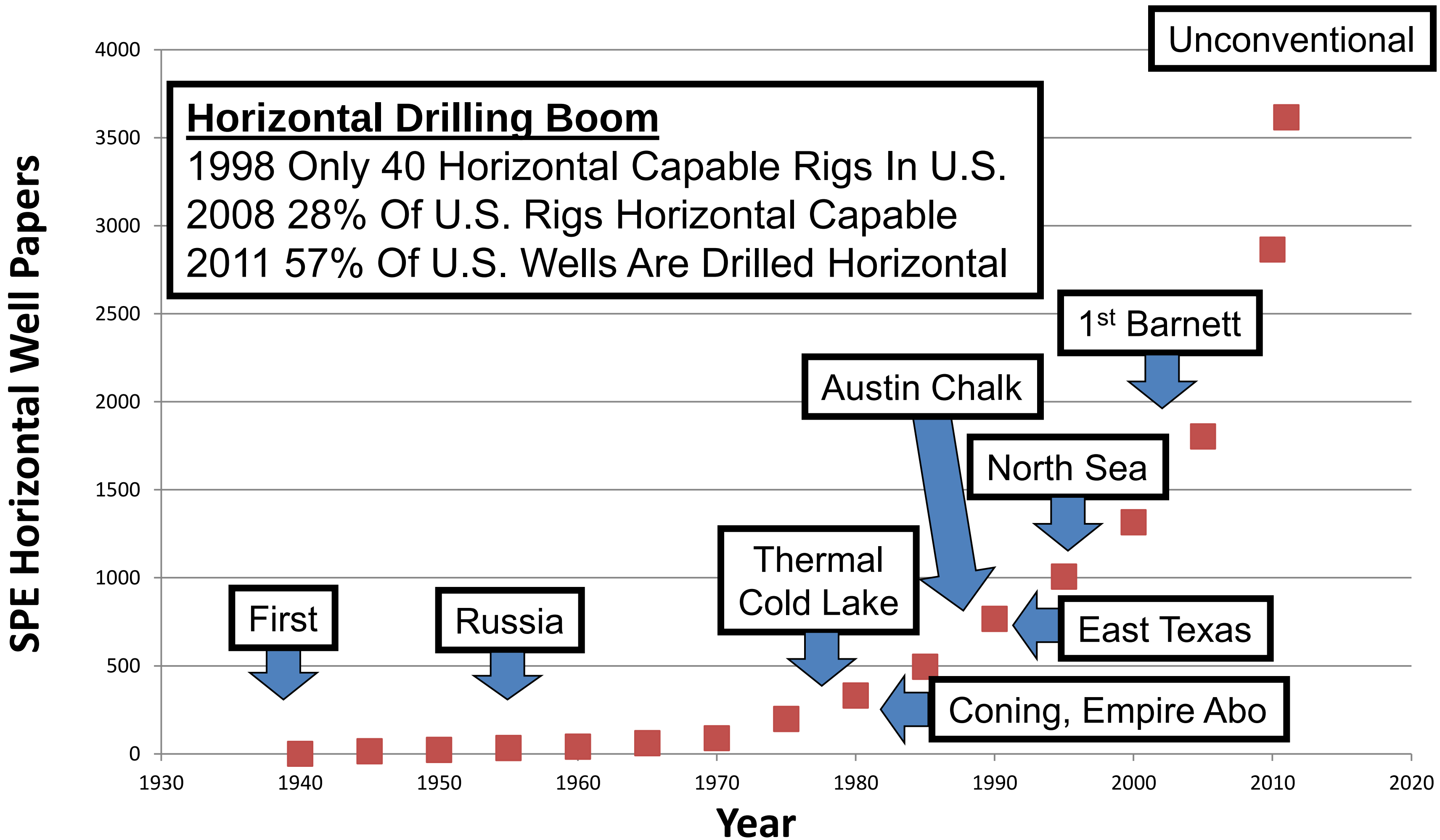
*Geomechanics And Permeability Are

The Keys To Success

Horizontals: A Historical Perspective



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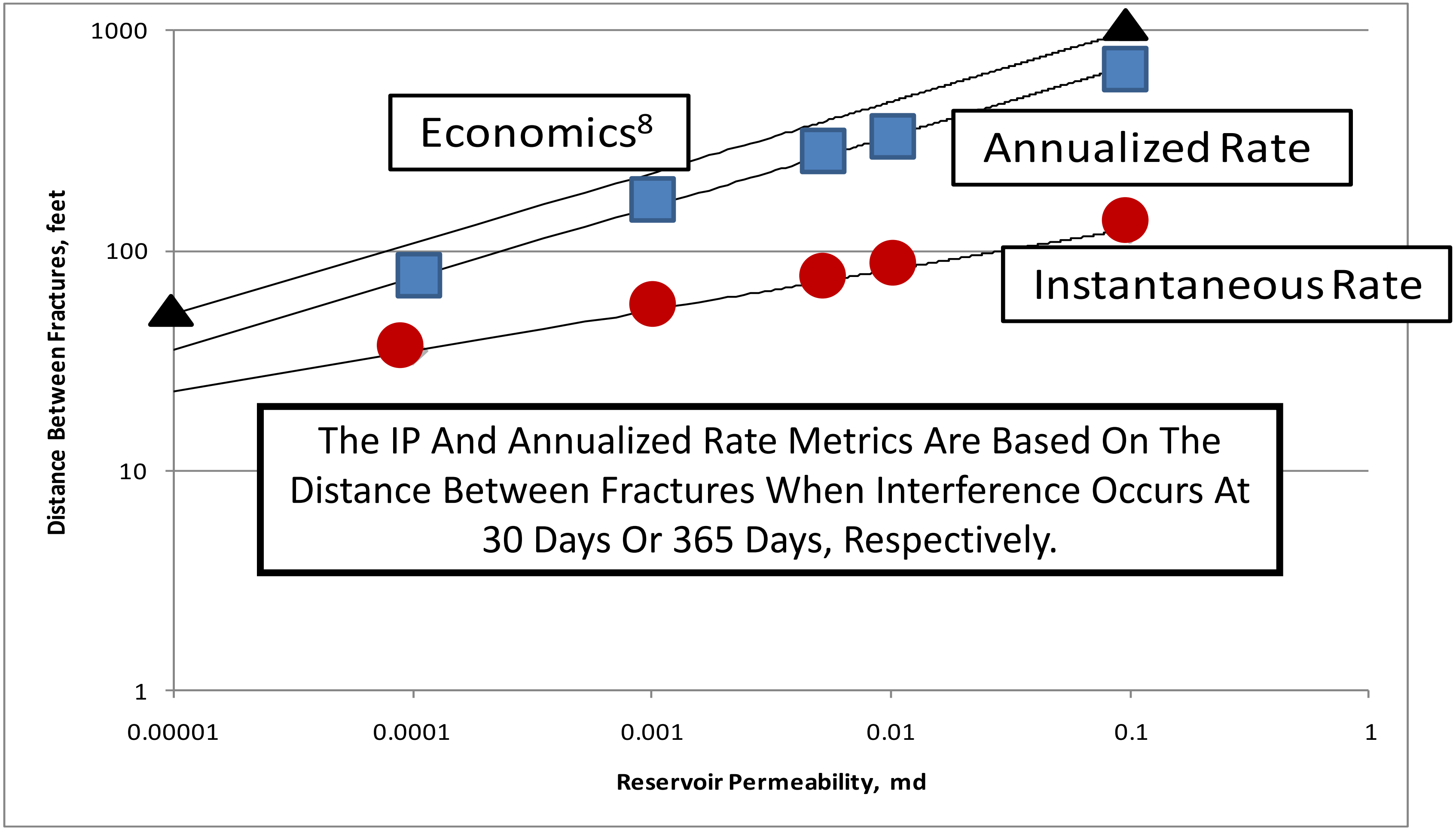
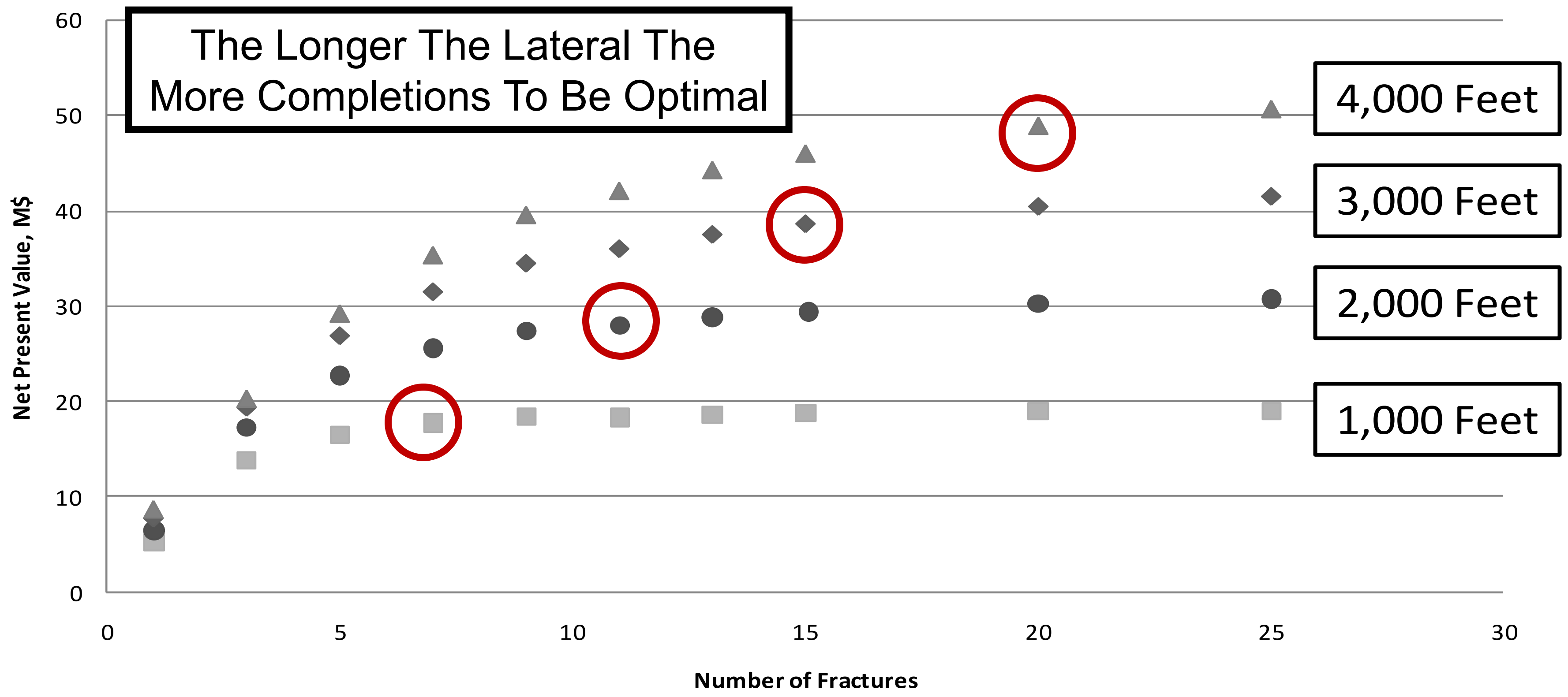
Well Characterization & Objectives

Metrics Used To Determine The Optimum Distance Between Fractures/Compleions



Well Characterization & Objectives

Effect Of Lateral Length On Completion Optimization



Well Characterization & Objectives

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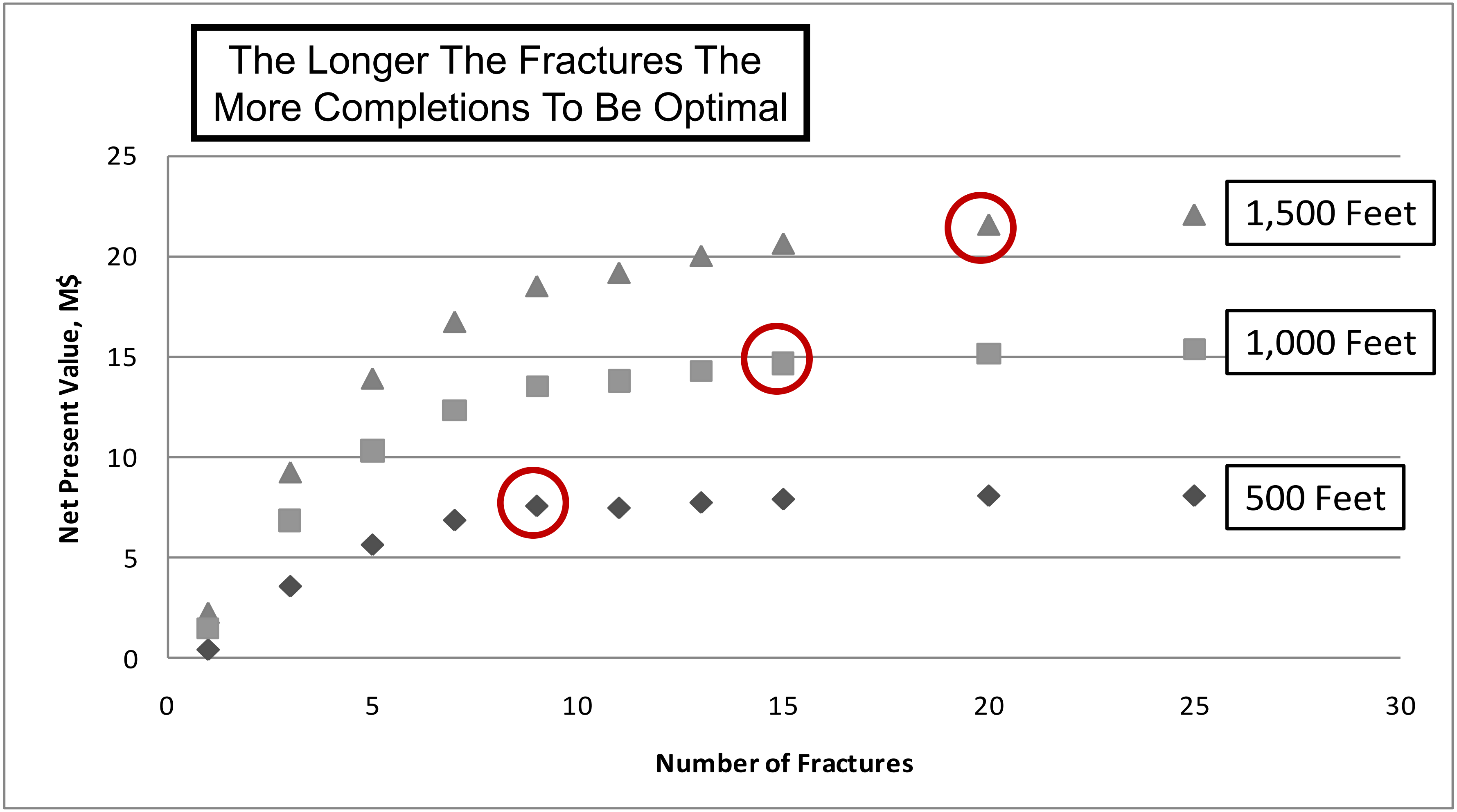
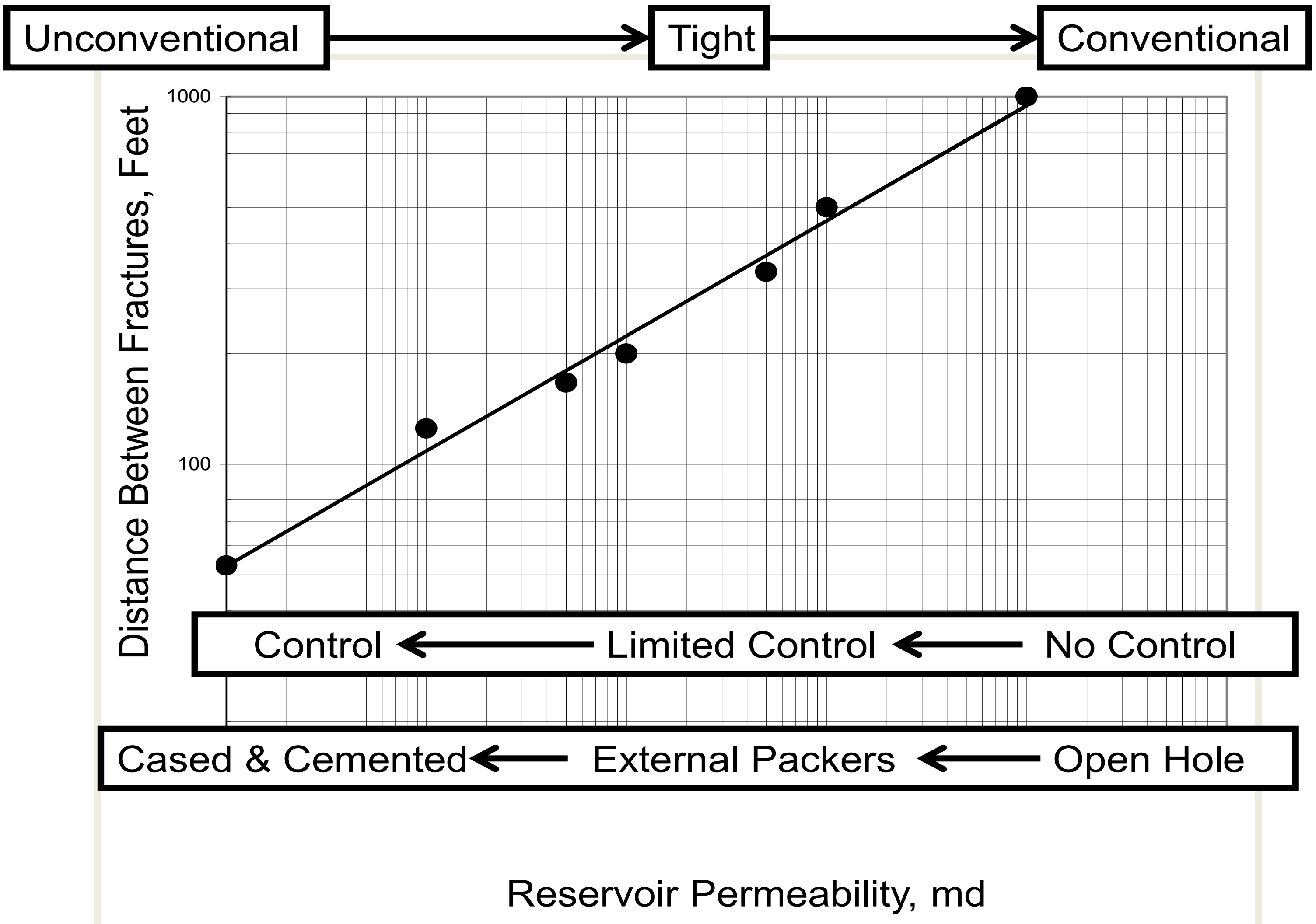


Well Characterization & Objectives



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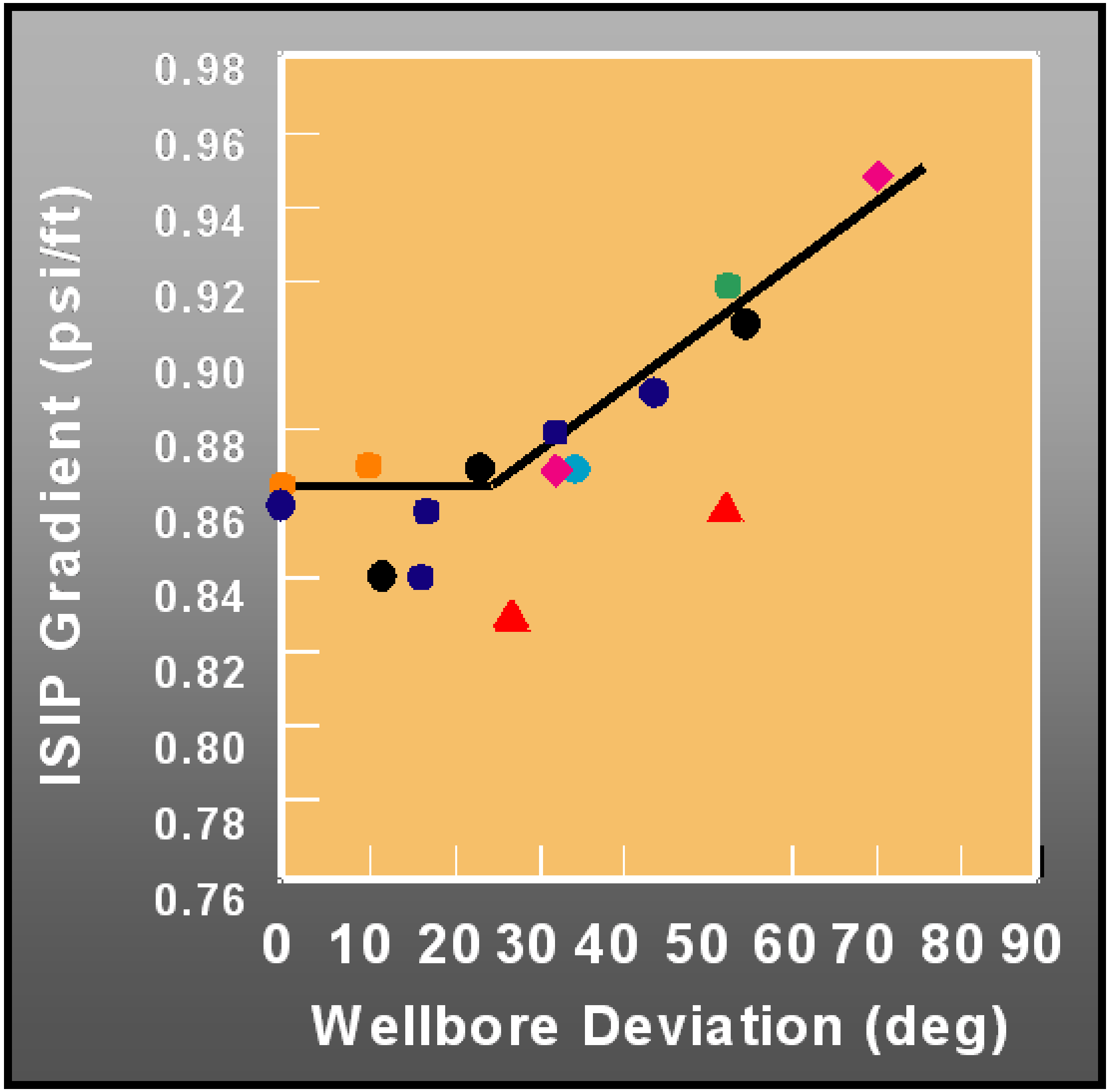
Geomechanics of Horizontal Wells

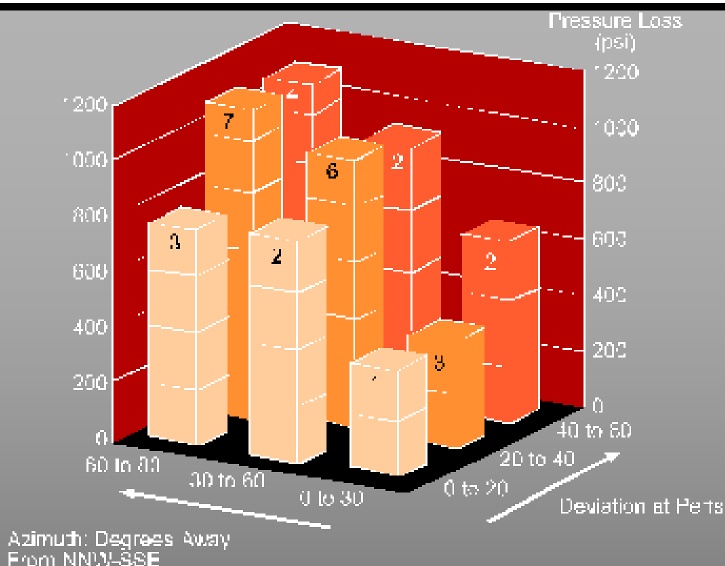


We Have Known Of The Effects Of Well Deviation, β, For A Long Time!

Slide Keys:

- Up to $\beta = 30^{o}$, No Real Effect on Pressures!
- Limited Proppant Was Placed In The High β Well!
- The Increased ISIP Is An Indication of Fracture Complexity "Tortuosity"!

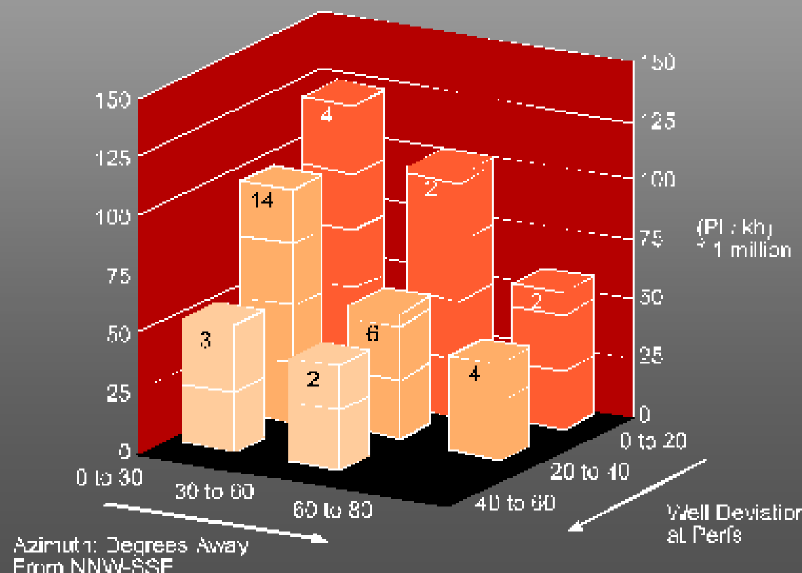
Geomechanics of Horizontal Wells



Slide Keys:

•The Further The Azimuth, α, And Perforations Were From σ_{Hmax}:

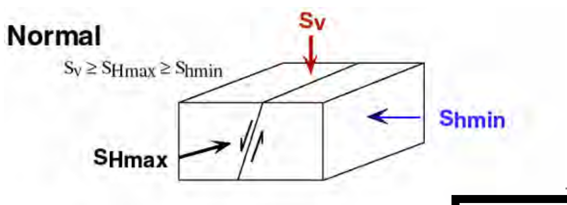
- ***•The Greater The Δp Lossed,***
- ***•The Poorer The Productivity***

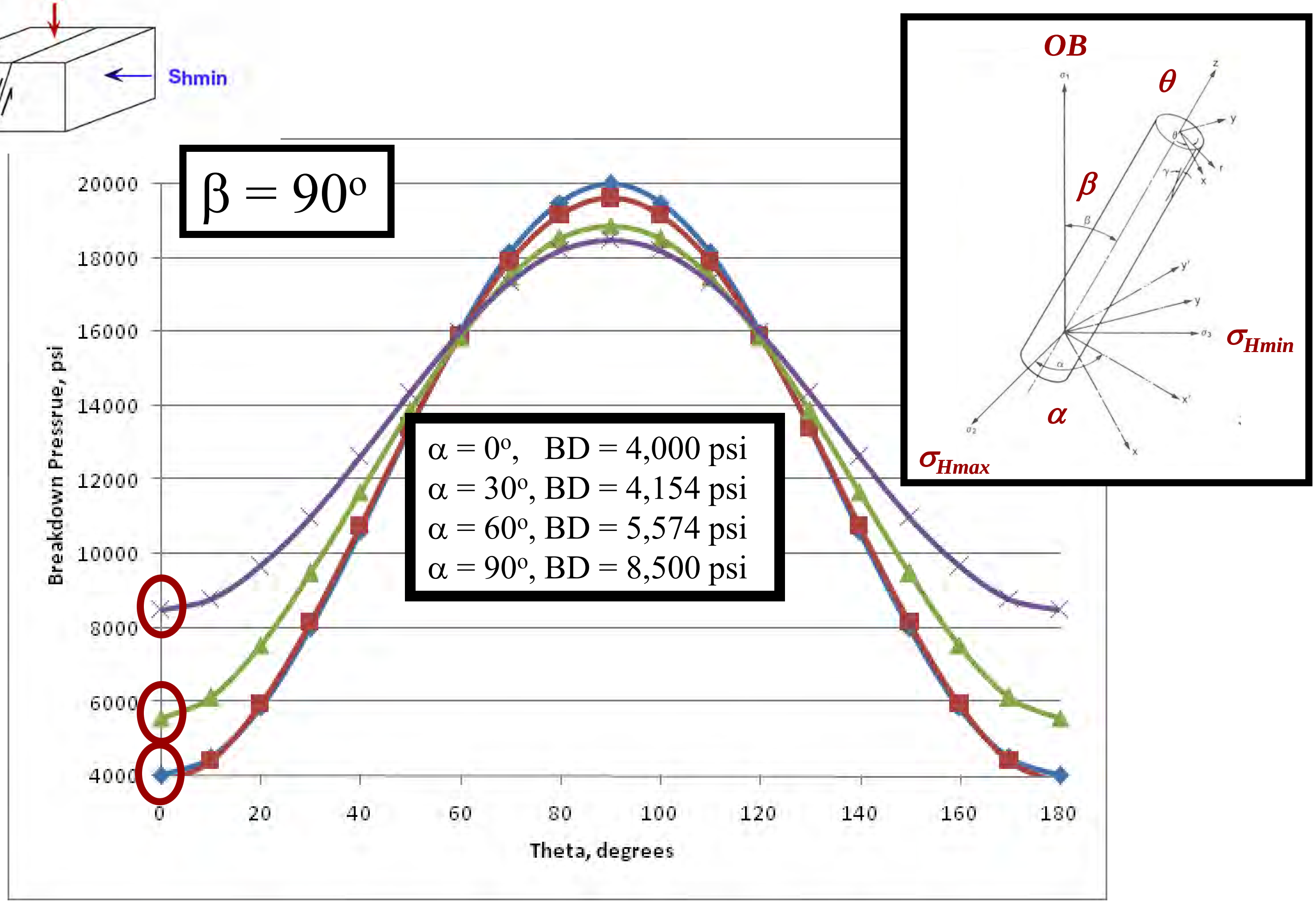


BP-Prudhoe Bay
Circa 1992, J. P. Martins

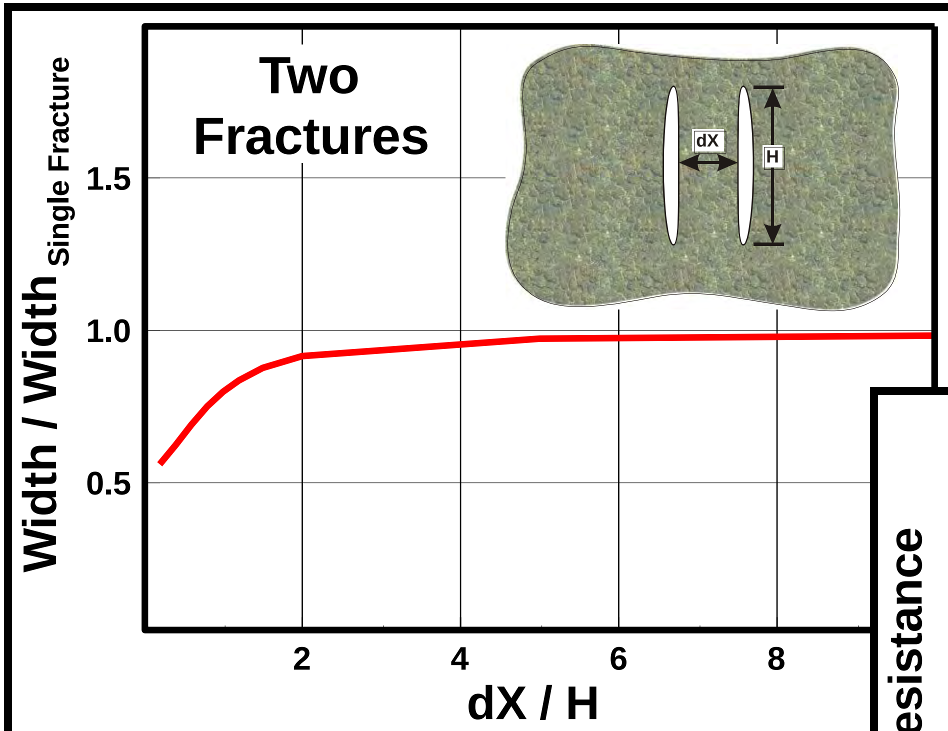
Geomechanics of Horizontal Wells

σ_V = 10,000 psi, σ_{Hmax} = 7,500 psi, σ_{Hmin} =6,000 psi

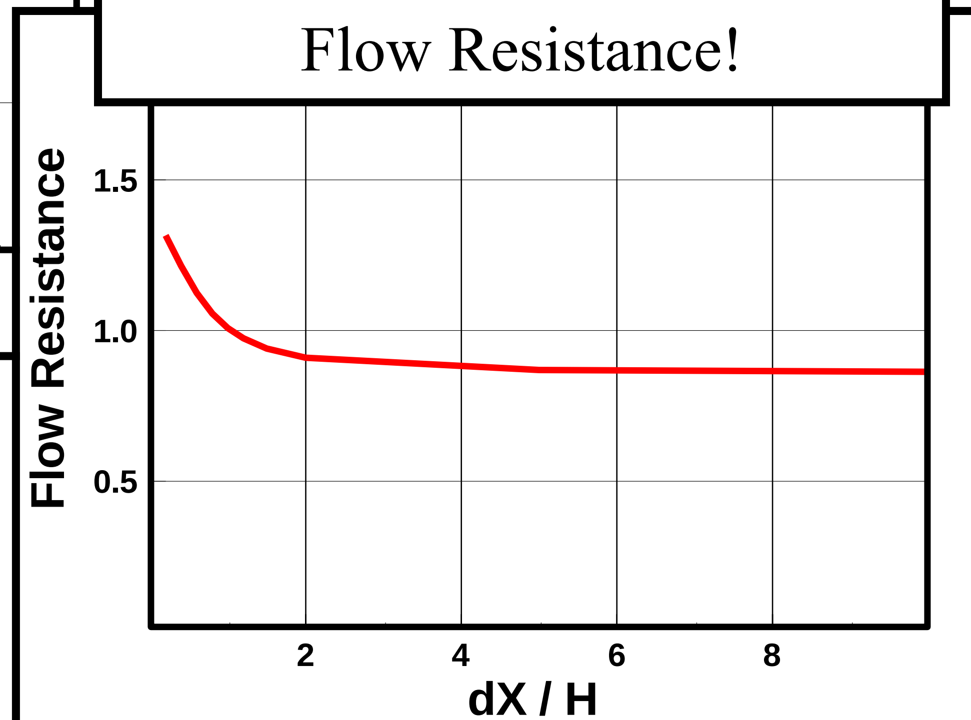




Geomechanical Implications

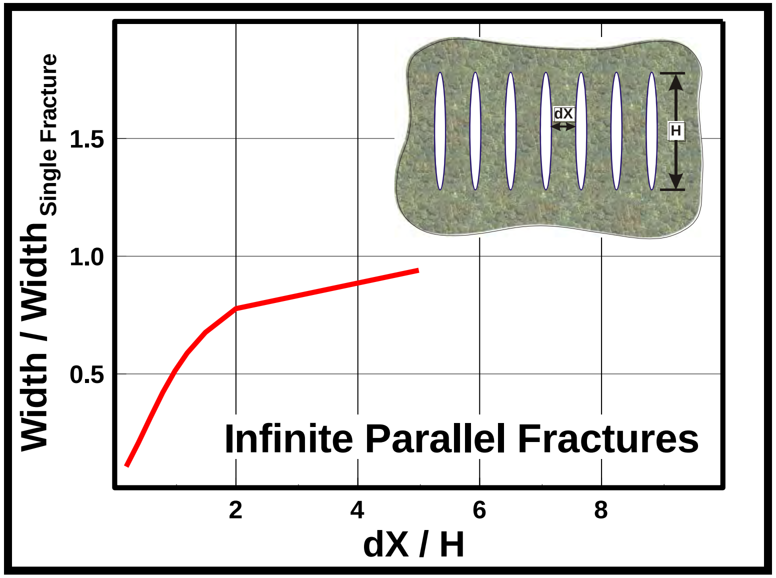


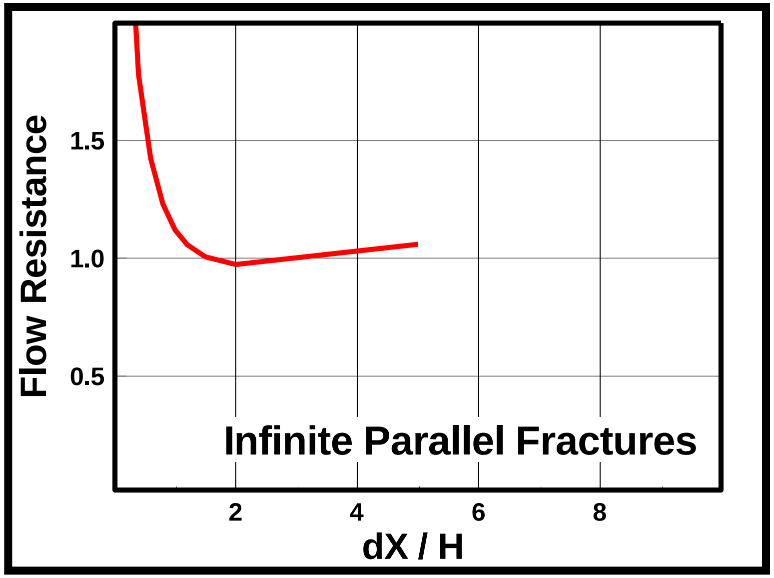
Slide Keys:
When The Distance Between The Fractures Is > 2 Times The Fracture Height Minimal Effect On Fracture Width & Flow Resistance!



Two Interfering Fractures w/ Contained Fracture Geometry

Geomechanical Implications





Description	Case 1	Case 2	Case 3	Case 4
Inter-perforation Distance (ft)	1000	500	250	100
Height/Interwell Distance Ratio	2.00	1.00	0.50	0.20
Transverse Horizontal Treating Pressure	5700	6600	9000	12000
Transverse Horizontal Fracture Width	0.188	0.125	0.063	0.025
Flow Resistance Multiplier	0.95	1.10	1.50	2.00
Fracture Width Multiplier	0.75	0.50	0.25	0.10

Vertical Well Treating Pressure Is 6,000 psi
Fracture Height is 500 feet
Single Fracture Width is 0.25 inches

Did we actually breakdown the perforations?
Were we able to place proppant?

Remember That The Bridging Criteria is Wf = 3 x Proppant Diameter

20/40 Ottawa Sand Avg Diameter Is 0.023 inches	0.069
40/70 Ottawa Sand Avg Diameter Is 0.011 inches	0.033

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Geomechanical Implications

The Object Of The Completion(s) & Fracture Stimulation(s) Is To Effectively Contact As Much Reservoir As Possible:

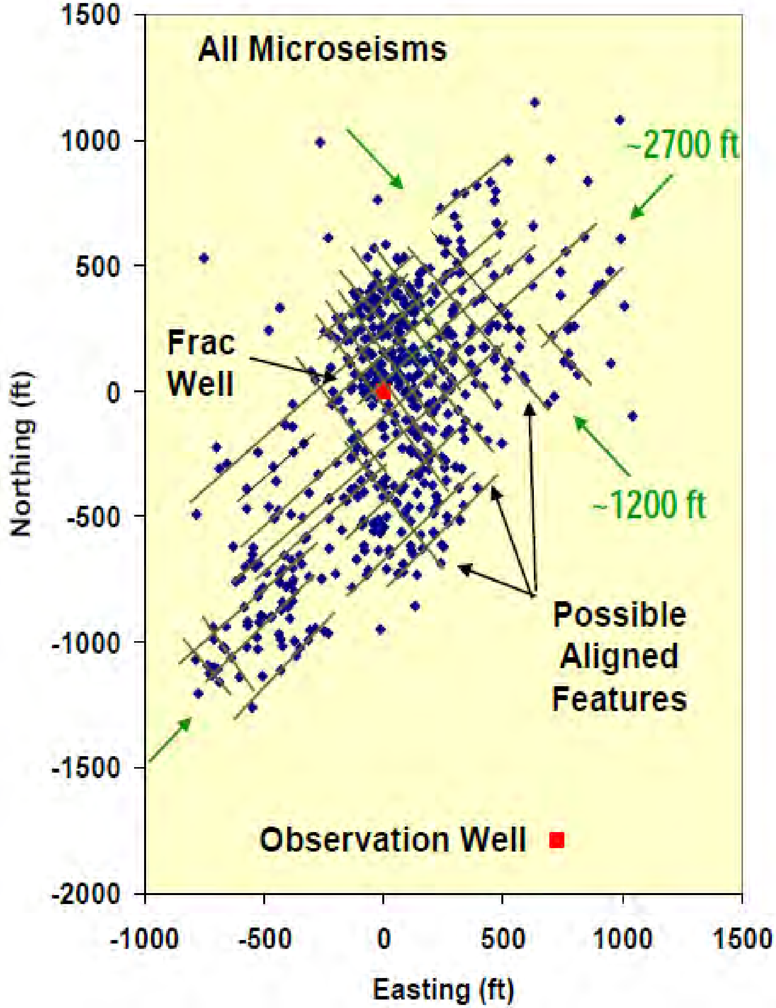
- Micro-Seismic Data Used To Assess Contacted Volume Or Stimulated Reservoir Volume Where:

SRV = L x H x W of Micro-Seismic Event Map

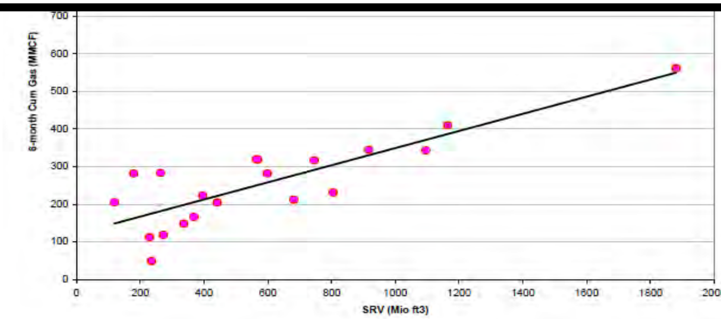
Often $2(x_f) \times H_f \times L_L$

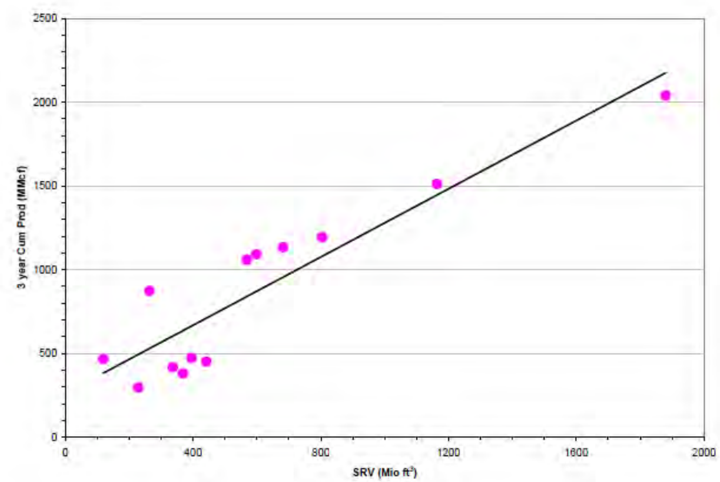
Geomechanical Implications

Stimulated Reservoir Volume



Bigger The Frac Volume The Greater The Stimulated Reservoir Volume & The Greater The Hydrocarbon Recovery

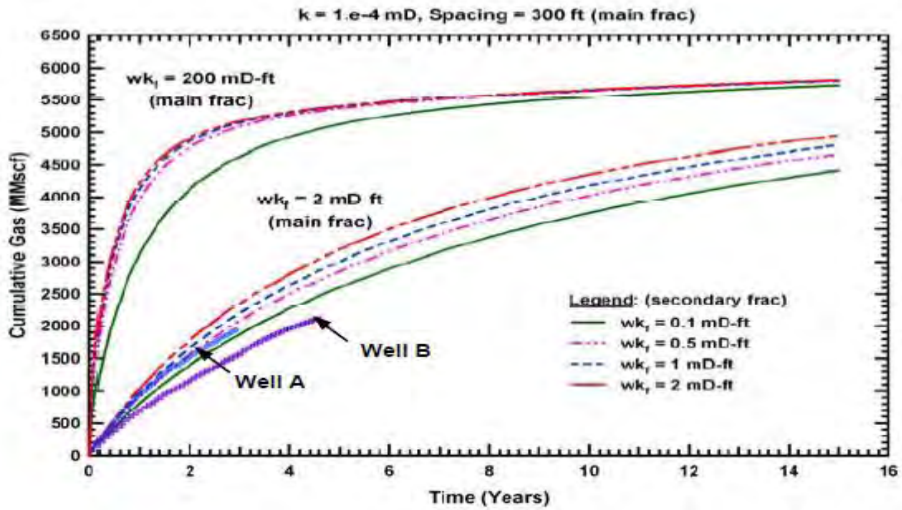




Fisher 2002

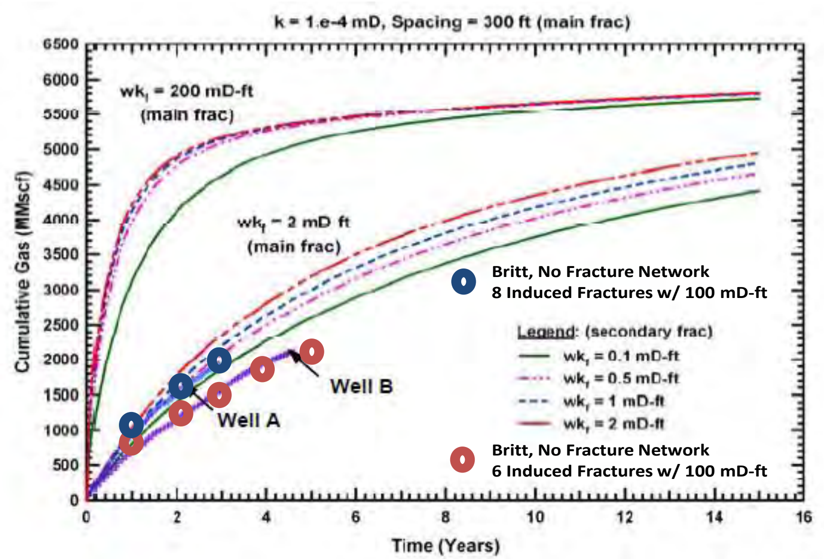
Geomechanical Implications

But Does Complexity Or Stimulated Reservoir Volume Add Up To Hydrocarbon Recovery



Study Showed That SRV Not Very Effective, Neither Was Induced Fracture For That Matter

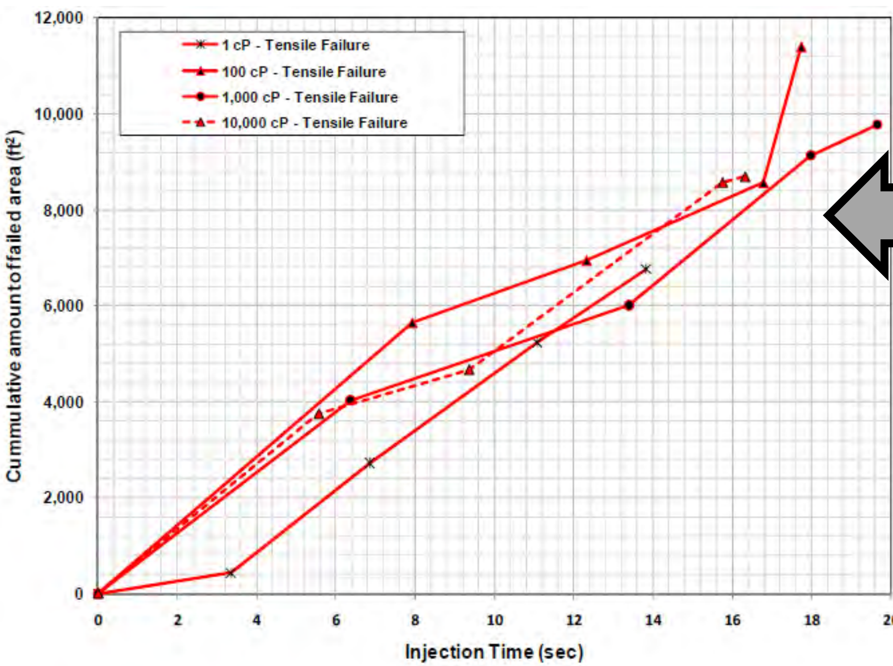
Additional Simulations Show That SRV May Not Be Critical Or Is It? What About Over The Long Term?



Cipolla

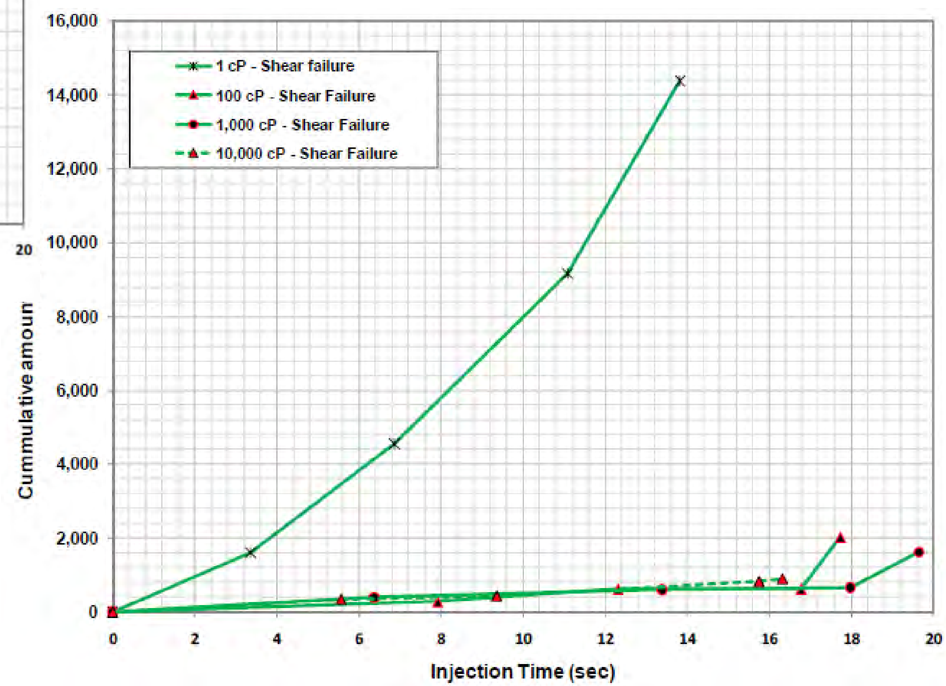
Geomechanical Implications

If SRV Important How Do You Get More?



Study Showed That Higher Fluid Viscosity Slightly Increased The Tensile Failure Area

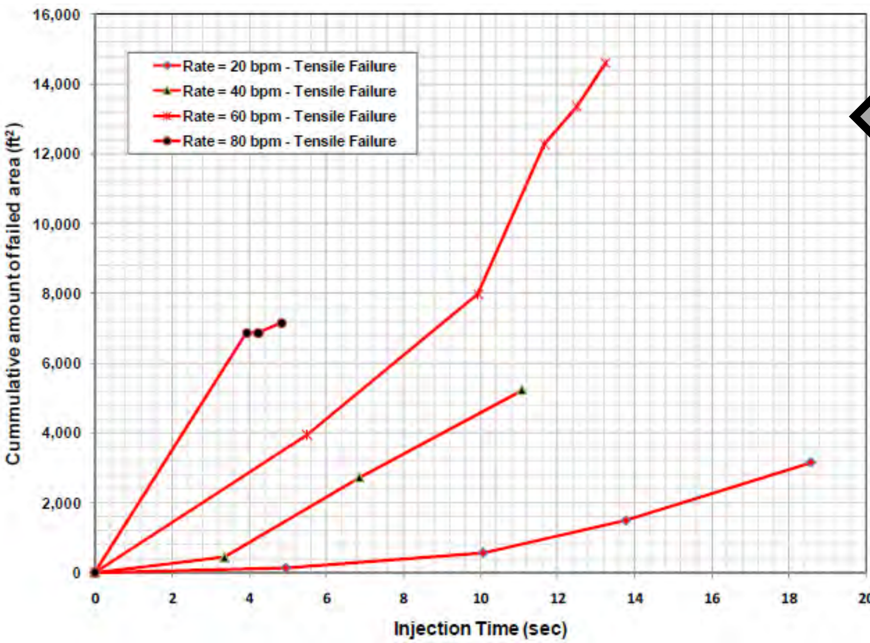
Study Showed That Low Fluid Viscosity Dramatically Increased The Shear Failure



Sanchez-Nagel

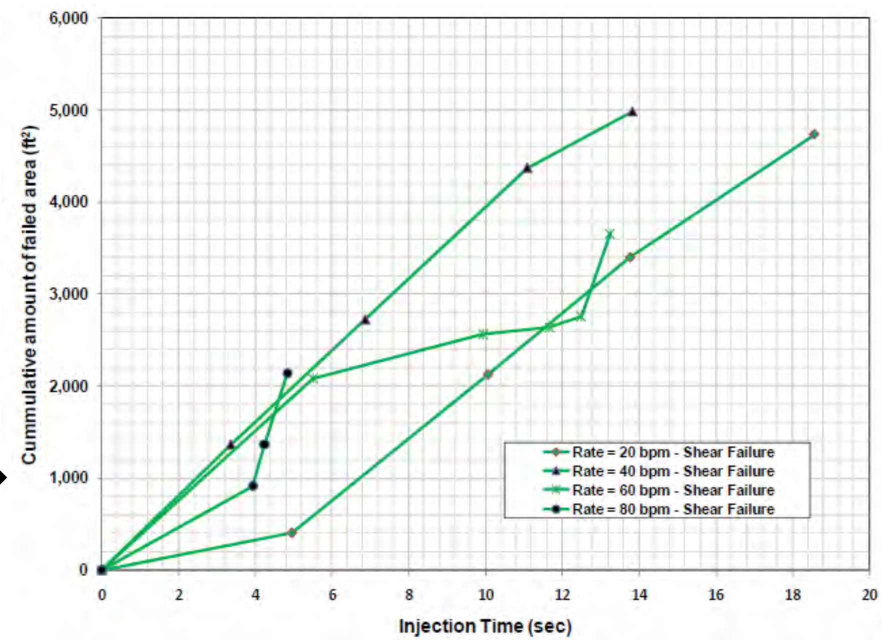
Geomechanical Implications

If SRV Important How Do You Get More?



Study Showed That Higher Treatment Rate Increased The Tensile Failure Area

Results Less Clear For Shear Failure

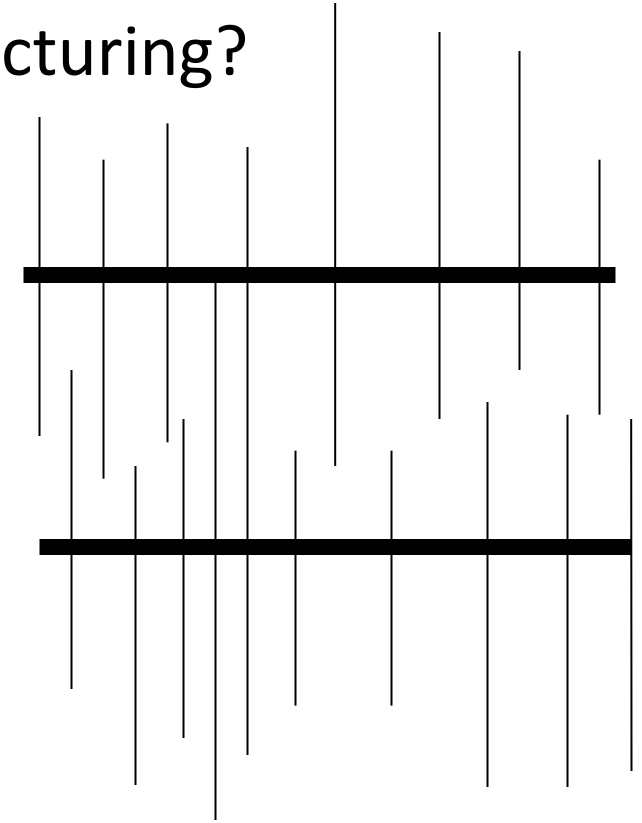


Sanchez-Nagel

Geomechanical Implications

If SRV Important How Do You Get More?

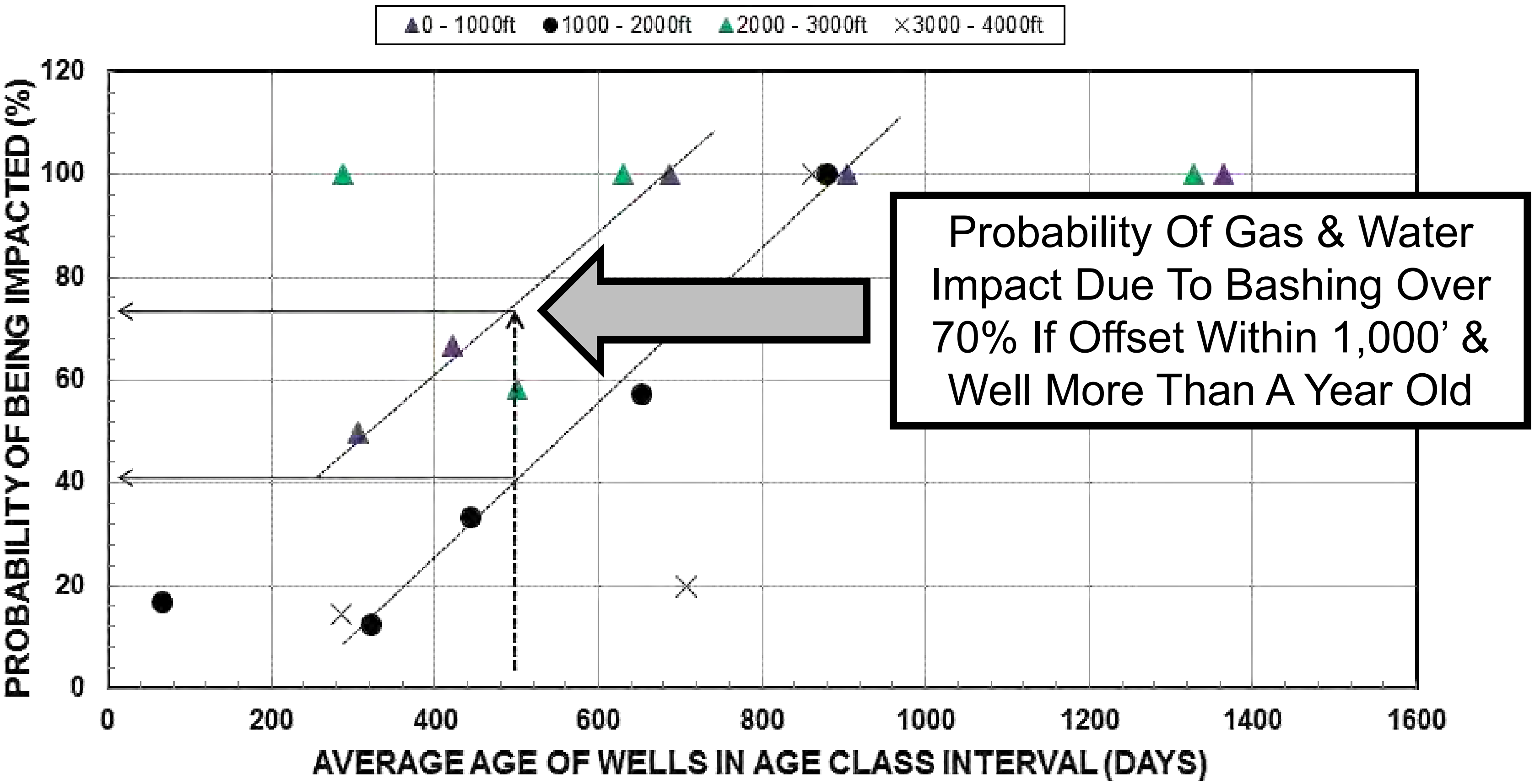
– How About Simultaneous Fracturing?



Fracture Stimulations Are Pumped In Two Parallel Horizontal Wellbores Simultaneously To Create Greater Stimulated Reservoir Volume

Geomechanical Implications

Woodford Case History Of Bashing

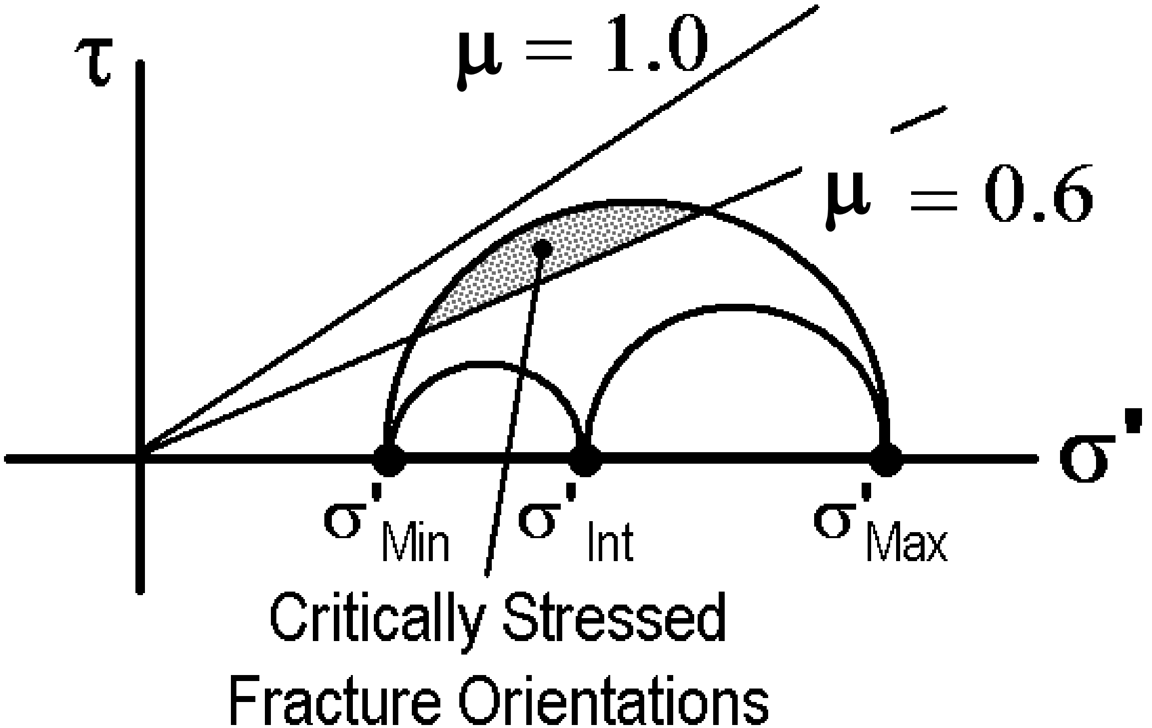


Kelkar

Geomechanical Implications

What Is The Likely Fissure Direction In The Current Stress State Whereby:

- The Natural Fissures Are Open,
- The Fissures Are Conductive, And
- Potentially Contributory To Well Performance



Such A Natural Fissure Is Deemed Critically Stressed

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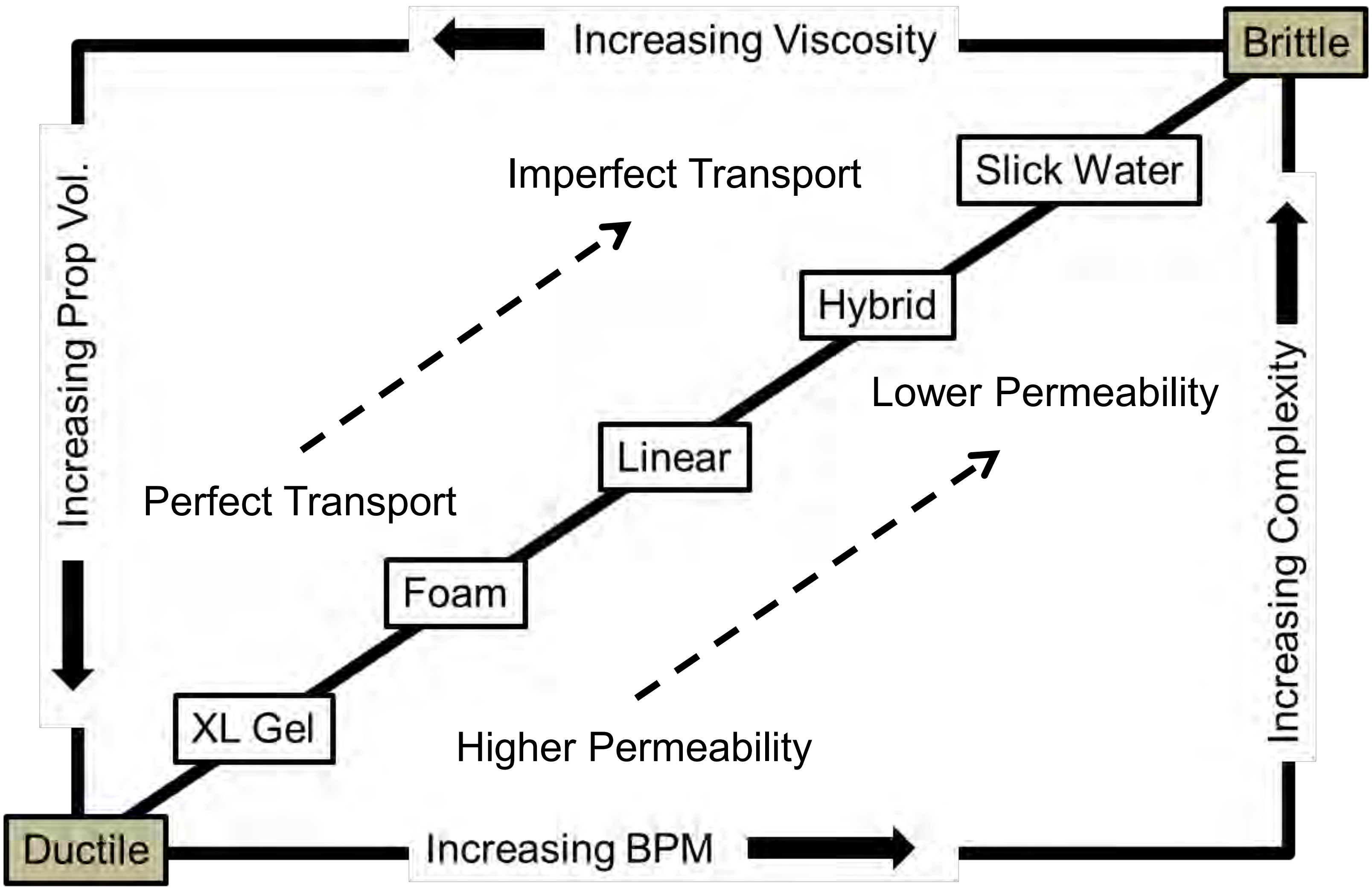
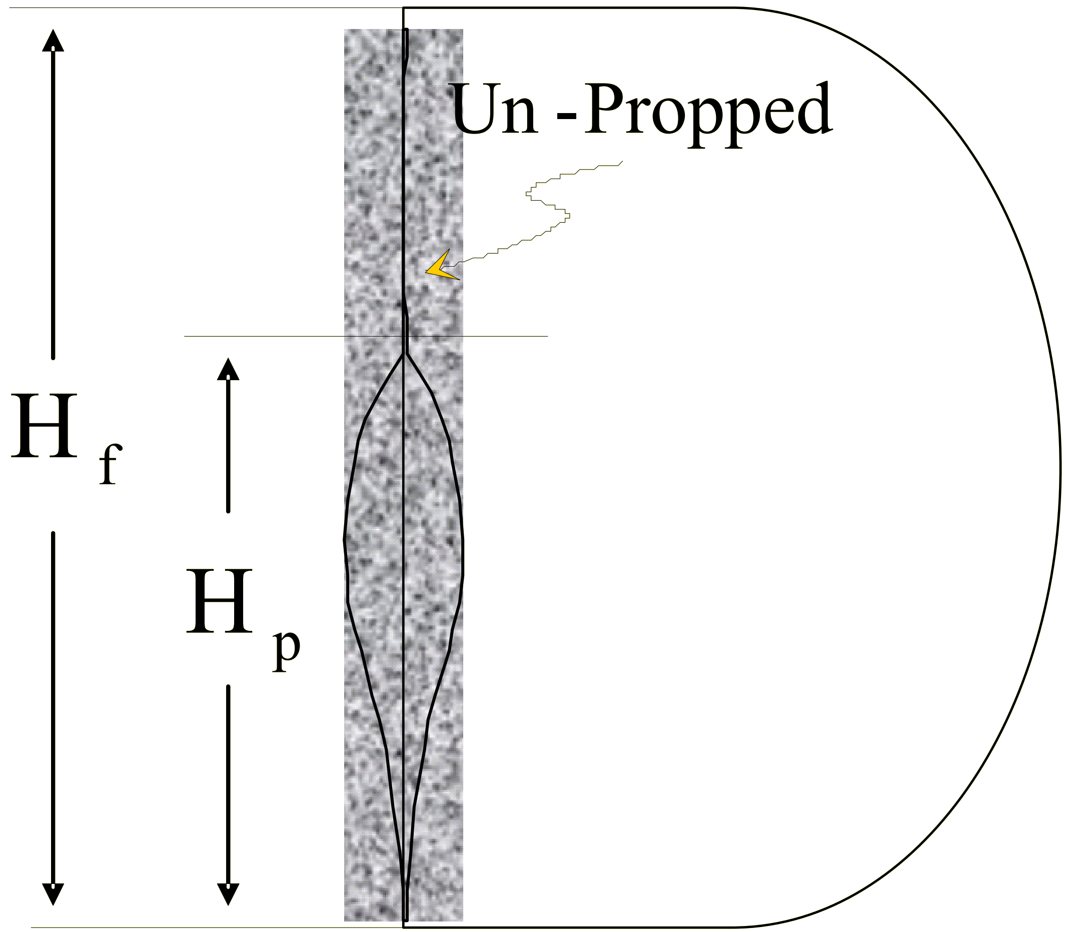
Basis of Fracture Design



Schematic of a Water-Frac



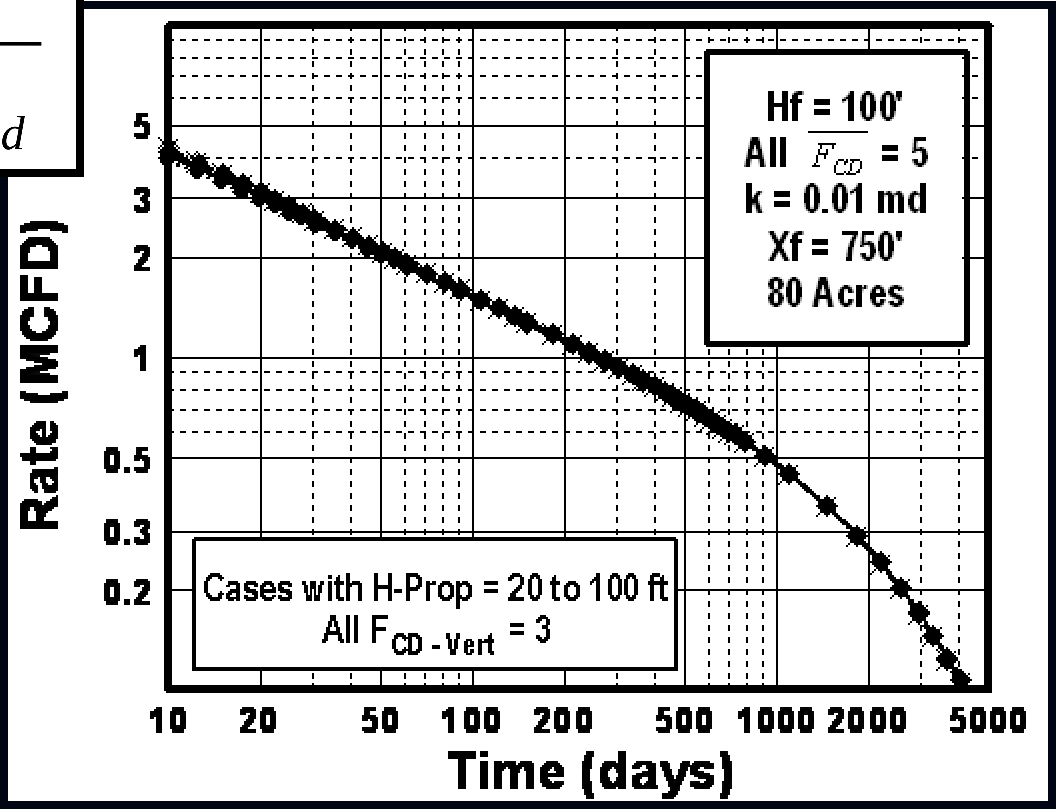
Un-propped Crack Tests Integrate The Lab Results With The Field & Explains The Effect Of Poor Proppant Coverage!

Water Frac Guidelines Must Depend on Un-Propped $k_F w$

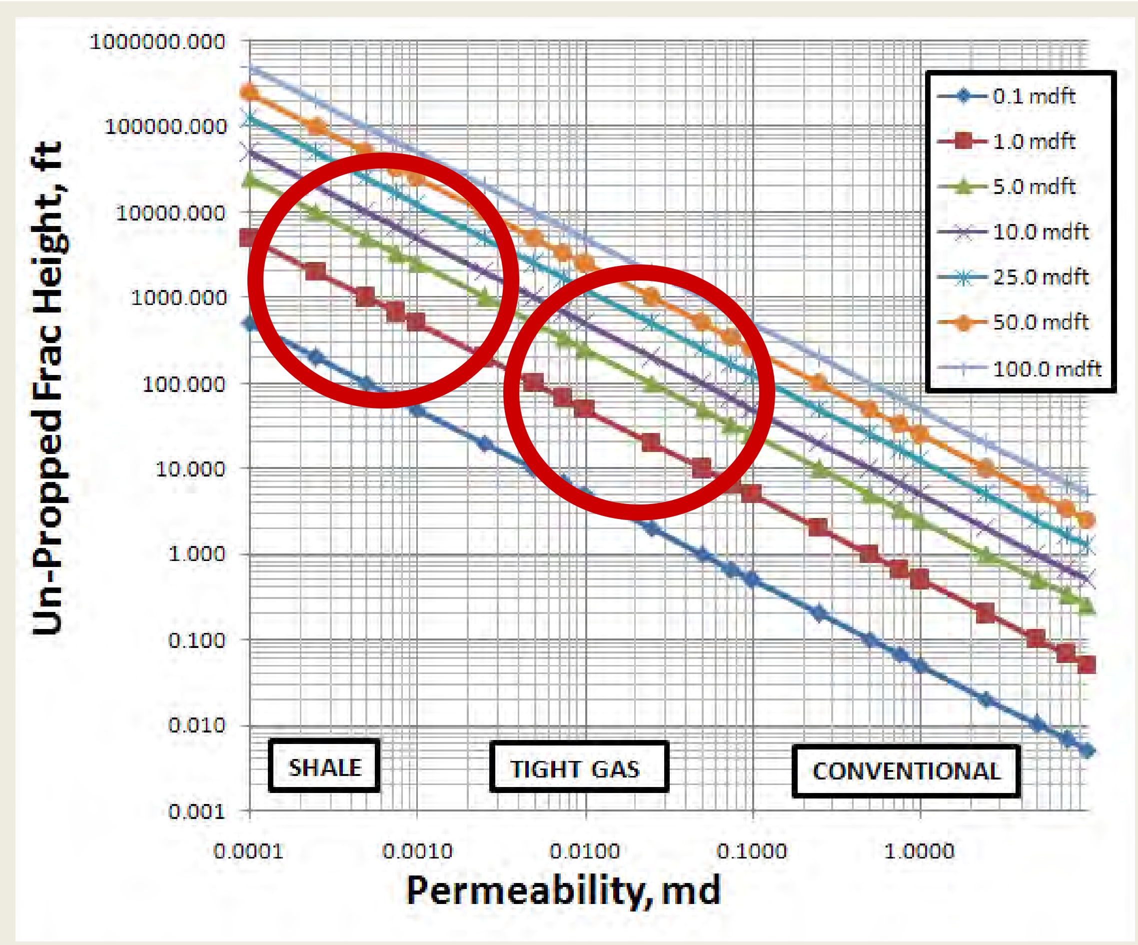
$$F_{CD-Vert} = \frac{(k_f w)_{Unpropped}}{k \quad H_{F-Unpropped}}$$

As Long As $F_{CD\text{-}Vert} > 2$
The Propped Fracture
Height Doesn't Matter!

For $(k_f w)_{Un\text{-}propped} = 1$ mdft
$H_{F\text{-}Un\text{-}propped} < 50$ feet



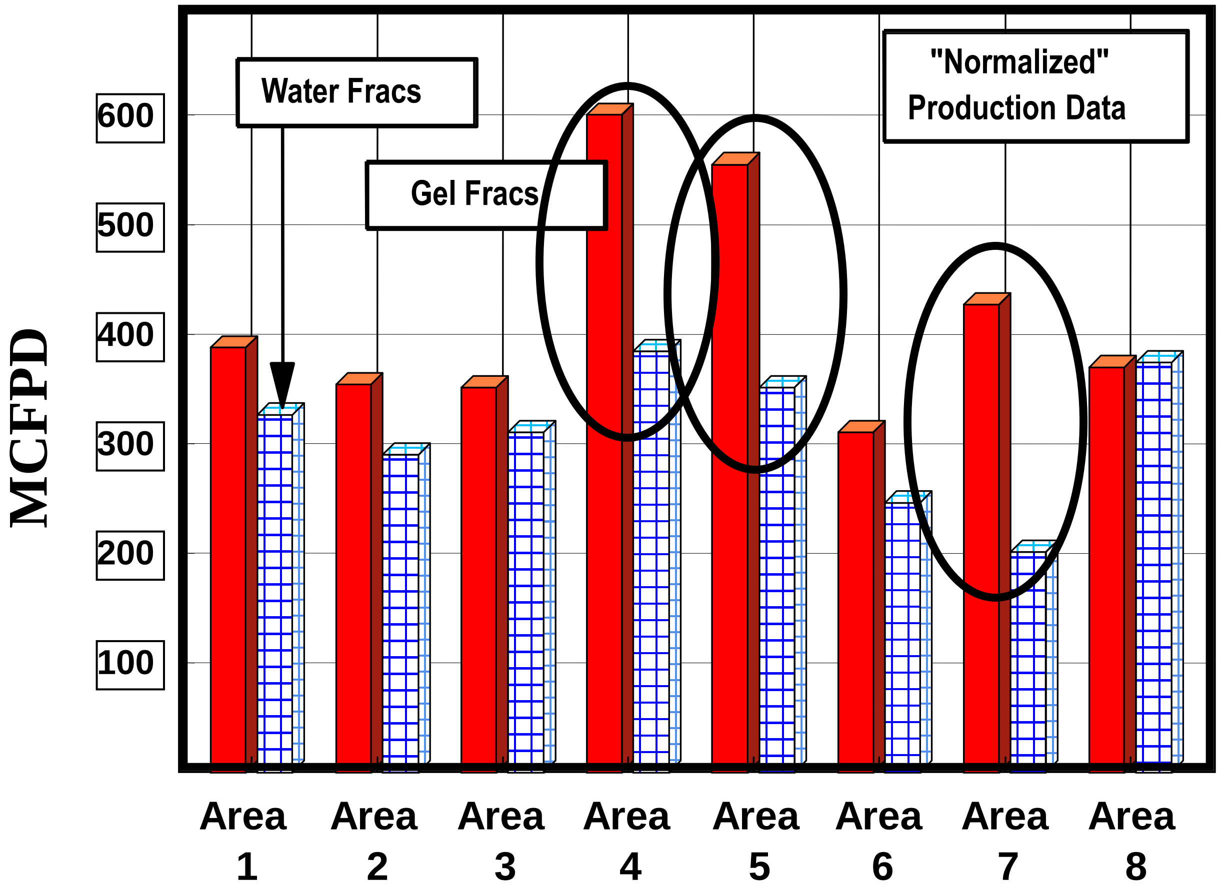
Why Un-Propped Crack Testing?



With Un-Propped $k_f w$ A Shale Reservoir Can Support Hundreds Of Feet Of Un-Propped Fracture!

This Is Why Water-Fracs Should Only Be Applied To Tight Unconventional Reservoirs & Proppant Is Always Needed!

Water-Frac's Must Depend On Un-Propped Fracture Conductivity



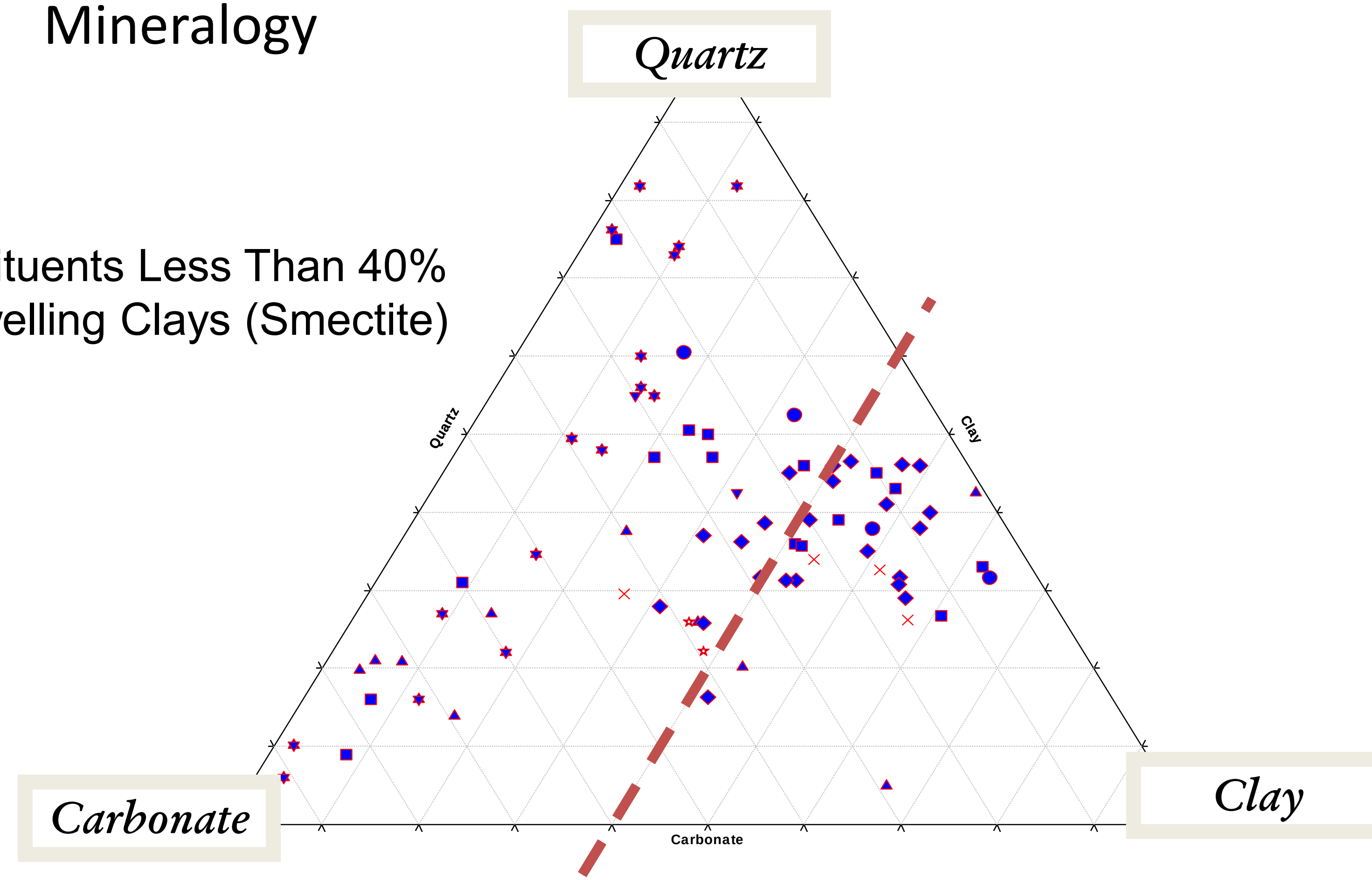
Area 4,5, & 7 Represents Woodlawn & Blocker Fields Where Taylor (CV) Sand Is 100+ Feet Thick!

Mineralogy & Ductility

Proppant And Fluid Selection & Quantity:

Mineralogy

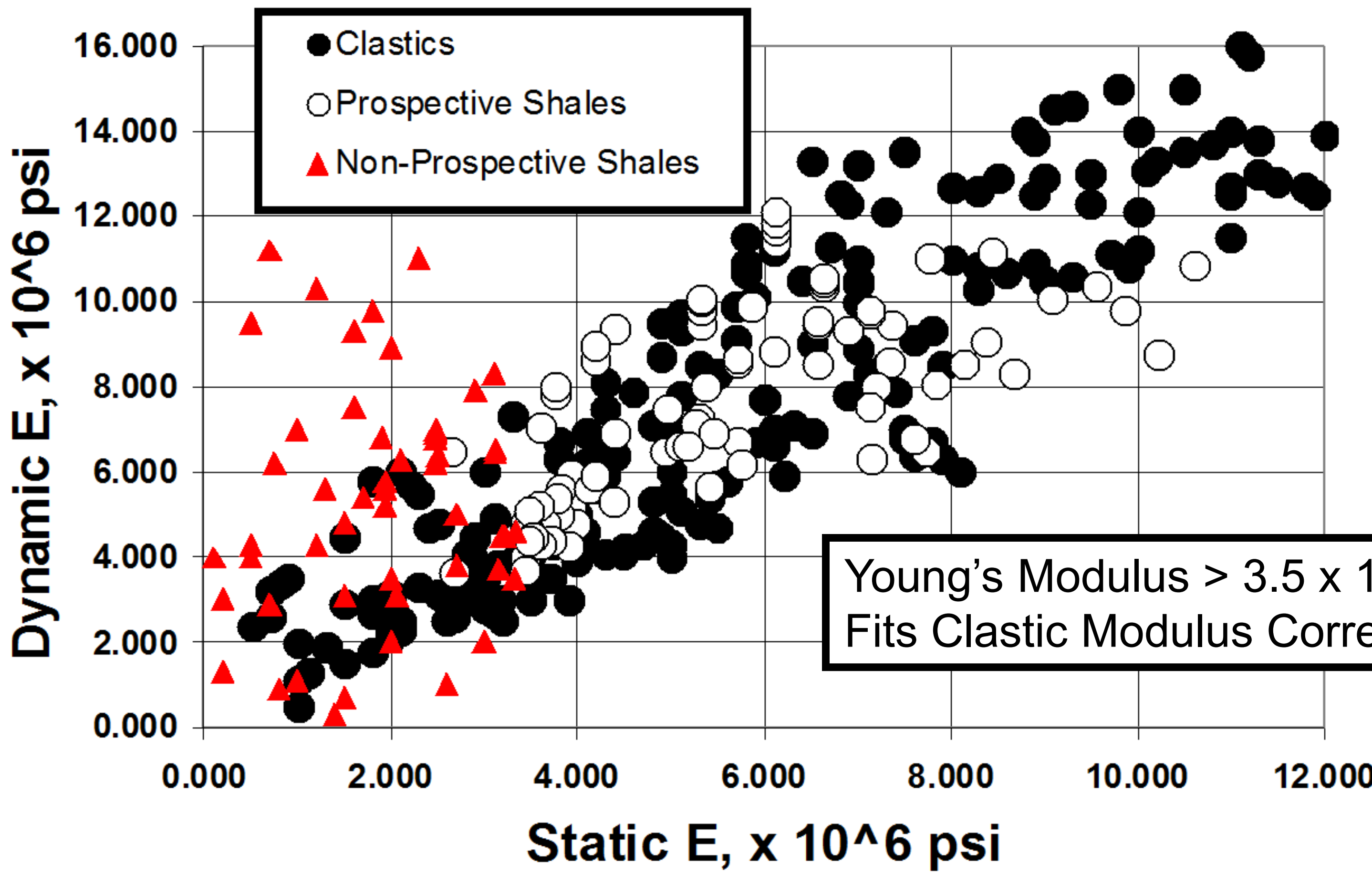
Clay Constituents Less Than 40%
Minimal Swelling Clays (Smectite)



Young's Modulus & Brittleness

Proppant And Fluid Selection & Quantity:

Young's Modulus

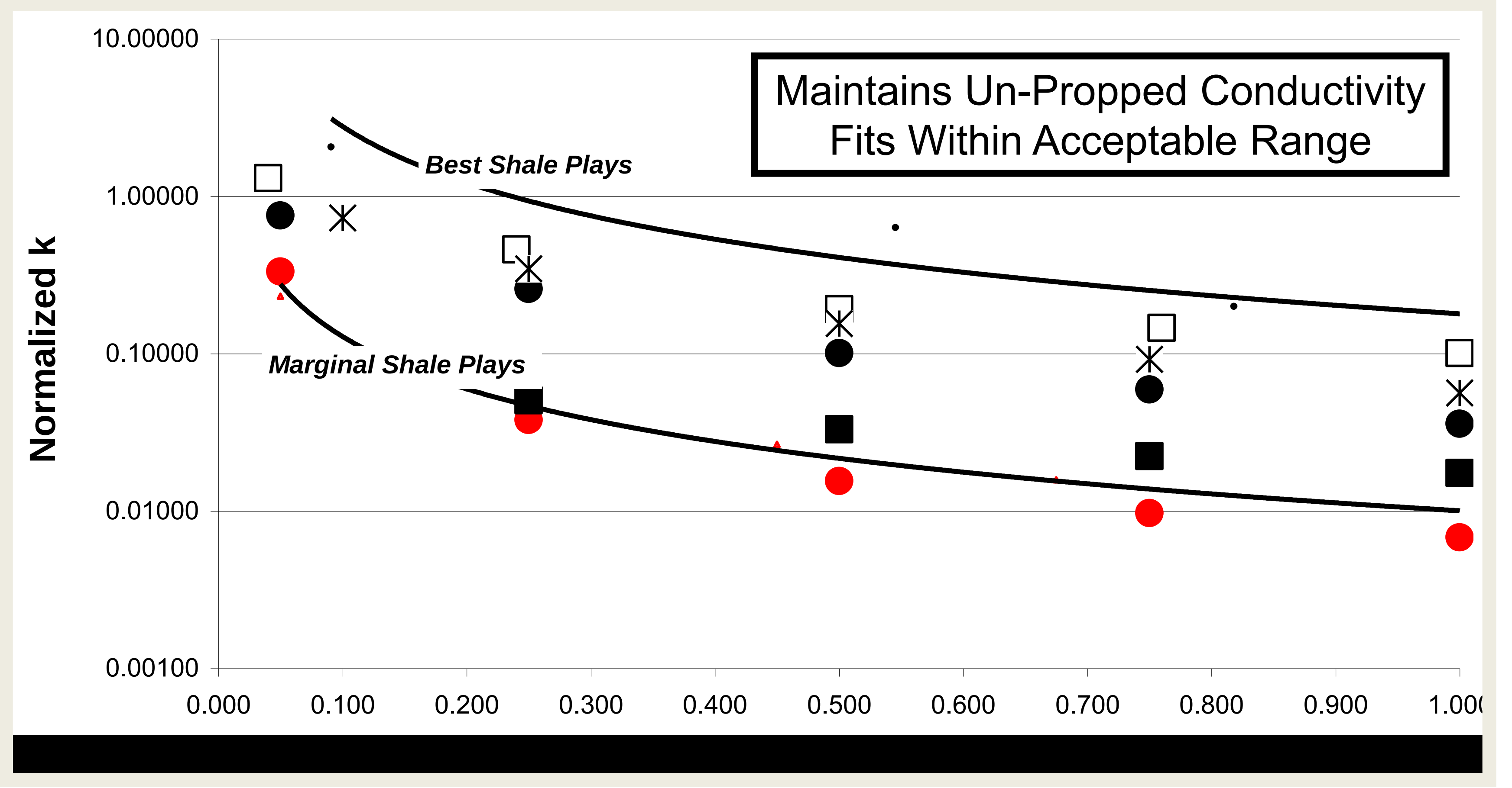


Young's Modulus > 3.5 x 10^6 psi
Fits Clastic Modulus Correlation

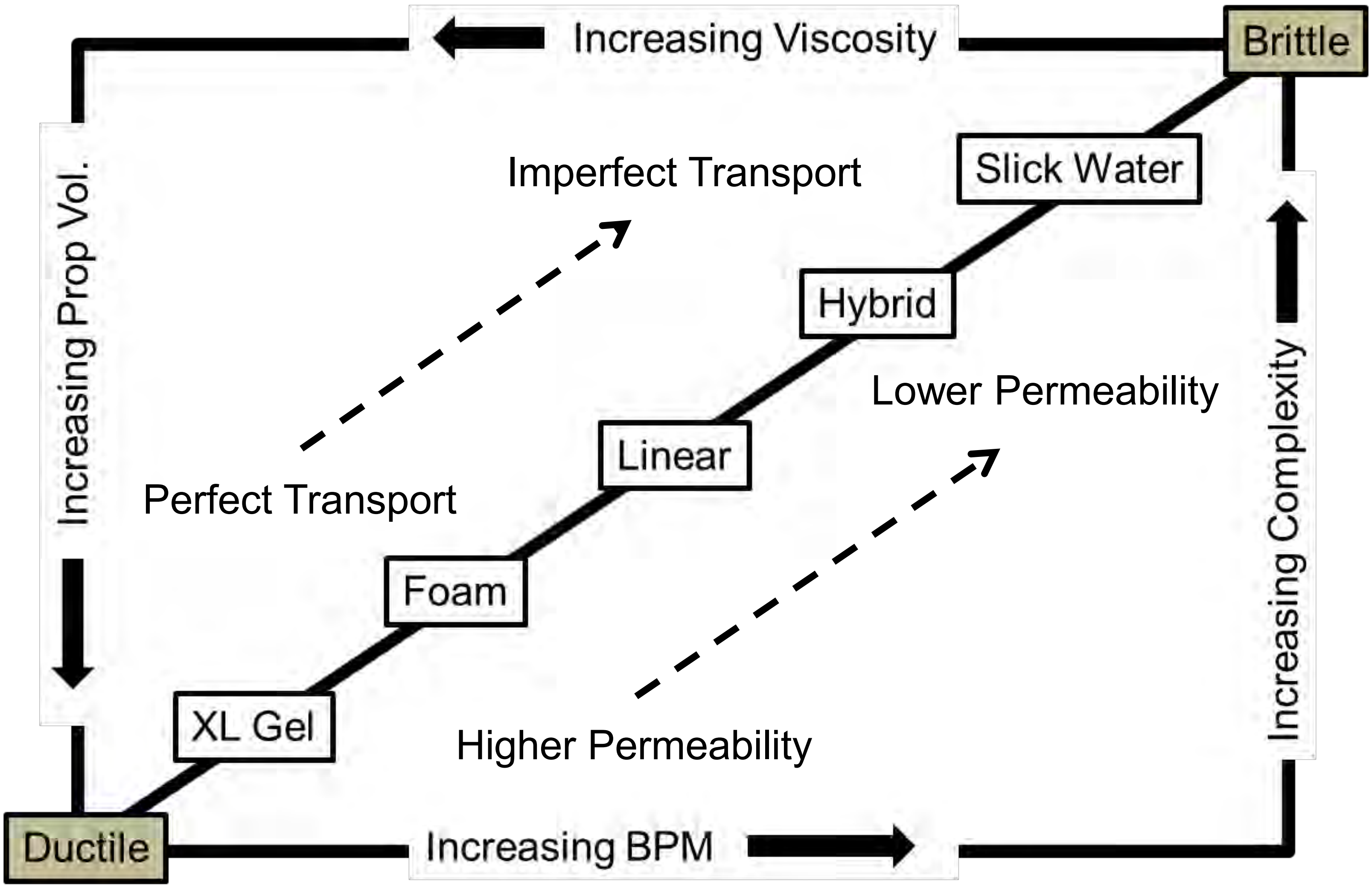
Un-Propped Crack Test & Ductility

Proppant And Fluid Selection & Quantity:

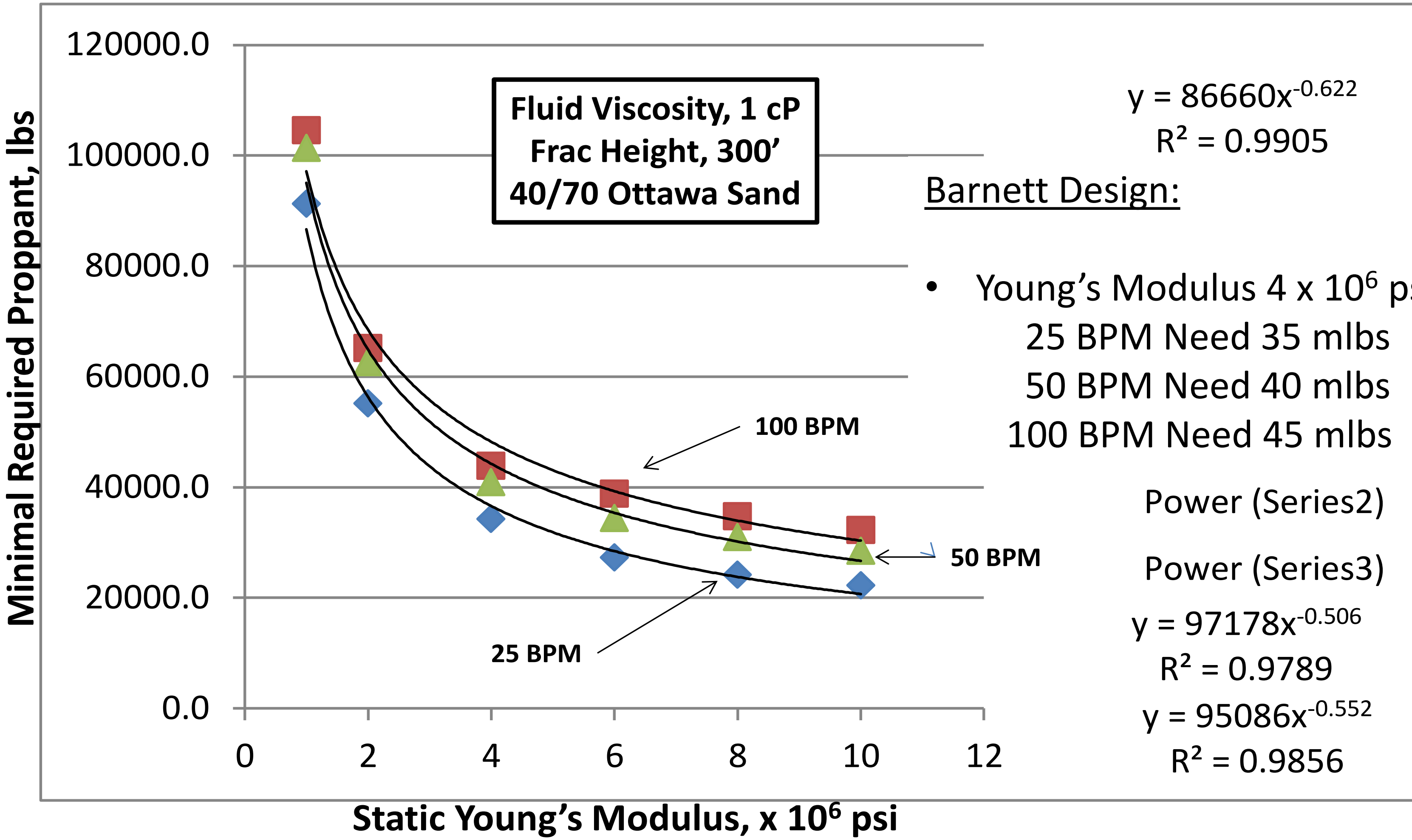
Un-Propped Crack Conductivity



Basis of Fracture Design



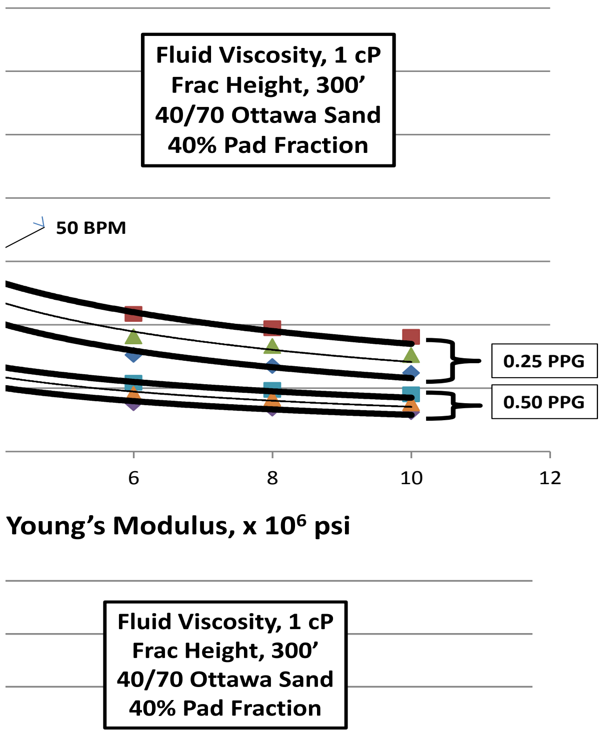
Water Frac Design Example



Barnett Design:

- Young's Modulus 4 x 10^6 psi
  - 25 BPM Need 35 mlbs
  - 50 BPM Need 40 mlbs
  - 100 BPM Need 45 mlbs

Water Frac Design Example



Barnett Design:

- Young's Modulus 4 x 10^6 psi
  - 0.25 PPG Need 250 mgals
  - 0.50 PPG Need 110 mgals
  - 1.00 PPG Need 60 mgals

Minimum Fluid Requirement
Does Not Consider Dilation!

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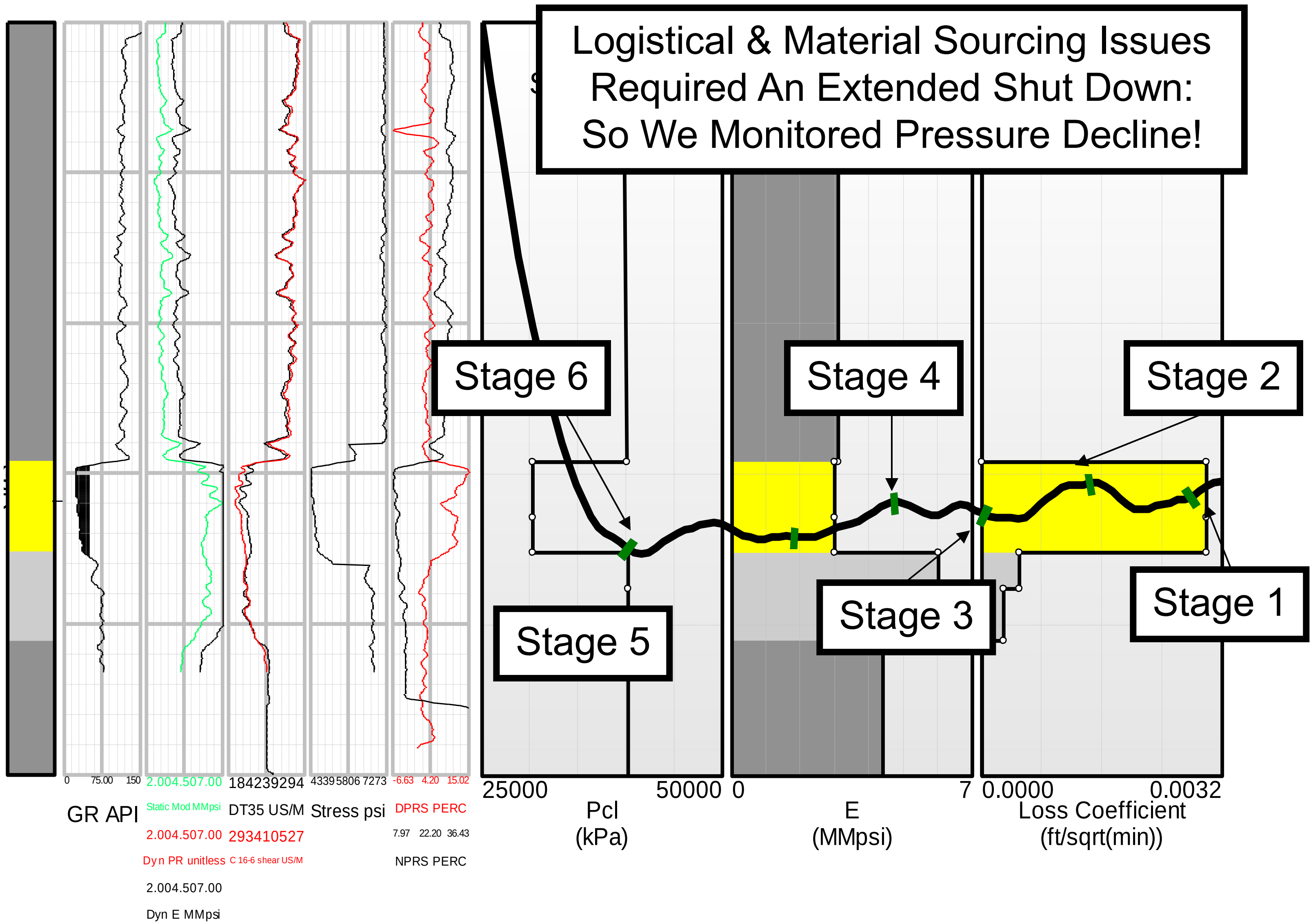
Post Fracture Decline Analysis Example



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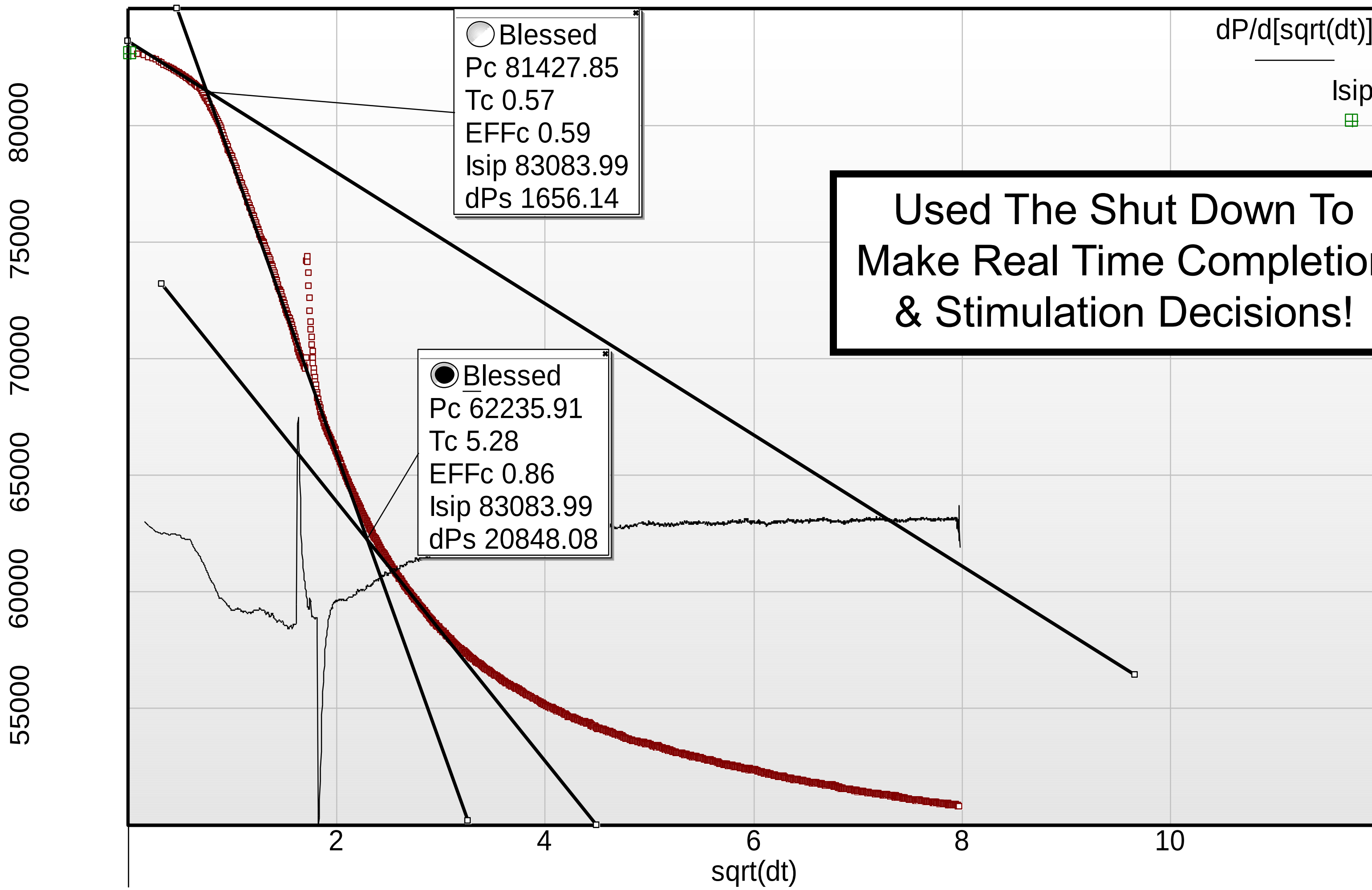

Used The Shut Down To Make Real Time Completion & Stimulation Decisions!

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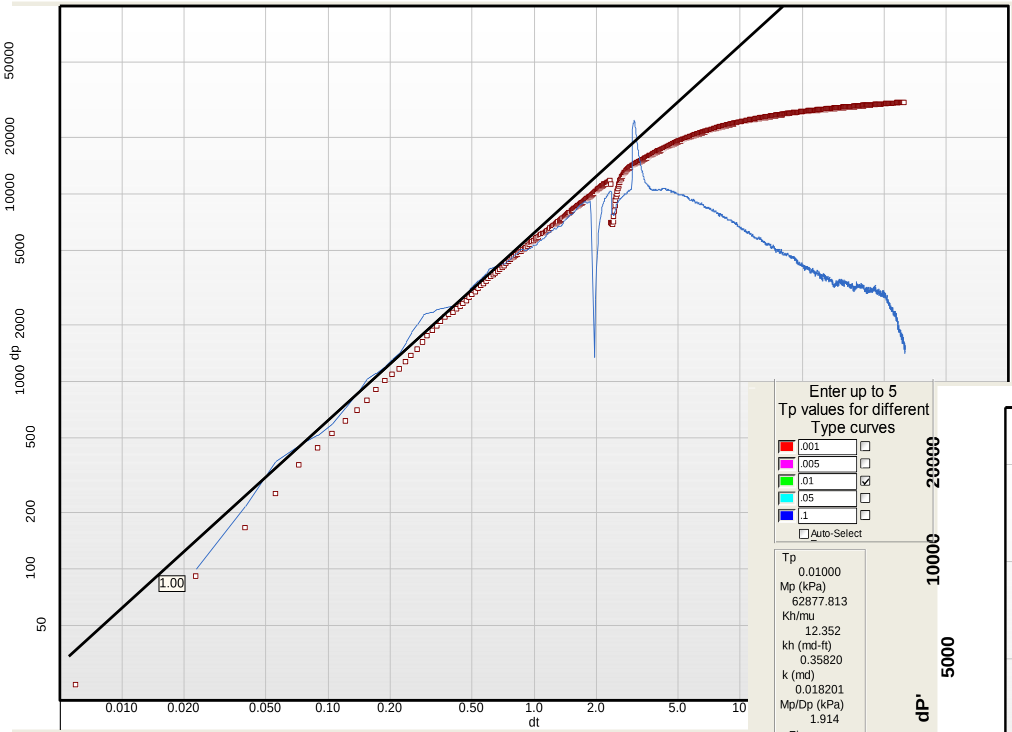
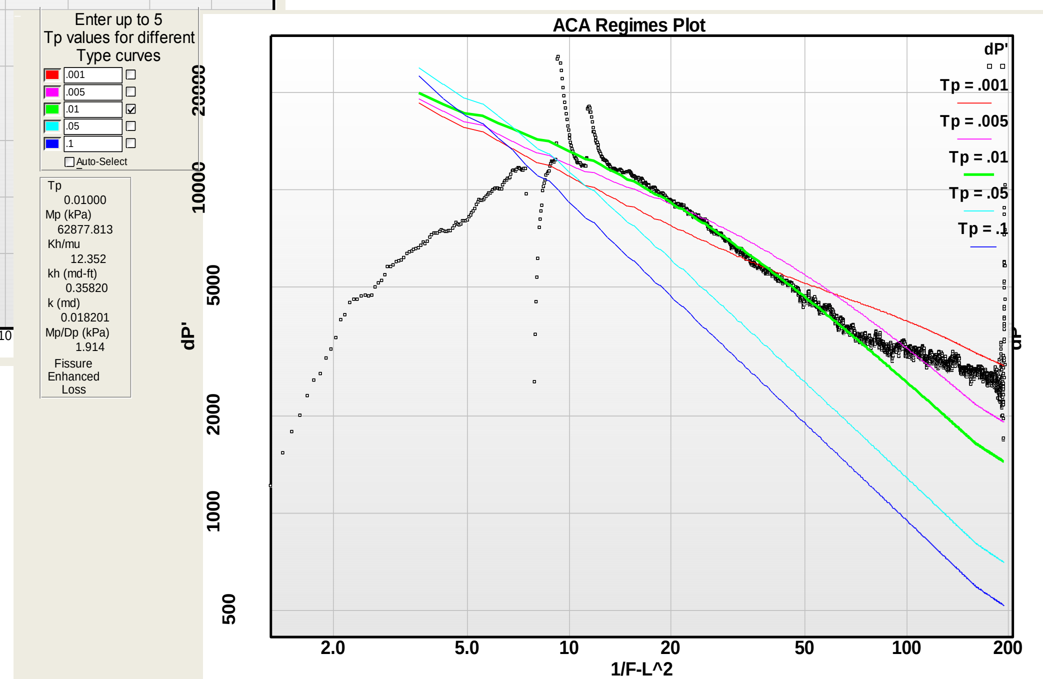


Type Curve Analysis Of Post Fracture Pressure Decline!



Type Curve Analysis Indicates A Permeability Of 0.018 md!

Keys to Horizontal Success

- Understand The Keys For Success
  - Ductility (Mineralogy, Rock & Geomechanics)
  - Permeability
- Completion(s) & Stimulation(s)
  - Fracture Length & Lateral Length
- Execute, Execute, Execute