Distinguished Lecturer Program

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Distinguished Lecturer Program

Completion of Hydrocarbon Bearing Shale Reservoirs

George Waters

Schlumberger

Society of Petroleum Engineers
Distinguished Lecturer Program
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Evolution of US Shales

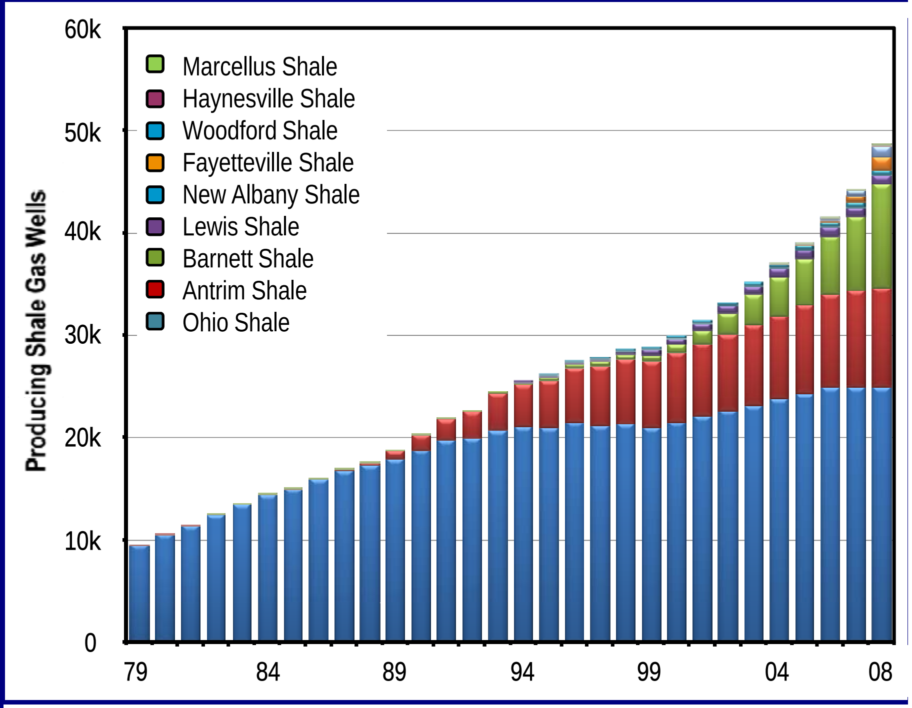
Initially driven by desportion

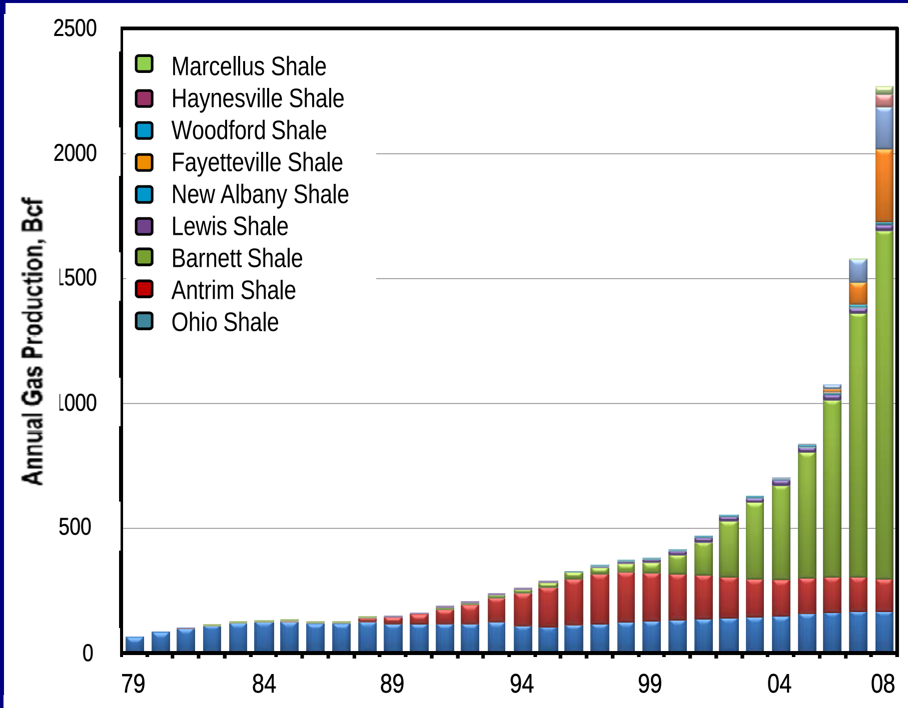
Focus shifts to pore gas

- Deeper
- Higher Reservoir Pressures

Dramatic increase in production

- ~1 BCF/day in 1997
- +6 BCF/day in 2009

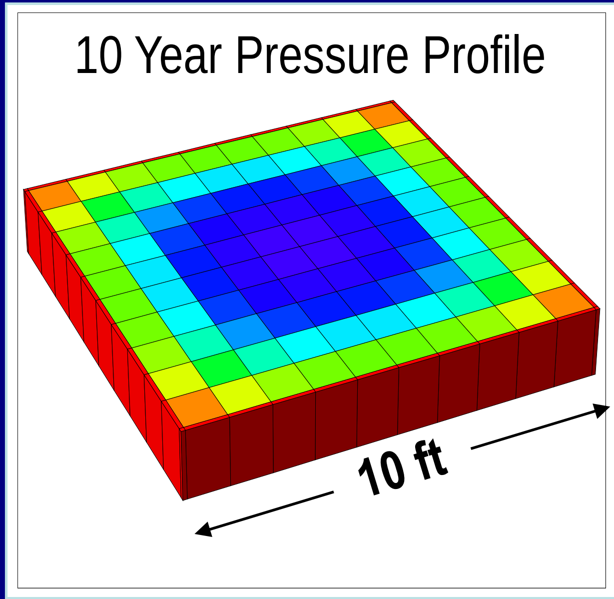




Shale Stimulation Requirements: Closely Spaced Fractures

- Extremely Low Matrix Permeabilities
  - Majority of Pressure Drop at Fracture Face
  - At Initial Reservoir Pressure 10s of feet from fracture for years
  - Hydraulic Fracture Complexity induces pressure drop from multiple points

- Horizontal Wells Frequently Employed
  - Drilled in direction of s_h
  - Generate multiple, transverse hydraulic fractures



Lateral Landing Guidelines

Best Petrophysics

- ϕ, k, GIP

Mineralogy

- Lowest Clay Volume

Borehole Stability

- Breakout
- Expandable Clays

Stress

- Lowest Closure Stress

Optimum Landing Points

Frac Simulations to Quantify

Calibration of In-Situ Stress

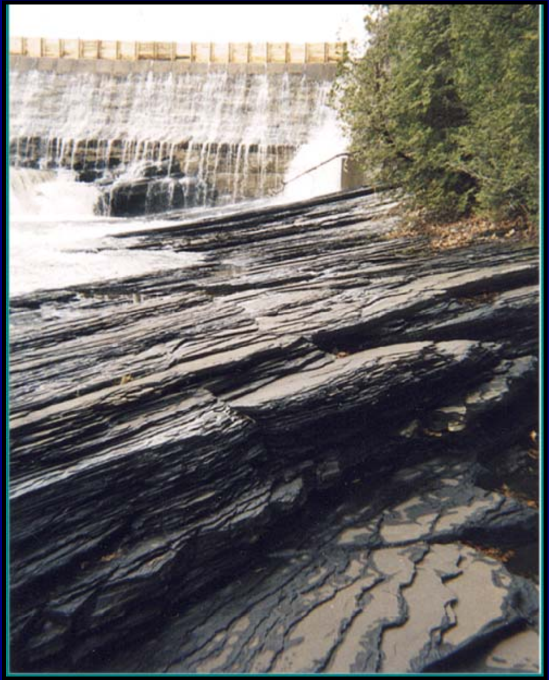
Isotropic Stress Profile
versus
Anisotropic Stress Profile

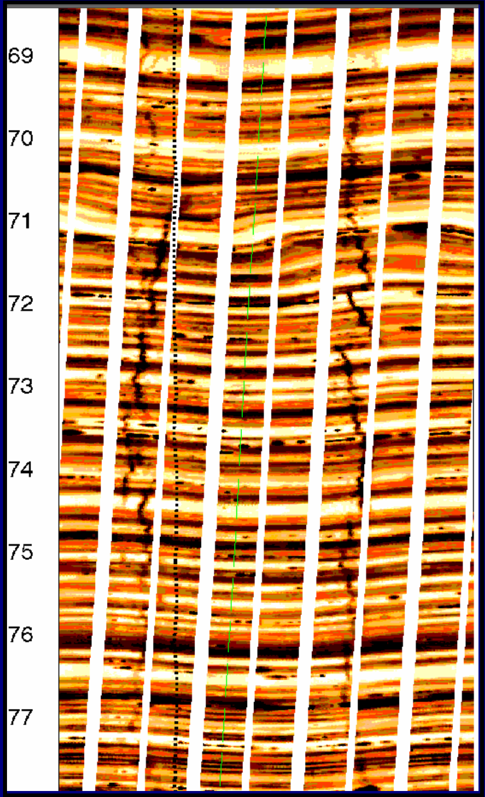
Isotropic Stress

$$\frac{\nu}{(1-\nu)} \times (\sigma_V - \alpha P_r) + \alpha P_r$$

Anisotropic Stress

$$\frac{E_h}{E_V} \times \frac{\nu_V}{(1-\nu_H)} \times (\sigma_V - \alpha P_r) + \alpha P_r$$





Laminations impact stress

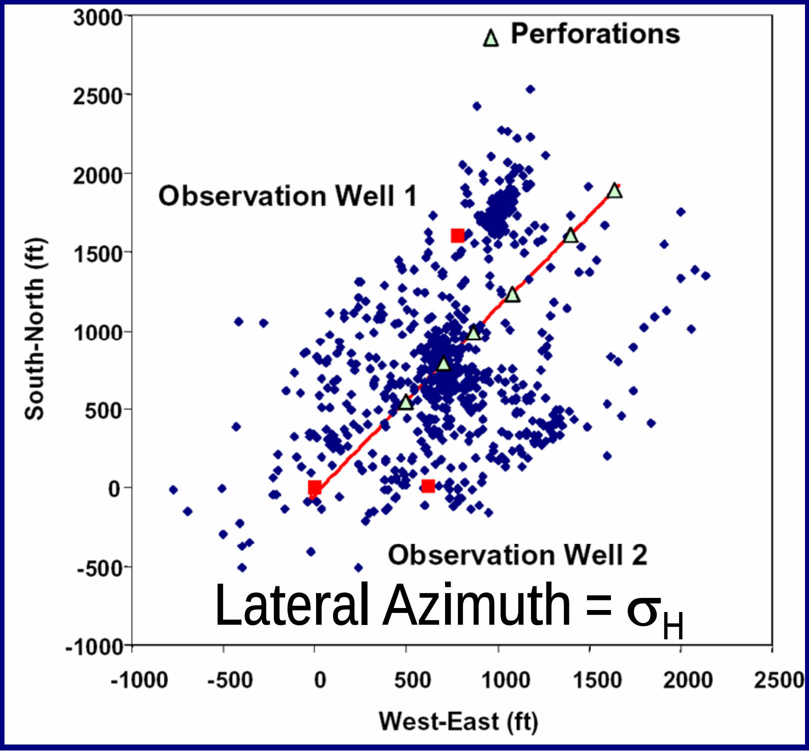
Laminations may impact fracture geometry

Barnett Shale Fracture Geometry

Natural Fractures normal to σ_H

Low Horizontal Stress Anisotropy

Wide Hydraulic Fracture Networks

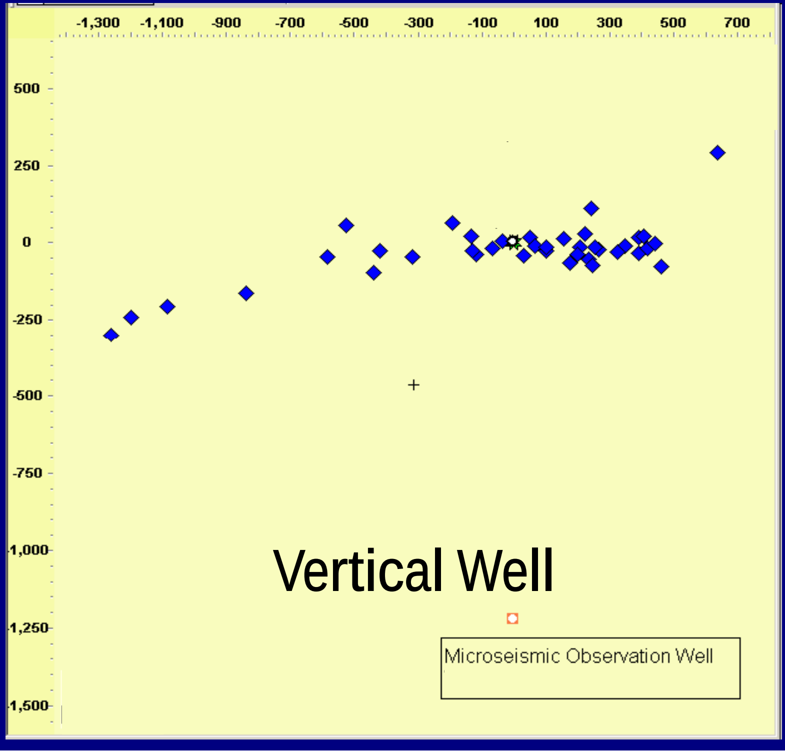


Arkoma Shale Fracture Geometry

Natural Fractures Parallel to σ_H

High Horizontal Stress Anisotropy

Narrow Hydraulic Fracture Network

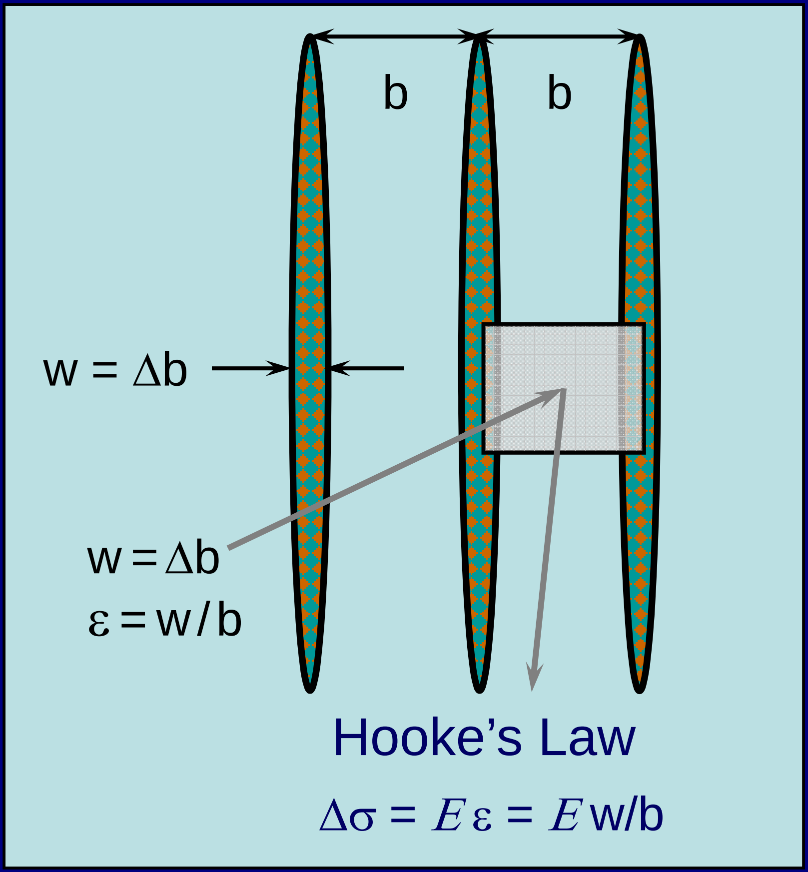


Spacing of Hydraulically Fractures

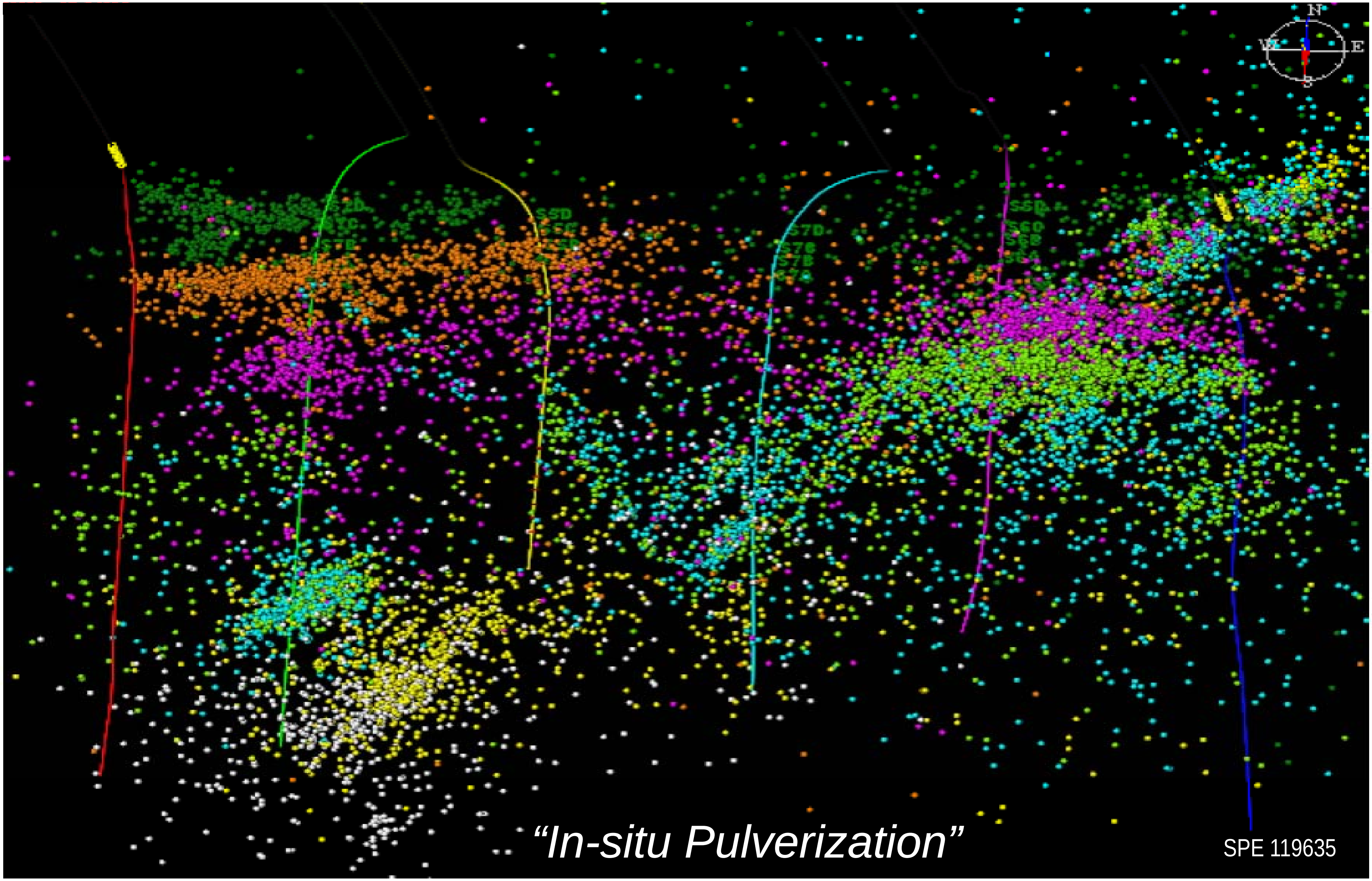
Example:

Young's Modulus = $3x10^6$ psi
Hydraulic Width = 0.05 in

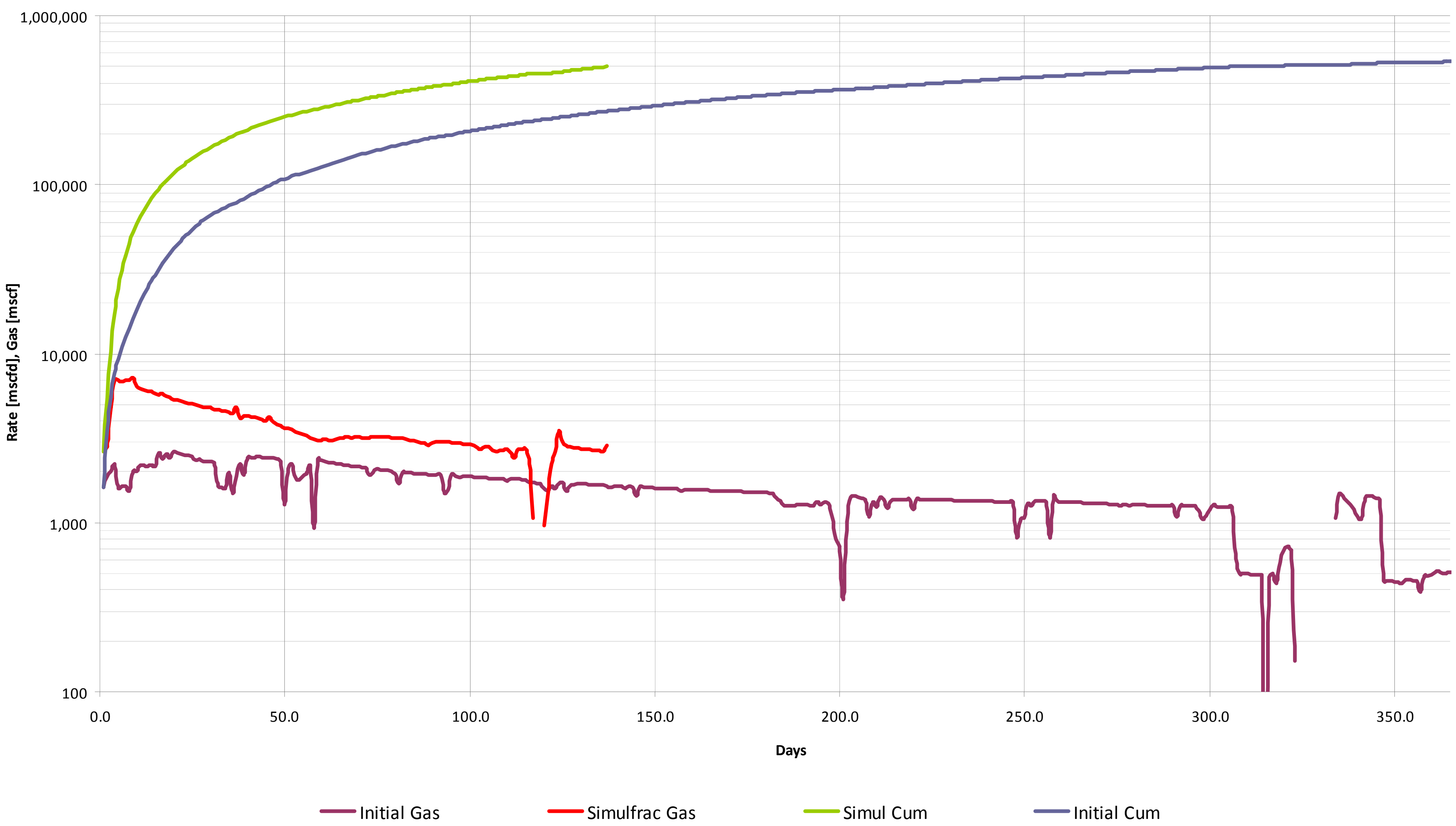
Spacing (ft)	Stress Increase (psi)
1	12,500
10	1,250
25	500
50	250
100	125



Simultaneous Hydraulic Fracturing



Simultaneously Hydraulically Fracturing Results



The Role of Effective Stress – Do We Need Proppant?

Force acting on fracture systems

$$\sigma' = \sigma - \alpha P_f$$

Barnett Shale Example

D = 7,000 ft

P_r = 0.55 psi/ft

σ_h = 0.60 psi/ft

P_{wf} = 500 psi

σ_H = 0.65 psi/ft

Initial Conditions

σ'_h = 350 psi

σ'_H = 700 psi

$\Delta\sigma'_{H-h}$ = 350 psi

During Production

σ'_h = 3,700 psi

σ'_H = 4,050 psi

Haynesville Shale Example

D = 11,000 ft

P_r = 0.85 psi/ft

σ_h = 0.95 psi/ft

P_{wf} = 7,500 psi

σ_H = 1.00 psi/ft

P_{wf} = 3,000 psi

Initial Conditions

σ'_h = 1,100 psi

σ'_H = 1,650 psi

$\Delta\sigma'_{H-h}$ = 550 psi

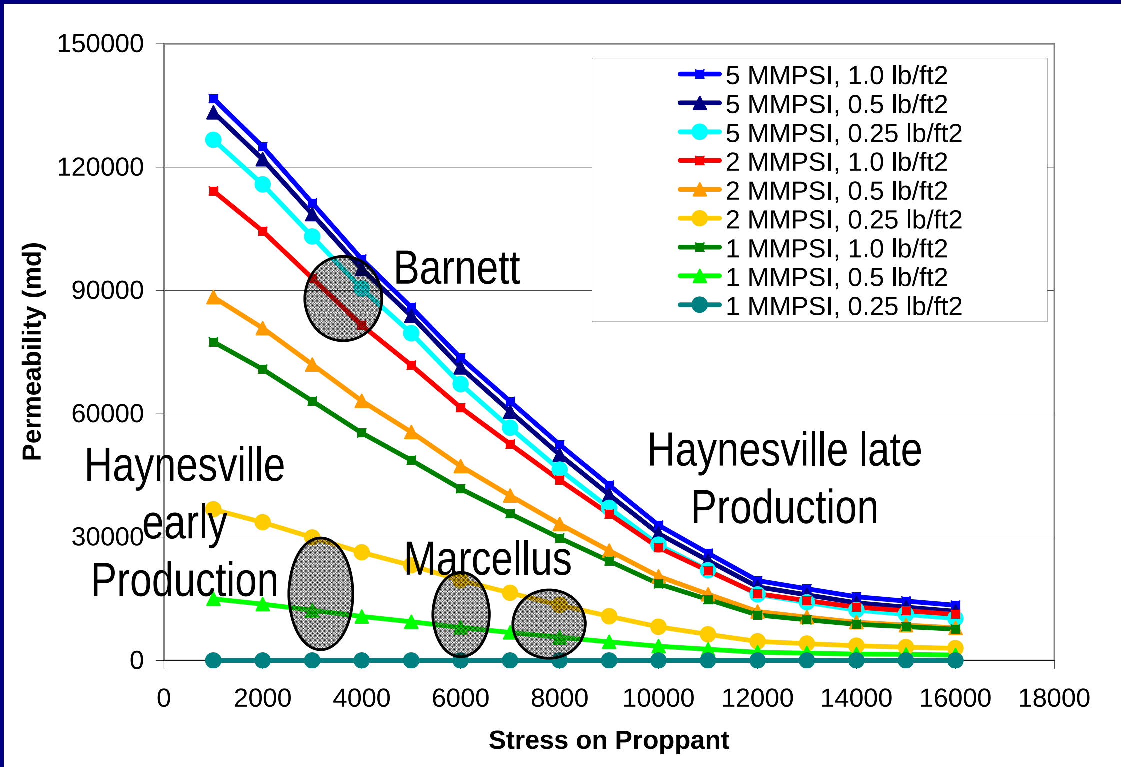
During Production

σ'_h = 2,950 psi

σ'_H = 3,500 psi

σ'_h = 7,450 psi

σ'_H = 8,000 psi



Fracturing Fluid Selection

Slickwater

- More Surface Area/Unit Cost
- Wider Fracture "Fairways"

Gels

- Fracture Initiation

Foams

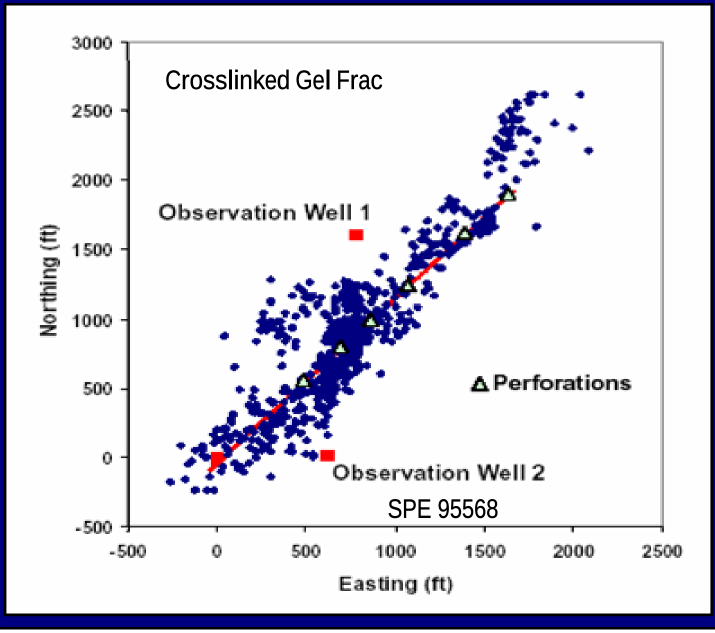
- Low Pore Pressure
- Swelling Clays
- Water Shortages

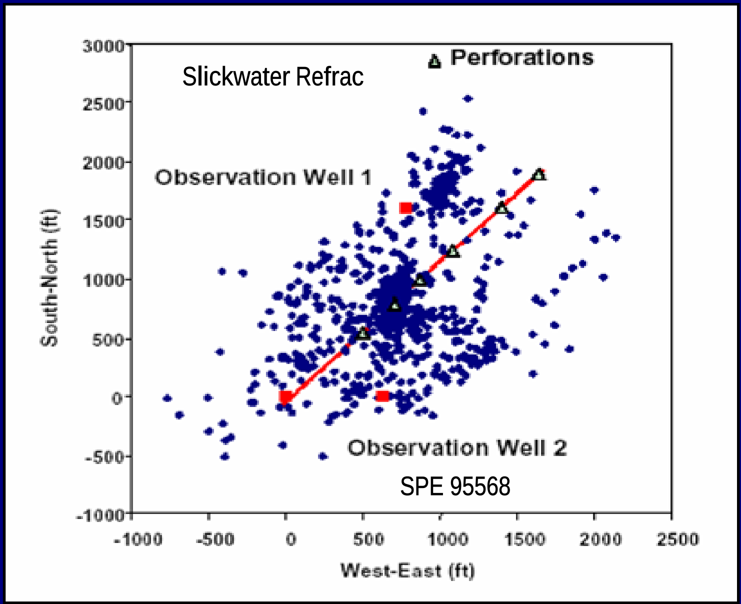
Diversion

- Fibers, Ball Sealers, Sand Slugs
- Simul-fracs, Zipper-fracs, Refracs

Propped Fractures

- Effective Frac Conductivity
- Prop Volume, Viscous Fluids, Light Weight Props, Foams…





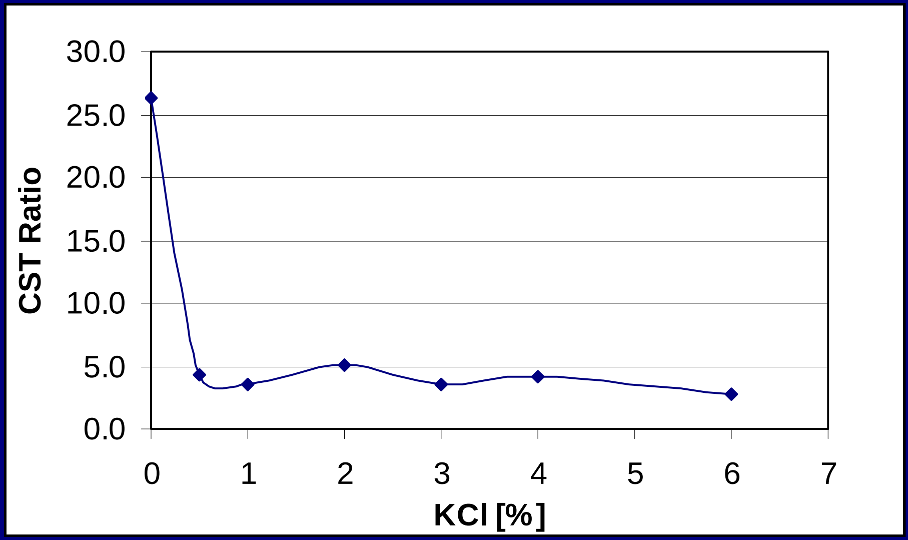
Fracturing Fluid Additives

Salts

- Shale Compatibility
- Swelling Clays

Scale Inhibitors

- Mixed/Reused Waters
- High TDS Waters



Fracturing Fluid Additives

Salts

- Shale Compatibility
- Swelling Clays

Scale Inhibitors

- Mixed/Reused Waters
- High TDS Waters

Surfactants

- Impact Wetting Phase
- Exacerbate Imbibition
- Oil or Non-Wetting

Bactericides

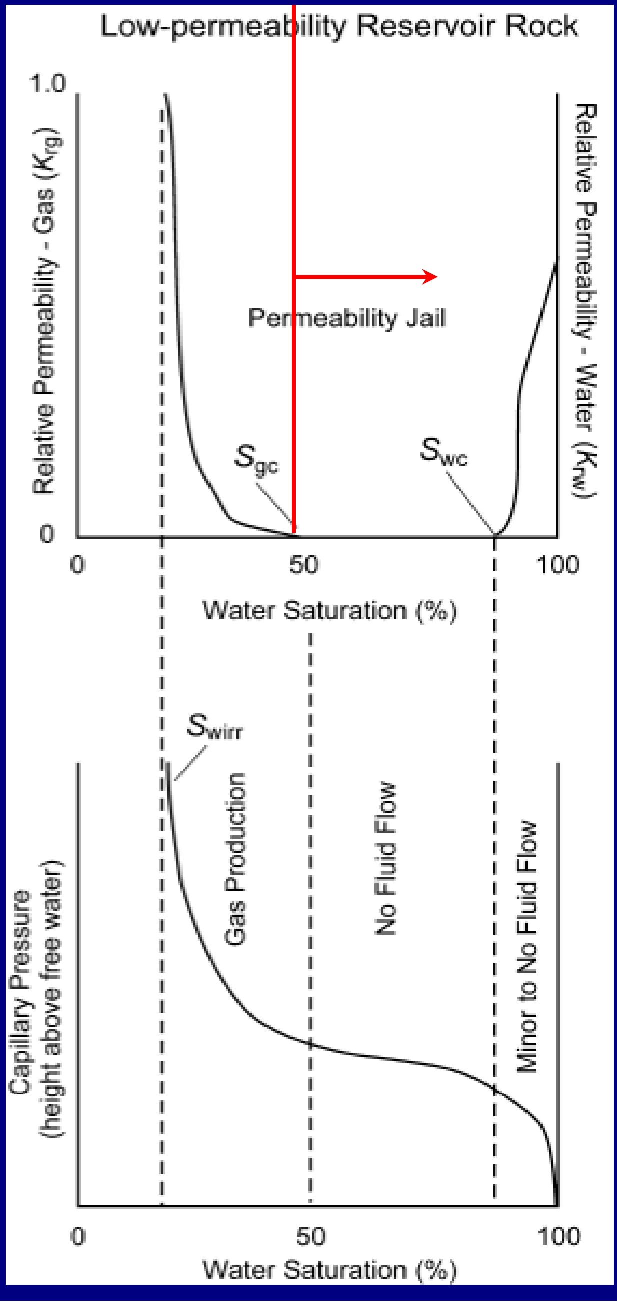
- Untreated Water

Breakers

- High MW Polymers

Iron Stabilizers

- Chlorite & Pyrite



Perforation Practices – Impact on NWB Complexity

Longer Perforation Clusters

Can induce Parallel Fracturing

High Density Phasing

Tortuous Path leaving the Wellbore

Limited Entry Design

Perf Clusters per Frac Stage

Perf Cluster Spacing

Can create Fracture Interference

Perforation Performance

Hard Rocks – Shorter Penetration

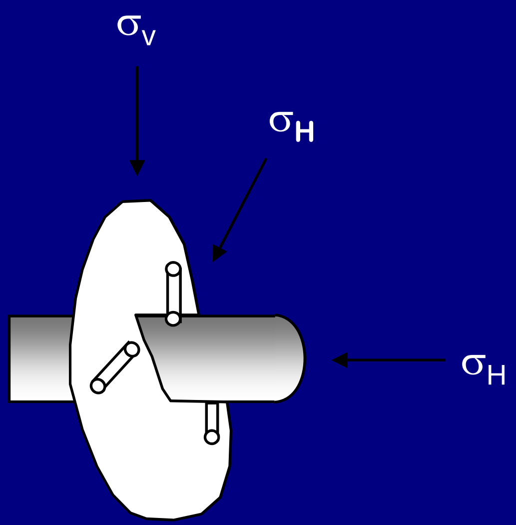
Argillaceous Rocks – Collapsed Tunnels

Sand Jetting

Deeper Penetration

Physically Remove Rock

Single Plane Phasing



$$\Delta p_{perf} = \frac{1.98\, Q^2\, \rho}{c^2\, d_p^{\,4}\, N_p^{\,2}}$$

Summary

Keys to Optimizing Shale Gas Completions:

- Identify Stimulation Drivers
  - Fracture Height Growth & Complexity
  - Fracture Conductivity & Fluid Compatibility
- Must Perform "Science" At Beginning of Development
  - 3D Seismic Acquisition to understand Structure
  - Core Analysis for Mechanical Properties, Conductivity & Fluids Testing
  - Log Analysis to quantify Petrophysics and Geomechanics
  - Microseismic Monitoring to Quantify Hydraulic Fracture Geometry
- Evolves to Manufacturing Process
  - Maximize Drilling Efficiency
  - Optimize Well Spacing & Completion Process
- Change Process as Acreage Changes
- Continually Learn as Project Evolves