# Development of tight gas sand stimulation techniques

Art Milne – Stimulation Domain Manager

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# Stimulation Considerations - Review

- Reservoir characterization (petrophysics)
- Rock mechanics (geomechanics)
- Best completion practices (casing, tubing, perforating, etc.)
- Obtaining designed effective fracture half-length
  - Less damaging, cleaner fluids
  - Proppant transport / placement
  - Flowback methodology
  - Number of stages
- Effective stimulation for horizontal wells

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# Technologies

- VES-based fluids (ClearFRAC)
- Fiber-based fluids (FiberFRAC)
- Fluid recovery additives (F108)
- Geomechanics
- CONTACT fracturing (StageFRAC, TAP, AbrasiFRAC, PerfFRAC)
- Realtime monitoring (StimMAP)

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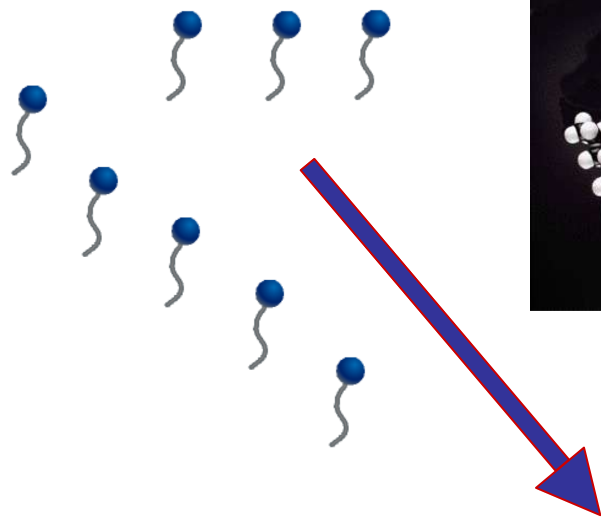
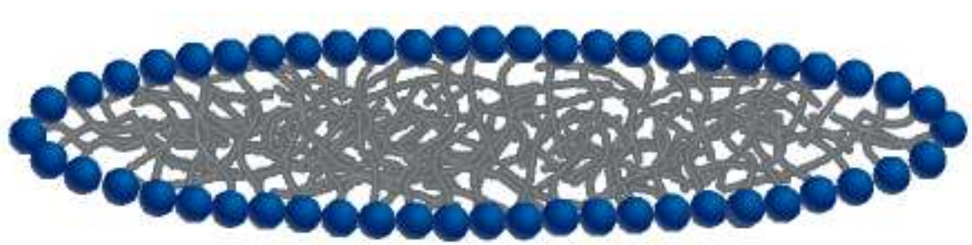
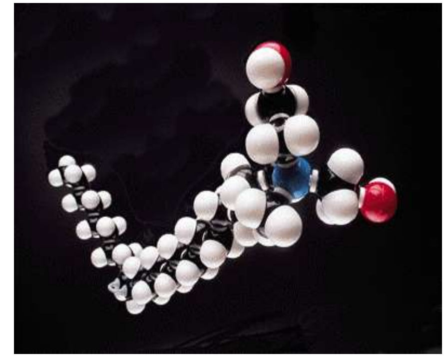
# Fracturing fluid technology – Viscoelastic surfactants (VES)





"Entangled micelles" provide viscous and elastic properties

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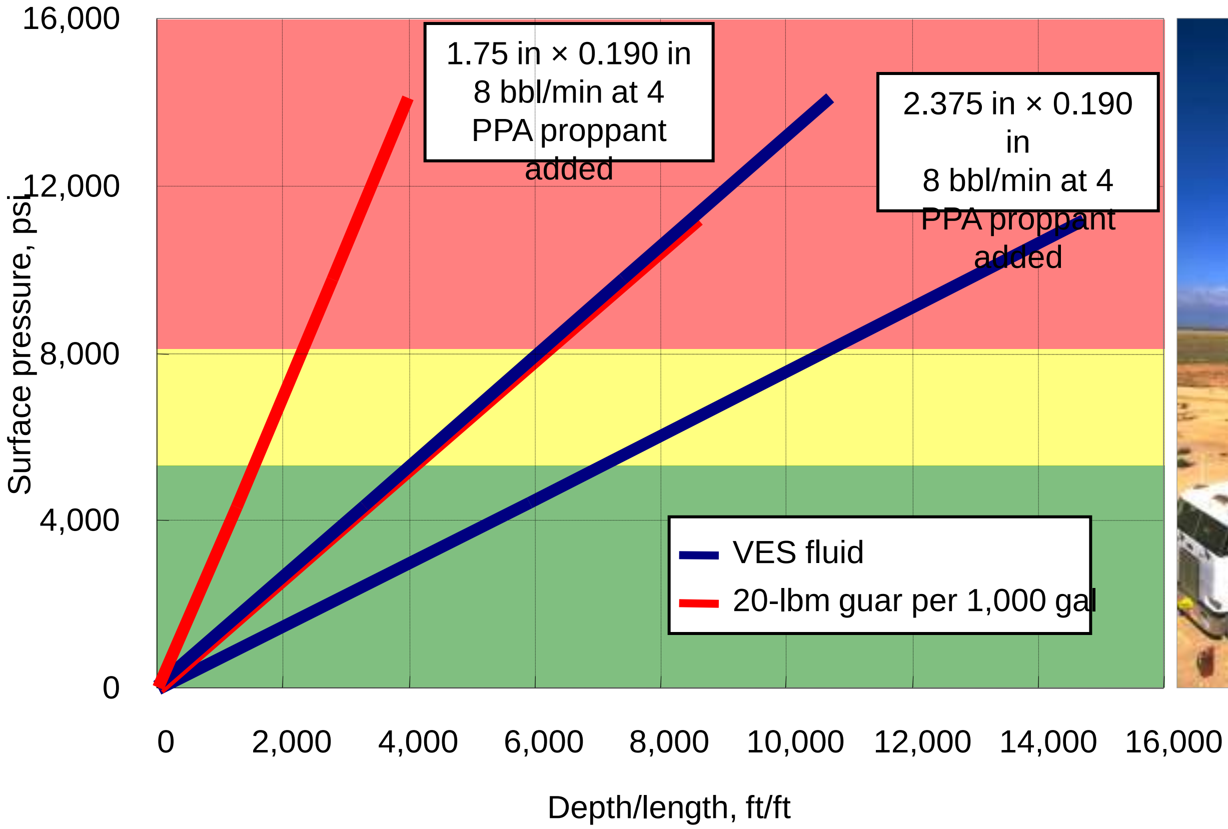
# Reduced friction pressure

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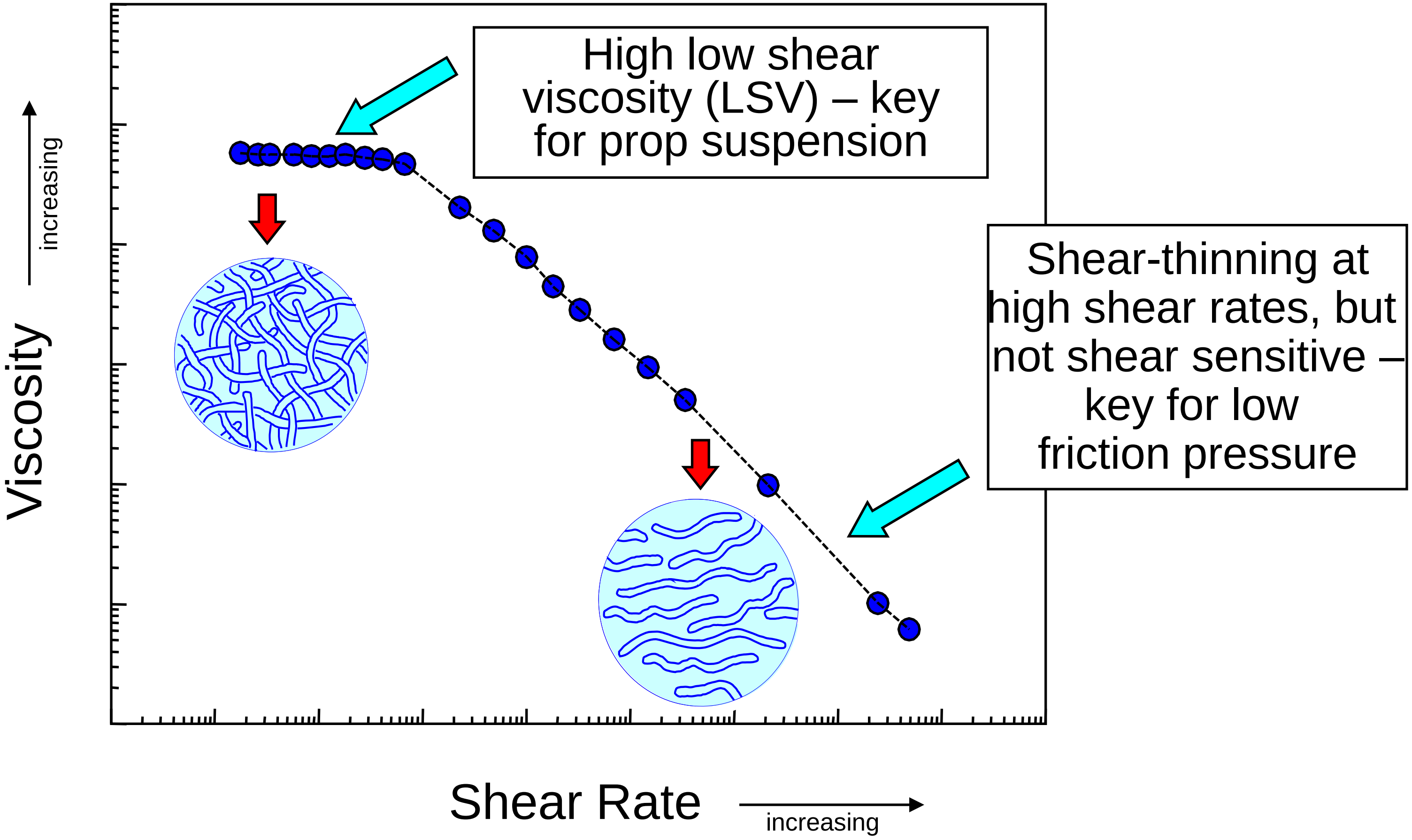
# Improving proppant transport

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# What do VES fluids do to improve stimulation in tight gas reservoirs

- Better control of fracture geometry – improved fracture height containment
- No damage in the proppant-pack - >95 % retained conductivity
- Excellent proppant transport – viscosity is a function of temperature, not time and there is no shear sensitivity
- Significantly lower friction pressure behavior – allows higher pump rate and/or lower HHP
- Operationally simple system – fewer additives required

- Increased effective fracture half-length

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# Proppant distribution solutions

- Fracturing fluid viscosity
  - Requires higher polymer loading – results in more damage to proppant-pack conductivity
  - Increased viscosity leads to higher $P_{net}$ – unwanted height growth
  - Reduction in leakoff can result in longer fracture closure time
- Forced closure (also called "reverse screenout")
  - Can result in proppant flowback or make more severe
  - Closure at the wellbore – can take long time to impact entire fracture
- Lightweight proppants or higher density base fluid
  - Reduces the density differential between the fluid and the proppant
  - *Normally sacrifice conductivity vs closure pressure*

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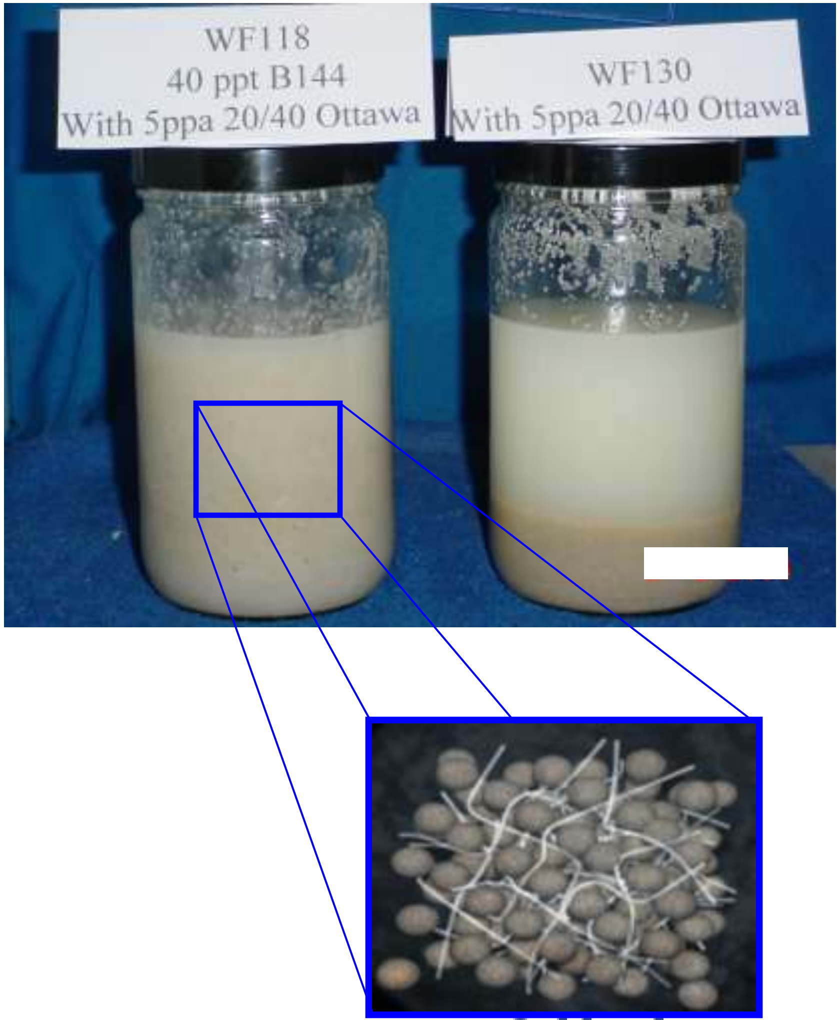
# Proppant distribution solutions (con't)

- Addition of fiber to the base fluid
  - Doesn't impact the base viscosity of the fluid system
  - Can decrease polymer loading
    - Improve retained proppant-pack permeability
    - Lower viscosity for preventing unwanted fracture height growth
  - Independent of the type of proppant used
  - Is a mechanical method

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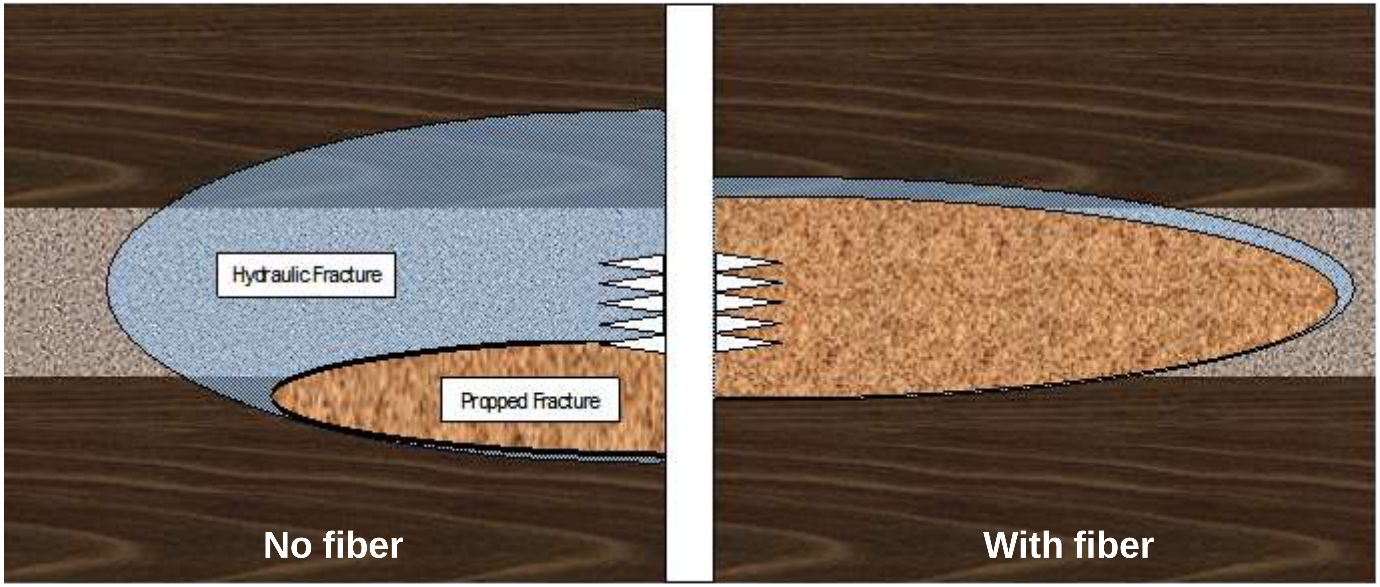
# Proppant distribution solution with fiber




- Stimulation efficiency
  - Better control of fracture geometry and proppant placement
- Stimulation effectiveness
  - Long closure time can result in severe proppant settling leading to improved $C_{fD}$ and therefore productivity

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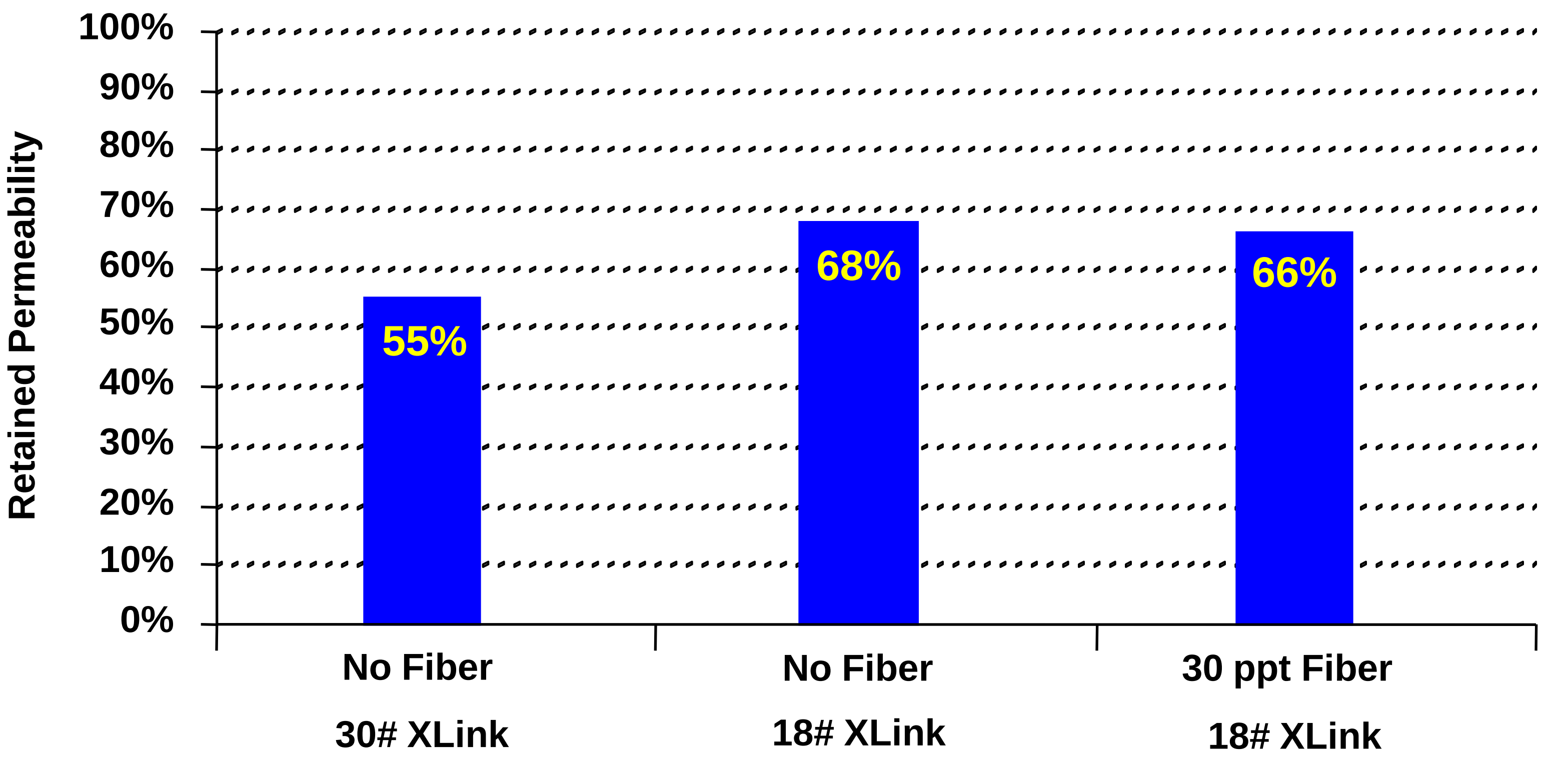
# Effect of fiber on proppant-pack conductivity

## Test condition - 20/40 bauxite; 2 lb/ft$^2$; 200 degF; 5,000 psi

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# Formation damage in tight gas reservoirs

- Tight gas reservoirs are often under-saturated (subnormally) saturated with water (no existing/distinguishable GWC)
  - After initial deposition gas displaces water to a capillary equilibrium
  - Tight gas reservoir becomes effectively disconnected from water source
    - Due to structural changes
    - Due to lateral heterogeneity within the reservoir
  - Remaining migration of gas has a desiccating effect

- Capillary forces are a significant issue when stimulating

$$P_c = \frac{2\,\sigma\,\cos\theta}{r}$$

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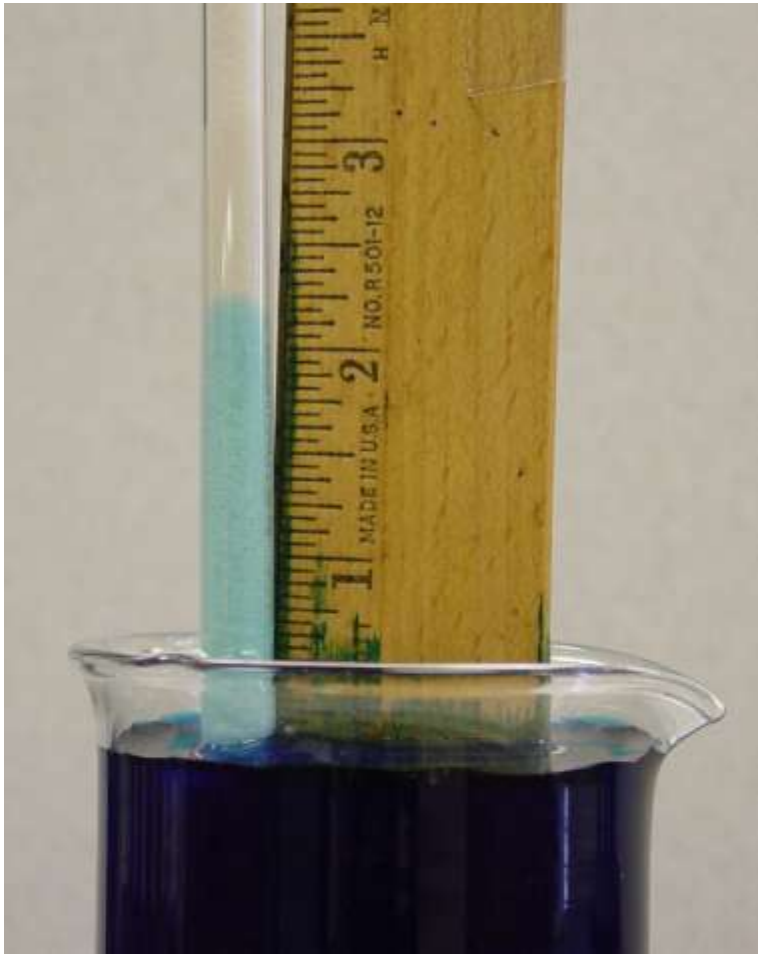
# Formation damage (cont.)

- Conventional wisdom
  - would suggest pumping a non-wetting fluid (hydrocarbon) to reduce capillary effects
  - would suggest not pumping large volumes of a hydrocarbon-based fluid because of the potential impact on relative permeability to gas
- In reality we typically pump water-based fluids containing surfactants
  - to reduce the surface tension, which reduces the capillary pressure
  - in order to recover more of the water and prevent water blockage

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# Use of surfactants in tight gas reservoirs

- Surfactant is a contraction for the term: "*surface-active agent*"
  - Adsorbs onto the surfaces or interfaces of a system
  - Alters the surface or interfacial energies
- Interface is the boundary between two immiscible phases

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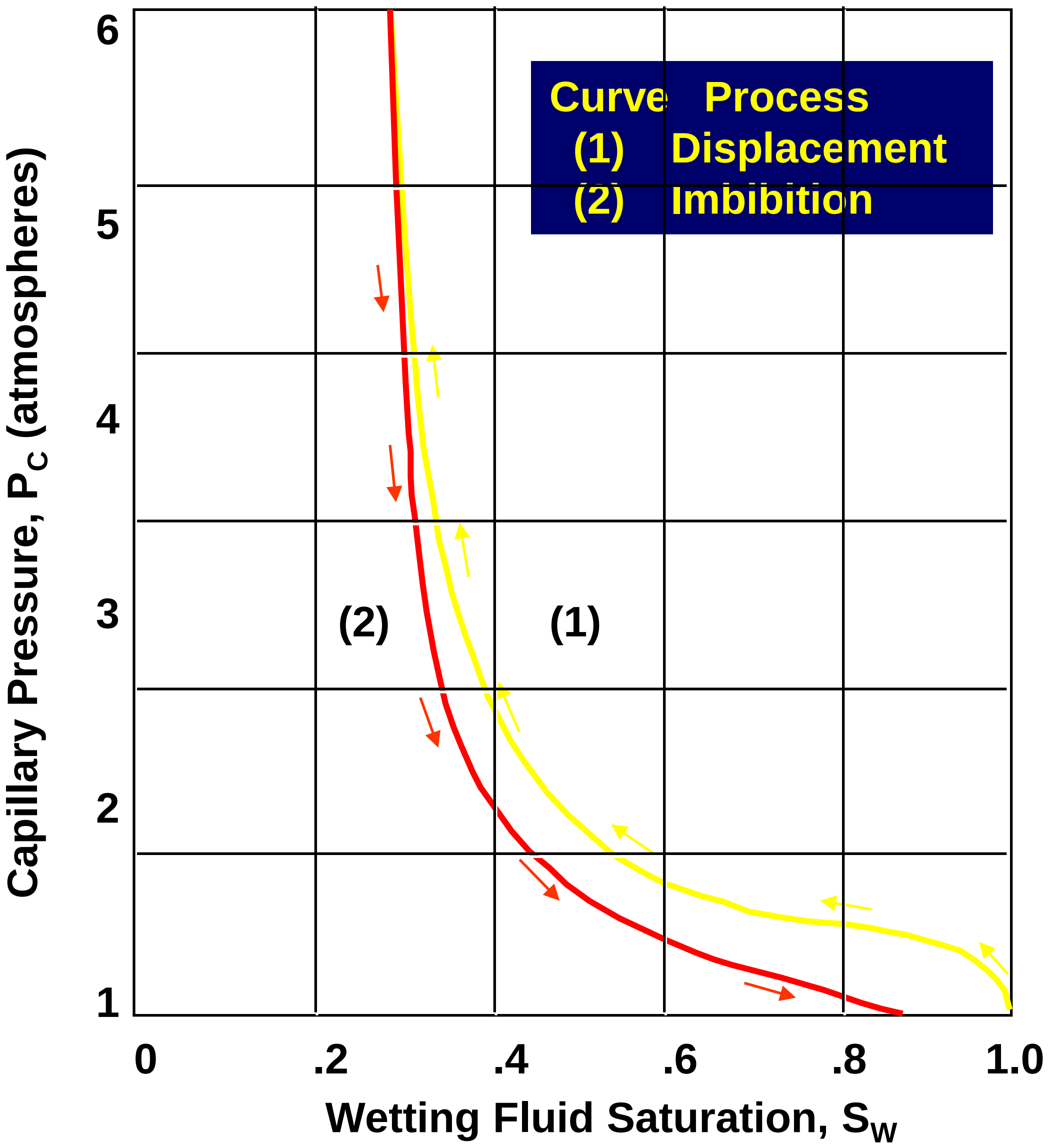
# Equivalence of Imbibition and Displacement




From: R.E.Collins

Slight hysteresis

- ✓Displacement Ultimately Driven by Hydrostatic Pressure
- ✓Imbibition Ultimately Controlled by Capillary Effects

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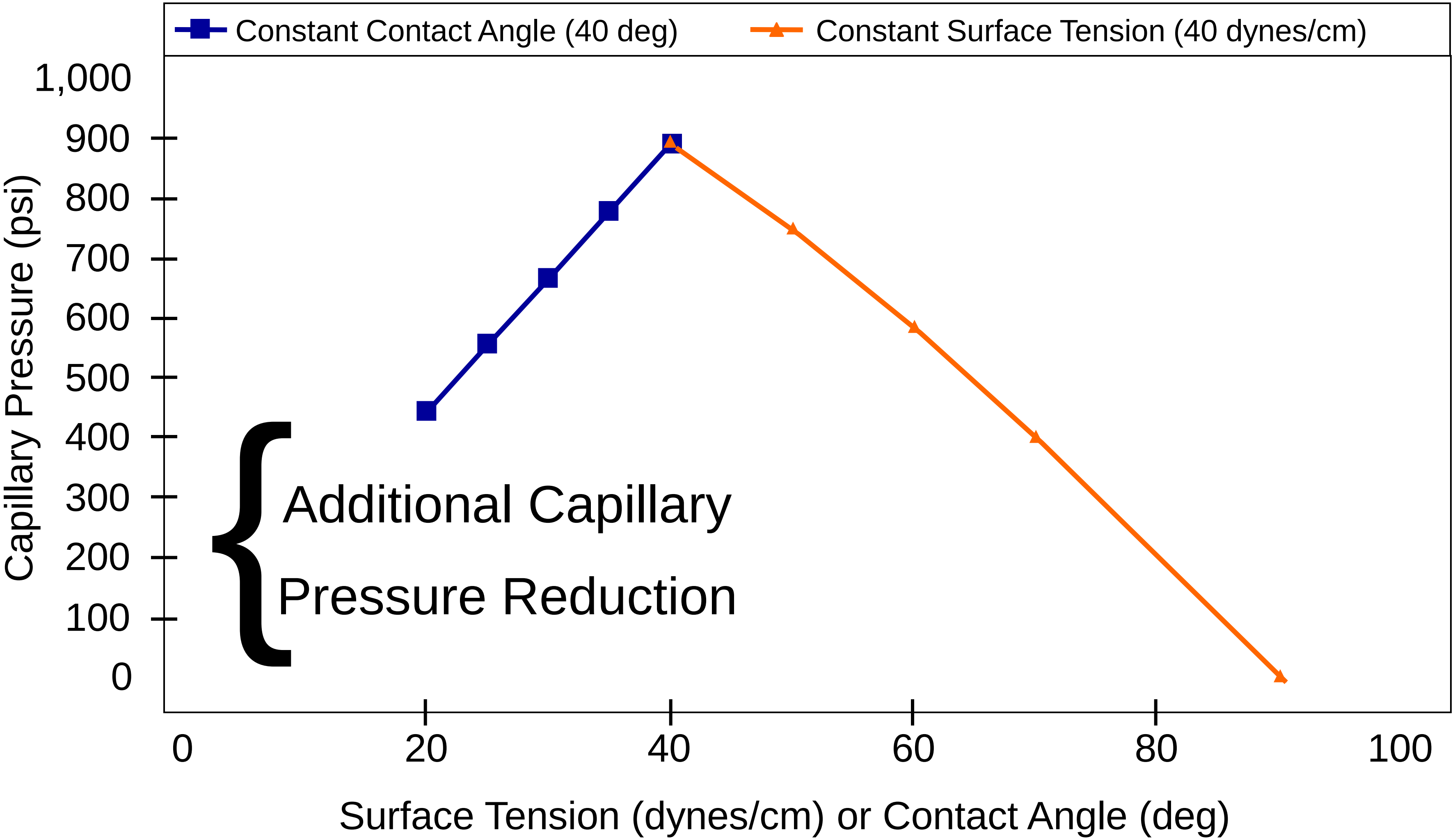
# Experimental analysis

| Material | Surface Tension | Viscosity | Imbibed Weight | Contact Angle | Capillary Pressure | Capillary Pressure |
|---|---|---|---|---|---|---|
| | $\gamma_{12}$ | $\eta$ | $m$ | $\theta$ | $P_c$ | $P_c$ |
| | dynes/cm | cP | relative | degrees | dyne/cm$^2$ | psi |
| Blank | 72.0 | 1.0 | 1.00 | 0.0 | 1.44E+08 | 2089 |
| Surfactant A | 33.0 | 1.0 | 0.26 | 81.6 | 9.69E+06 | 141 |
| Surfactant B | 39.9 | 1.1 | 0.36 | 75.2 | 2.04E+07 | 295 |
| Surfactant C | 39.2 | 7.5 | 0.21 | 54.6 | 4.54E+07 | 658 |
| Surfactant D | 39.7 | 13.5 | 0.20 | 11.7 | 7.78E+07 | 1128 |
| Fluorocarbon Std. | 21.0 | 1.0 | 0.41 | 54.8 | 2.42E+07 | 351 |
| Surfactant E | 28.0 | 1.0 | 0.60 | 22.2 | 5.18E+07 | 752 |

# Maximizing fluid recovery

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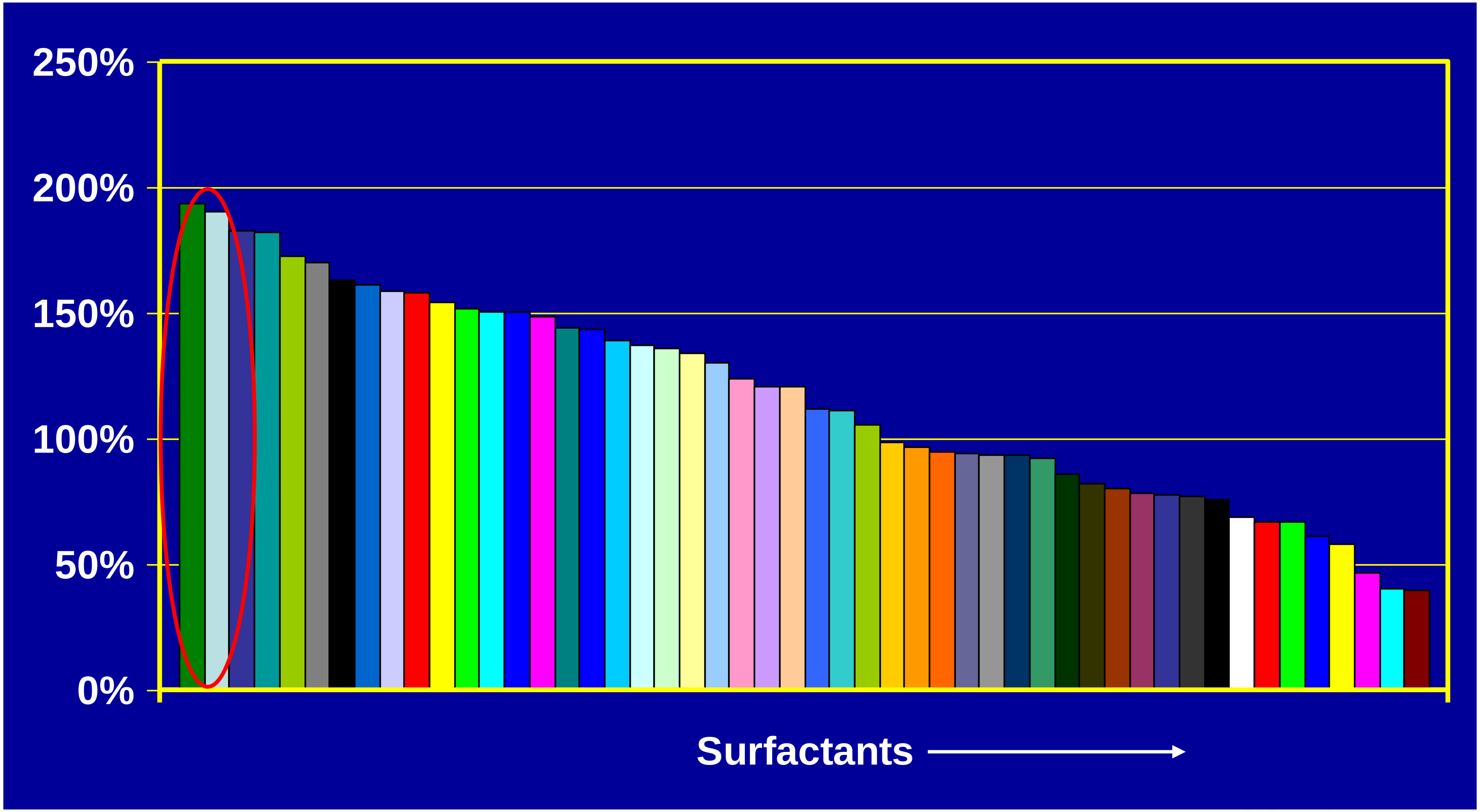
# Coreflow results –

## Regained permeability to $N_2$

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# Geomechanics is a key to success – Methods of investigation

| | |
|---|---|
| ❑ Scientific method<br>– Data and model<br>– Goal is insight, understanding<br>– Decisions-based on understanding<br>– Result-accurate predictions | ❑ Empirical method<br>– Data without model<br>– Goal is solution w/o insight<br>– Decisions-based on supposition<br>– Result-limited predictions |
| ❑ Religious method<br>– Model without data<br>– Goal is believable model<br>– Decisions-based on faith<br>– Results-cannot be checked | ❑ Political method<br>– No model or data<br>– Goal is solution w/o insight<br>– Decisions are imposed<br>– Result – Depends on decisions |

Ref., Herrick, PETROPHYSICS Vol. 43, No. 3, 2002

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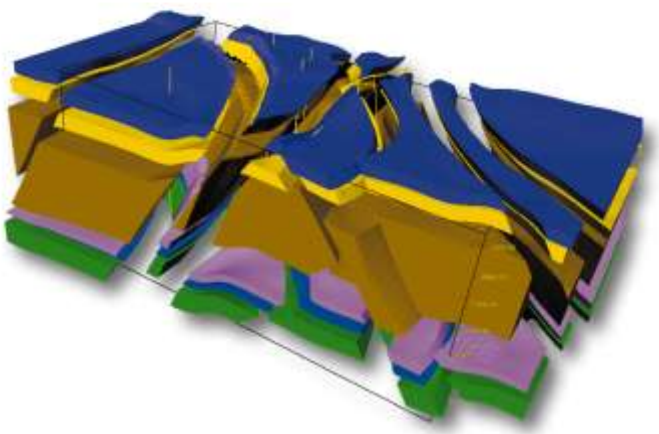
# Geomechanical modeling

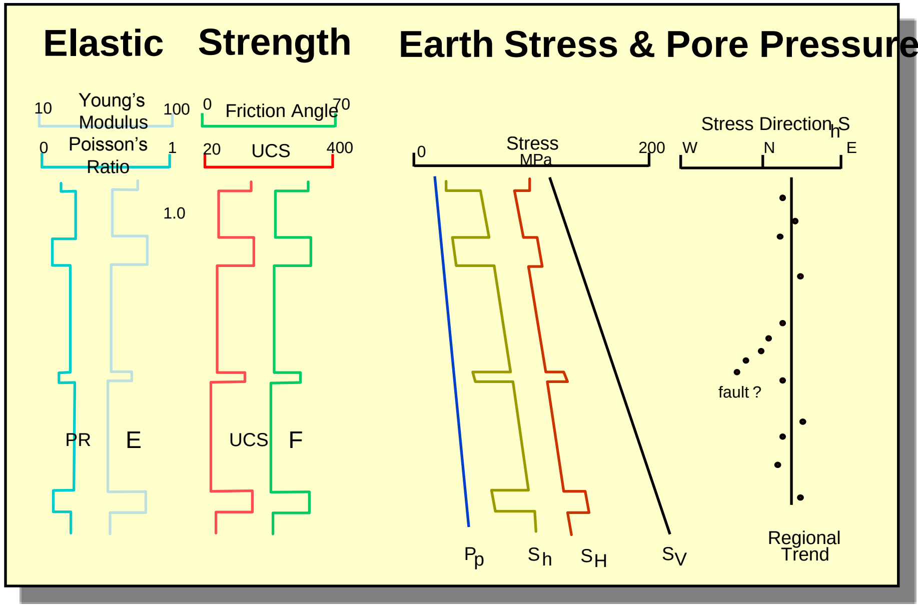
- Combines rock mechanical properties, earth stress and pore pressure

Structure



Mechanical Stratigraphy

Rock Mechanical Parameters




Mechanical Earth Model

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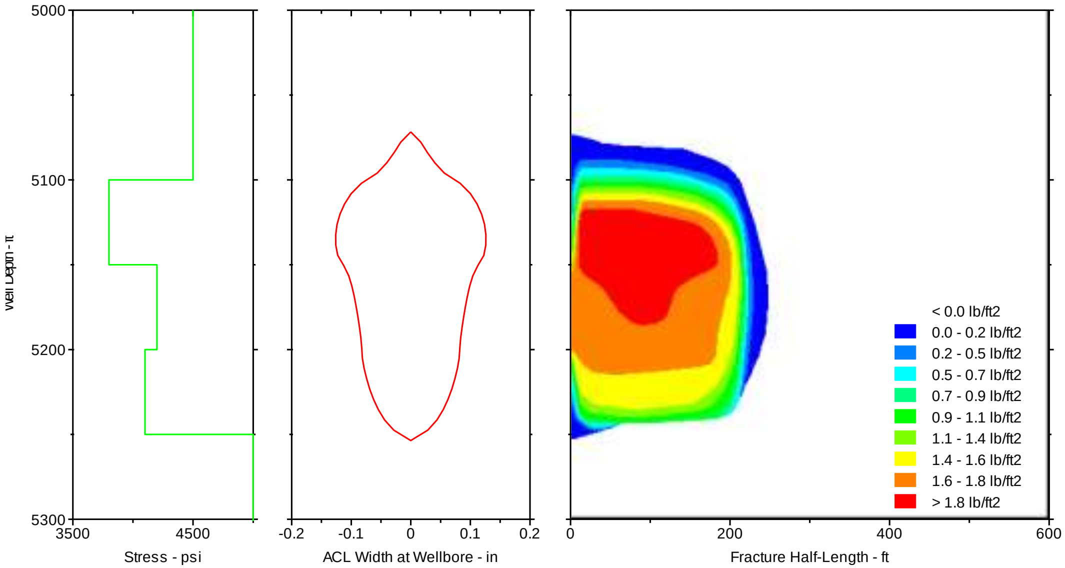
# Pseudo 3-D vs Planar 3-D

## Example in a simple 3-layer reservoir

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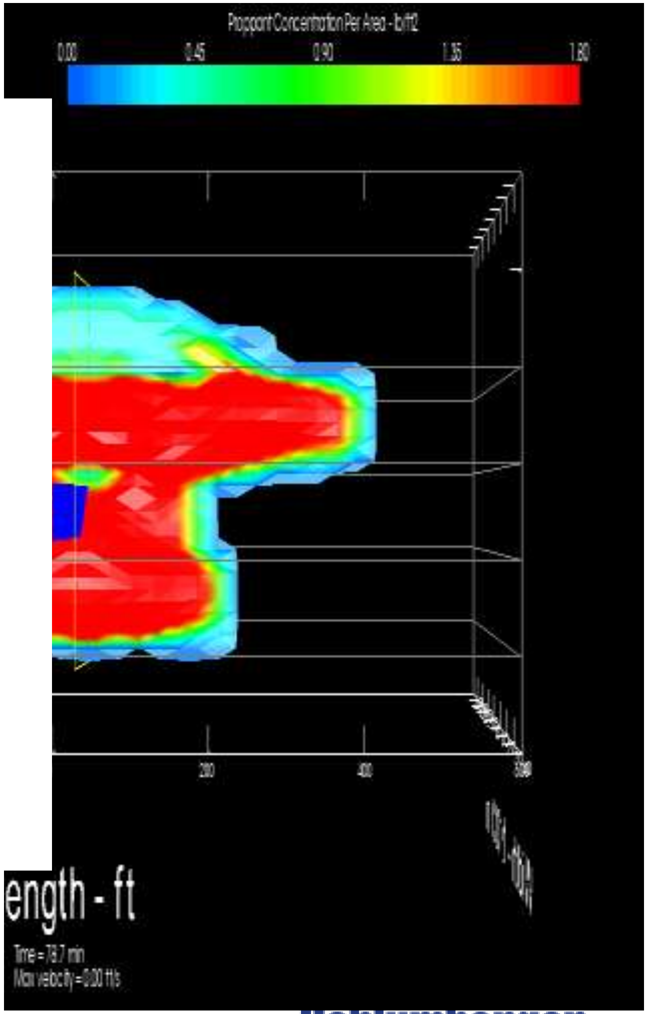


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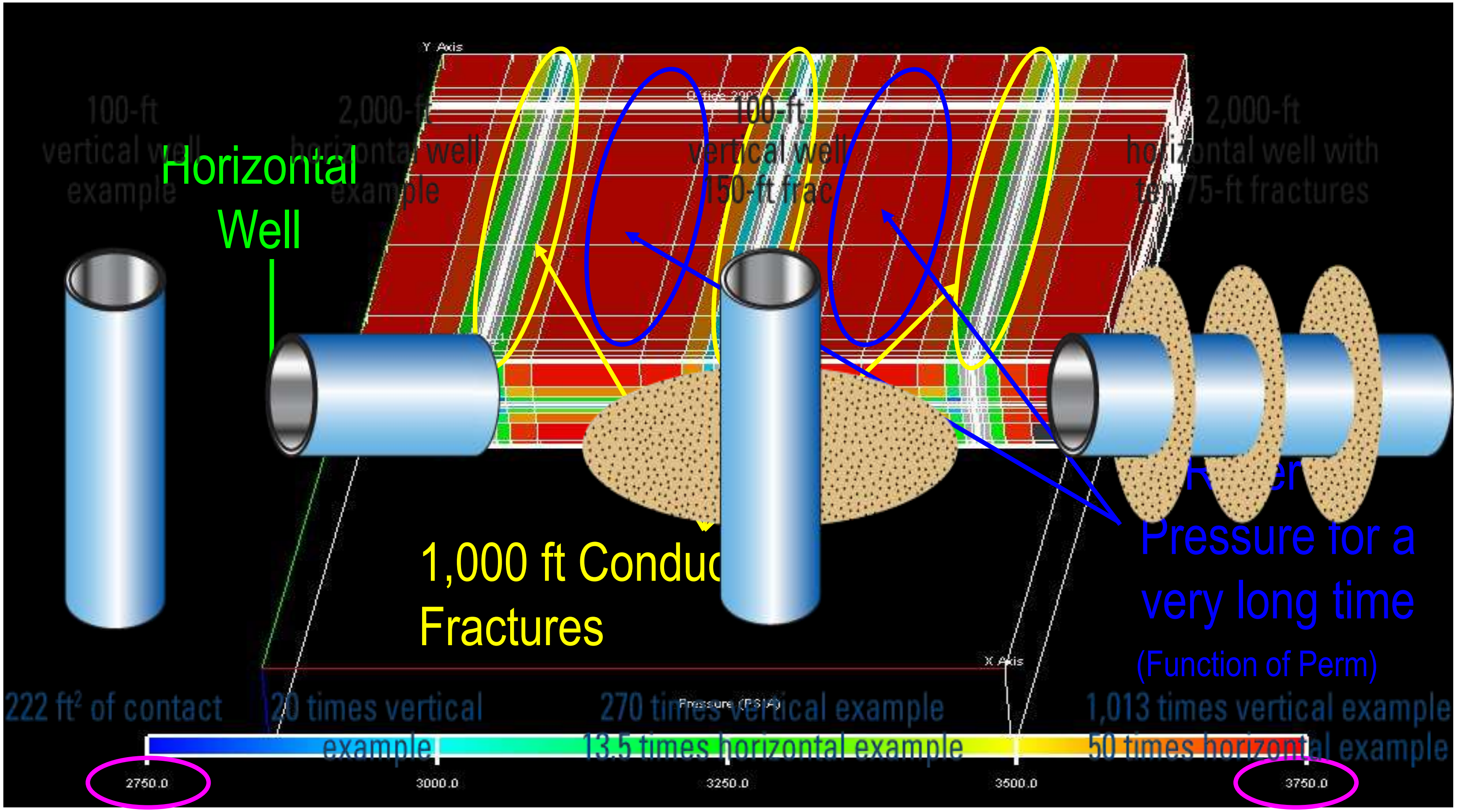
# Tight gas reservoir development

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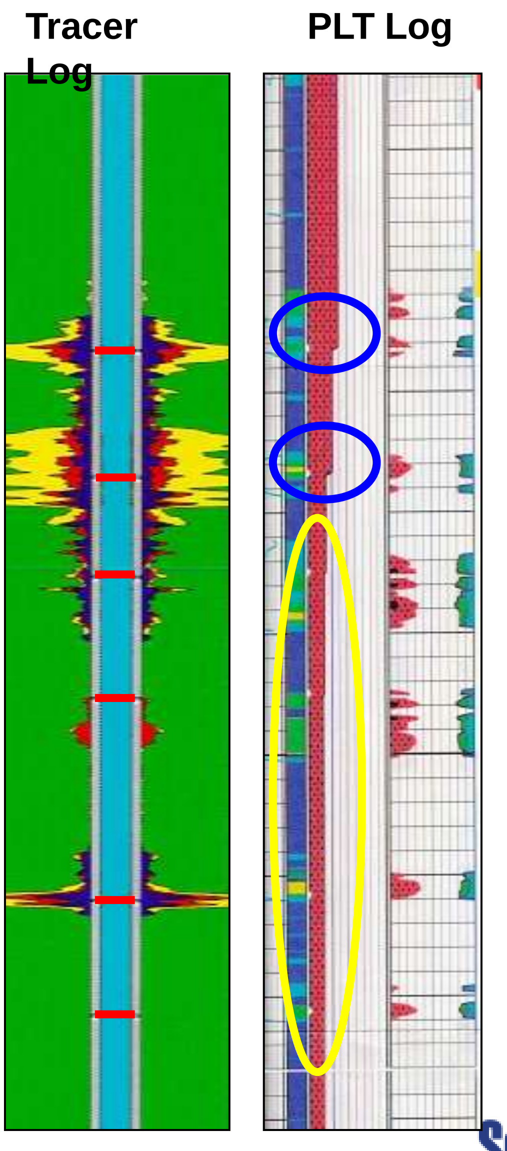
# Must stimulate to produce

- Limited entry completion
- Tracer logs detect fracture fluid entry (yellow, red, blue)
- Top two zones
  - Majority of fracturing fluid entry
  - Gas production

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# AbrasiFRAC

- Coiled Tubing
  - Conduit for abrasive jetting slurry
  - Dead string for monitoring
- ABRASIJET
  - Provides access into the formation
- Stimulation Treatment
  - Pumped down the coiled tubing annulus
- Isolation
  - Sand Plugs


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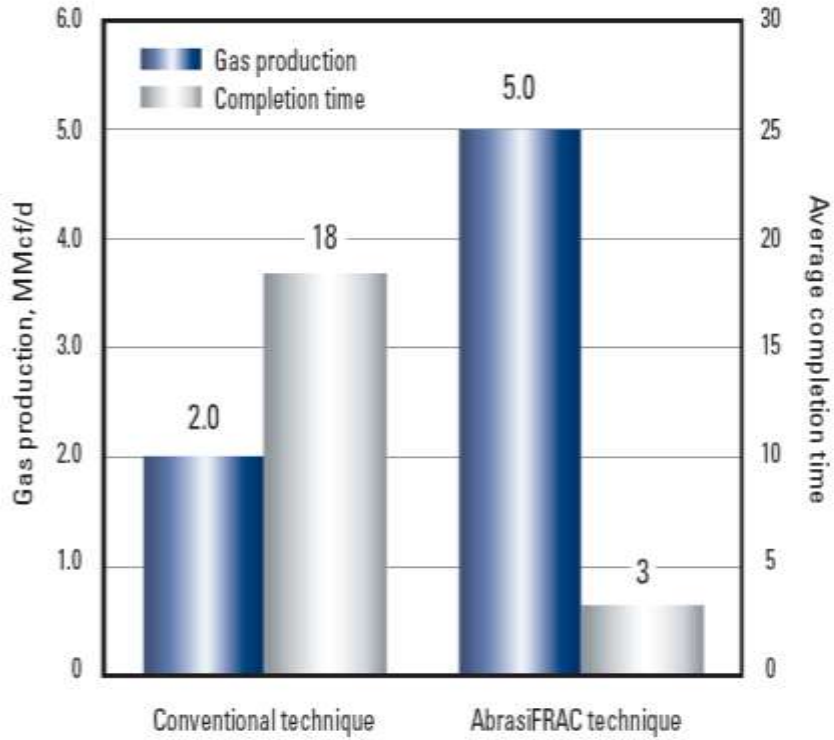
# Coiled Tubing Fracturing

Well Information

- Location: South Texas, USA
- Well Type: Gas Producer
- Formation: Sandstone
- Permeability: 0.01 to 0.08 mD
- Reservoir Pressure: 4900 psi
- Completion: 4 ½" Monobore
- Depth: 8500'




Results

- Decreased Time from 21 to 3 Days
- 150% Stabilized Production Increase

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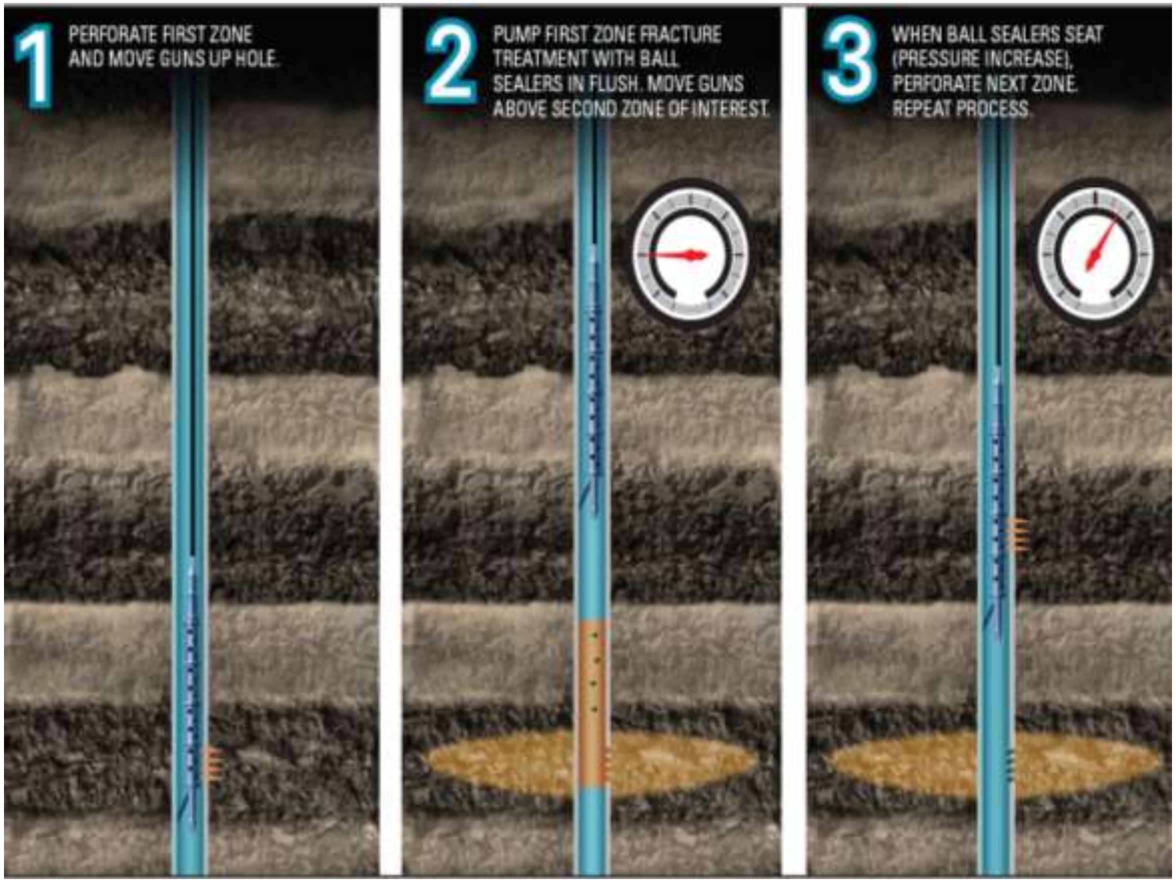
# PerfFRAC

- Open up intervals one at a time vs all at once
- Ball sealers for additional diversion
- Enhanced diversion provides more reservoir contact
- Treat each zone separately = less HHP requirement
- Eliminate composite plugs and milling




PerfFRAC is a technology licensed from ExxonMobil URC

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# StageFRAC Completion

**Effective**

Annular Isolation

Continuous Operation

Immediate Flow

b

**Efficient**

Rig less Completion

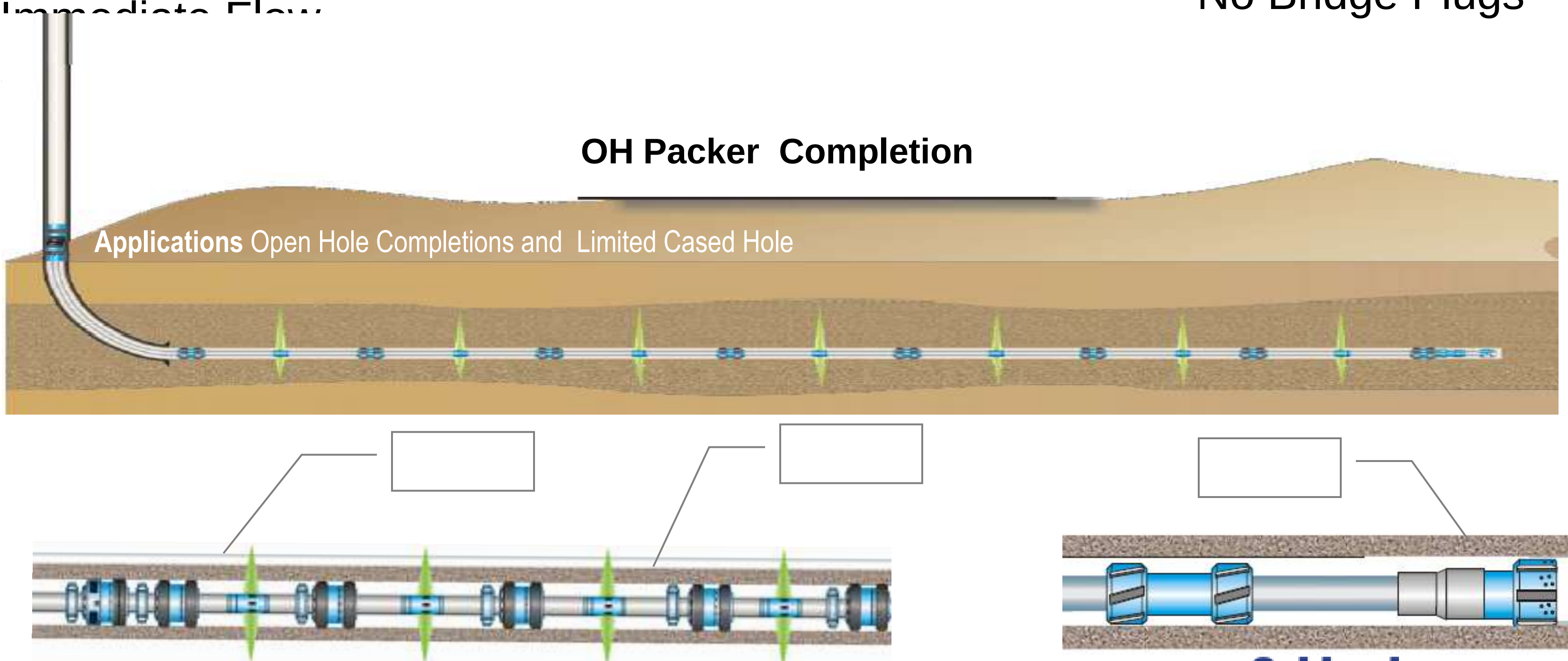
One Day Pumping

**Simple**

No Perforating

No Cementing

No Bridge Plugs

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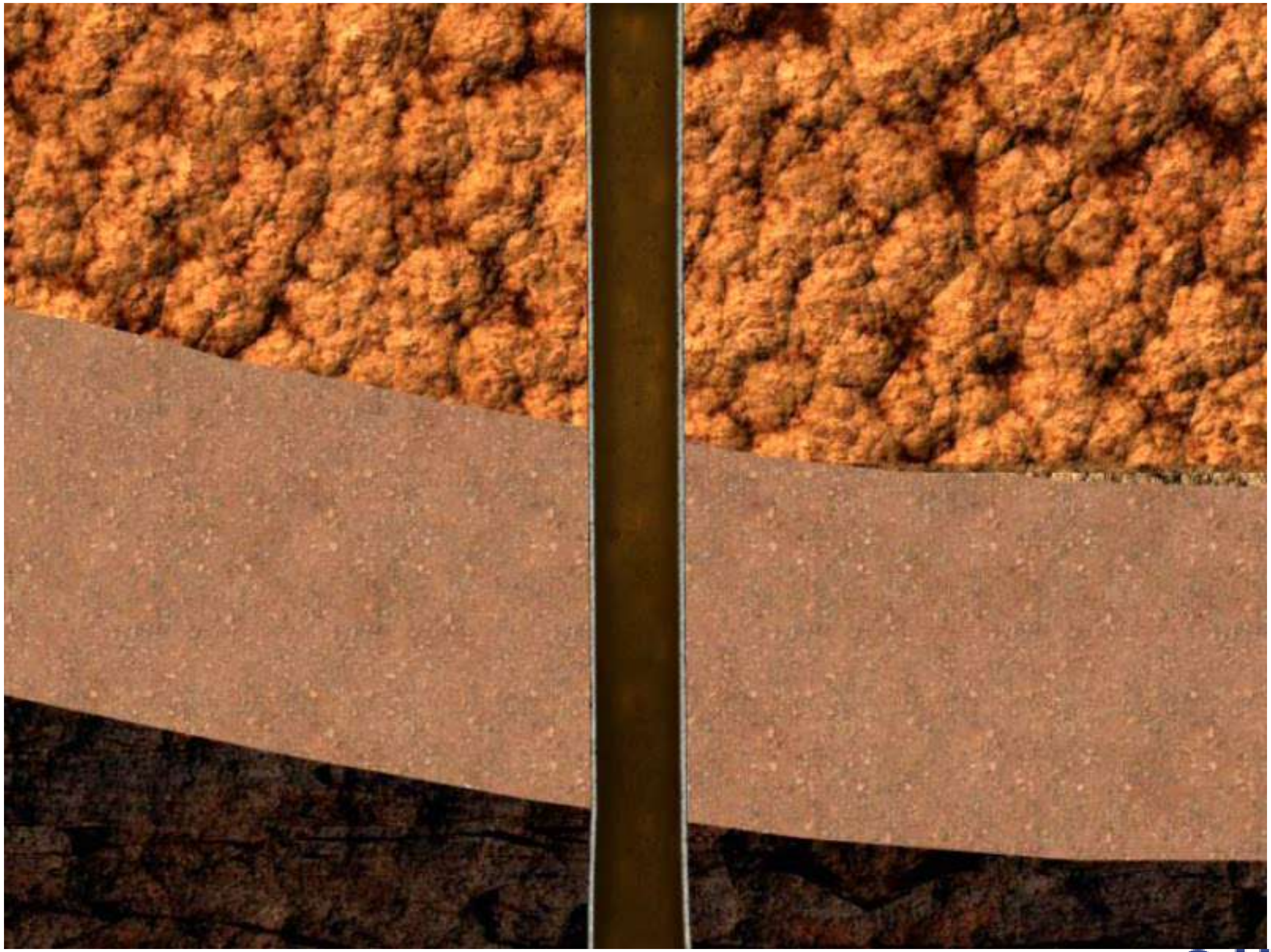
# StageFRAC Completion



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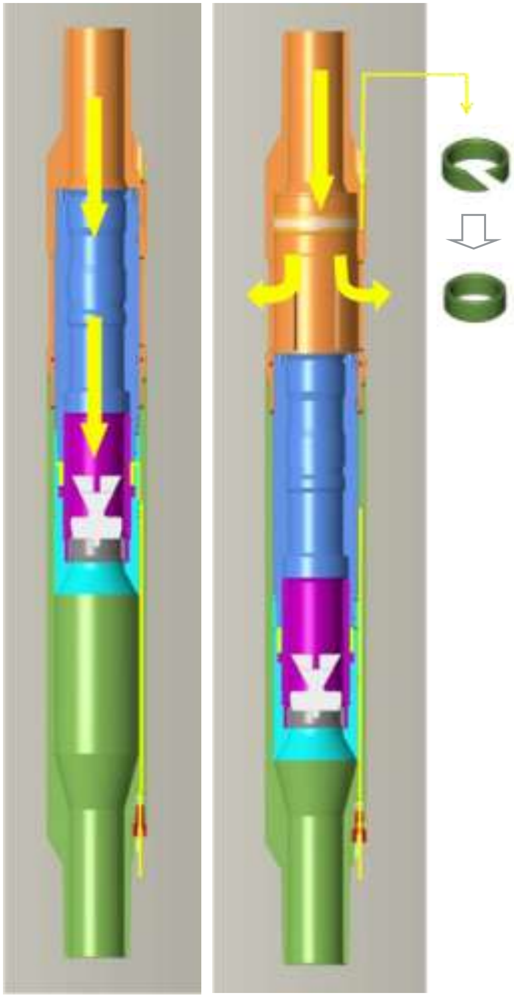
# Treat & Produce

**Completion based solution**

- Permanent part of completion
- Sliding sleeve
  - Dart activated
  - Sliding sleeve prepares next valve to land dart

**Benefits**

- Maintain full wellbore access
- Unlimited number of stages
- Eliminate fracture plugs
- Reduce perforating costs



**Flowback**

- 2 7/8” Flow Through Area
- Retrievable Dart
- Millable Dart & Seat
- Close Sleeve

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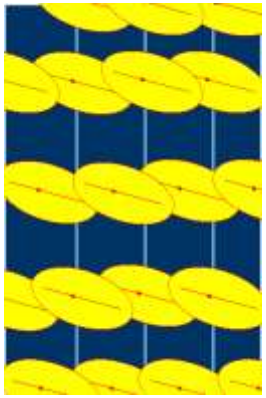
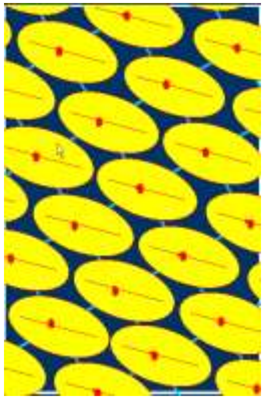
# Value of fracture geometry measurements

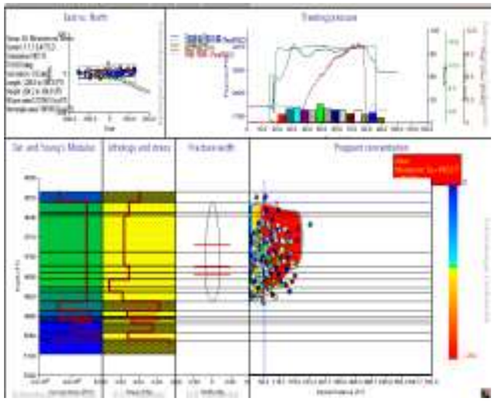
- ❑ Optimize Stimulation and Completion Effectiveness
  - – Determine optimum well spacing & placement
  - – Calibrate fracturing models
  - – Optimizing fracture designs



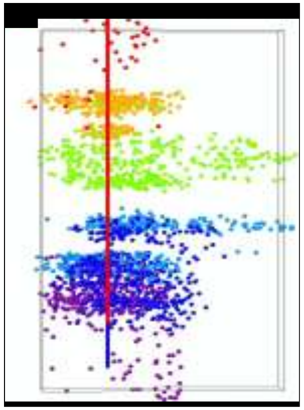
**Well placement without fracture detection**



**Well placement with HFM fracture geometry**



**Integration of reservoir properties, fracture modeling and micro seismic detection aid in reservoir optimization (SPE 102493)**



**Actual Microseismic map of a 6 stage completion**

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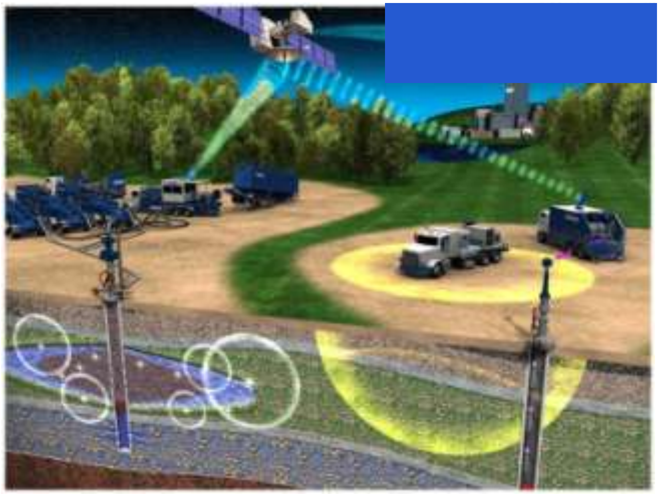
# Micro seismic

- Monitoring and evaluation of hydraulic fracture in real-time
  - Fracture orientation and extent
- Micro seismic events
  - Created by the fracture propagating
  - Detected in neighboring well



- Create animated graphics
  - Progressive growth of hydraulic fracture
    - Height, length, orientation, symetry
  - Used to make real-time decisions
  - A key to effective reservoir development

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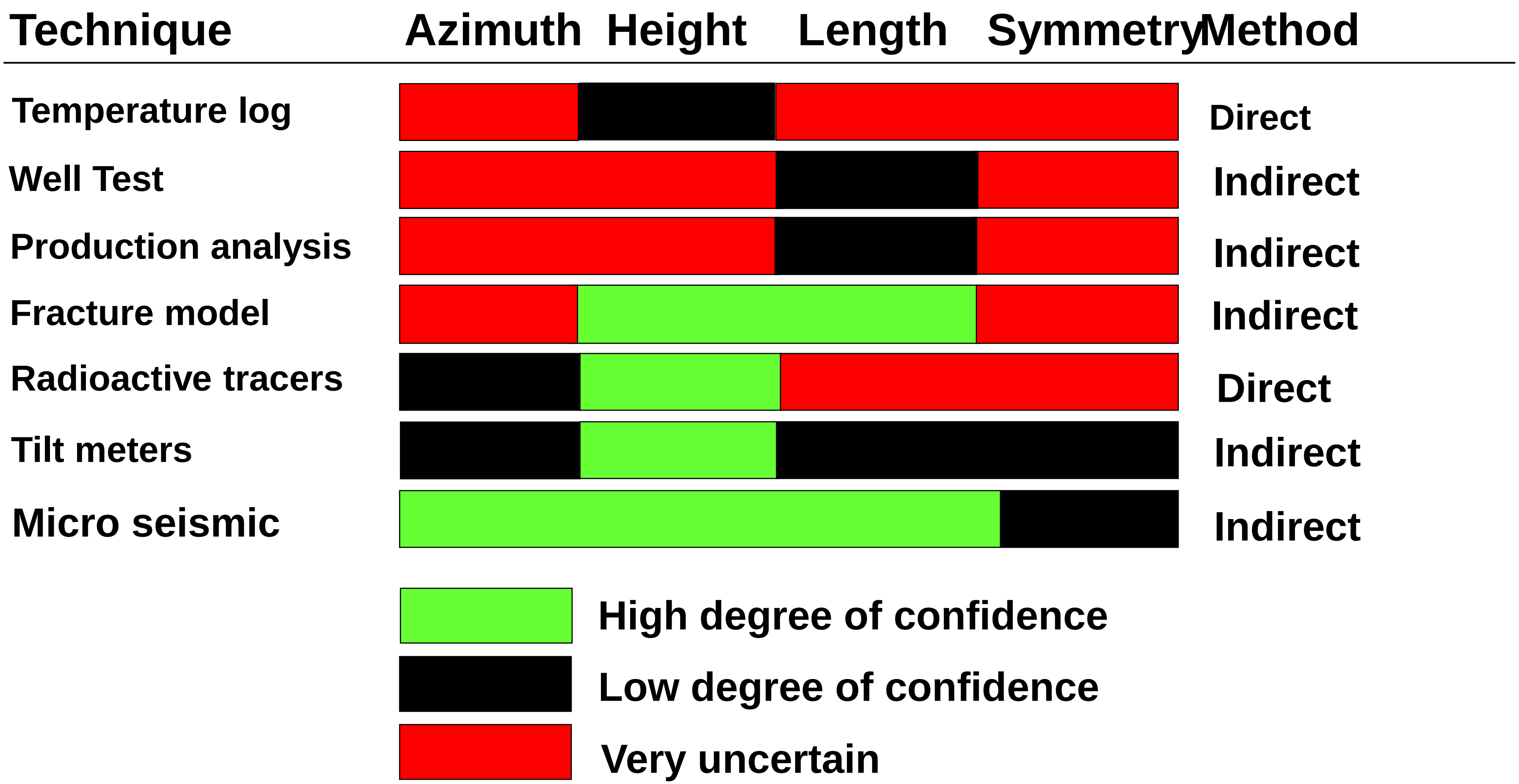
# Micro seismic – Fracture Properties

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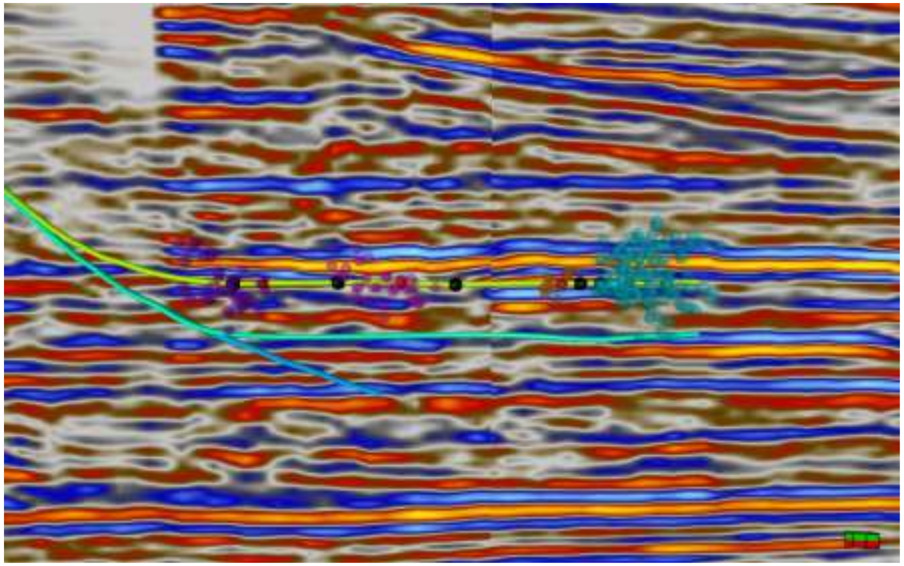
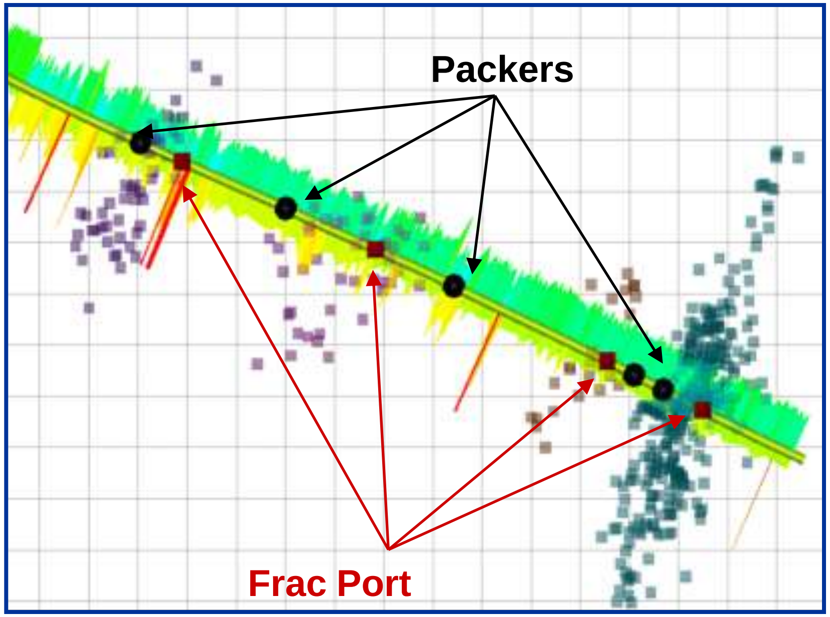
# Micro seismic

- 4 separate hydraulic fractures
- Monitoring well 300 m to the South



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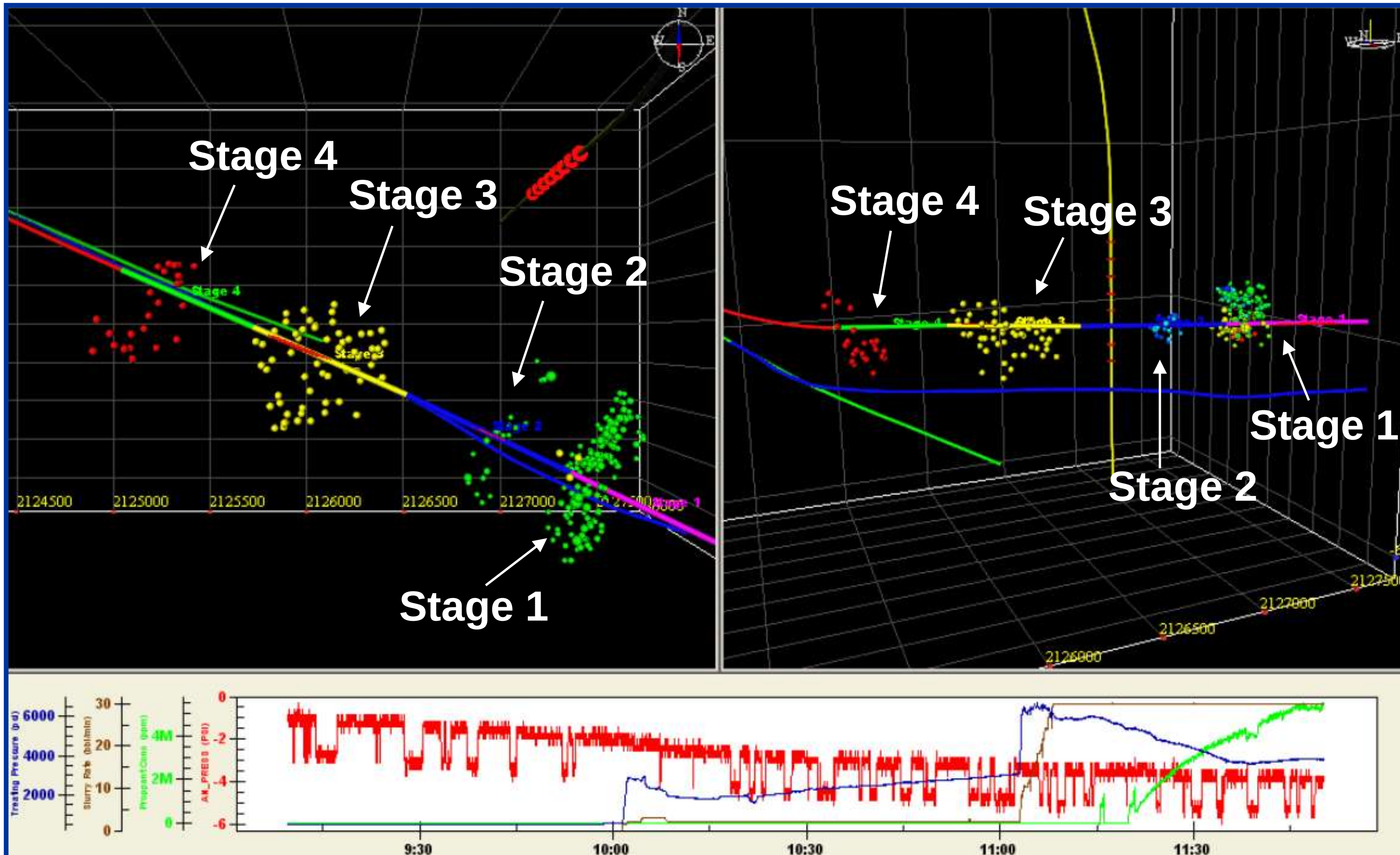
# Micro seismic



# Questions?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