Development of tight gas sand stimulation techniques

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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

Technologies to present

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

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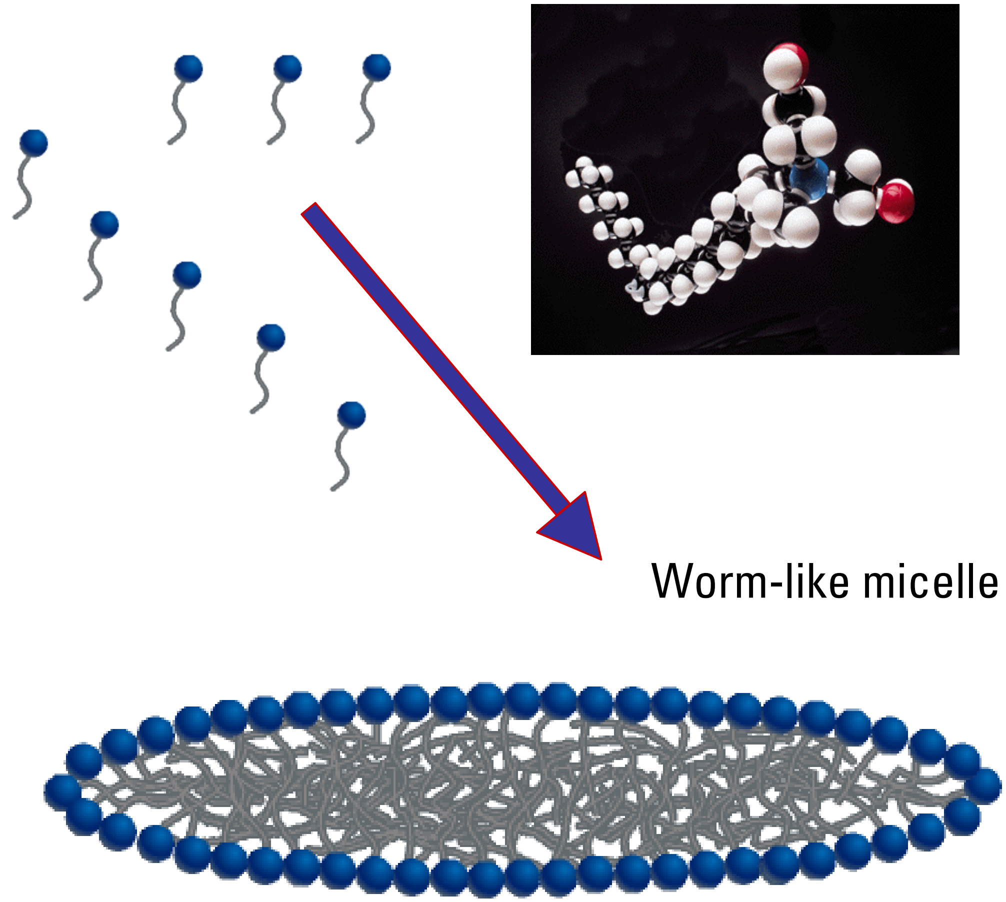
Fracturing fluid technology – Viscoelastic surfactants (VES)



"Entangled micelles" provide viscous and elastic properties

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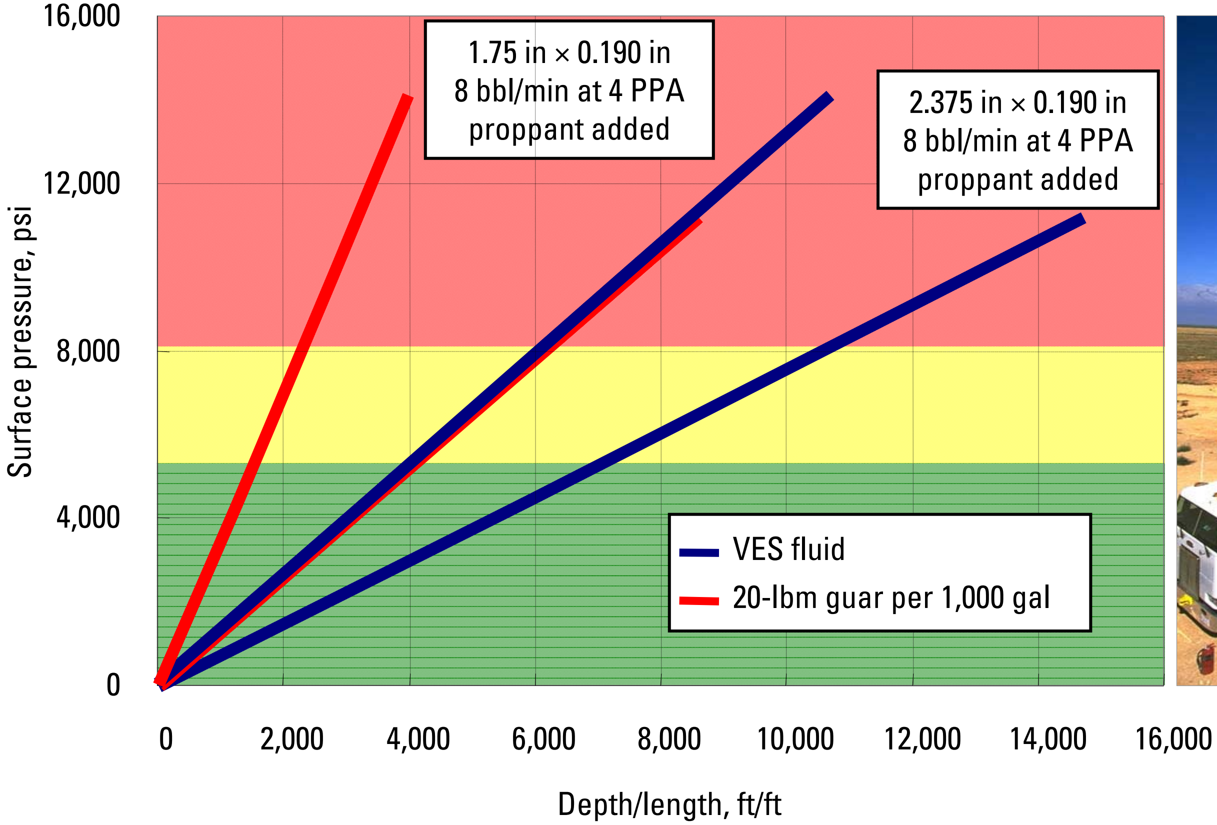
Reduced friction pressure



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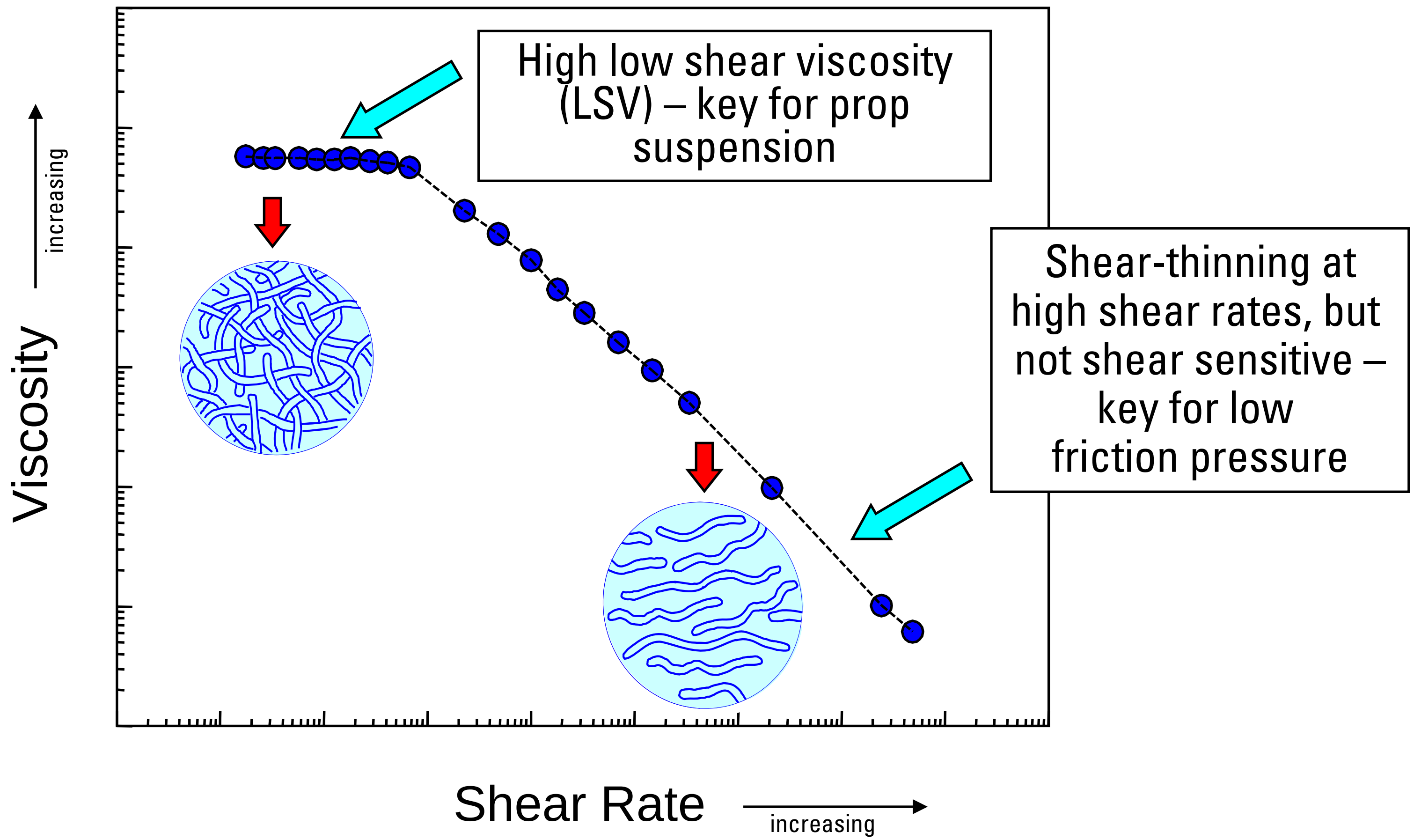
Improving proppant transport



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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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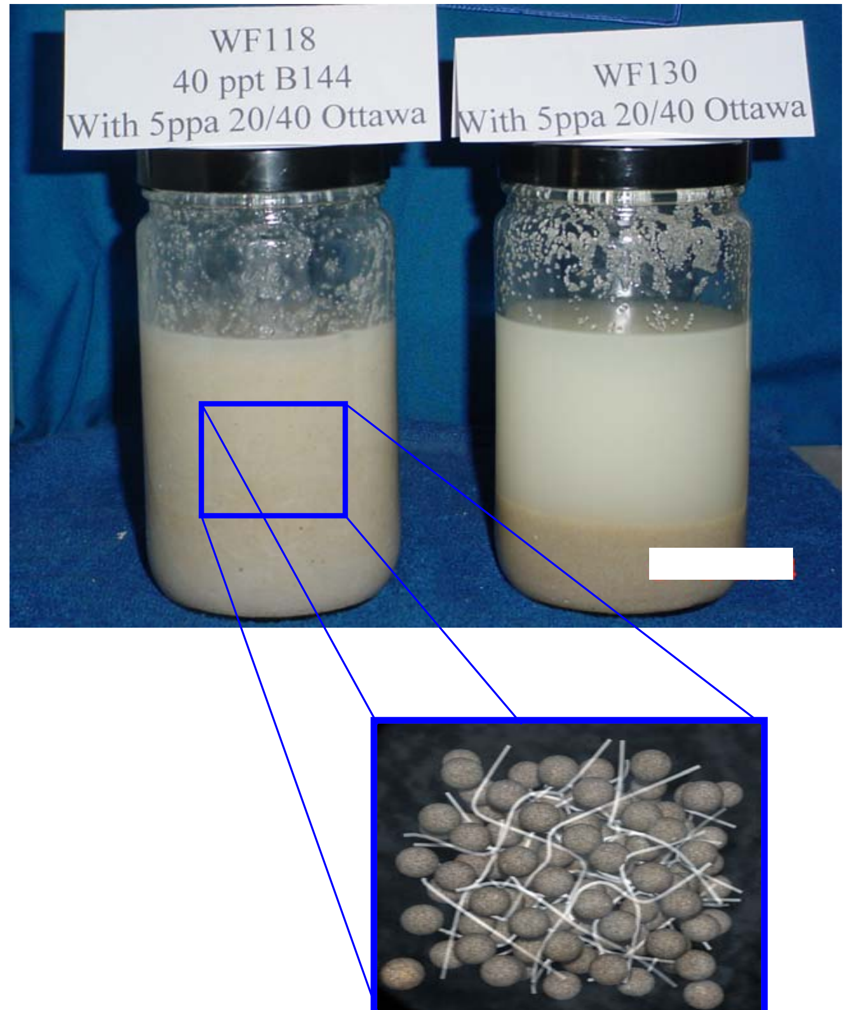
Proppant distribution solutions

- 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*

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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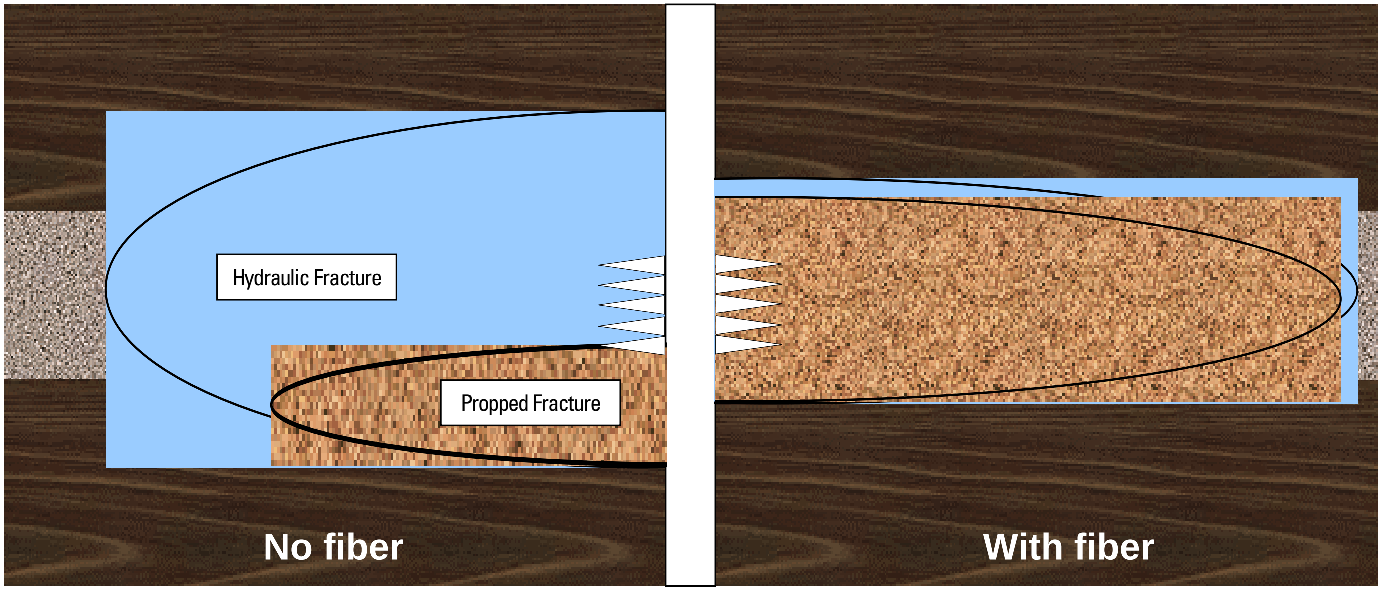
Proppant distribution solution with fiber



- 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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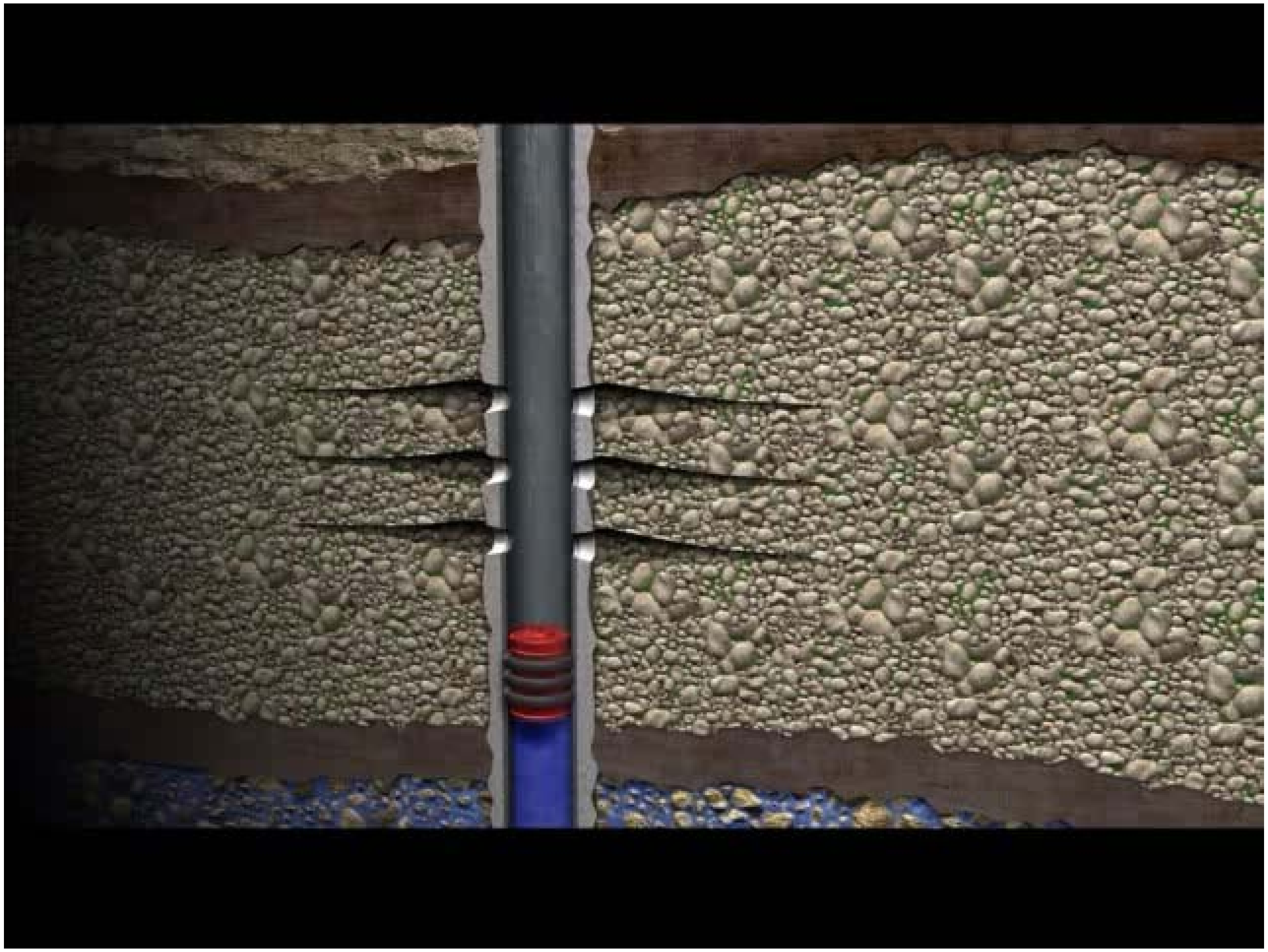

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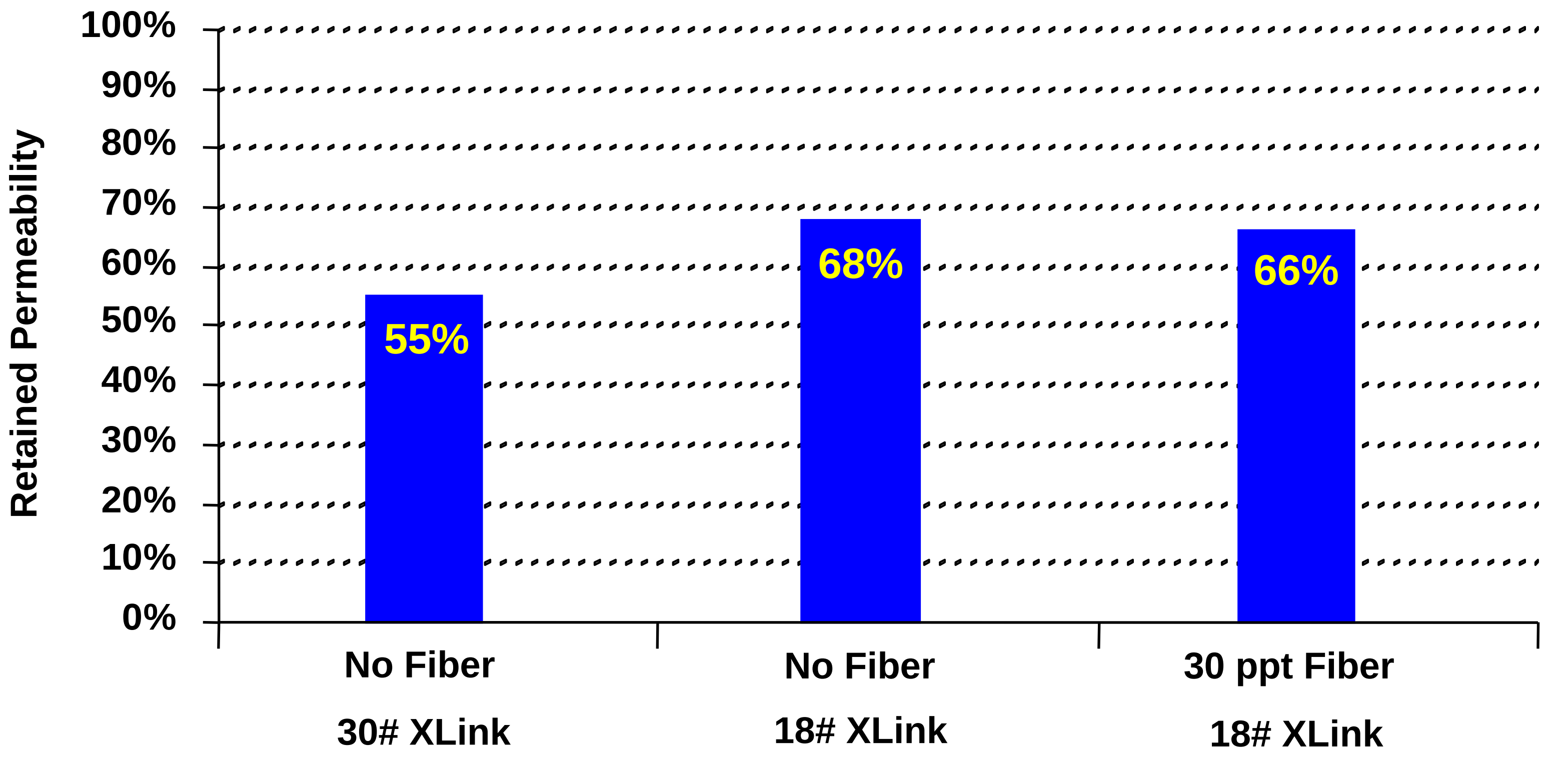
Effect of fiber on proppant-pack conductivity

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



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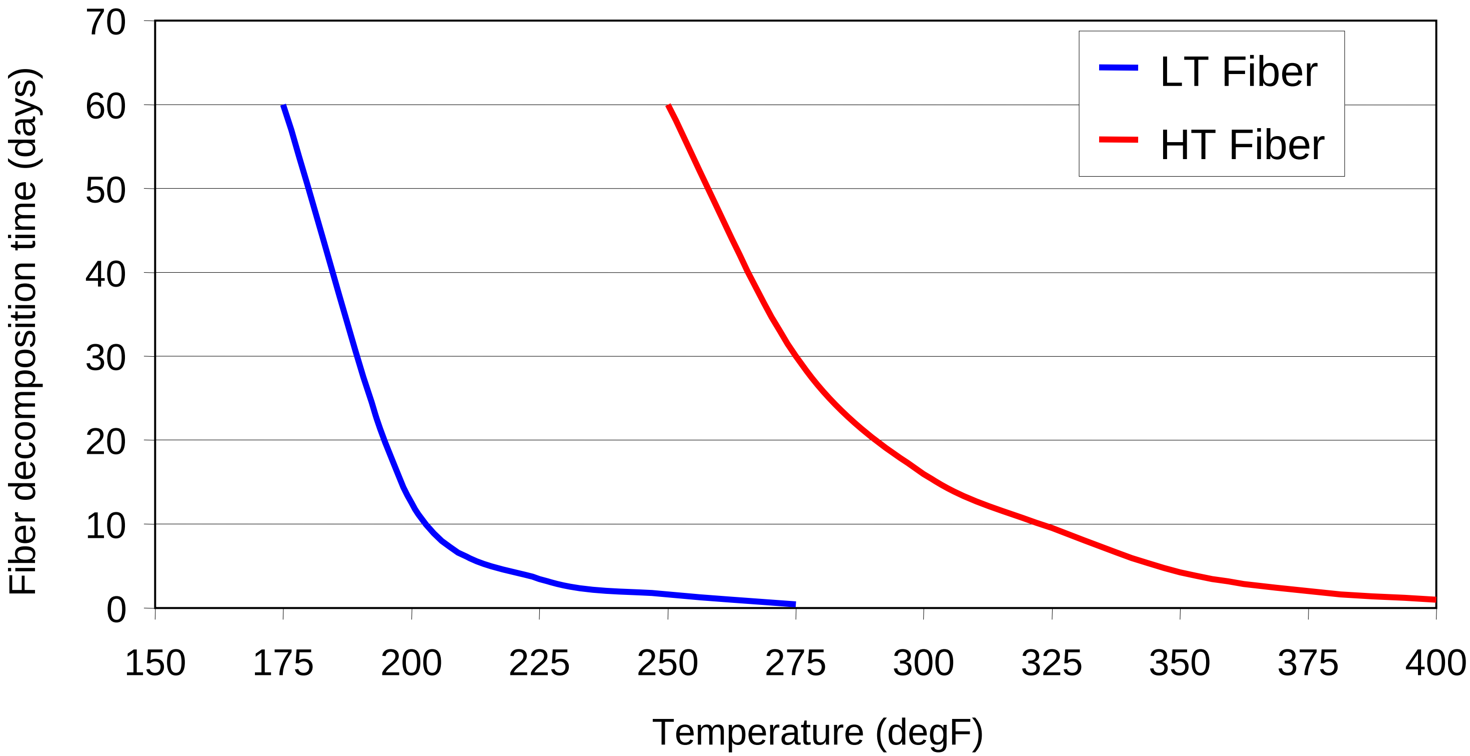
Fiber decomposition



- LT fiber decomposes in about 1 day at 250 degF and 2 months at 175 degF
- HT fiber decomposes in about 1 day at 400 degF and 2 months at 250 degF

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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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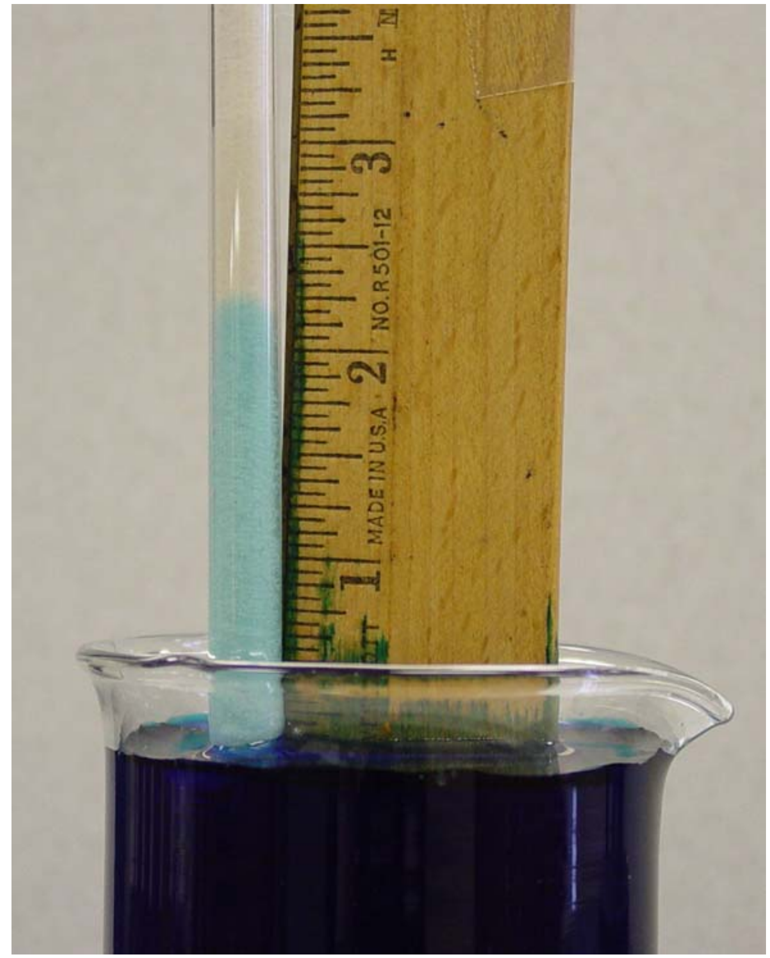
Formation damage (cont.)

- 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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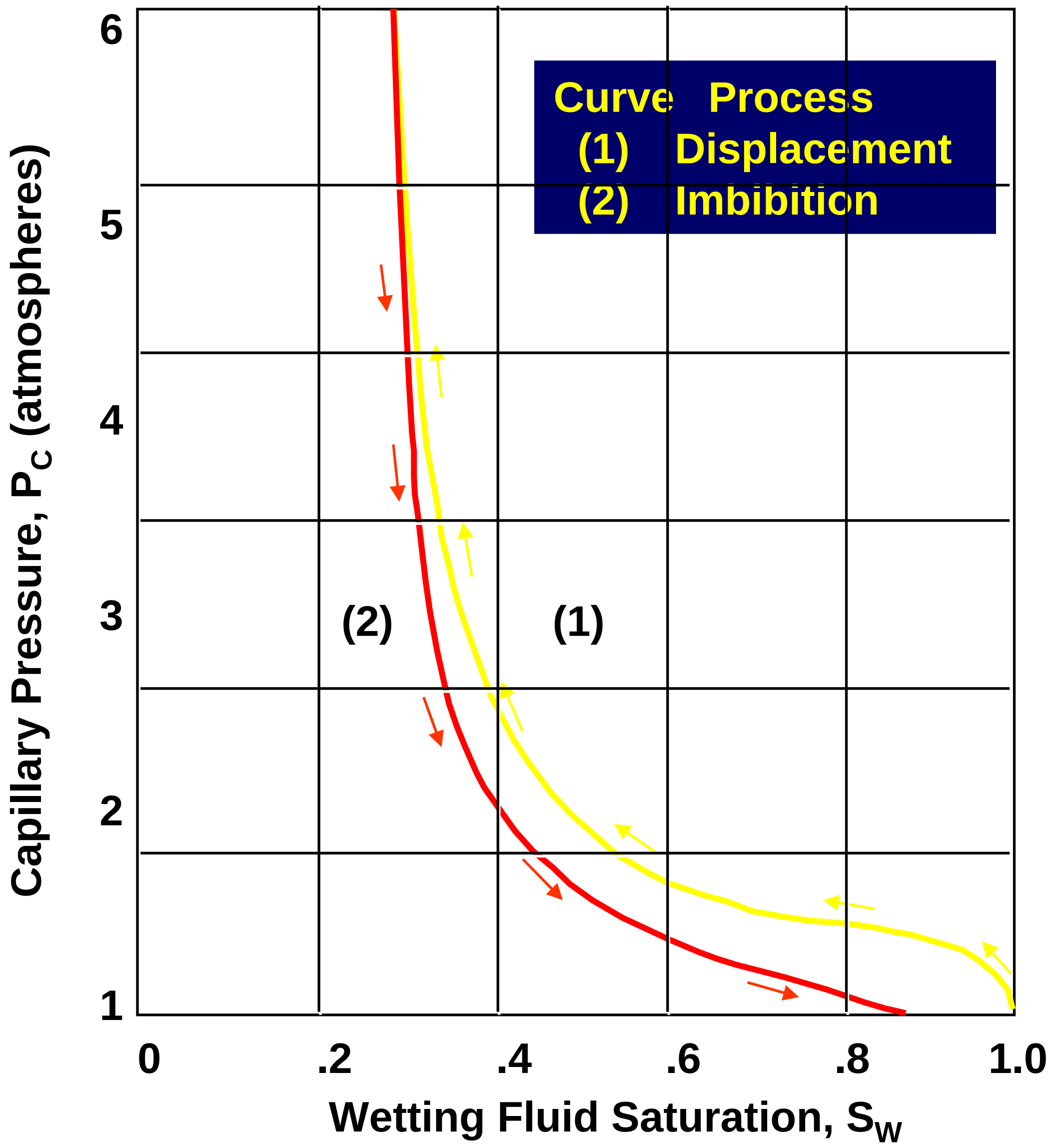
Use of surfactants in tight gas reservoirs

- 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

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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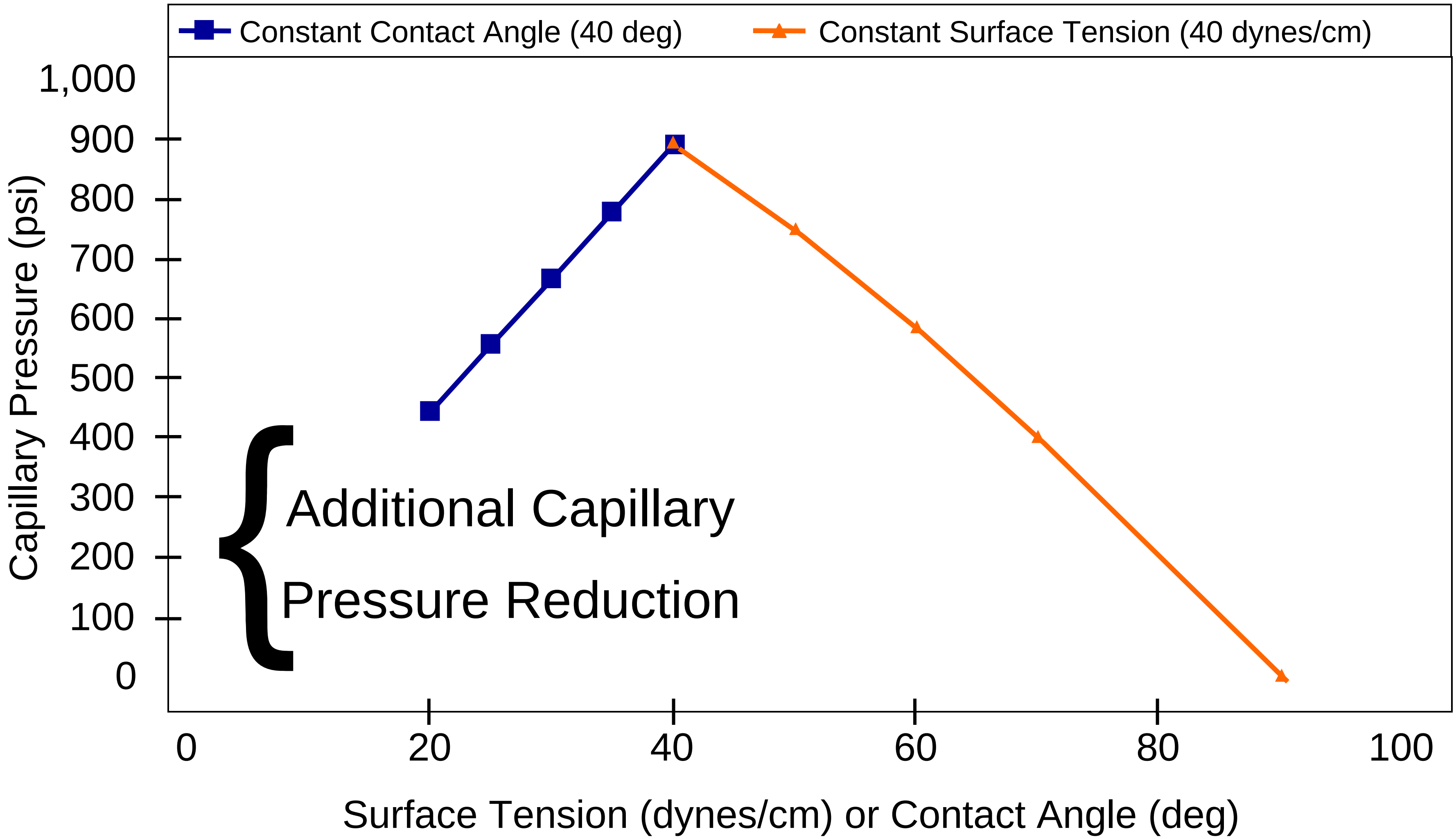
Experimental analysis

Material	Surface Tension	Viscosity	Imbibed Weight	Contact Angle	Capillary Pressure	Capillary Pressure
	γ_{12}	η	m	θ	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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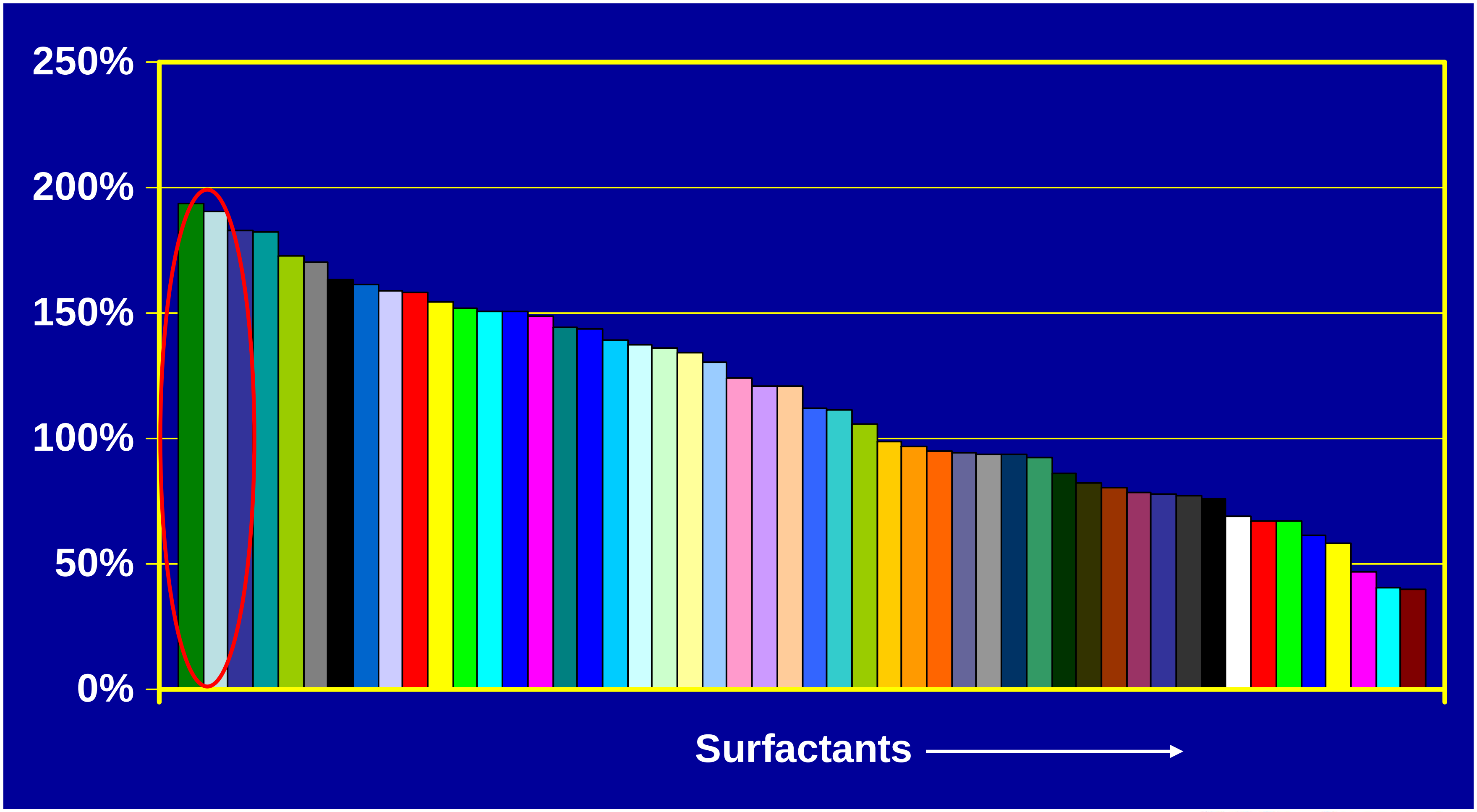
Coreflow results –

Regained permeability to N_2



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Geomechanics is a key to success – Methods of investigation

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

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

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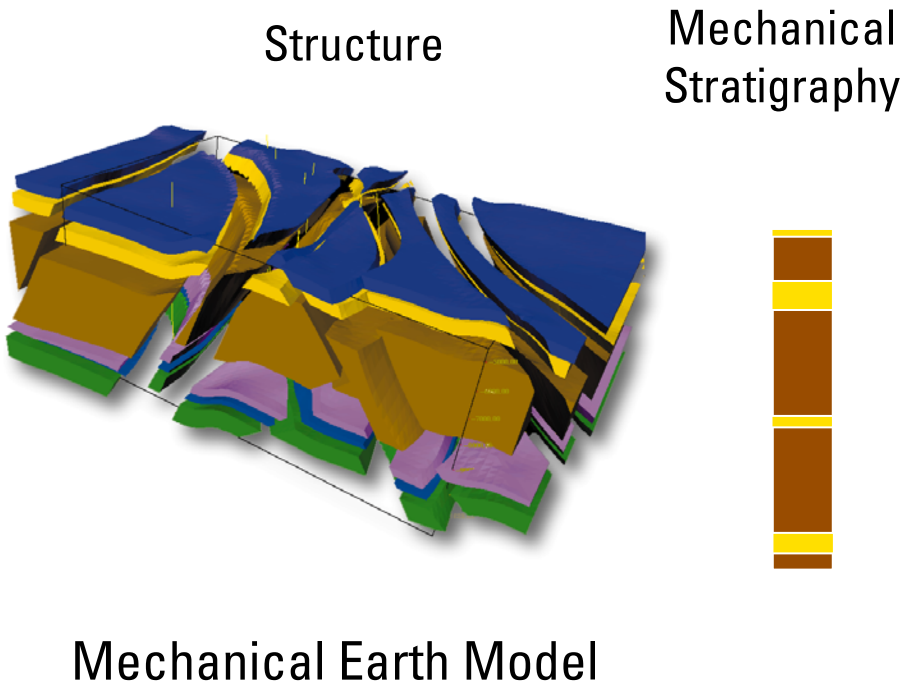
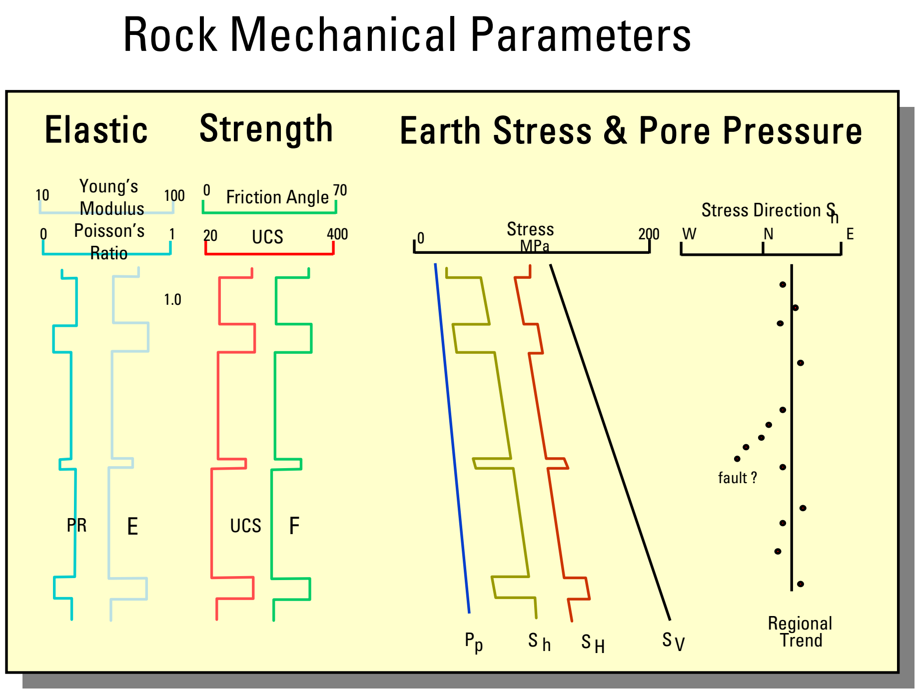
Geomechanical modeling

- Combines rock mechanical properties, earth stress and pore pressure





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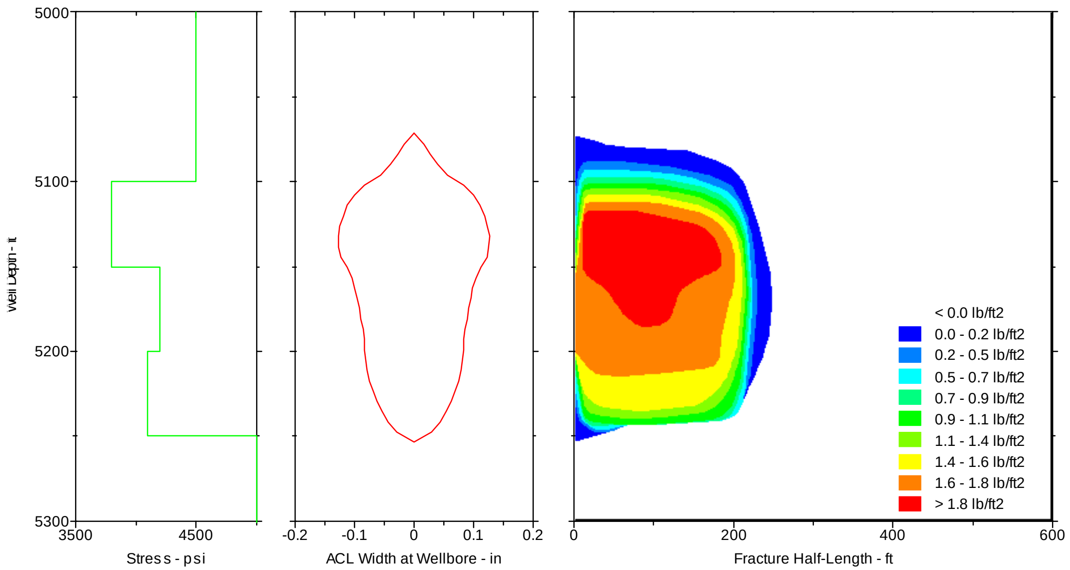
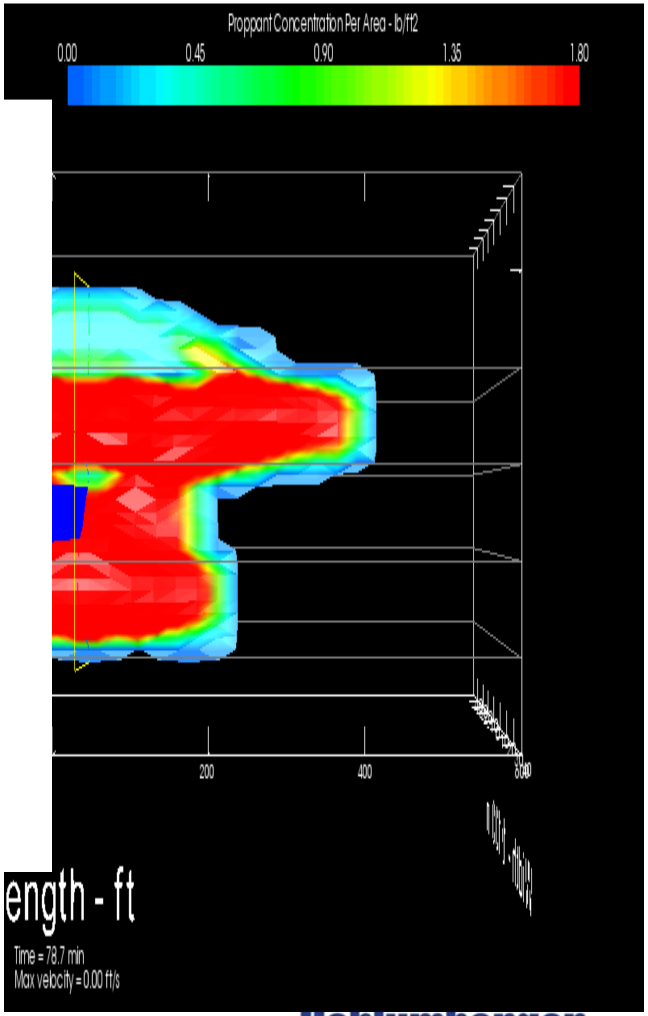
Pseudo 3-D vs Planar 3-D
Example in a simple 3-layer reservoir





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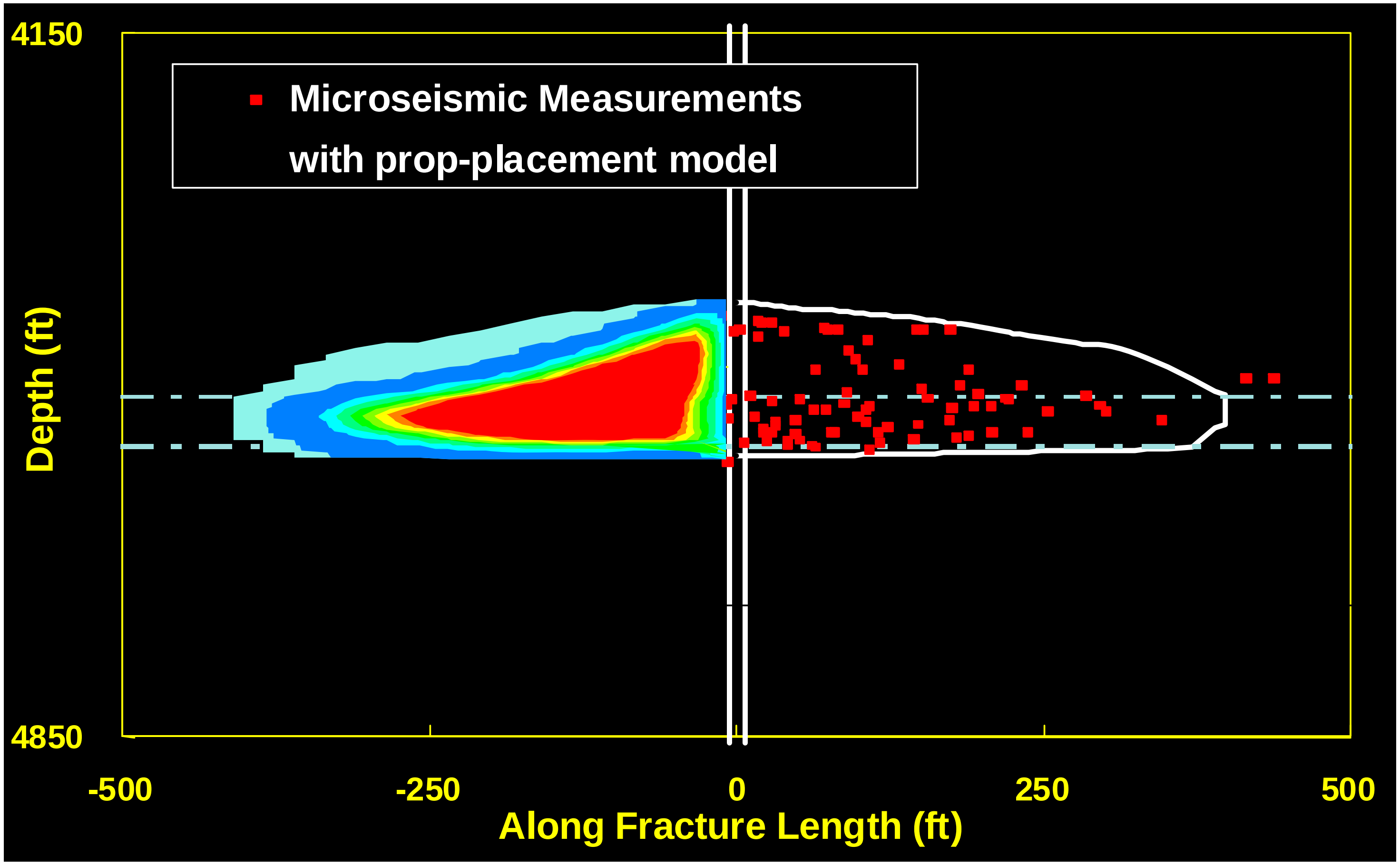
Hydraulic fracture mapping for evaluation



SPE 38575 (DOE-GRI MWX data)

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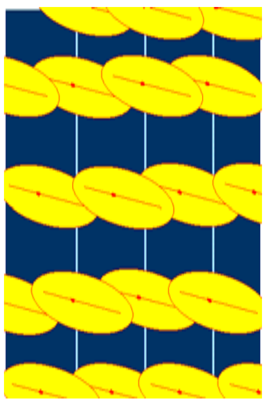
Tight gas reservoir development

- Drainage away from reservoir contact is greatly reduced
- Require hydraulic fractures and closer well spacing than conventional reservoirs
- Require fit-for-purpose technologies and efficiencies to be economic
- The key to tight gas reservoir development is: MAXIMIZING RESERVIOR CONTACT - EFFICIENTLY

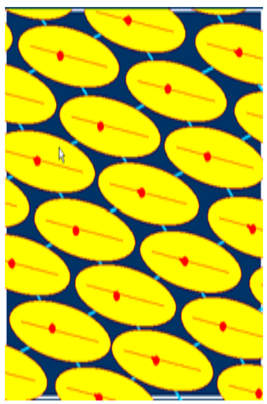
Accurate characterization of hydraulic fractures is critical for effective and efficient development of tight gas reservoirs

Value of fracture geometry measurements

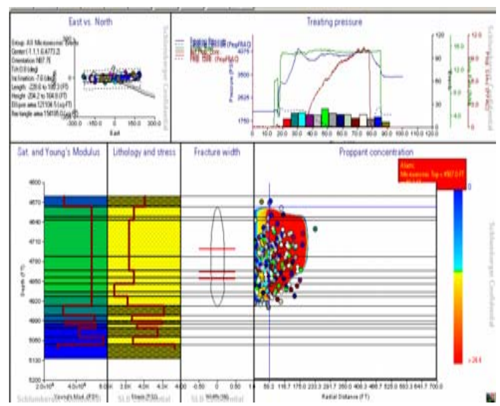
- Optimize Stimulation and Completion Effectiveness
  - Determine optimum well spacing & placement
  - Calibrate fracturing models
  - Optimizing fracture designs



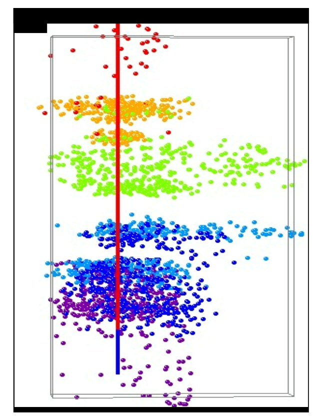
Well placement without fracture detection



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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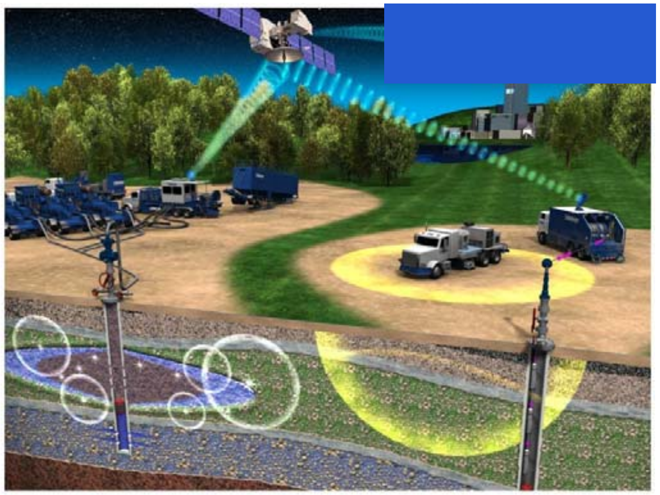
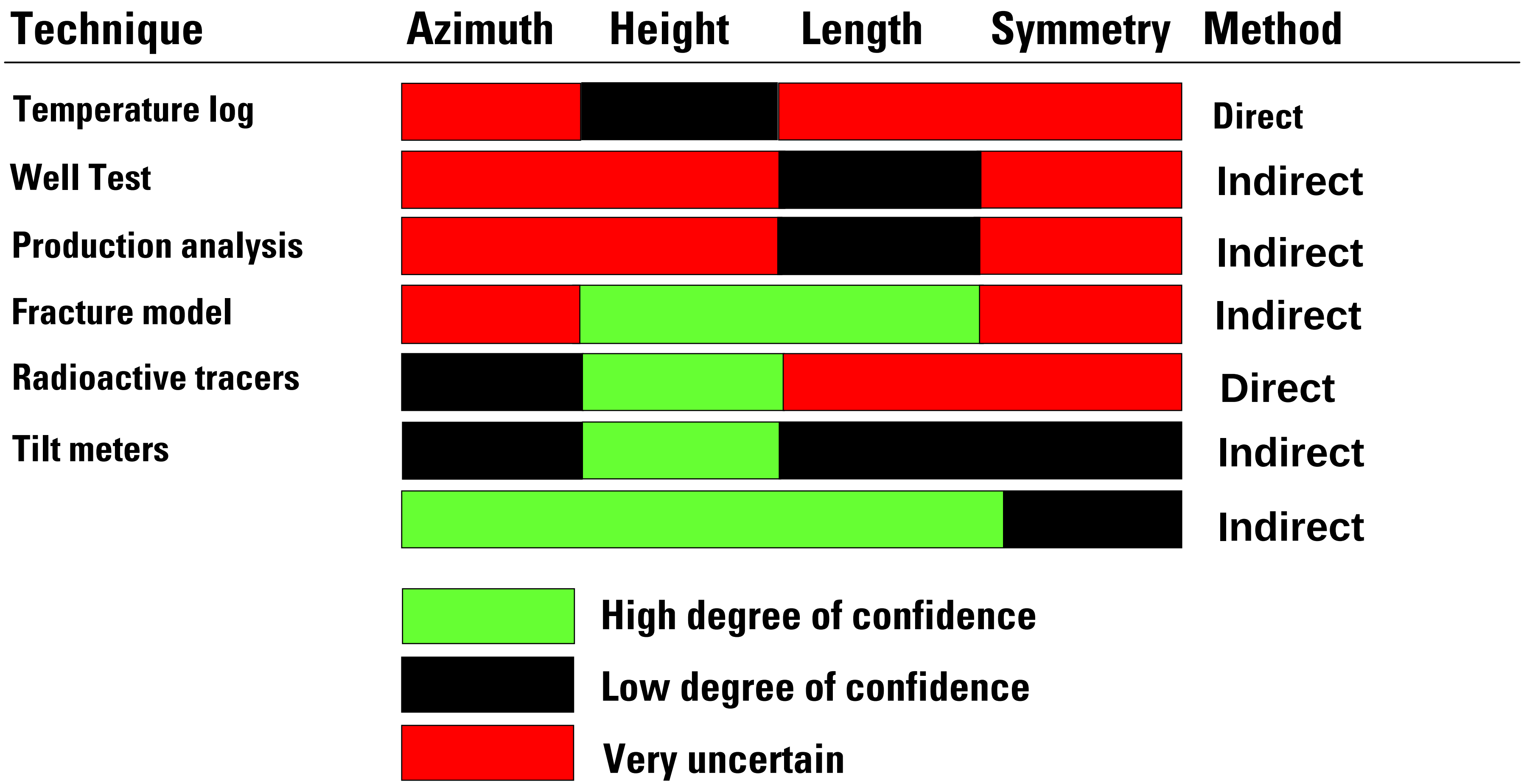
Micro seismic

- 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



Micro seismic – Fracture Properties



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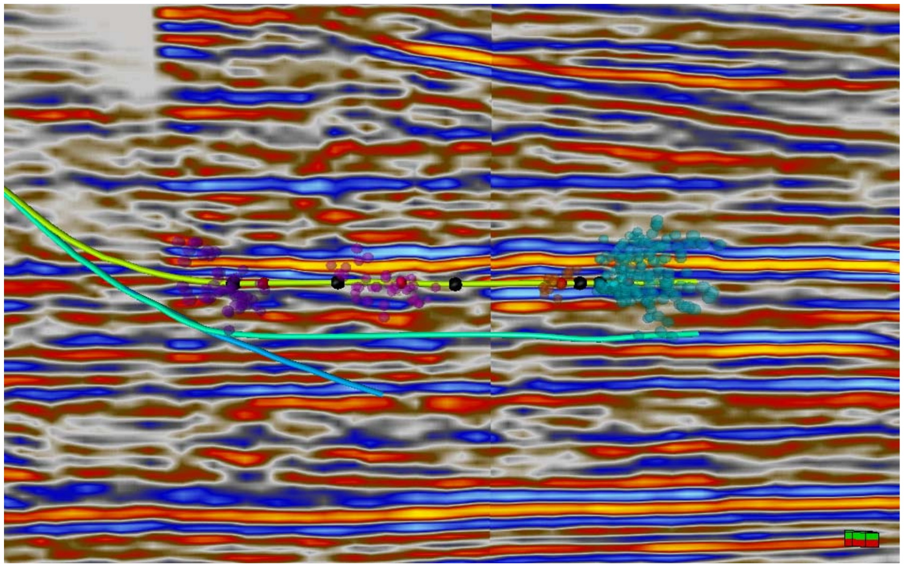
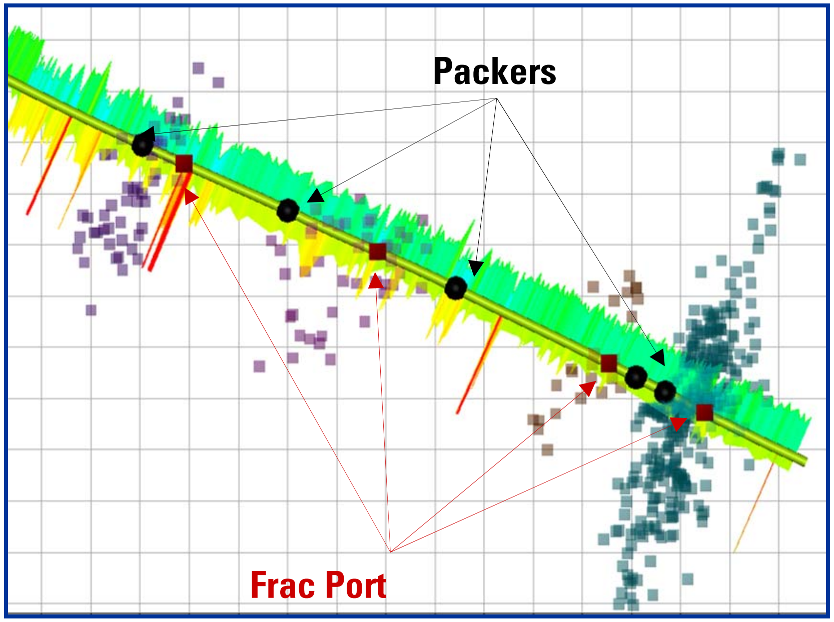
Micro seismic

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





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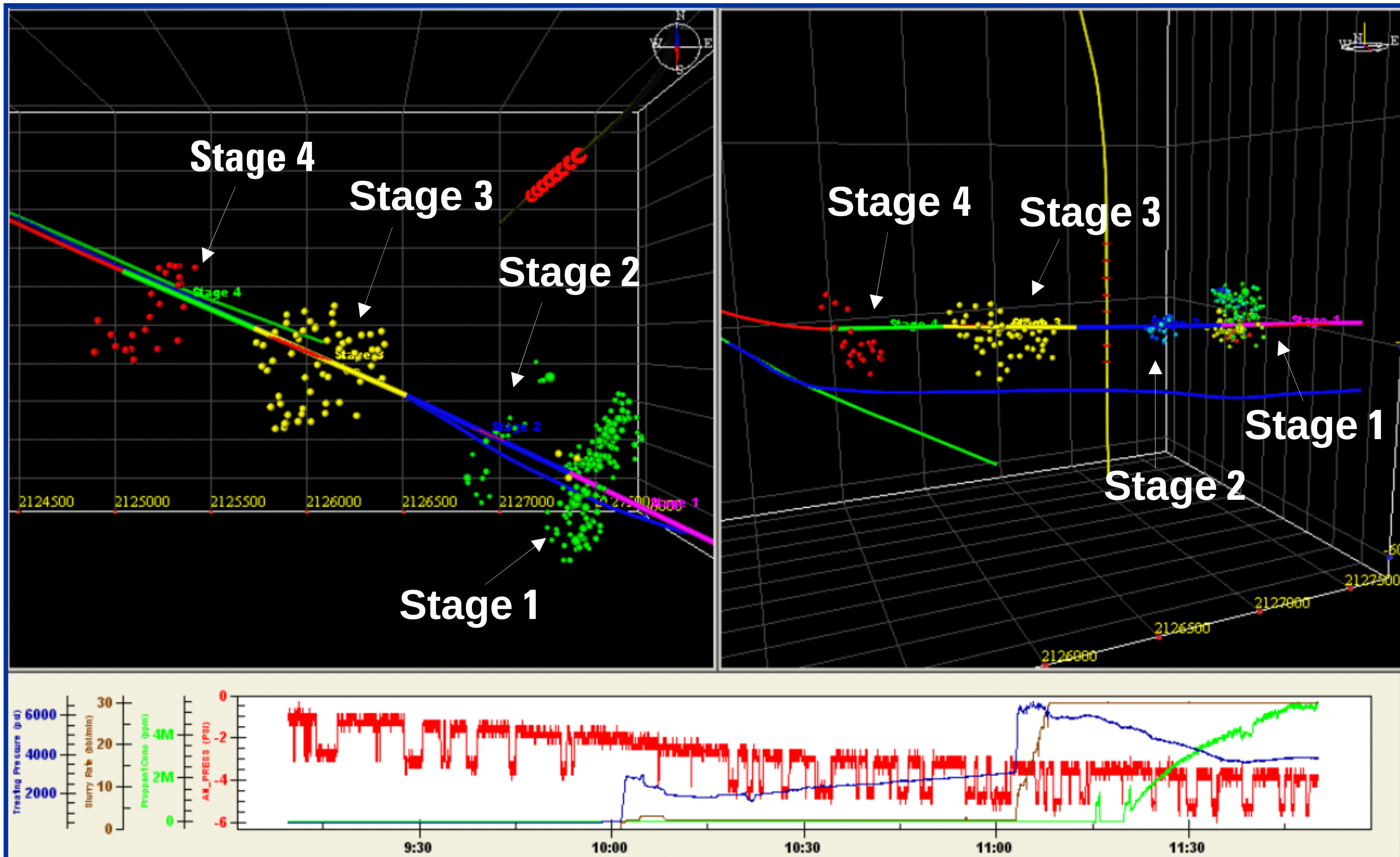
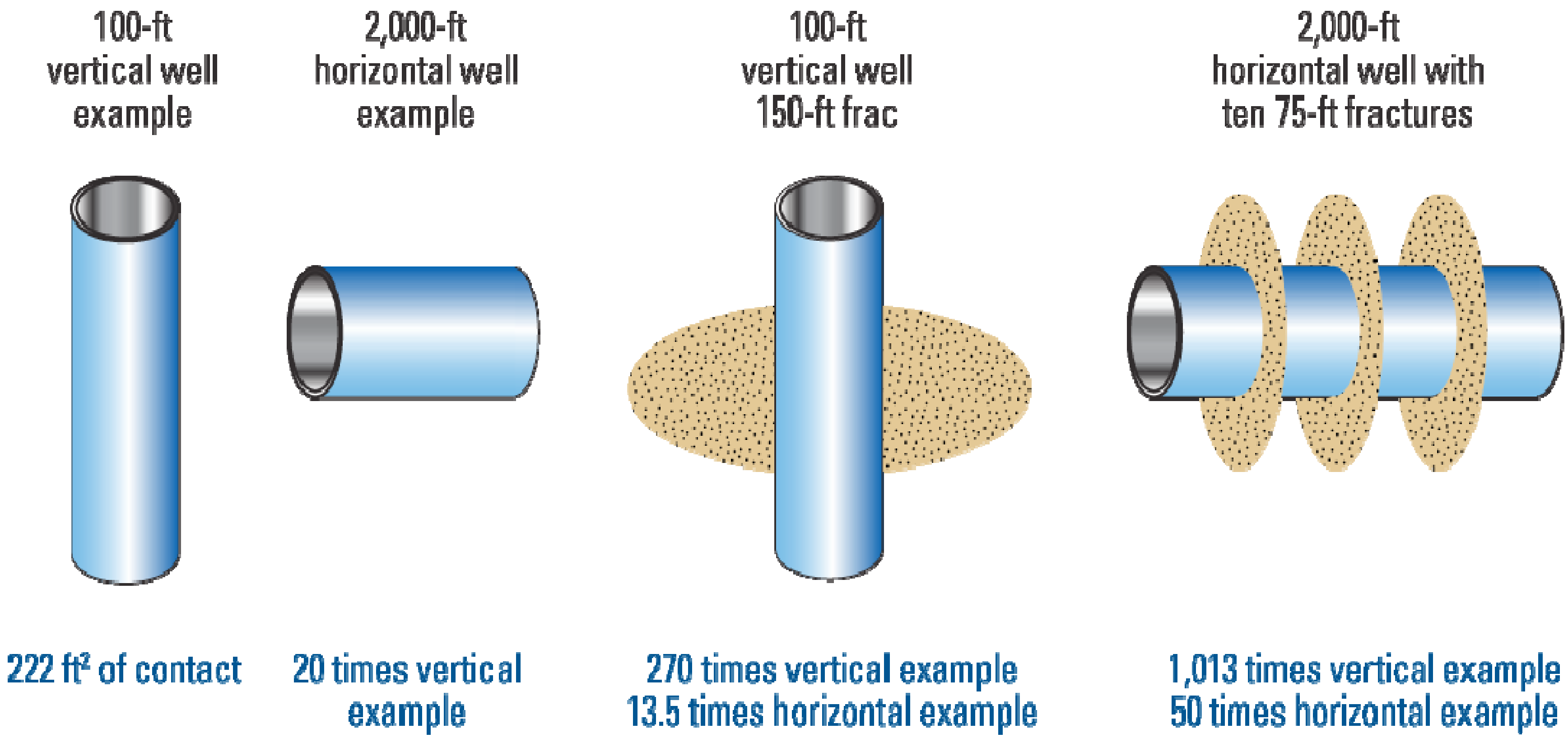
Micro seismic



Contact – The Reservoir



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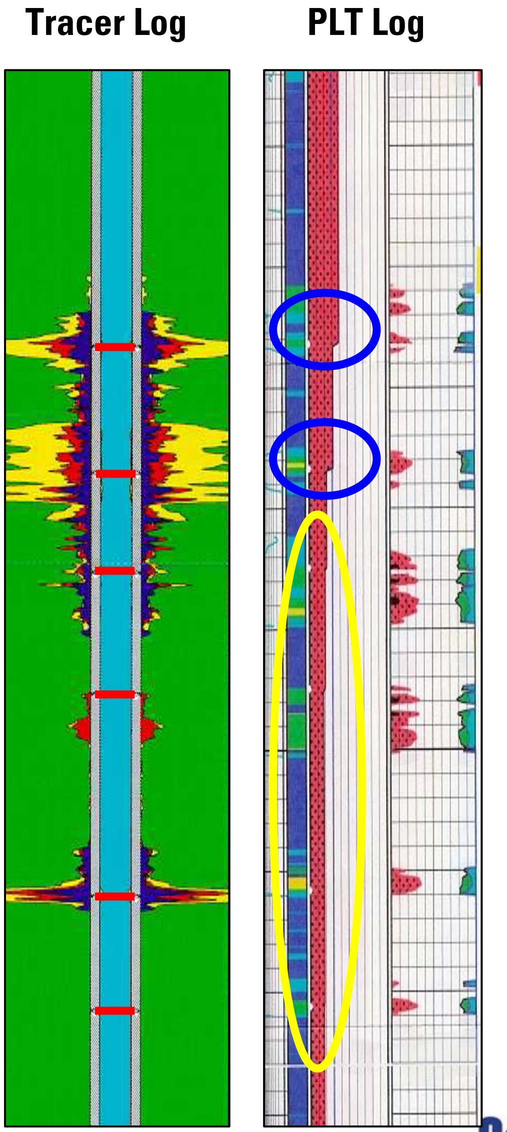
Must stimulate to produce

- 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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Methods for contacting more reservoir

Bridge plugs
Packers
Sand plugs
Jetting
Limited Entry
Ball Sealers

AbrasiFRAC™

CoilFRAC™

PerfFRAC™

StageFRAC™

RapidSTIM™

Treat & Produce

Fiber Diversion

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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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AbrasiFRAC

Applications

- Monobore Completions (3 ½", 4 ½", 5 ½" & 7")
- Vertical, Deviated and Horizontal Cased and Cemented Wellbores

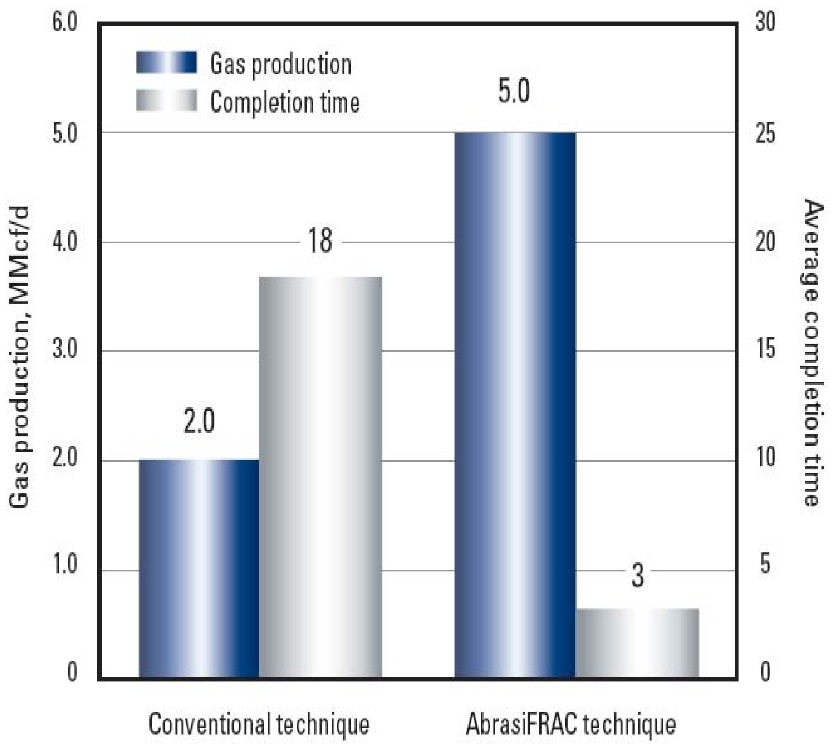
Limitiations

- Casing and Wellhead Withstand Frac Pressure
- 30' Between Stages for Sand Plug
- No Existing Perforations Above Interval of Interest

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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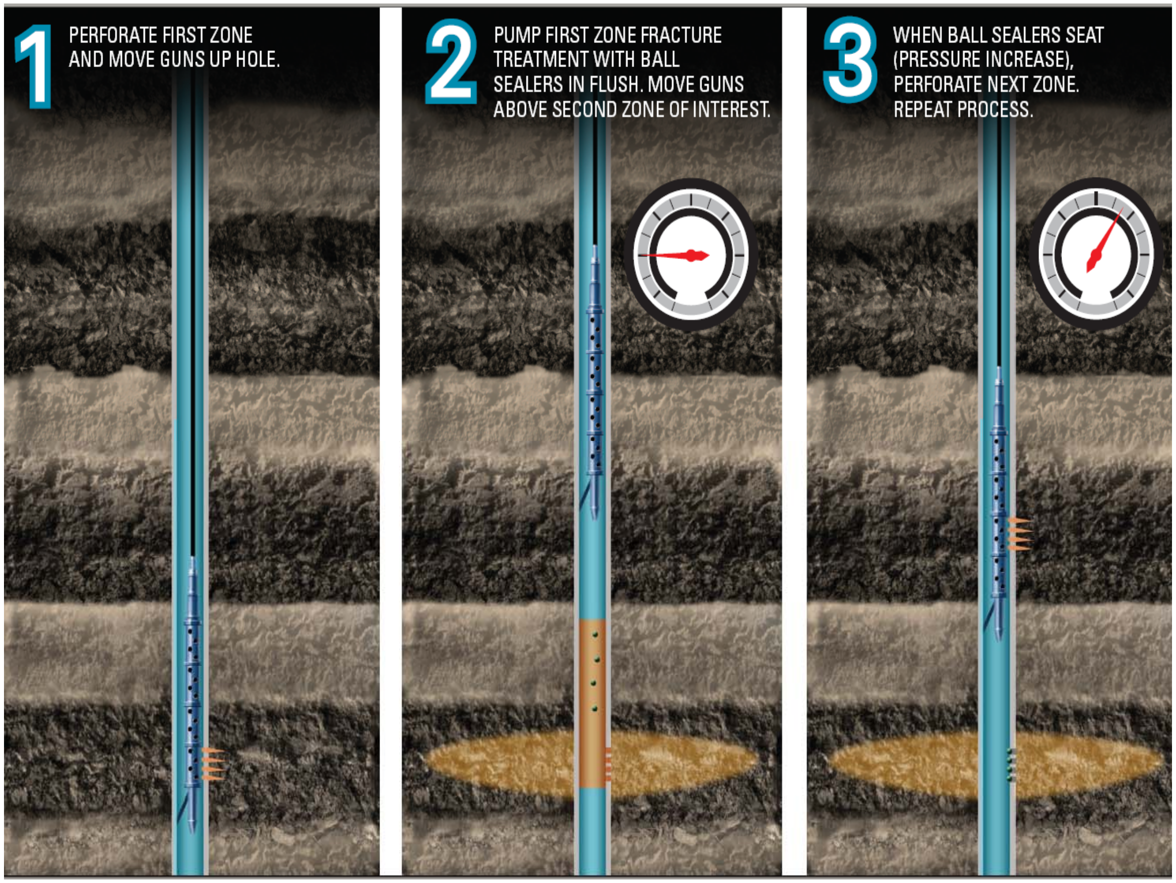
PerfFRAC

- 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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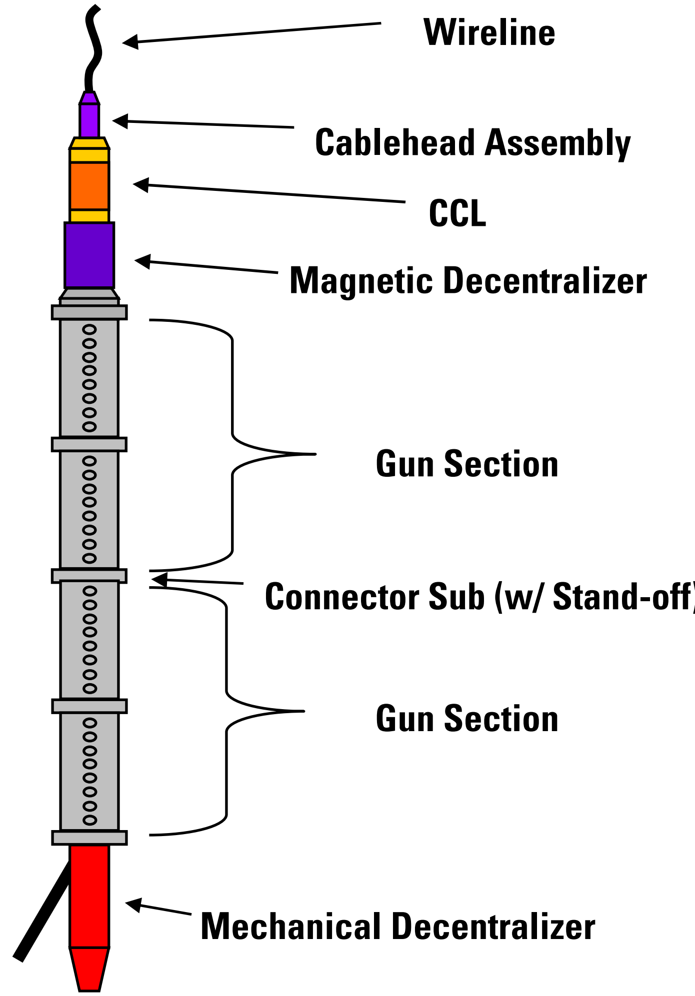
PerfFRAC

Features

- ❑ Wireline CCL for Depth
- ❑ Decentralizers
- ❑ Stand Offs
- ❑ Bouyant Ball Sealers



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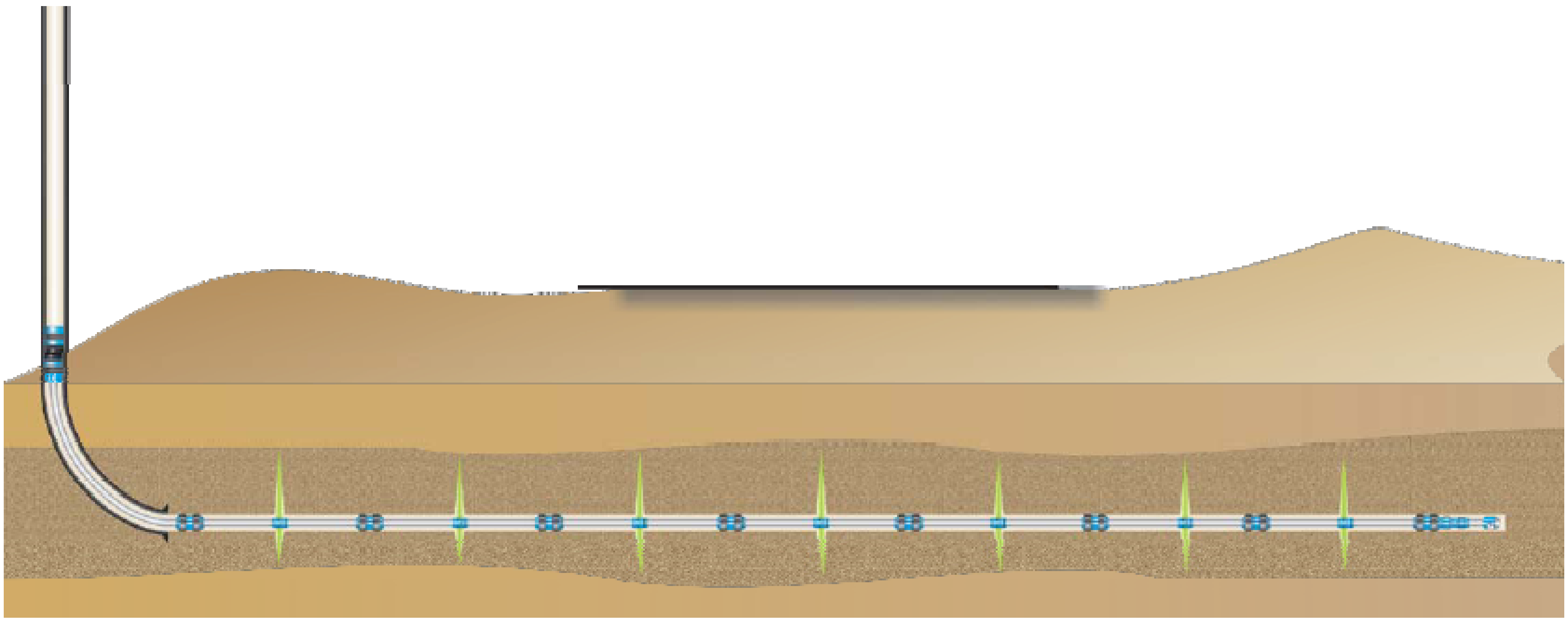
StageFRAC

Effective

- Annular Isolation
- Stage Fractures
- Immediate Flowback

Efficient

- Rigless Completion
- One Day Pumping
- Fewer Mob / Demobs



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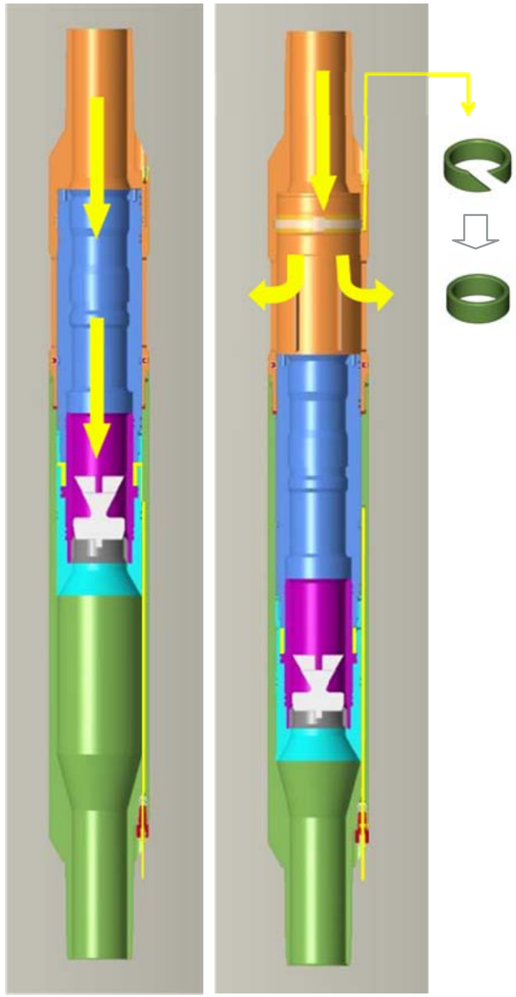
Treat & Produce

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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Questions?

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