Halliburton
Engineering for Success in Developing Shale Assets

HALLIBURTON

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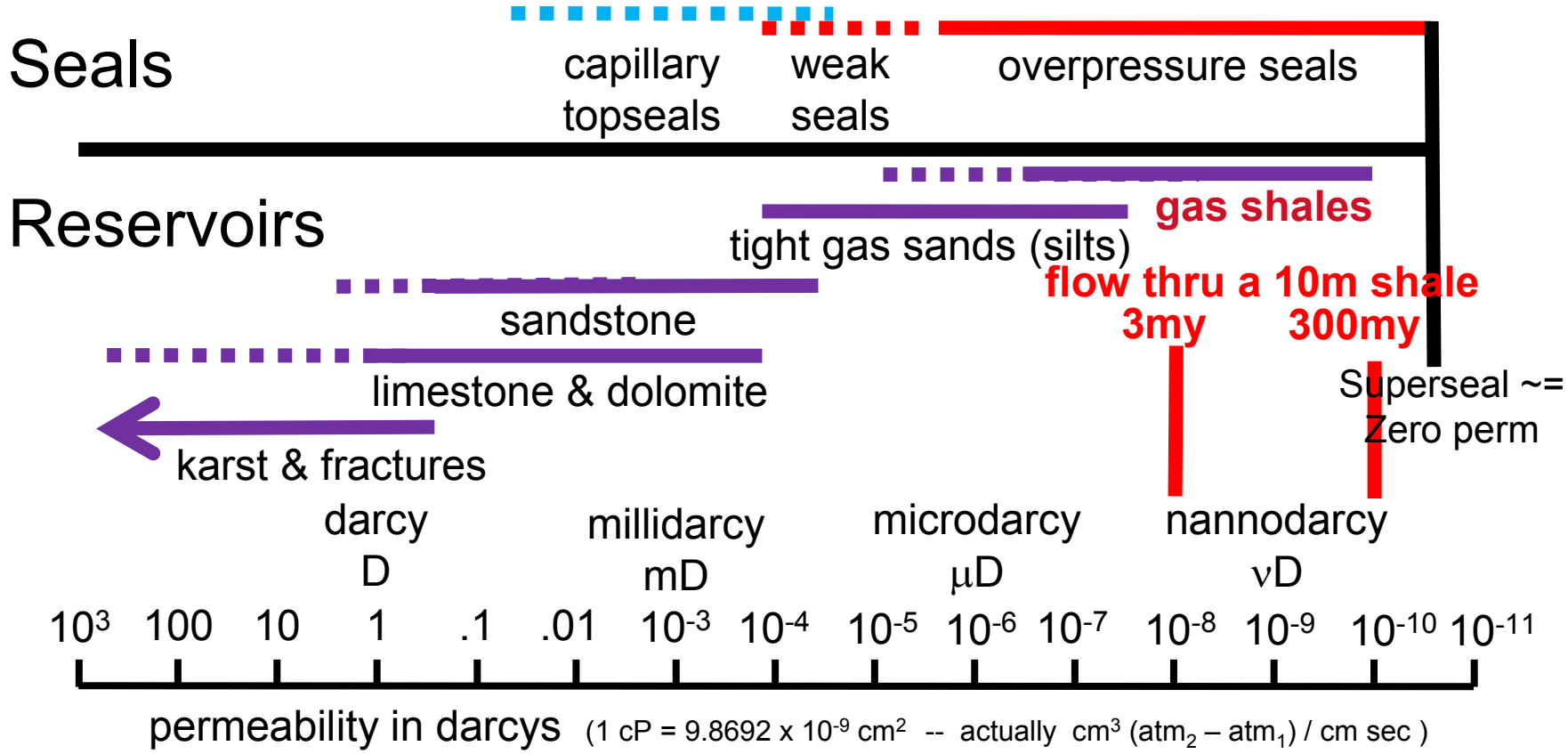
Shale is a Very Broad Name Used to Describe a Large Category of Rock

- In conventional petroleum geology shale is thought of as either a source rock or a seal to create an effective trap.
  - Conventional reservoirs require 5 key elements
    - Trap
    - Source
    - Seal
    - Reservoir
    - Maturity

In productive Shale, the rock acts as its own source, reservoir, trap and seal.

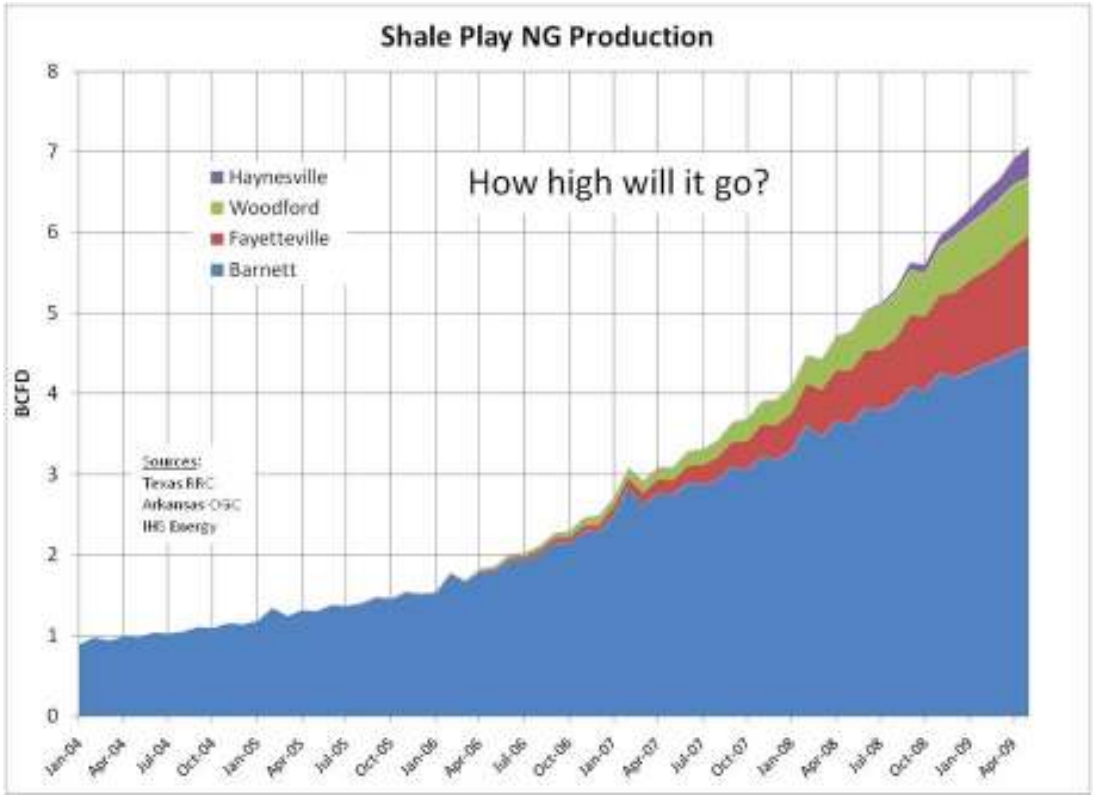
Perspective on Shale Reservoirs

Conventional Gas // Unconventional Gas



There is, however, no doubt as to the impact that shale gas has had on the US market.

- Shale gas has had a phenomenal impact on the domestic market in the US and Canada creating a reasonable cost, domestic supply of energy
- Recent developments in the Bakken and Eagle Ford shale reservoirs are also producing significant volumes of oil



Plot provided by www.GasMarketInsight.com
Schubarth Inc and Bazan Consulting, Incb

Identifying good productive shale opportunities

PROSPECT SCREENING

What is Required to Make Shale Productive?

- For Shale screening, four key requirements to look for are:
  - Total Organic Content (TOC)
    - There must be sufficient TOC to generate the hydrocarbon
    - There is a minimum TOC requirement to create inter-connectivity
  - Maturity
    - The age and burial history must be sufficient to generate hydrocarbon and generate connectivity
  - Complexity
    - Thickness and extent of the deposit
    - Fracturing and faulting
    - Bedding layer complexity
  - Stimulation Potential
    - Suitable mineralogy and mechanical properties
    - Natural fracturing
    - Geomechanical condition and pore pressure
    - Containment barriers and hazards (eg water producing zones)

Total Organic Carbon (TOC)

- TOC represents the potential to generate hydrocarbons
- The quantity of organic carbon is important
  - Minimum of 2%
  - Maximum ~ 10%
- The thermal maturity of the organic carbon is important

Information Sources

- Core Analysis is the primary tool, but estimates can also be made from logs.
- Geochemical Analysis
  - Hydrocarbons present
  - Hydrocarbon potential
- Vitrinite Reflectance
  - Thermal maturity of TOC

Maturity

- Basin Modeling is used to determine the burial history of a formation to determine if conditions were favorable for hydrocarbon generation
  - Burial depth
  - Temperature exposure
  - Overburden
- Core and cuttings analysis
  - Porosity and permeability
  - Vitrinite Reflectance to help identify the level of maturity
    - Immature >> oil window >> wet gas / condensate >> dry gas >> no gas

Complexity

- The degree of complexity can have a significant impact potentially complicating the ability to keep a horizontal wellbore in zone and make stimulation difficult. Some features that are cause for concern include:
  - High fault frequency
  - Bedding layer complexity
  - High dip angle

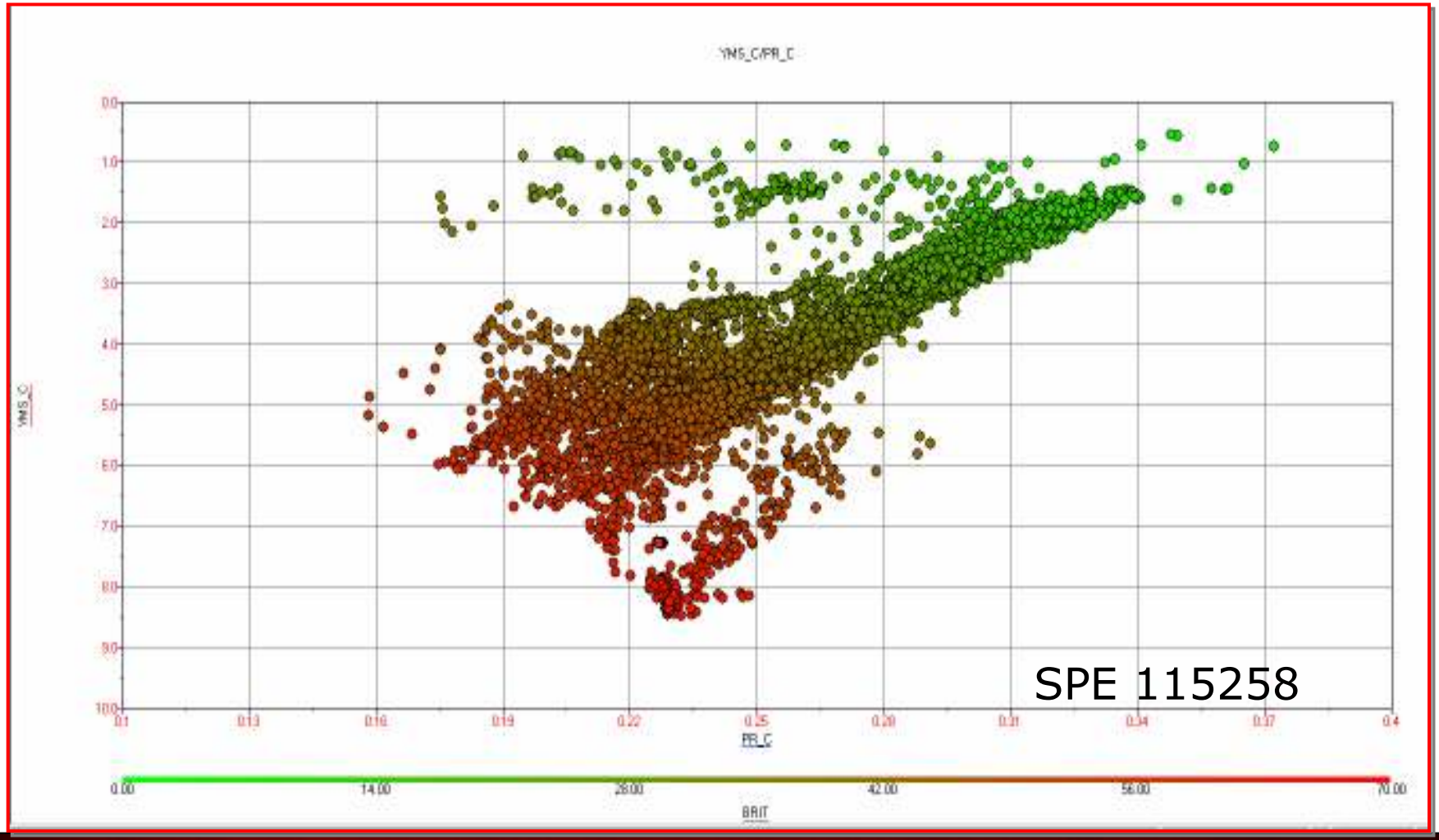
Stimulation Potential

- For economic production from a nanodarcy reservoir, effective stimulation is an absolute requirement
  - Mineralogy
    - For hydraulic fracturing, sustaining long term fracture conductivity is essential
    - Higher strength, more brittle rock
      - High quartz or calcite content with lower clay contents
  - Production fluid (oil or gas)
  - State of stress in the reservoir (fracture growth behavior)
    - Isotropic
    - Anisotropic
  - Degree of natural fracturing
  - Manageable hazards
    - Fracture containment

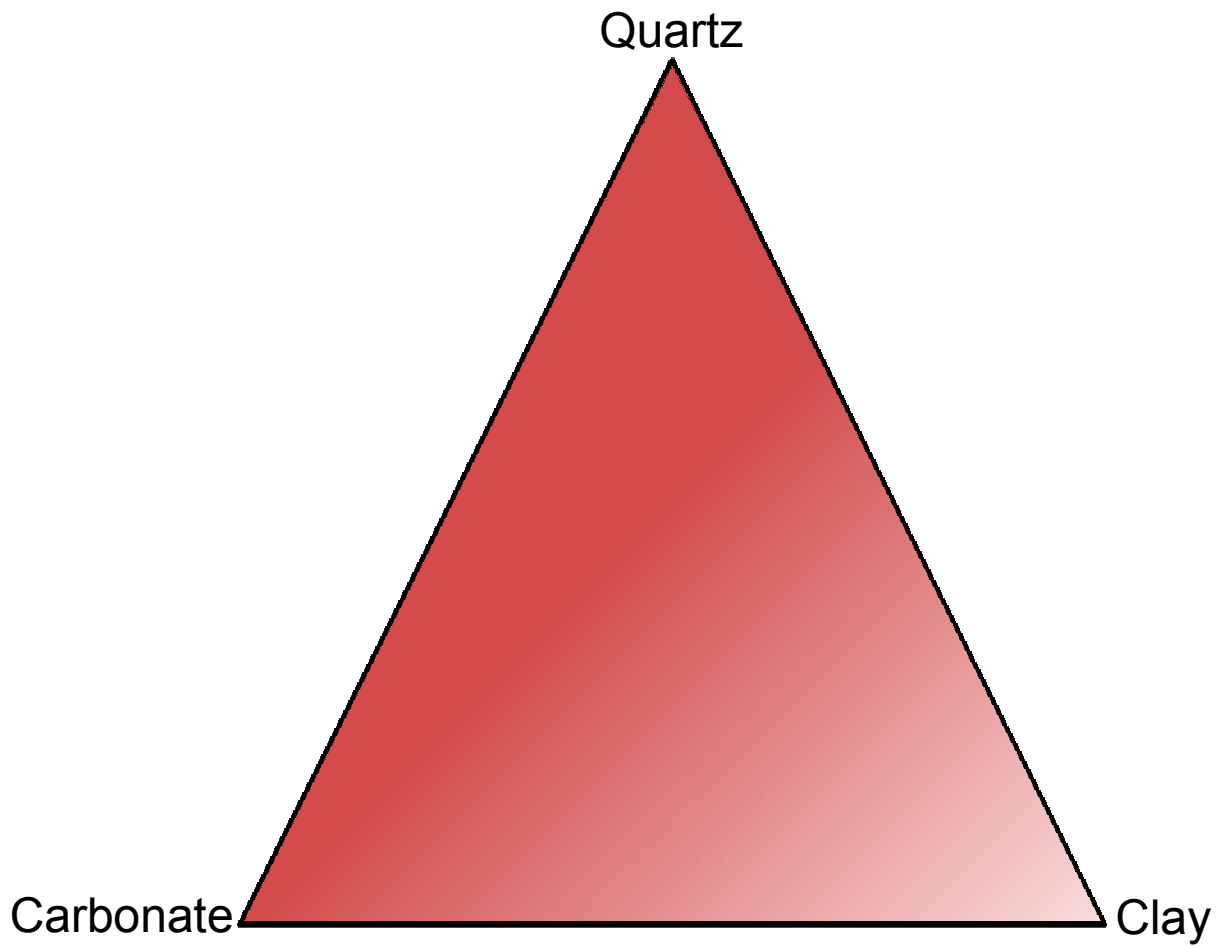
Mechanical Properties

Harder, More Brittle Material = Improved Conductivity

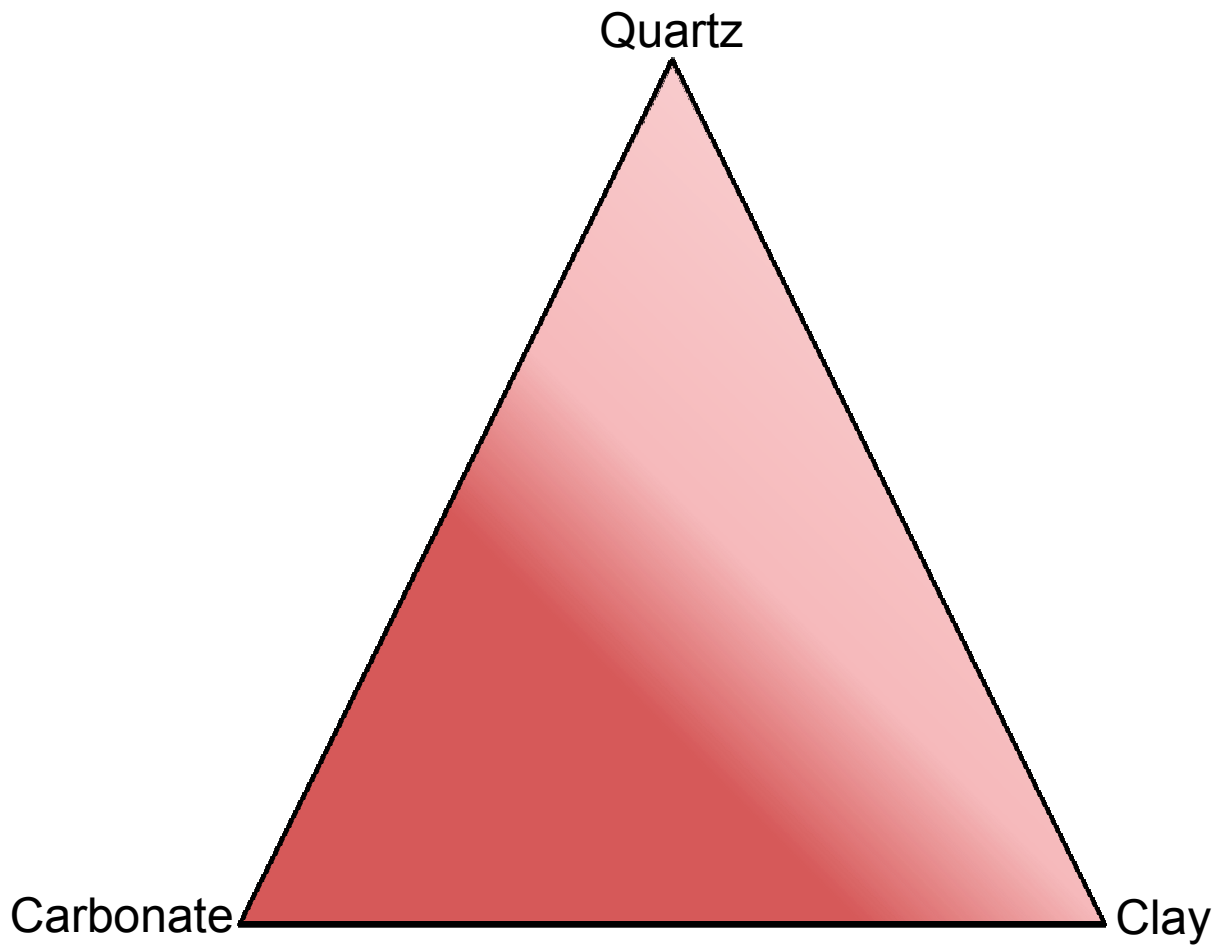
Harder, More Brittle Material = More Natural Fractures



Typical Fingerprints for Productive Shale



Typical Fingerprints for Productive Shale



How do we find the sweet spots within the reservoir

IDENTIFYING THE BEST RESERVOIR TARGETS

Identifying the Best Reservoir Targets

- After working through the screening process and identifying a good opportunity, how do you determine the best well location in the reservoir?
  - Reservoir is extremely heterogeneous
  - Reservoir quality is bad

Look for locations that have the best stimulation potential

Identifying Reservoir with Good Stimulation Potential

Key indicators to identify good stimulation potential

- Mechanical properties
- Local stress conditions (Geomechanical model)
- Presence of natural fractures
- Fracture containment

Information sources

- Pre-Stack Seismic interpretation – low resolution on mechanical properties
- Wide Azimuth Seismic interpretation – stress anisotropy and natural fractures
- Well log data
- Core data

Primary Objectives

Target Locations

- Identify areas within the reservoir where the stimulation potential is best
  - Mechanical properties
  - Barriers
  - Low fault density
  - Stress conditions

Target Layers

- Identify key layers within the identified region where the stimulation potential is best
  - Mechanical properties
  - Stress conditions

DRILLING AND FORMATION EVALUATION

Two Key Areas of Focus

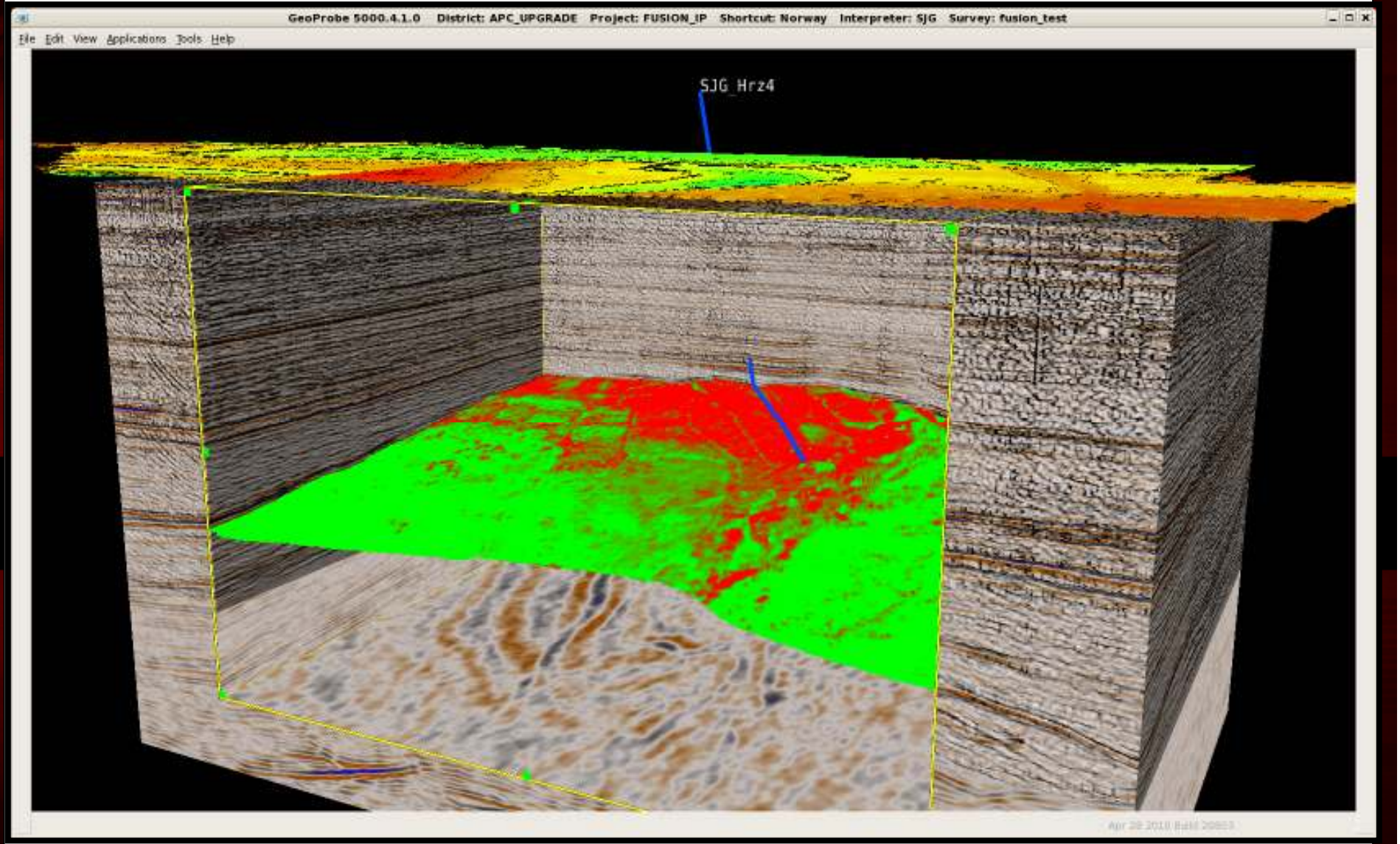
Identify Target Layers

- Sufficient information must be obtained to identify the target layers in the reservoir
- Pilot hole logs, mud logging and ChemoStrat tools should be used
- Geological modeling should be incorporated

Keep the Well in Target

- Geosteering within the geological model is recommended
- The Geological model can be continuously updated
- Logging should target layers with the best stimulation potential
  - Sonic logs may provide the best information

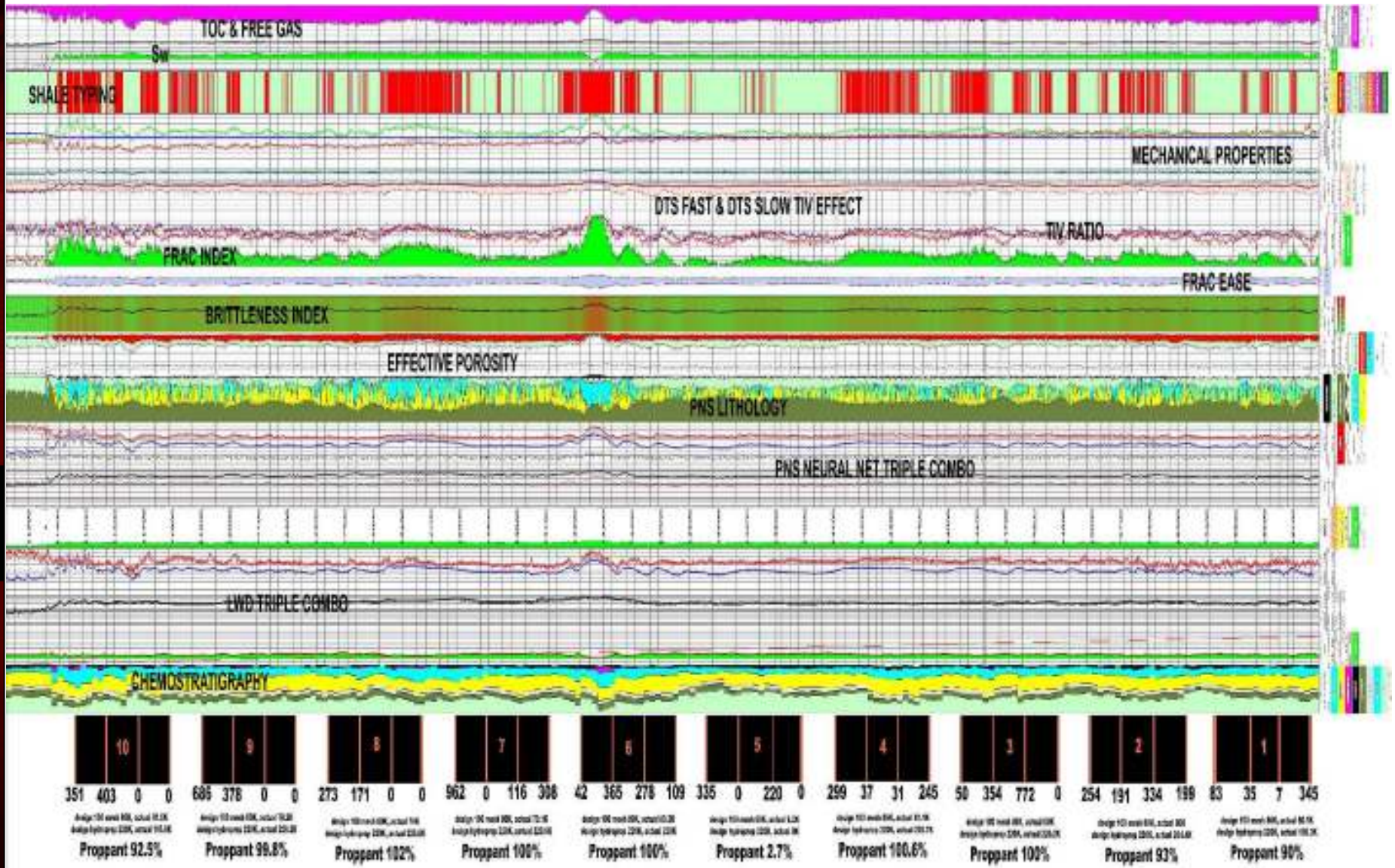
Planning and Drilling in the Geologic Model



BP George A9H

SPE 132990

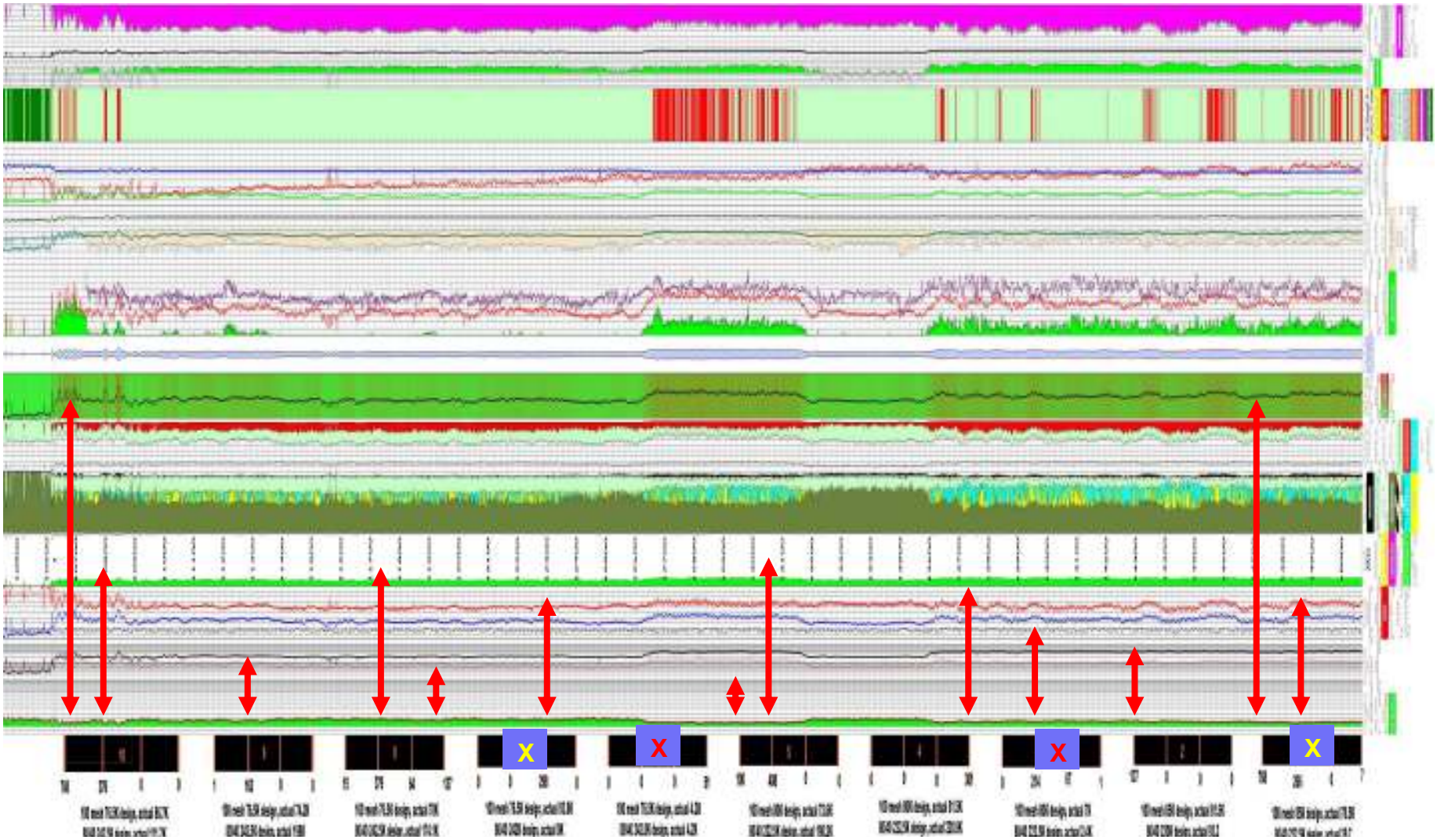
Well path covers a large portion of the reservoir showing heterogeneity



SPE 132990

BP CGU 13-17H

Well path is stuck in a narrow region with high clay content



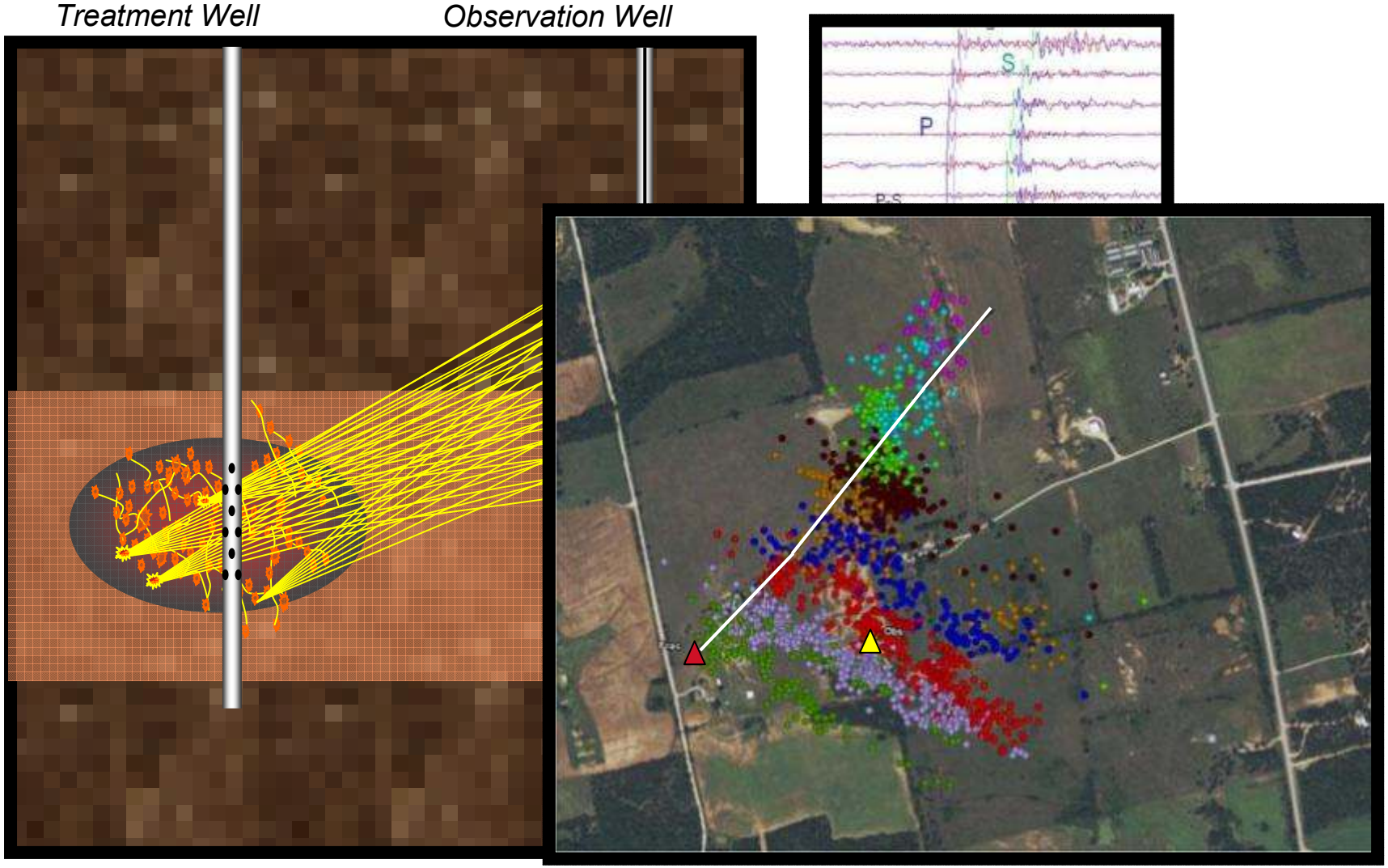
How can economic production be achieved from nano-Darcy shale reservoirs?

GETTING ECONOMIC PRODUCTION FROM SHALE

Economic Production from Shale Reservoirs

- The Barnett shale has proven to be a massive natural gas reservoir after several years of incremental improvements in technology and methods.
- **Microseismic fracture mapping** has played a very significant role improving our understanding of fracture growth in the Barnett Shale.
  - Complex fracture networks were being created generating huge surface areas when compared to conventional bi-wing fracture treatment designs

Microseismic Fracture Mapping



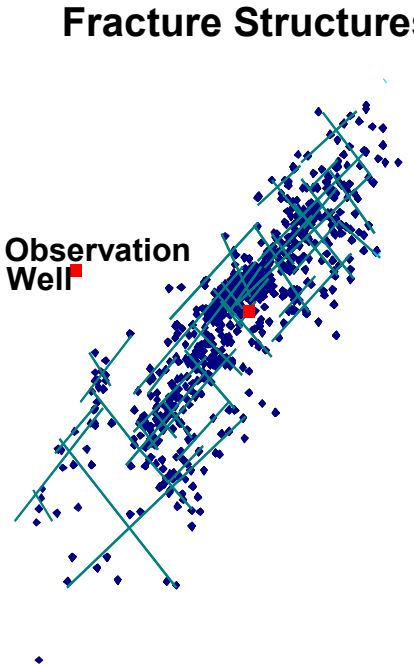
Economic Production from Shale Reservoirs

Complex Fracture Networks

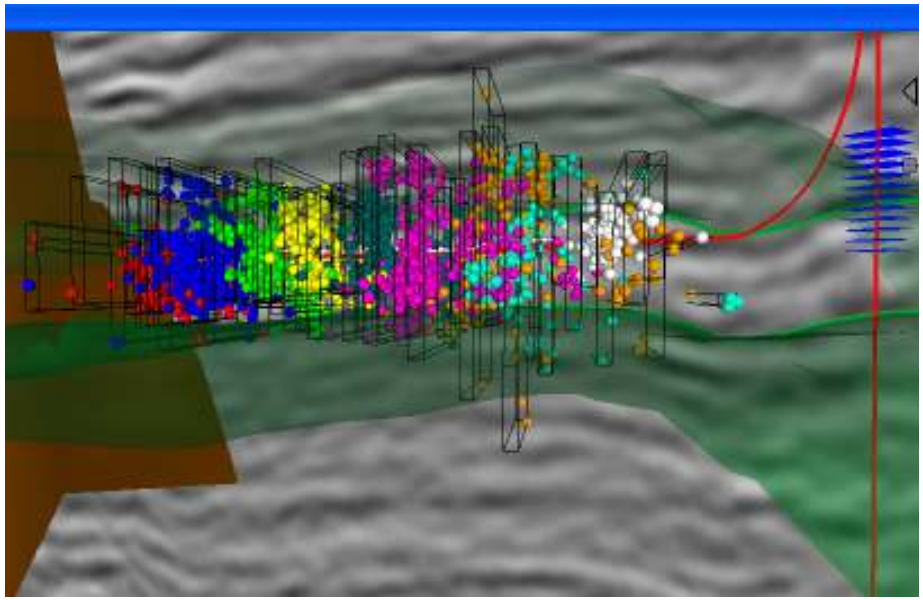
- Create maximum reservoir contact and providing a conductive path back to the wellbore. The stimulated region around the well has been termed the Stimulated Reservoir Volume or SRV.
- Inefficient or high leak off fluids such as ungelled water have proven to be very effective in maximizing fracture complexity in the Barnett Shale
- The brittle nature and stress state within the Barnett shale helps to maintain open fractures, even with minimum proppant to support the fracture
- Horizontal wells with multiple frac stages create even more reservoir contact.

Transition from Vertical to Horizontal Well Completions

Vertical Well: Complex Fracture



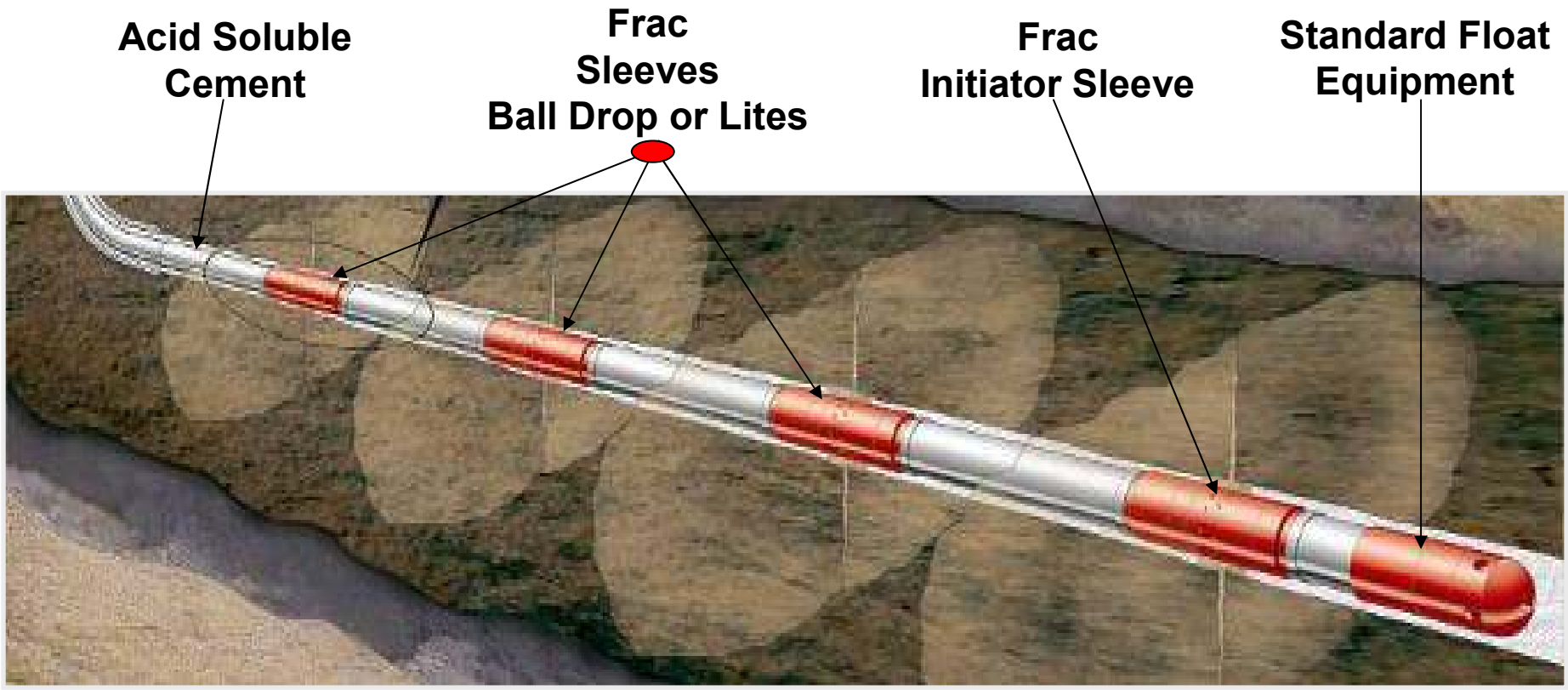
Horizontal Well, Multi-stage Complex Fracture



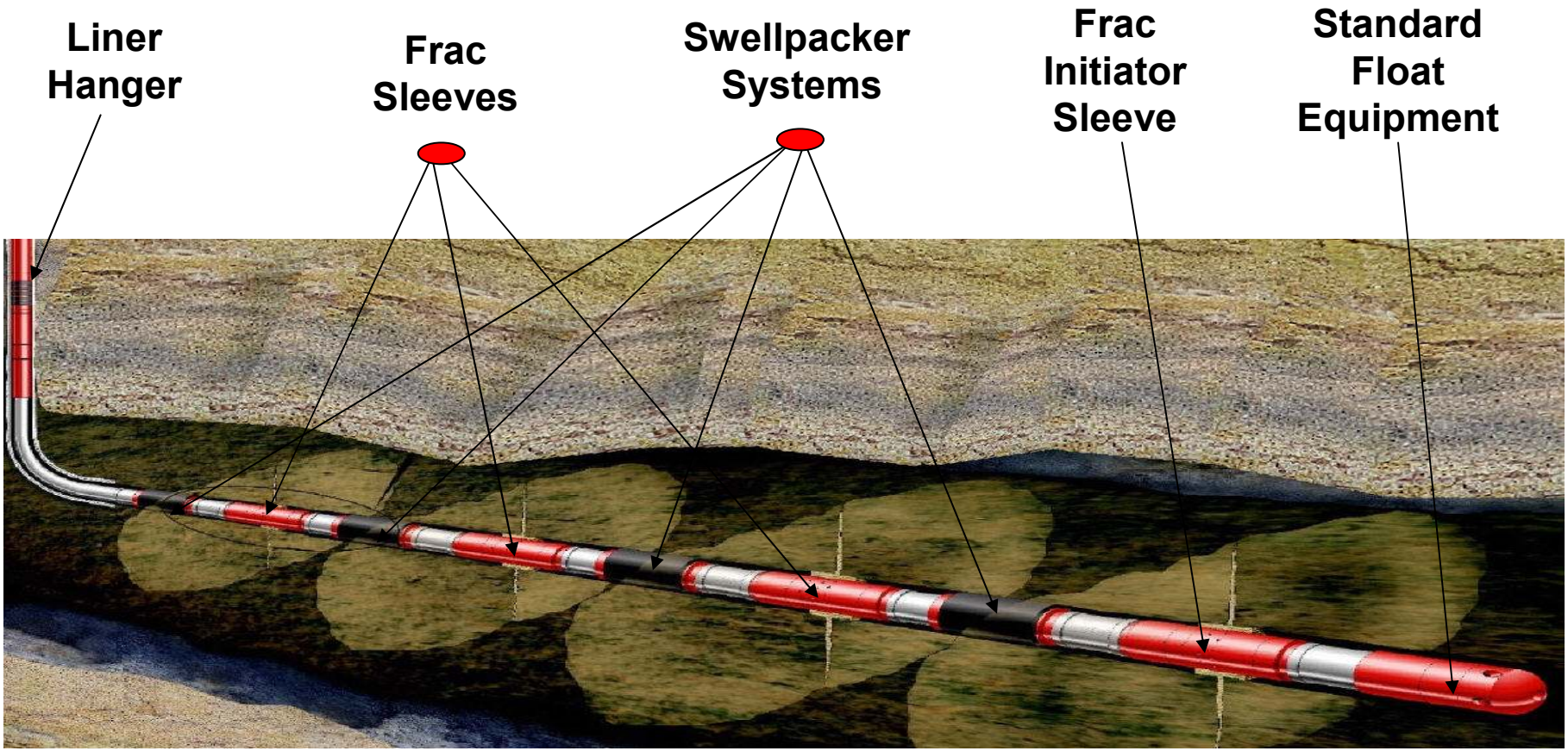
Advances in Completion Technology

- Microseismic fracture mapping
- Fracture designs to increase fracture complexity and maximize reservoir contact (High rate water frac)
- Transition from vertical wells to horizontal wells with multiple fracture stages
- Perf and Plug techniques for multiple stage horizontal wells (single interval, multi-interval)
- Ball operated frac sleeves and open hole packer systems
- Coiled tubing assisted fracturing
  - Jet perforating
  - Unlimited fracture stages

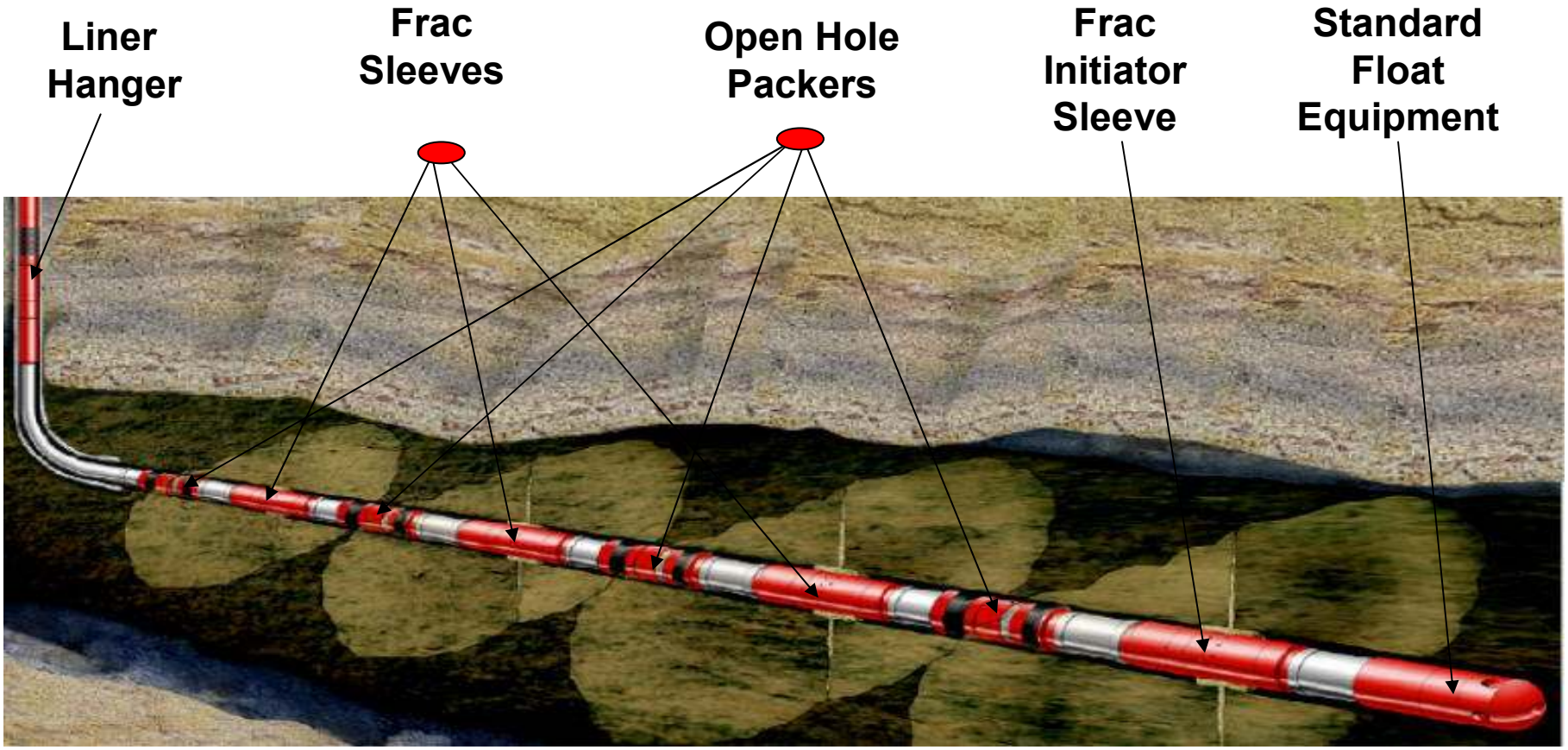
Horizontal Well Frac Sleeve Completion with Cement



Horizontal Well Frac Sleeve Completion with Swellpacker® Systems



Horizontal Well Frac Sleeve Completion with Open Hole Packers

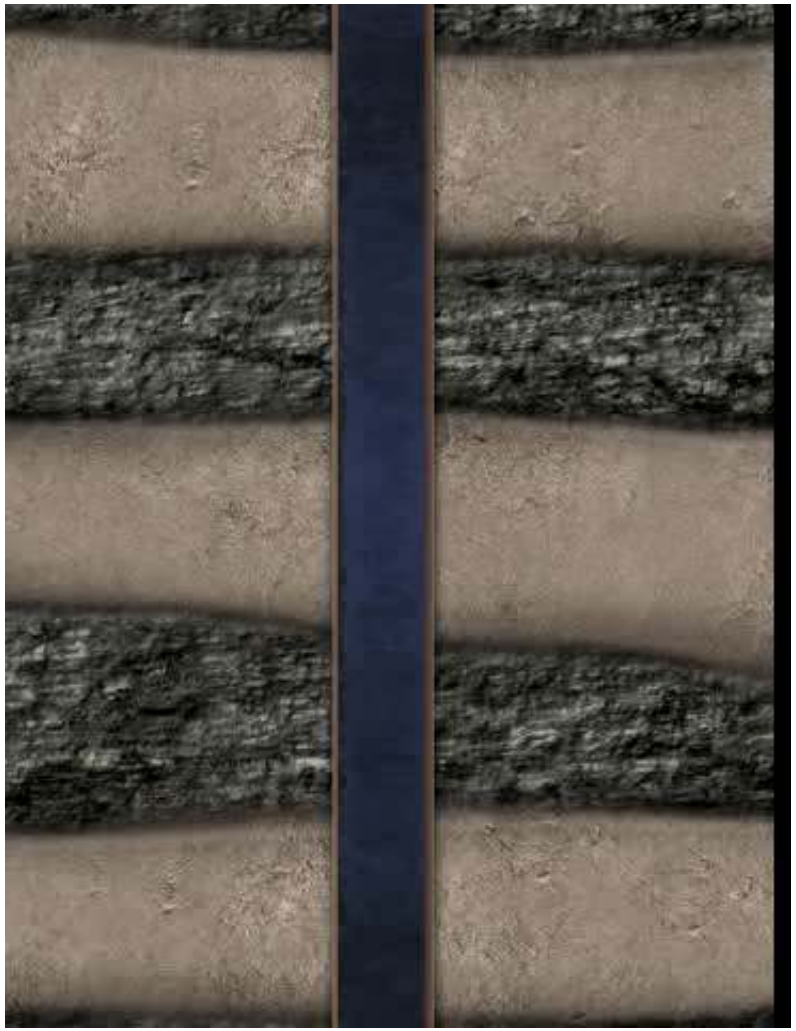


CobraMax and SurgiFrac

COILED TUBING FRACTURING

CobraMax – Coiled Tubing Fracturing

- Perforation Strategy
  - Hydraulic Jetting
  - Selective/focused
- Hydraulic fracturing
  - Connection to the reservoir
- Multi-staging for long interval coverage
  - CobraMax H designed for long interval horizontal wells



SurgiFrac

- SurgiFrac, hydrajet assisted hydraulic fracturing.
- Can be performed in cased hole or open hole environments.
- The fracture is surgically placed using the focused energy of a hydraulic jet for initiation

The Pros and Cons of Different Fracturing Techniques

Perf and Plug

- Proven technique preferred by many operators
- Time required between frac stages to set the bridge plug and perforate is significant
- Screen outs result in significant delays to clean out the wellbore (Frac designs become over conservative)
- Over displacement is required to get guns and plugs placed.

Sliding Sleeve Systems

- Time between stages is reduced helping improve efficiency
- Screen outs will result in significant delays to clean out wellbore. Tools can also be accidentally shifted during clean out operations.
- Limited number of stages due to ball sizes. (being addressed by opening multiple valves per ball)
- Over displacement is required to place balls or plugs and activate valves.

The Pros and Cons of Different Fracturing Techniques

CobraMax

- Unlimited number of stages in 1 trip
- Fractures can be closely spaced
- More tolerant of screen outs, coil can be used to clean out without losing much time
- Reduced flow area limits injection rate
- More complex operations create some concern
- No over displacement

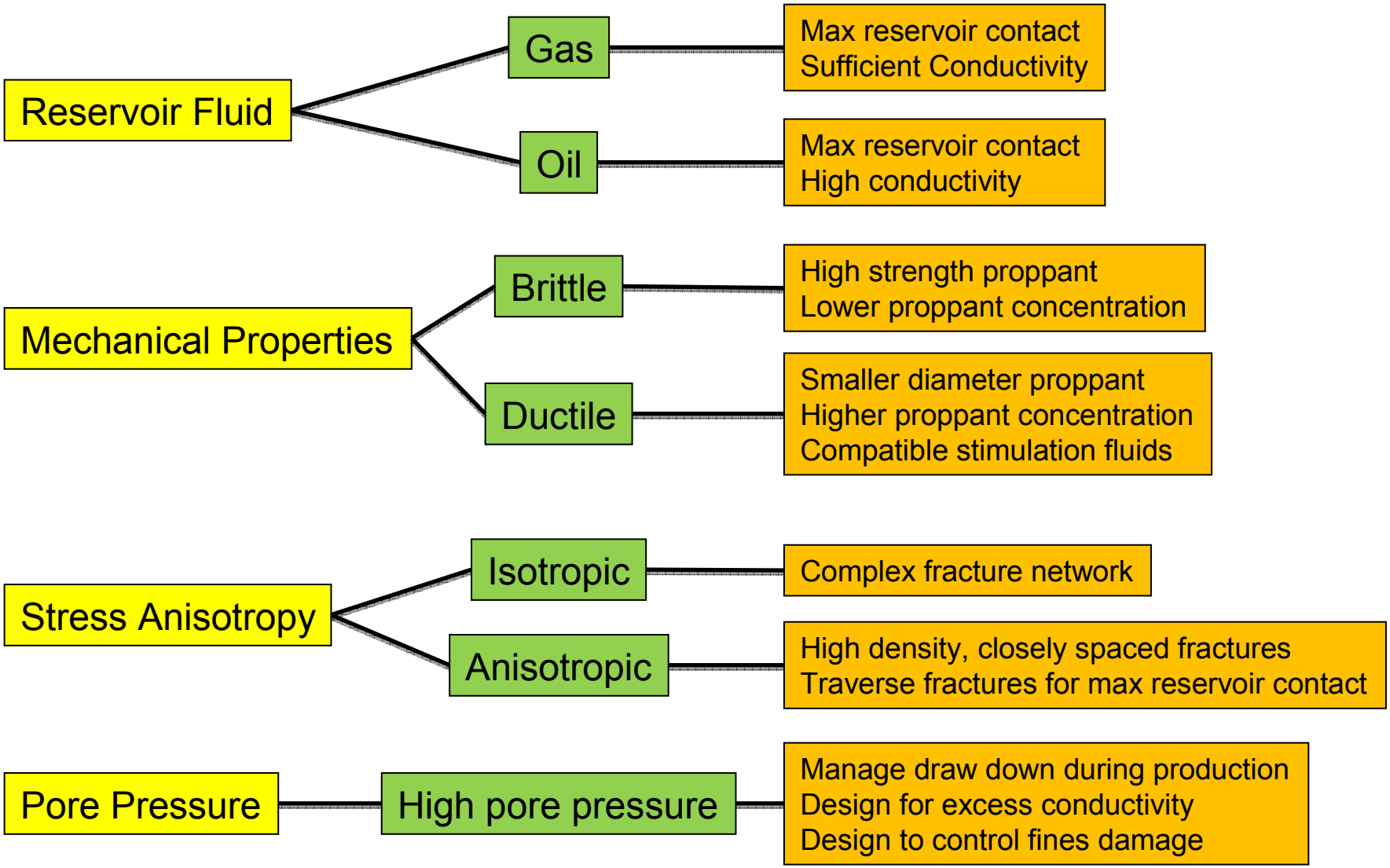
SurgiFrac

- Can be used for cased hole or open hole, making it a remediation option
- More tolerant of screen outs, coil can be used to clean out without losing much time
- Jet erosion will limit the total number of stages per trip
- Injection rates and proppant volumes are limited by jet size and durability
- More complex operations create some concern
- No over displacement

A Problem!

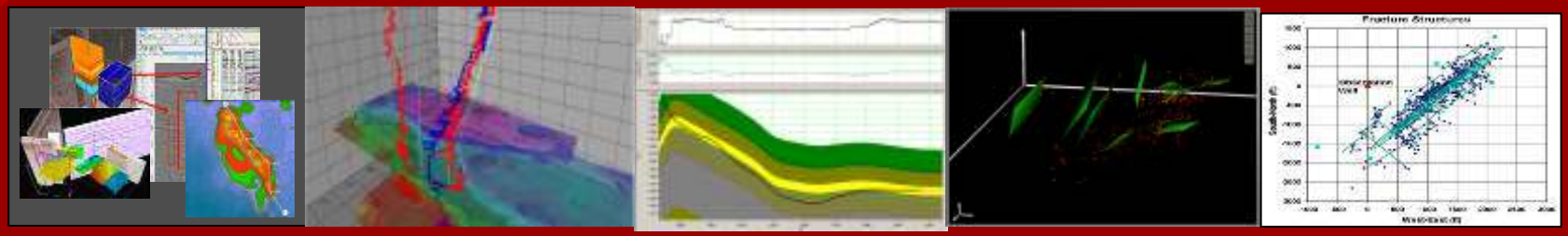
- Not all shale reservoirs behave like the Barnett Shale. In fact nearly all of them are different!
- The Barnett Shale is a brittle shale with high quartz concentrations that sits in a relaxed stress state. There is very little stress anisotropy meaning it is relatively easy to create complex fracture networks.
- Many other shale reservoirs are softer with more clay or carbonate.
- Many other shale reservoirs also have significant amounts of stress anisotropy meaning the fractures will tend to be more planar and less complex.

Reservoir Based Stimulation Design

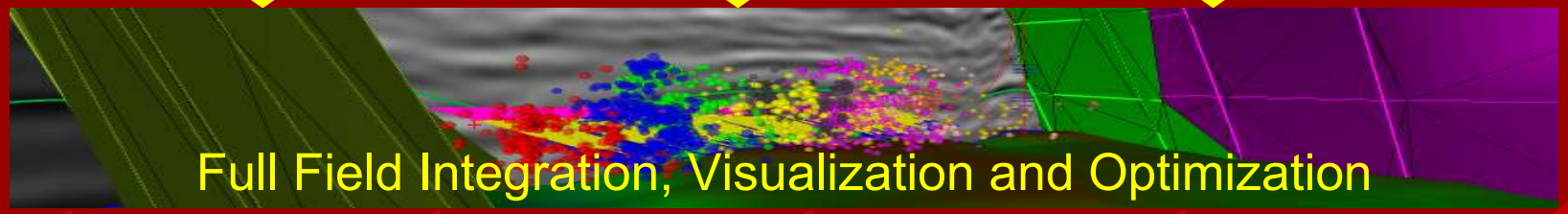


Shale Development – An Integrated Approach

- Proactively address reservoir and full field development challenges in shale reservoirs
  - An integrated process from exploration through to production is needed to maximize the asset potential



Reservoir Understanding → **Well Optimization** → **Validation**

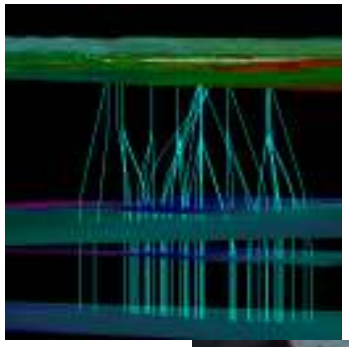


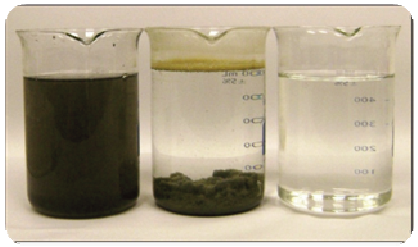
Technology Challenges

- Horizontal drilling and hydraulic fracturing have been critical in achieving economic production from shale.
  - Huge volumes of fresh water are used in hydraulic fracturing operations.
  - Chemical usage in hydraulic fracturing has created concerns of ground water contamination.
- Some reservoirs are very close to urban centers creating logistical challenges
- Horizontal wells require several fracturing treatments for each wellbore. The demand for fracturing services has grown exponentially.
  - Equipment and personnel are in short supply
  - The industry is growing rapidly to try to keep pace
  - New equipment concepts are being explored to meet the demand.

New Technology to Address Shale Needs

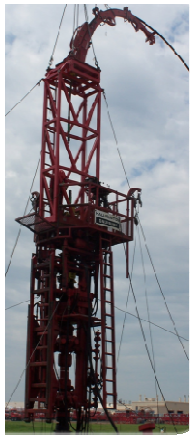
- Collaborative well planning
  - Minimize environmental impact
  - Pad drilling





- Water treatment
  - Re-cycling produced fluids (CleanWave^{SM})
    - Electrocoagulation
  - Reduced biocide usage (CleanStream)
    - High power UV

- Treating fluids
  - Tolerant with produced fluids
  - Environmentally friendly (CleanStim)



- New generation pumping equipment
  - PowerReach hybrid coiled tubing for long horizontal wells
  - Modular frac equipment

Williams, Dr. Bob Smith Pad, Denton County, Texas, USA

What do you think?

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