Advancing Reservoir Performance

Issues in Unconventional Oil Reservoirs

SIPES

Houston, TX

D. Nathan Meehan, Ph.D., P.E.

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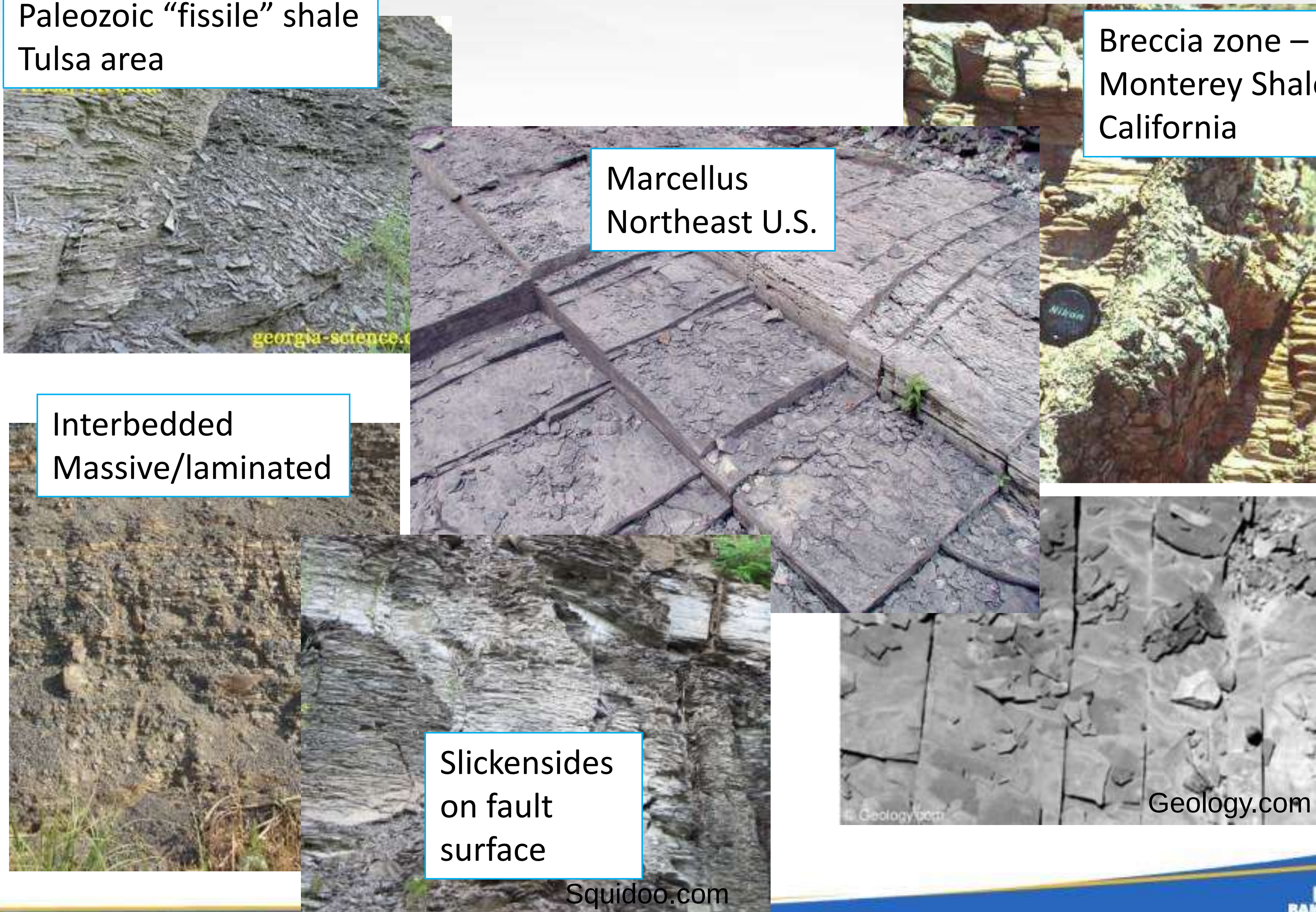
Some common **misconceptions** about shale reservoirs

- Shales contain few natural fractures
  - Broad stimulated zones are caused by an orthogonal network of hydraulically induced fractures
- Fracture barriers are due to stress contrasts between layers
- Stress contrasts between layers can be computed from elastic properties
  - Lateral constraint plus tectonic factors
  - Plus thermal stresses
  - Corrected for anisotropic elastic properties
- The ratio of Young's modulus to Poisson's ratio can be used to determine "brittleness," "fracability" or ease of fracturing
- Dipole-mode anisotropy is controlled by stress
  - The fast direction defines the orientation of SHmax
  - Relative stress magnitudes can be determined from velocities

Shales are often highly fractured / laminated



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Flow mechanisms

- Differences between Bakken and Marcellus
  - Huge
  - Gas shale link to kerogen. Pore and throat sizes.
  - D’arcy’s law? Molecules may be too large for Fick’s law type diffusion to apply
  - Crude oil sized molecules require better effective permeability to deliver the observed flow rates.
  - Critically stressed fractures
  - Yet another thing I changed my mind about over time…

Key Points: Fracture Permeability in Shales

- Fracture permeability depends on the relationship between the fracture orientation and the *in situ* stress field
- Fractures tend to "heal" over geological time
- Stresses are always compressive in the crust
- Mode I fractures (opening mode joints) are unlikely to be as important in controlling fluid flow as mode II and III shear fractures
- Shear fractures that could potentially slip in the current stress field (*i.e.,* that are critically stressed) provide pathways with enhanced permeability (hydraulically conductive)

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Relative stress magnitudes vary, resulting in varying fault regimes

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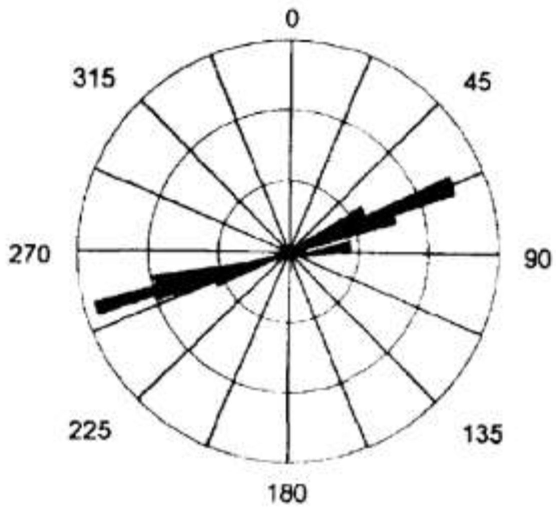
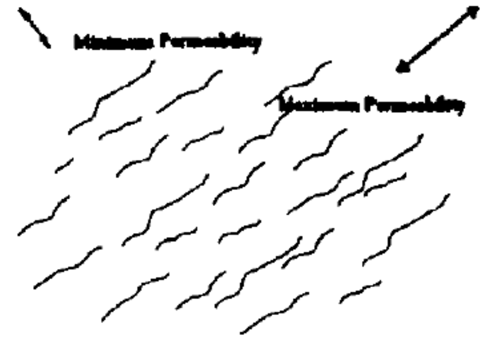
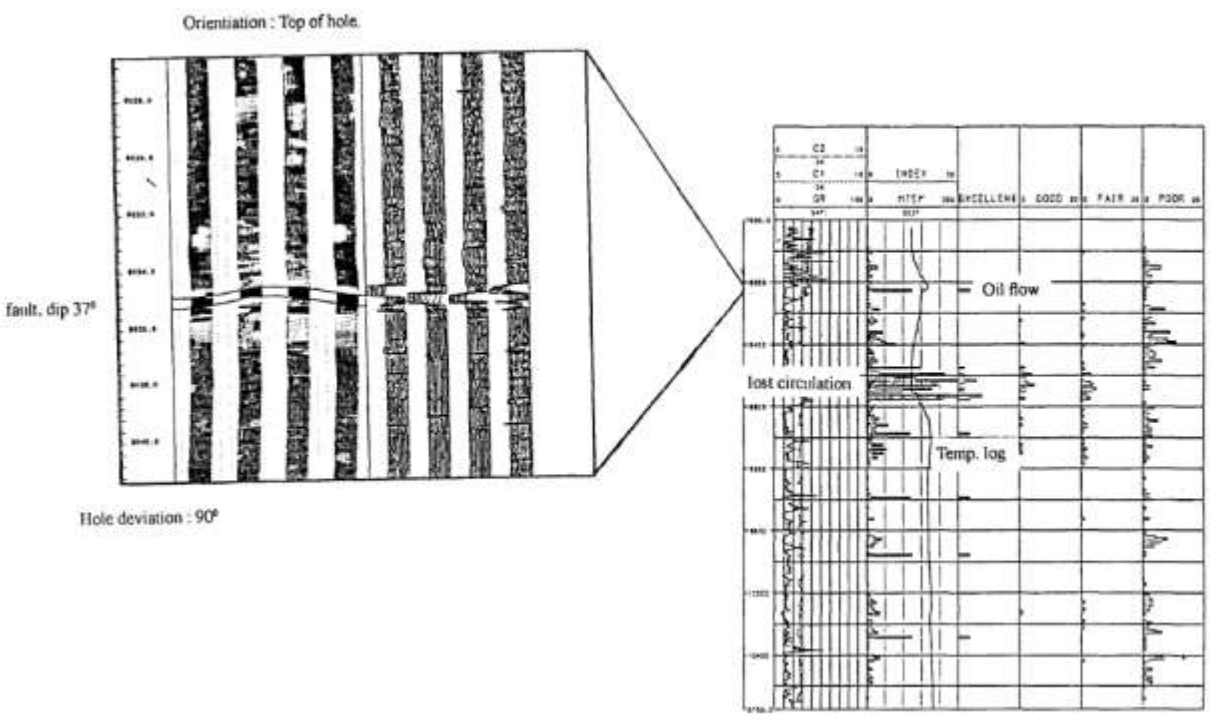


Figure 2 - Distribution of fracture





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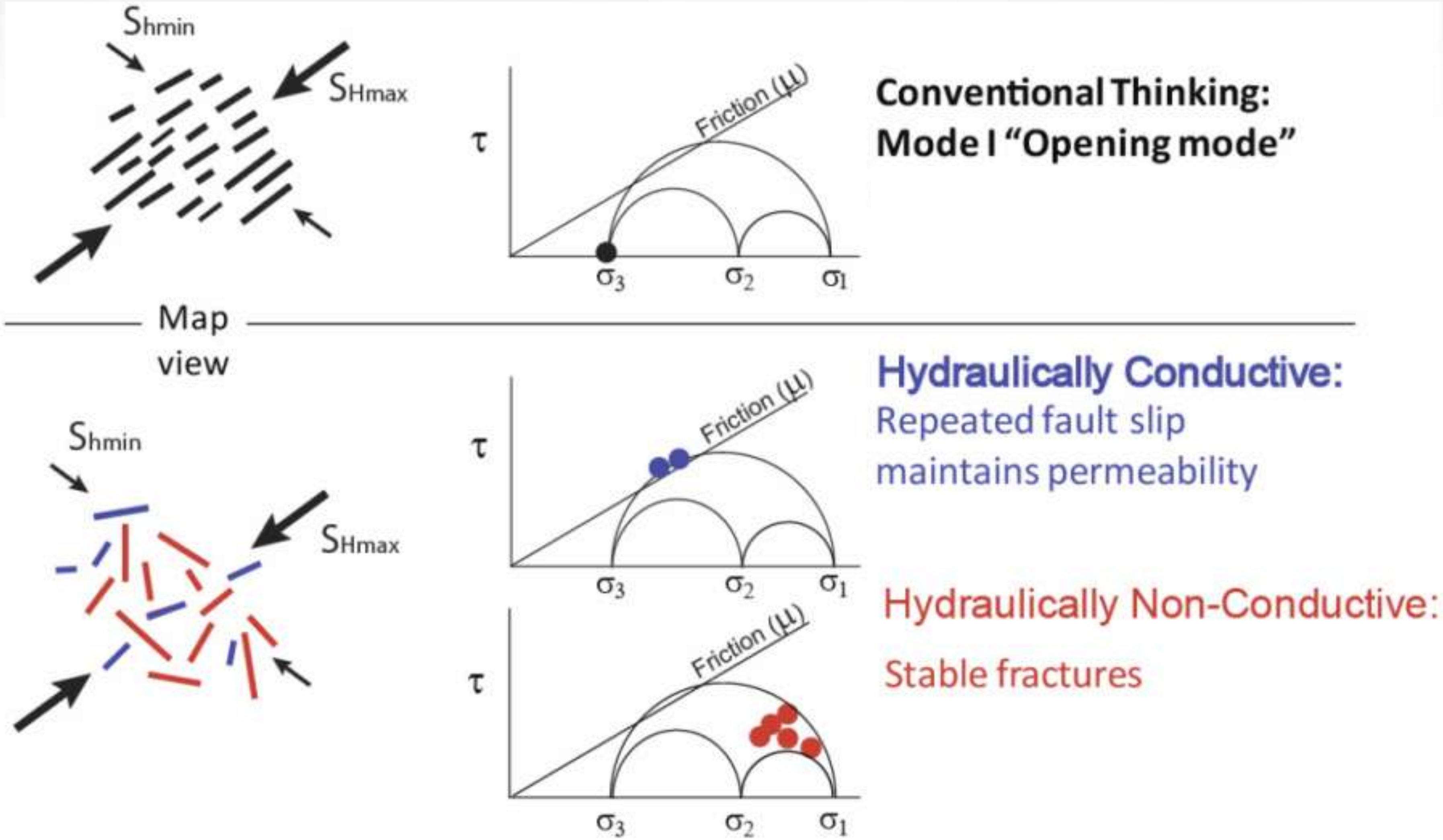
Mode I vs. Shear Modes II & III "Critically Stressed" Fractures



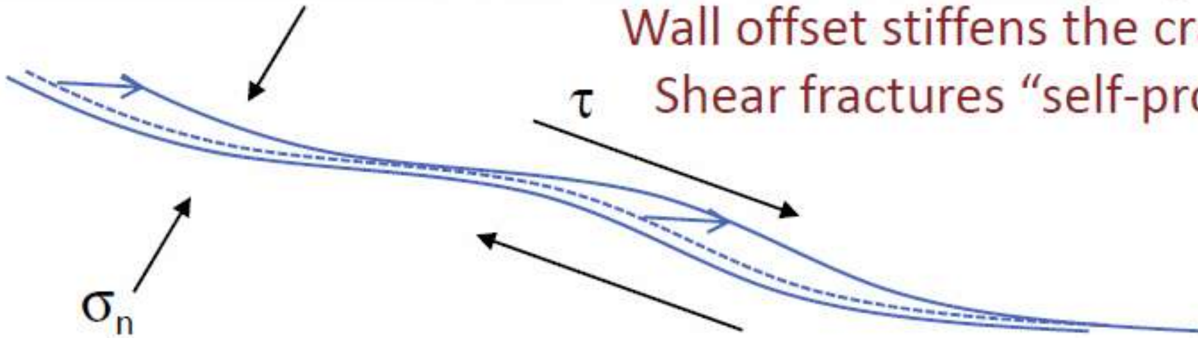
Fractures proximity to frictional failure is highly dependent on the relative stress magnitudes and pore pressures in the reservoir

Shear (Coulomb failure model) crack:

Slips, creating opening, if $\tau - \mu\sigma_n - S_o > 0$

Wall offset stiffens the crack

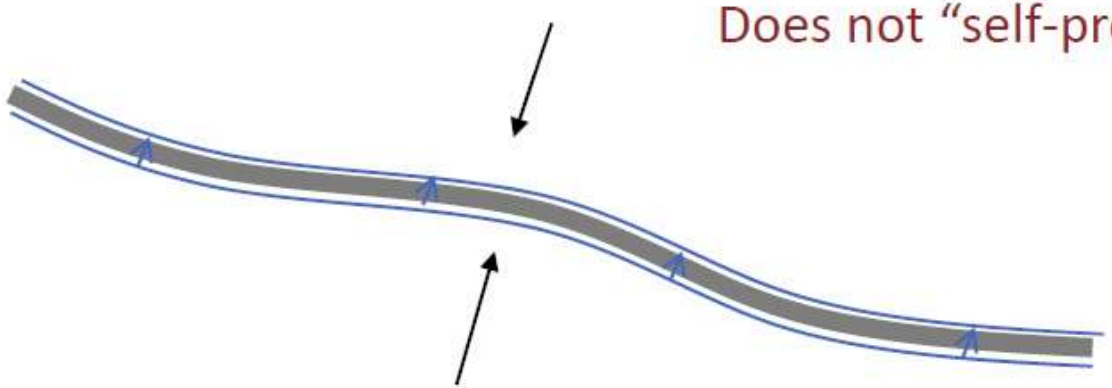
Shear fractures “self-prop”



Mode 1 (extensile) crack:

“opens” only if $\sigma_n < 0$

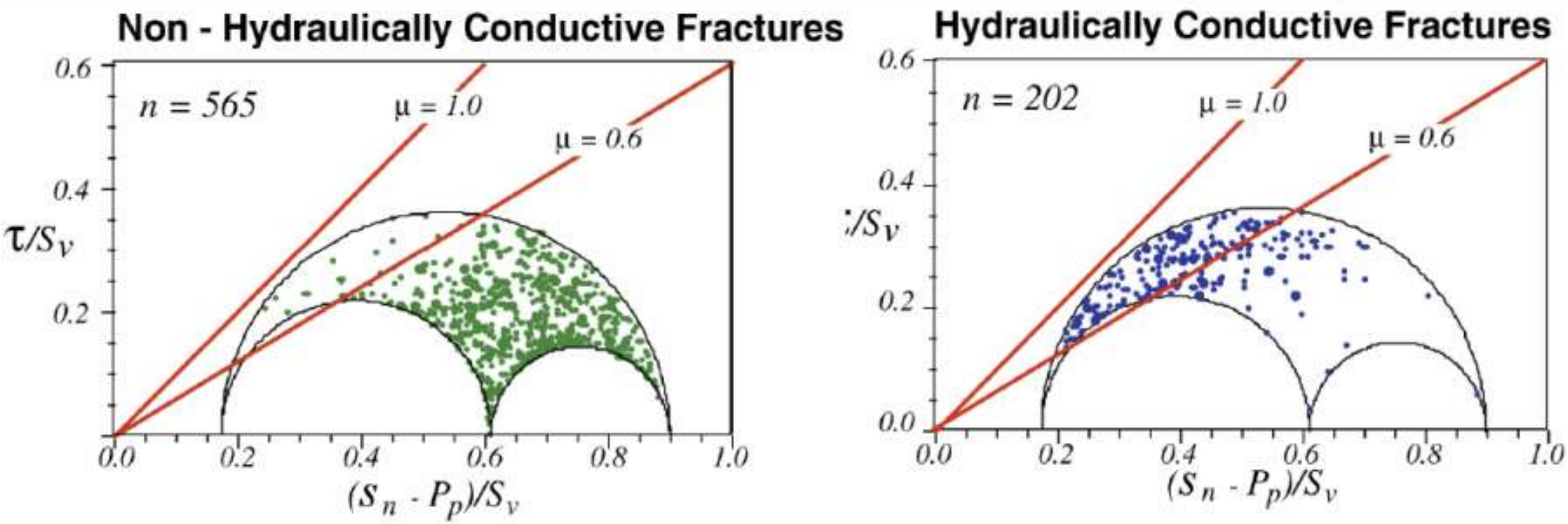
Does not “self-prop”



$\sigma_n = S_n - P_p$

To make a long story short, drilling normal to the most fractures may not be as productive as drilling normal to the most *critically stressed* fractures.

This brings us to the hydraulic fracturing problem.



Bakken SEM, Fabric, and Anisotropy

- Source and reservoir
- Primarily oil
- Contain both laminated and massive units
- Often jointed or fractured
- Kerogen and clays form part of the matrix
- Low porosity and micro-Darcy or less permeability

- Production almost always requires stimulation

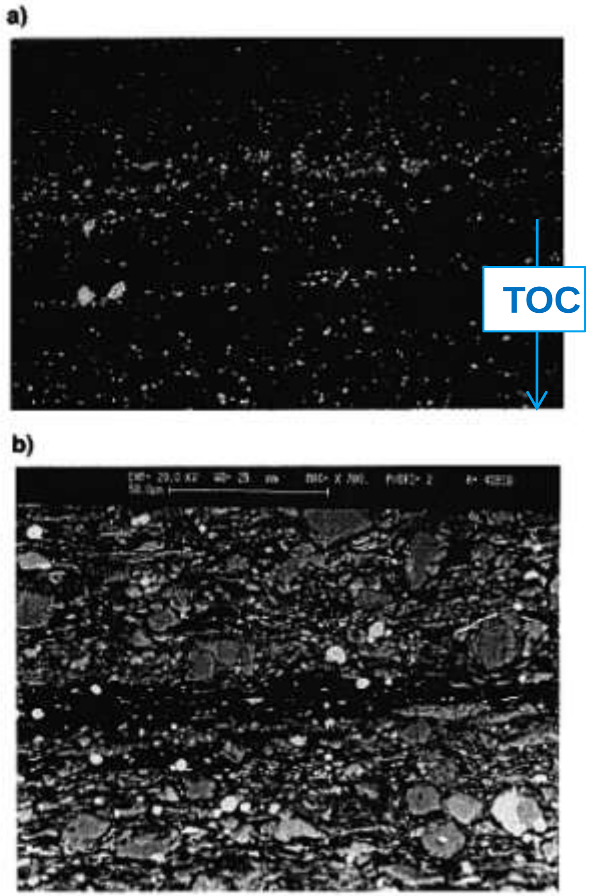


FIG. 2. (a) Photomicrograph of laminated black shale of the Bakken formation with bedding-parallel cleavage microcracks. The vertical dimension is about 3 mm. Note: alternation of silty and more organic-rich shaly laminae. (b) Backscatter SEM image of black shale displaying the distribution of kerogen (black) as lenticular microlayers dispersed among clay (illite) matrix and as sporadic layers (up to 10–15 μm) containing few clay particles.

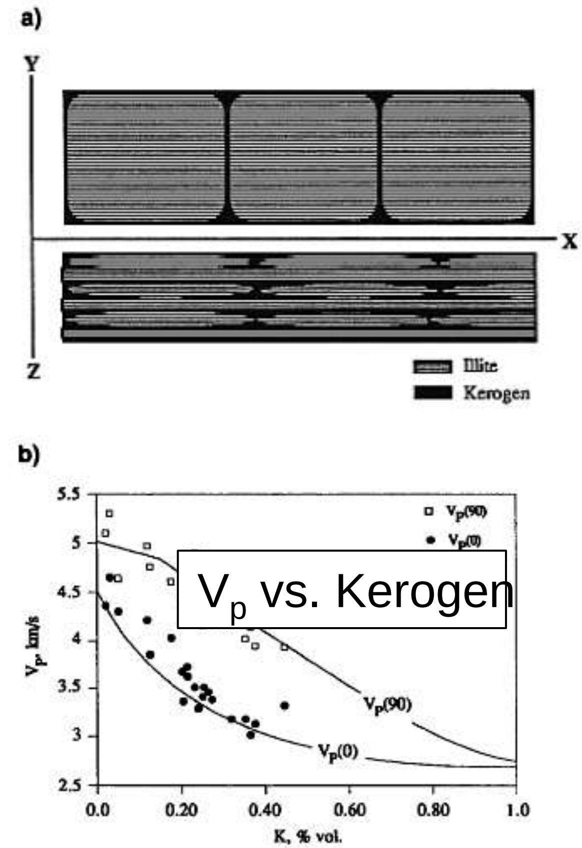


FIG. 10. (a) Schematic fabric topology of kerogen-rich (K > 0.15) shales showing discontinuity of some of the clay (illite) layers separated by kerogen in *XY* plane. *Z*-direction corresponds to the symmetry axis. (b) Modified model of velocity dependence on kerogen content taking into account the discontinuity in illite layers in the shale fabric. Note: much better fit to the data for the bedding-parallel propagation direction compared to the simple Backus model in Figure 9a.

Bakken examples from Vernik and Nur, 1992

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Observations on Bakken fracturing

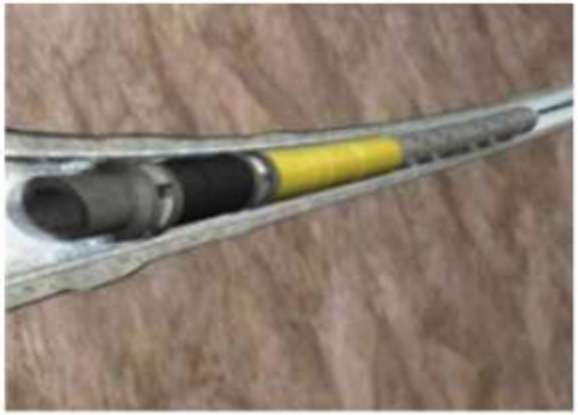
- Stimulated regions are not necessarily in the direction of S_{hmax}
- Current stress direction not necessarily the same as when microfractures were created
- Stimulation of large volumes by slick-water fracs is due primarily to shear slip on pre-existing natural fractures including maturation induced microfractures
- Stimulated region shape is controlled by
  - The stress state, primarily, stress anisotropy
  - The properties and orientations of natural fractures and pre-existing flaws
- Stimulated region efficiency is controlled by fracture prevalence, strength, flow properties, and local fluid pressure
- Anisotropies may have been caused by oil maturation leading to microfracturing

Some issues in Unconventional Oil

- Well completions and stimulations
  - Two major approaches
  - How hydraulic fracturing is conducted
  - How does this link to well performance and what we know about orientations

Completion Options – Shale Gas/Oil (For Hydraulic Fracturing of the Well)

- Cemented Liner
  - Plug-N-Perf Method
  - BHI QUIK Drill™ Composite Plugs
  - BHI Predator XS Perforating
- Openhole Completion System
  - BHI FracPoint™
  - BHI QUIK Drill™ Composite Plugs with RE Packers
- Multilateral Technology
  - BHI Frac-Hook™



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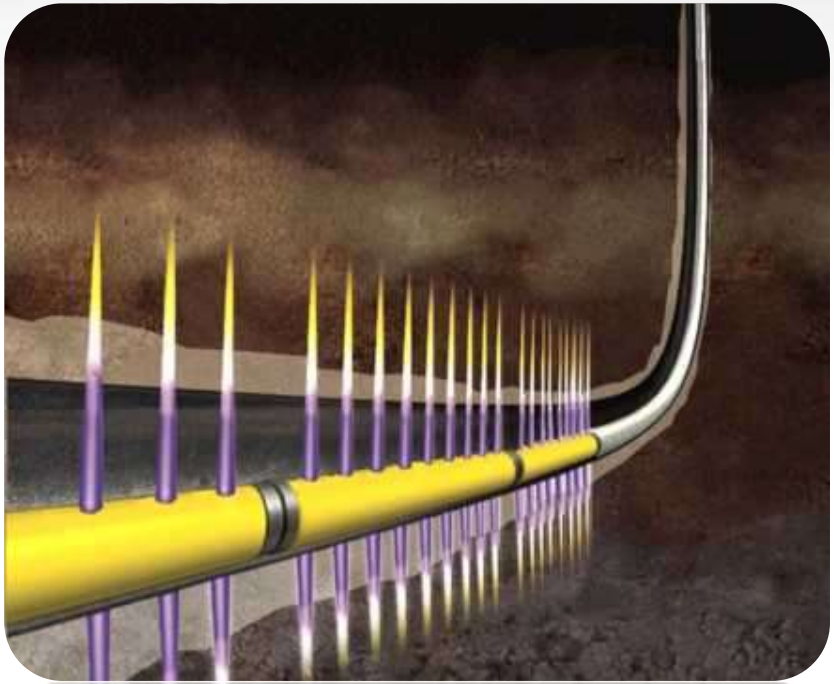
Plug-N-Perf Method



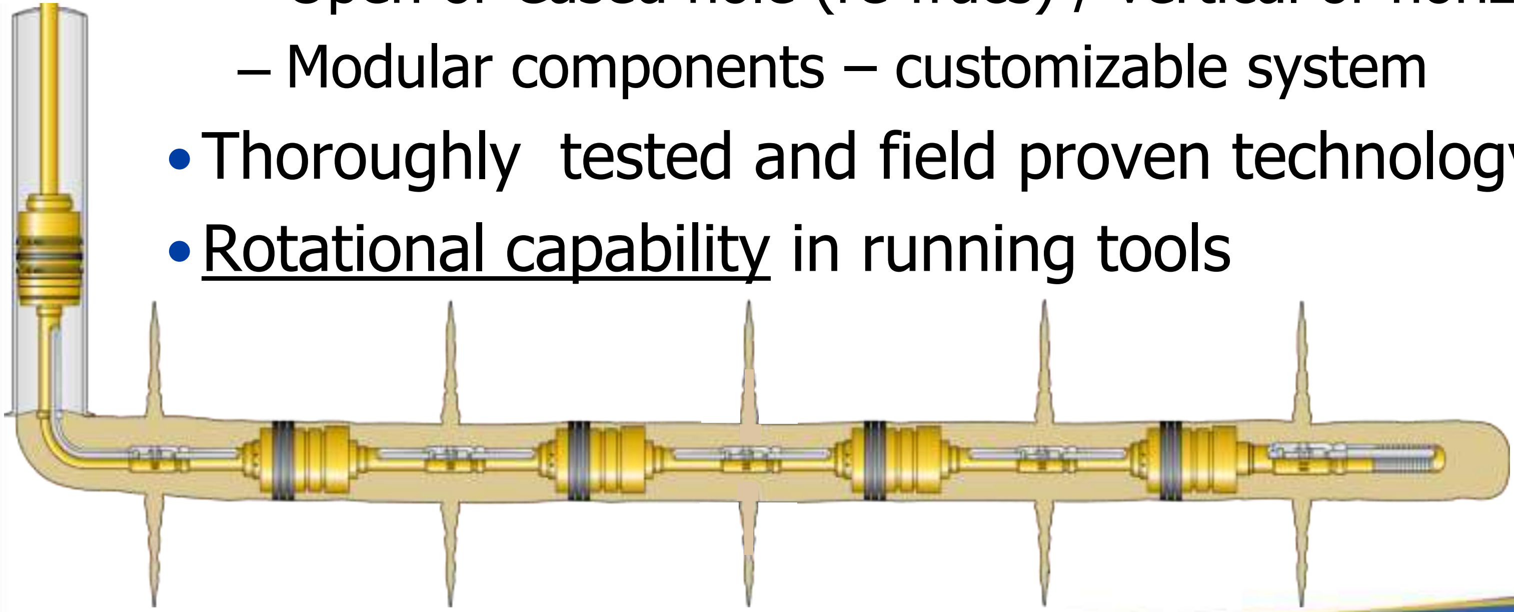
- Perforate and produce multiple stages with Perf Guns/TCP
- Fracture each individual zone
- Set Composite Plugs to provide zonal isolation between stages
- Horizontal/Vertical deployment

Plug-N-Perf Method: Bakken Implementation

- Uncemented liner / reactive element packers
  - Perforations perforate three short intervals per stage
  - Critical to perforate short intervals to avoid multiple initiations competing for fluid and thus small widths and larger shear components
  - Most (if not all) of the fracture would be in the initial fractures; fractures opened with sand laden fluid unlikely to propagate far
  - Production likely into the wellbore from each of the perforation intervals.
- Cemented liner
  - Control on initiation somewhat improved
  - Perforating straight down is unfavorable

FracPoint™ Completion System

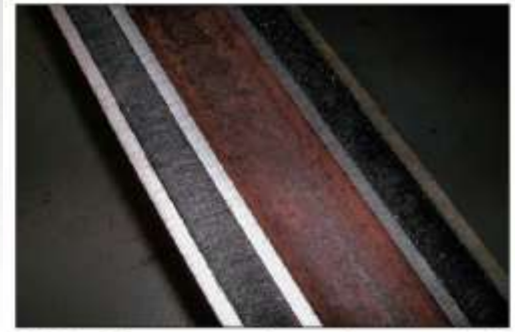
- One-trip system – up to 24 (+) stages
- Continuous frac operations save days of operations
- Eliminates perforating & liner cementing operations
- Versatile system
  - Primary and re-fracturing applications
  - Open or Cased hole (re-fracs) / vertical or horizontal
  - Modular components – customizable system
- Thoroughly tested and field proven technology
- Rotational capability in running tools



Reactive Element Packers

- Eliminates near-wellbore damage associated with cementing
- Versatile and customizable
- Tested to 10,000 psi
- No running tools reduces complexity and cost
- Lowers rig personnel requirements
- Reduces operational and HS&E risks
- Non-reversible elastomers won’t shrink if fluids are changed after swelling
- Seals self-energize in either oil- or water-based fluids

• Debris barrier



4.2-in.-OD pre-expansion packer expanded in 4.9-in.-ID test fixture

Post-expansion

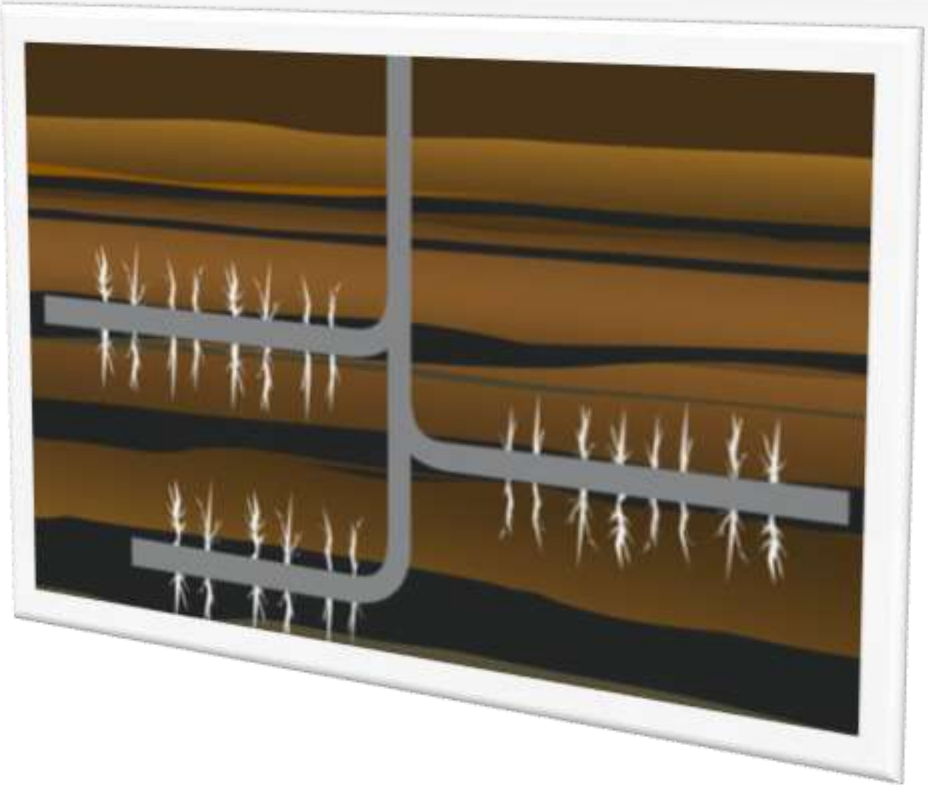
Relative Merits

- Plug-N-Perf
  - Decouples the Rig from the Frac
  - Drill and cement then standby to Frac and produce
  - Setting and Milling of plugs is a rigless operation
  - Maybe some added control on where to *initiate* the fracture, particularly in cemented laterals
  - Technically capable of selective shutoff
  - More attractive for transverse fracture implementation (CH)

- FracPoint
  - Rig needed to run the completion
  - Shortest overall time
    - Continuous Frac operation
    - No intermediate trips
  - Accelerates production!
  - Radical increase in the total wellbore exposure
  - Potential for lower initiation pressures associated with pre-existing flaws/fractures
  - RE packers less likely to frac across the packers
  - Minimal excess fluids pumped into formation

Frac-Hook™ Multilateral System

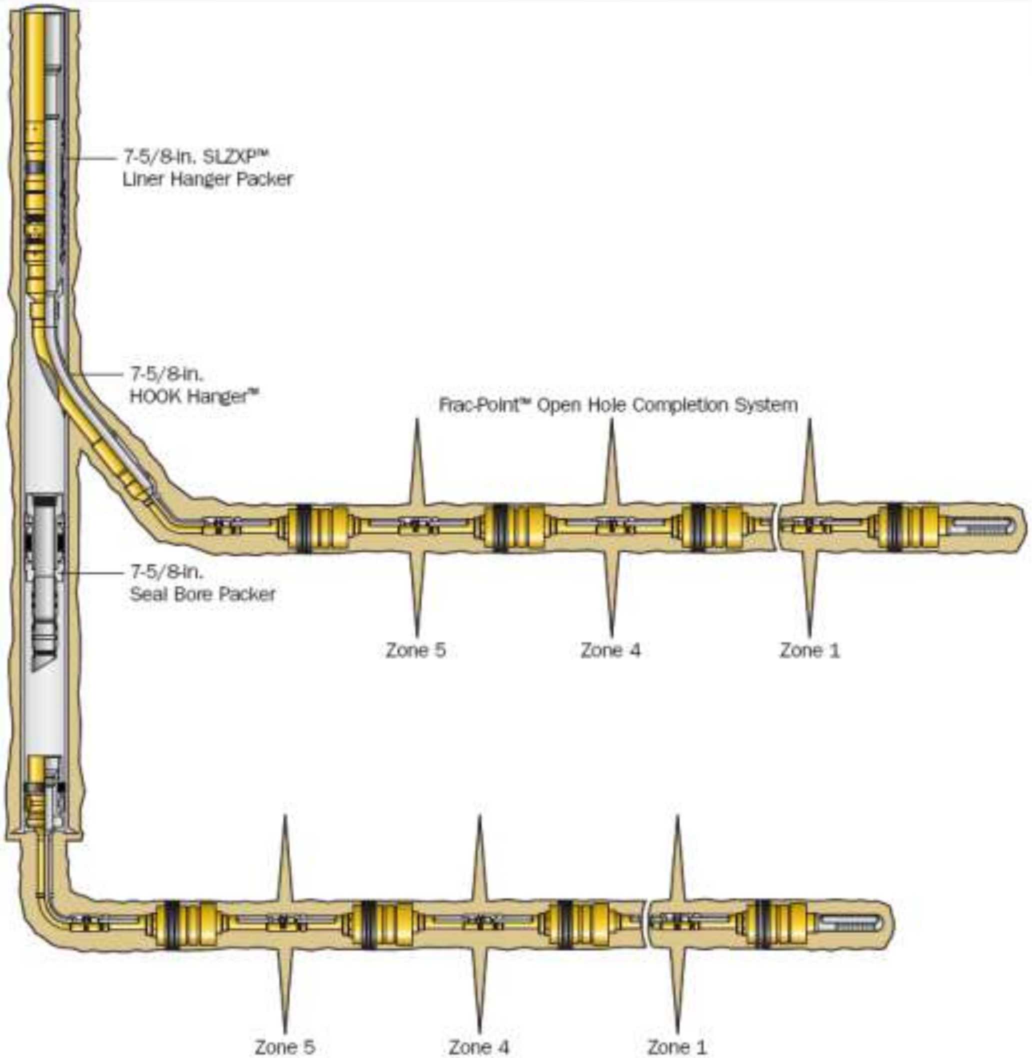
- Increased reservoir contact
- Reduced CAPEX
- Minimizes surface constraints
- Field-proven equipment
- Access to all laterals
- Deploy frac diverters with coiled tubing or threaded pipe
- Maintain current frac techniques
- “Back-to-back” fracturing
- Future re-frac capability
- 10,000+ psi rated equipment
- Rotating capability important



Installations

- CBM - Fruitland Coal & WCSB (Can)
- Shale/Tight (US)- Granite Wash, Eagle Ford, Woodford, Devonian , Tensleep, Amsden, Darwin, Fusselman
- Chalk

Frac-Hook™ Multilateral System – SPE 120478 (Case History)



Project Details

Well Location: Texas Panhandle (July, 2008)
Well Type: Gas & Oil Producer
Formation/Lithology: Granite Wash
Junction Type: Frac-Hook
Junction Depth: 10,404 ft MD
Main Bore Casing: 7-5/8″
Main Bore Liner: 4-1/2″
Main Bore Liner Length: 2,251 ft; 12,958 ft MD
Lateral Liner: 4-1/2″
Lateral Liner Length: 2,119 ft; 12,603 ft MD

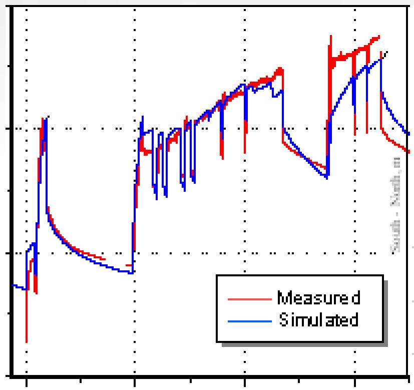
Results

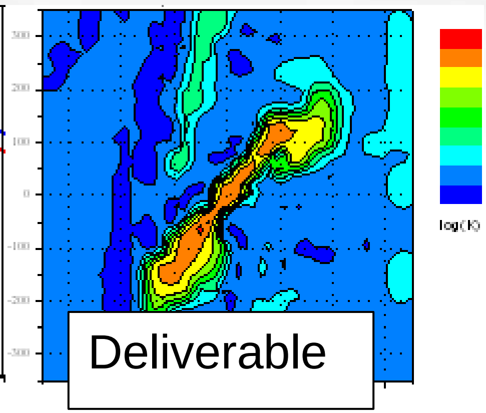
- Completion costs were **50%** less than operators average
- Average cost savings of **13%** compared to drilling **2** separate wells
- Production rates equivalent to **2** separate wells

(not) THE END

Integrated geomechanical reservoir modeling

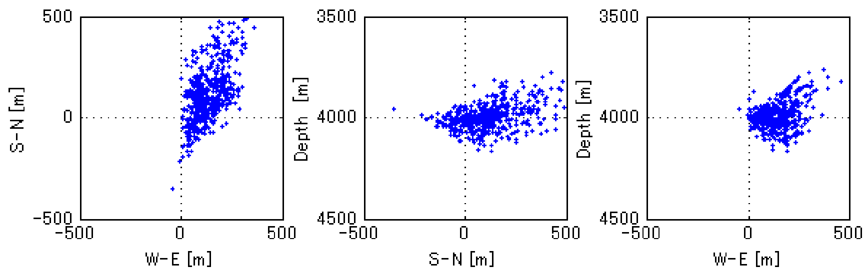
Pressure Match



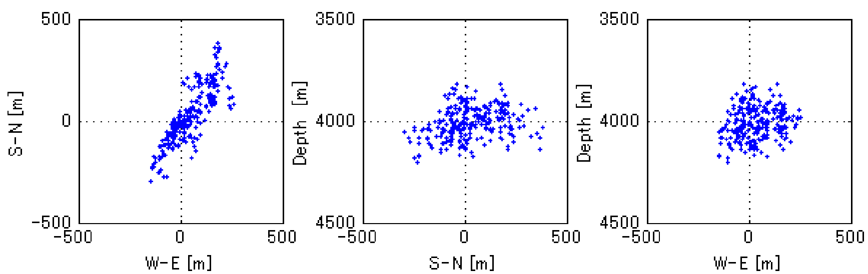


Predicted Permeability Improvement

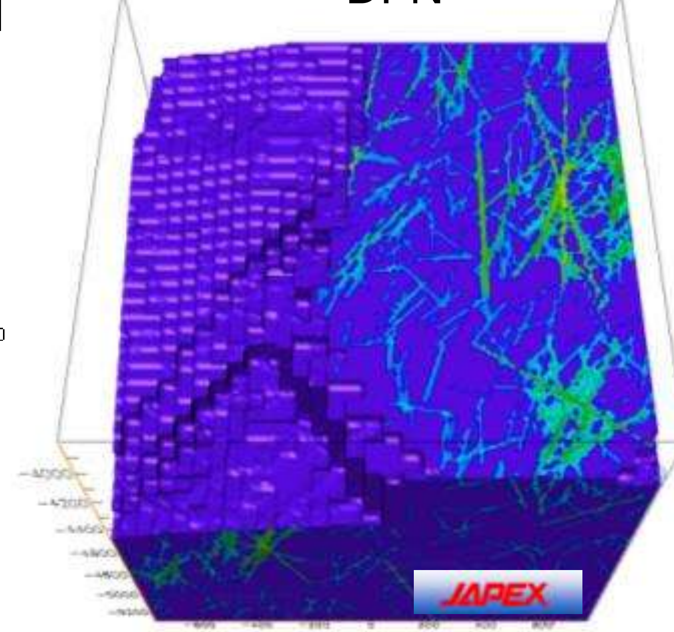
Observed events



Simulated Events



DFN



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