UNIVERSITY of HOUSTON
PETROLEUM ENGINEERING

Applied Geoscience Conference

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Role of multiple fracturing of vertical and Horizontal Wells in Maximizing production and extending life of the field

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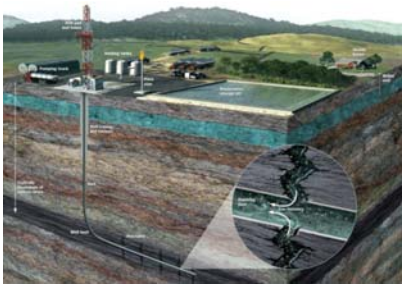
Outline

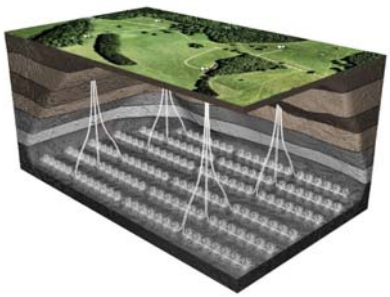
- Hydraulic fracturing and field development
- Hydraulically-fractured systems: design and arrangement
  - Why multiple fractures
  - Effect on production
  - Geomechanical consequences
- Fracturing and reservoir depletion
  - Low permeability formations
  - Naturally-fractured formations
  - Effect of pore pressure depletion on local stresses
- Re-fracturing and infill well fracturing
  - Is it required?
  - Vertical well: re-fracturing
  - Horizontal well: re-fracturing, infill well fracturing
  - Geomechanical considerations for infill drilling and refracturing
- Summary

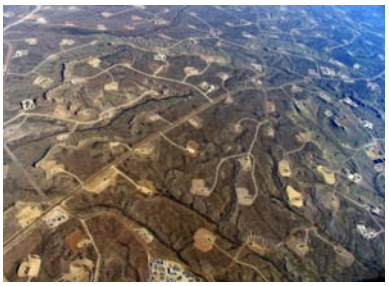
Hydraulic Fracturing and Field Development

Horizontal well fracturing



Pad drilling



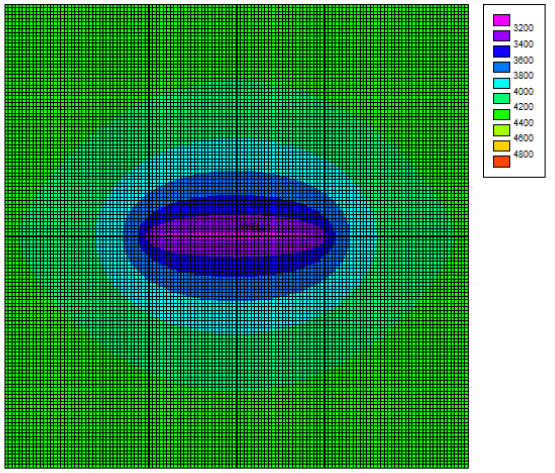


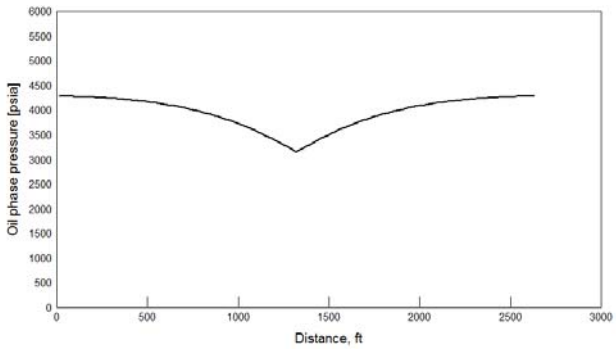
Haynesville Shale

Fracturing Low Permeability Formation

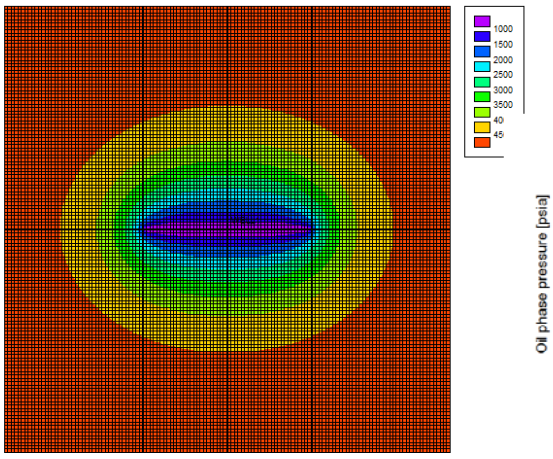
- High density fracturing is important to maximize fluid flow
- Re-fracturing may be necessary
- Both have Geomechanics consequence

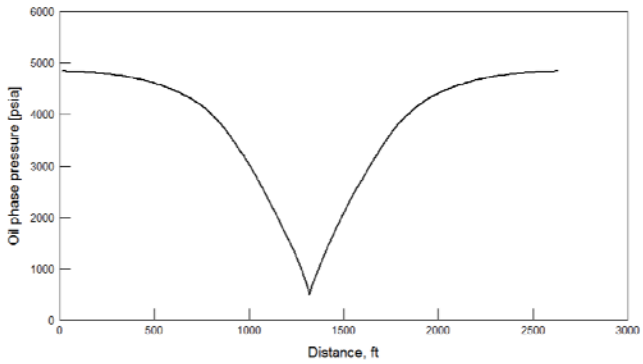
Oil Phase Pressure, Permeability = 1 md



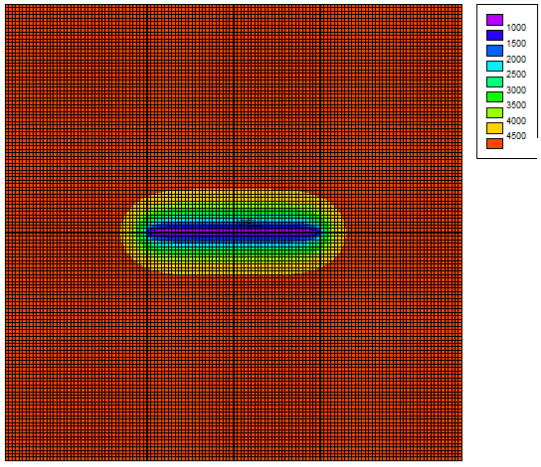


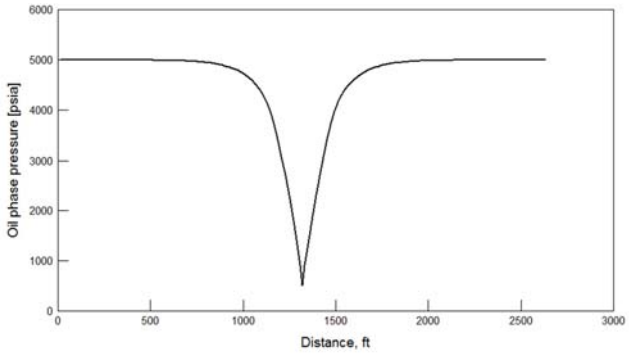
Oil Phase Pressure, Permeability = 0.1 md



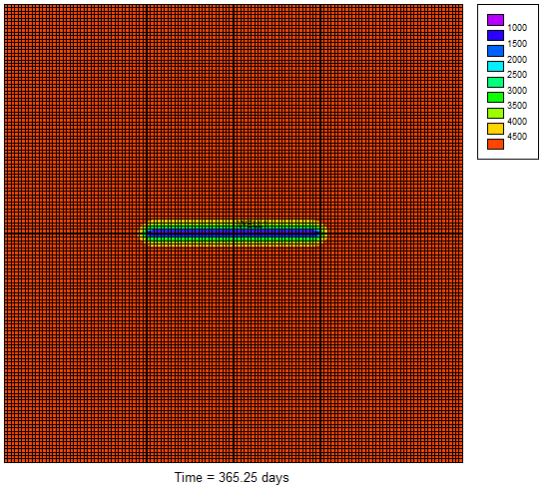


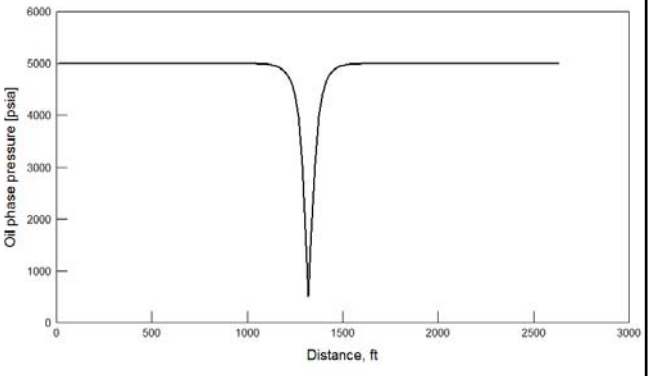
Oil Phase Pressure, Permeability = 0.01 md



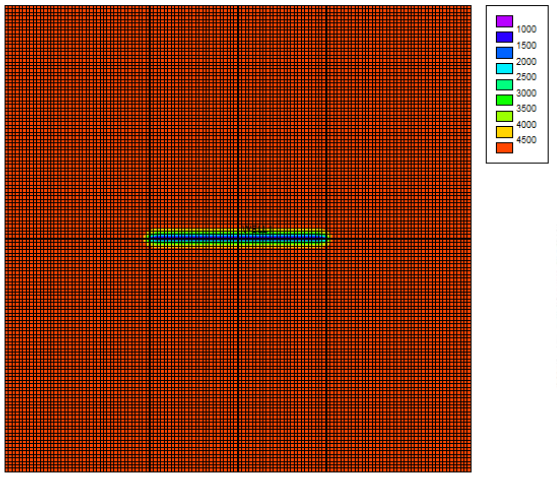


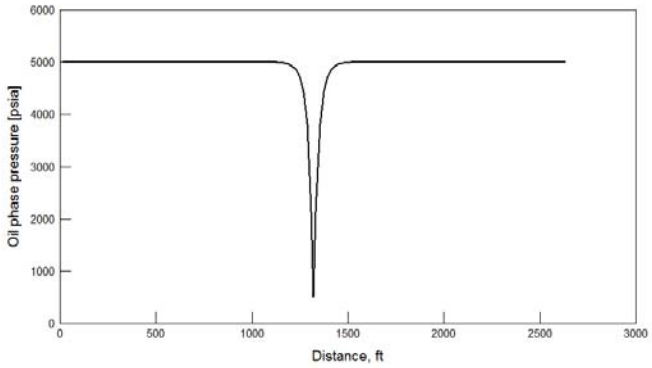
Oil Phase Pressure, Permeability = 0.001 md





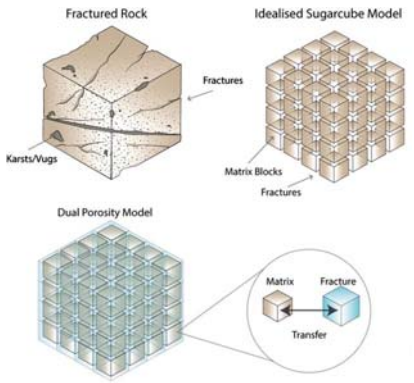
Oil Phase Pressure, Permeability = 0.0005 md





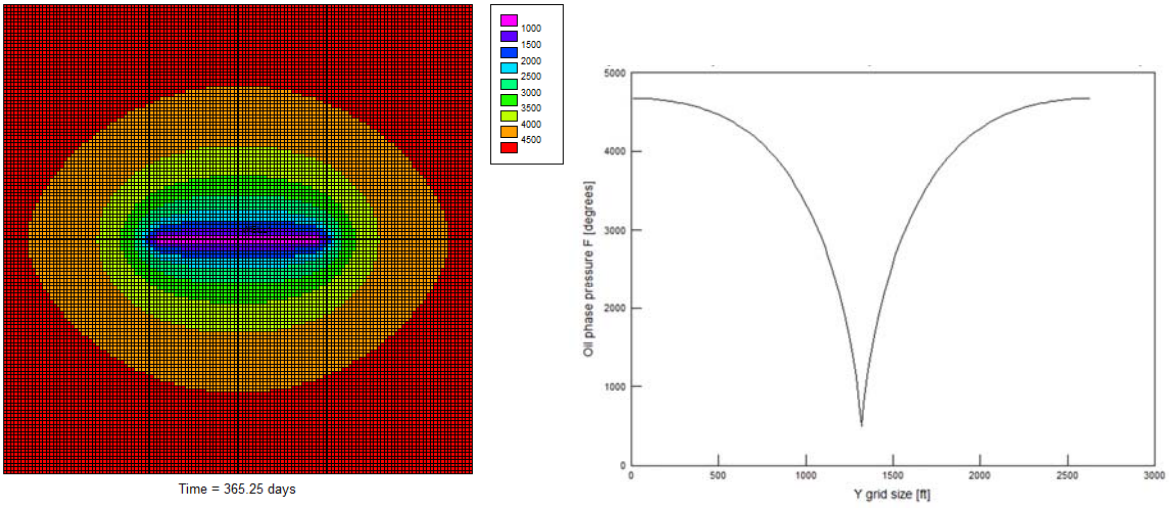
Fracturing Naturally-Fractured Formations

- Model consists of matrix and fracture (other than hydraulic fractures)
- Flow from both matrix and fractures

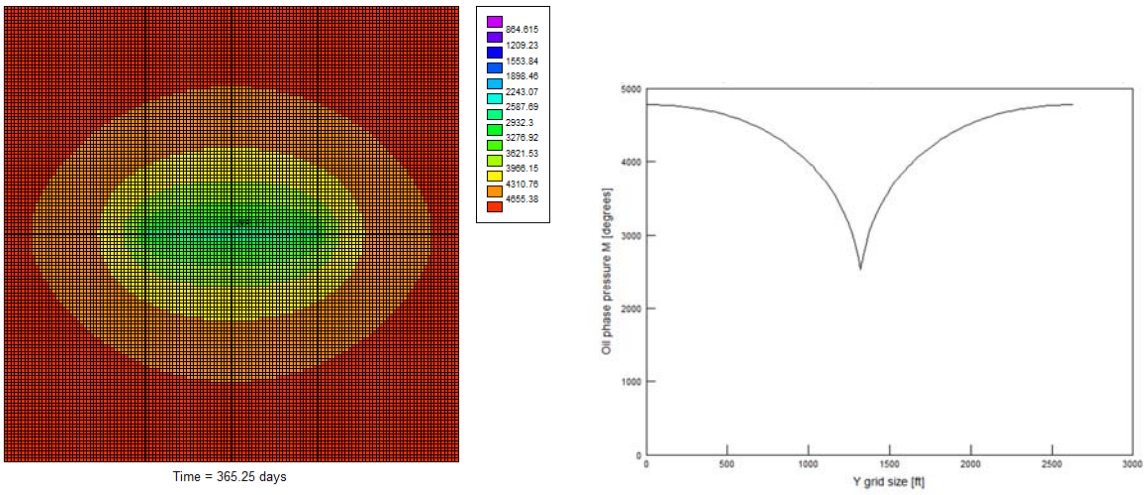


Kazemi et al, 1992

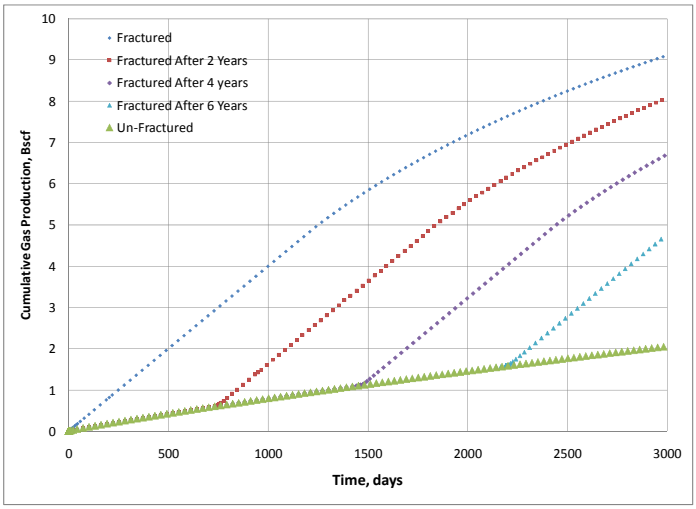
Oil Phase Pressure, Fracture System



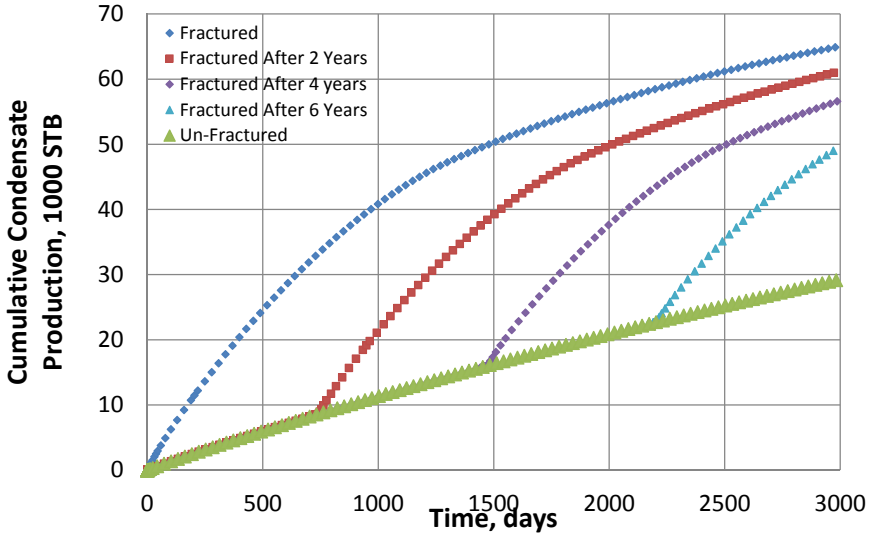
Oil Phase Pressure, Matrix



Cumulative Gas Production

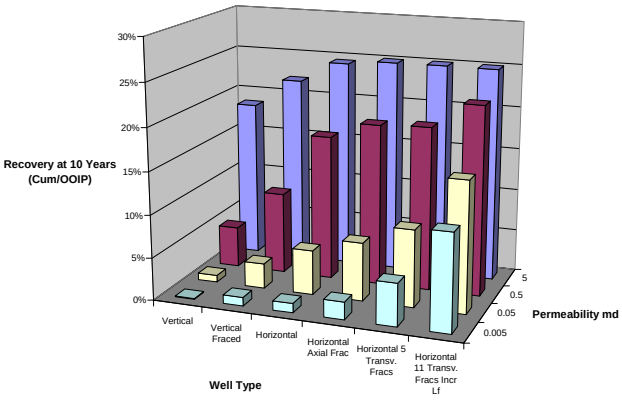


Cumulative Condensate Production

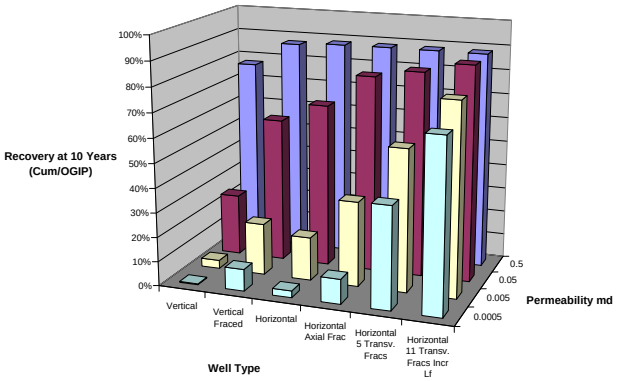


Hydrocarbon Recovery at 10 Years; Permeability vs. Well Type

Oil Well



Gas Well



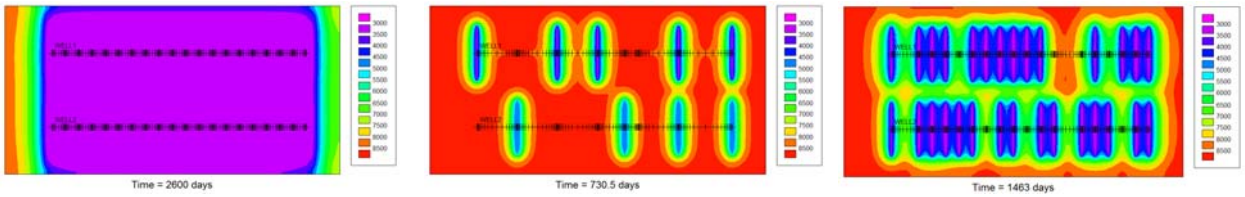
Fractured Systems

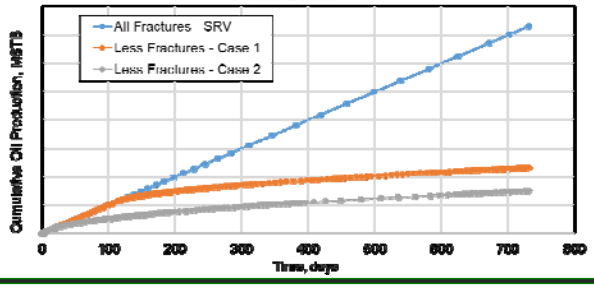
- Design and arrangement
- Effect on production
- Geomechanical consequences

HGS Applied Geoscience Conference (AGC) "Drilling and Completion Through the Life of the Field" November 2019

Effect of Fracturing and Refracturing

All fractures | Some fractures | Re-fracturing

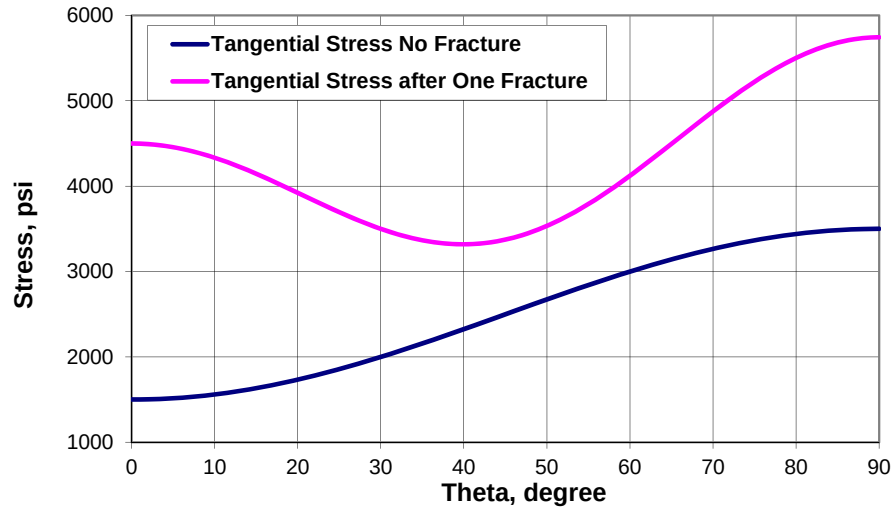




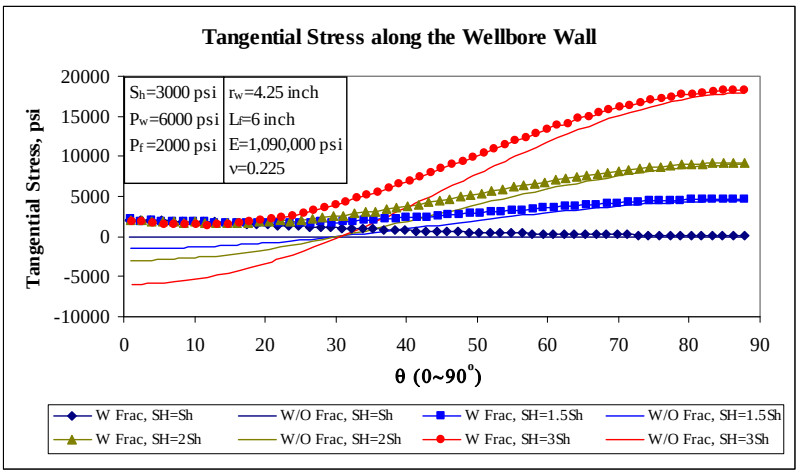
Multiple Fracturing of Vertical Wells

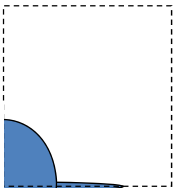
- Proposed for
  - Low perm formation
  - Declining fracture productivity
- Observed during drill cutting re-injection

Tangential Stress at Wellbore Wall



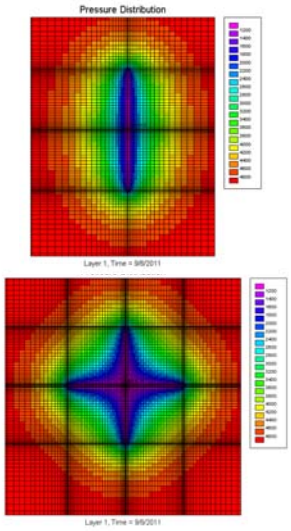
Tangential Stress at Wellbore Wall

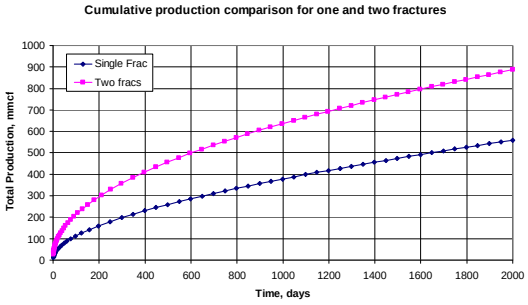


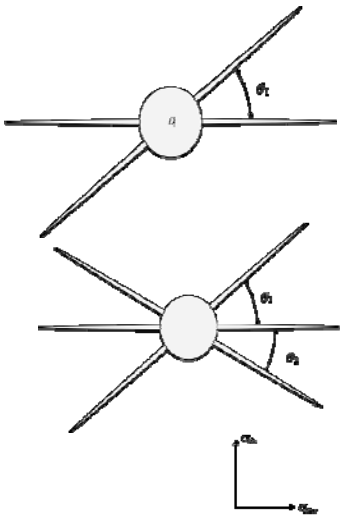


Wang, et al, SPE 201719

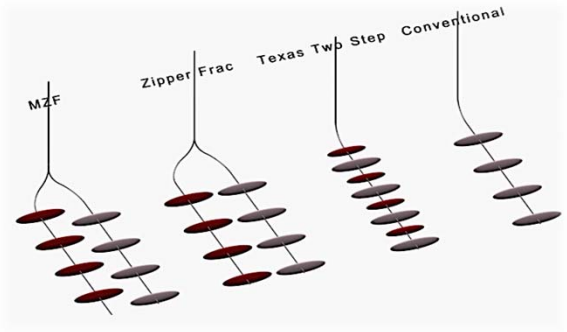
Multiple Fractures in Vertical Wells

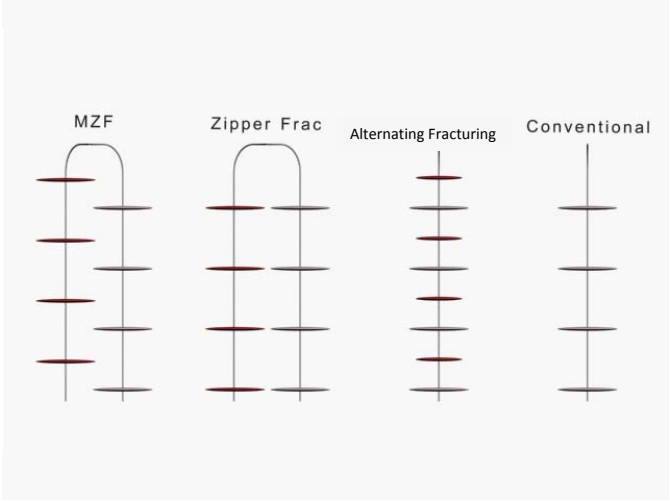






Multiple Fractures in Horizontal Wells

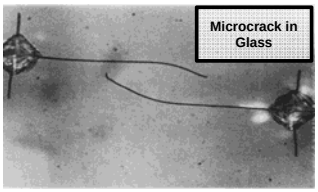


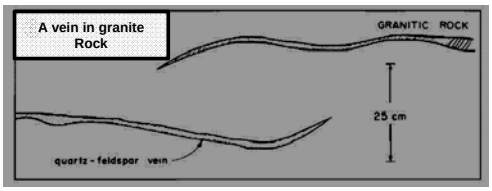


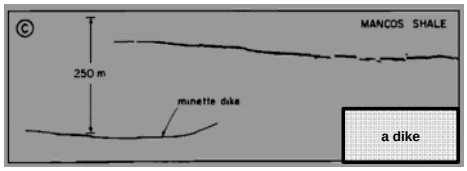
Propagation of Multiple Fractures (Clusters) from a Horizontal Well

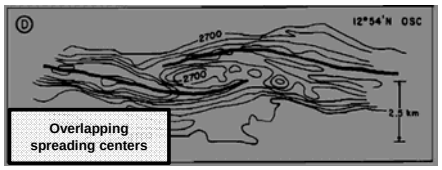
- Intra-Well fracture Interaction (frac-hits)
  - Interaction between active and passive fractures
- Inter-Well fracture Interactions
  - Interaction between fracture and offsetting wells
- Stress Shadowing
  - Stress alteration caused by deformation due to fracturing

Fracture Interactions in Nature



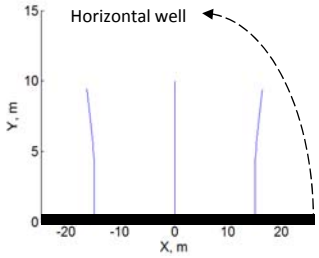


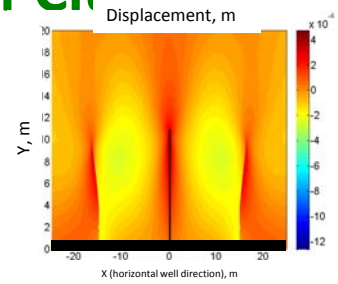


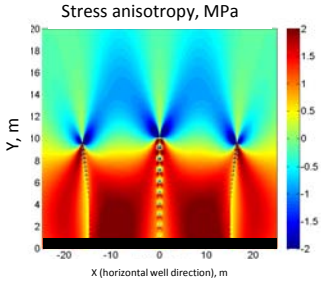


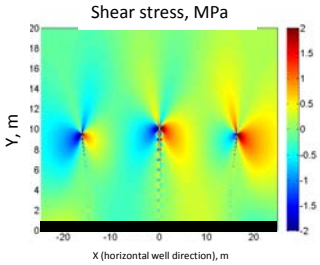
Swain 1978, Pollard 1984, Atkinson 1987

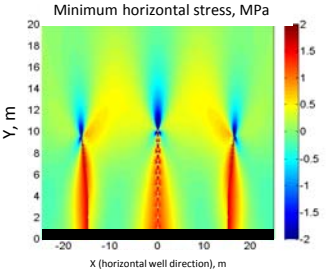
Propagation of Clusters

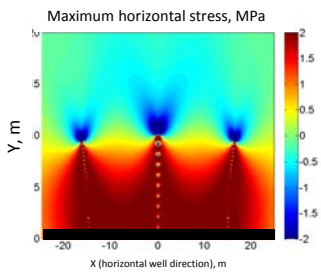




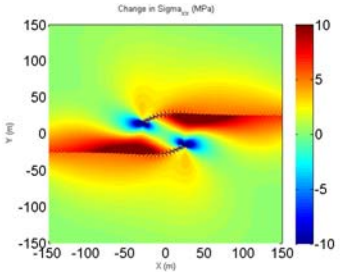


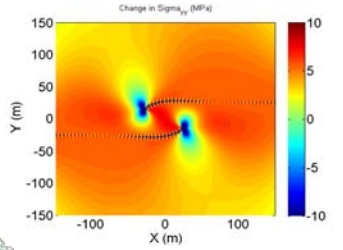




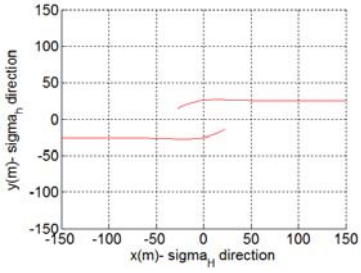


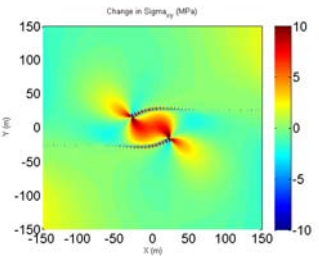
Overlapping Zones of Two Interacting Fractures

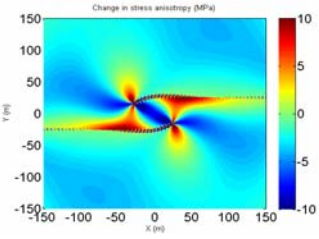




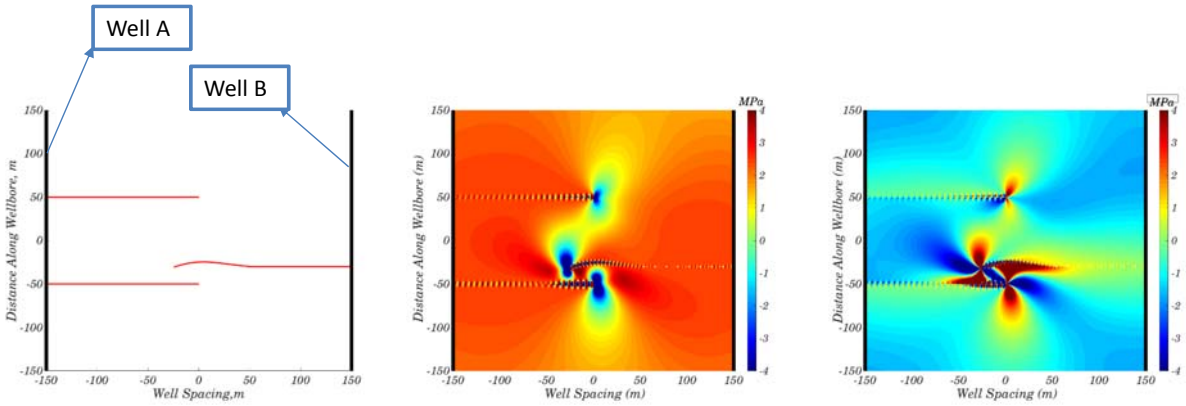
Rezaei, et al 2015
ARMA-2015-449



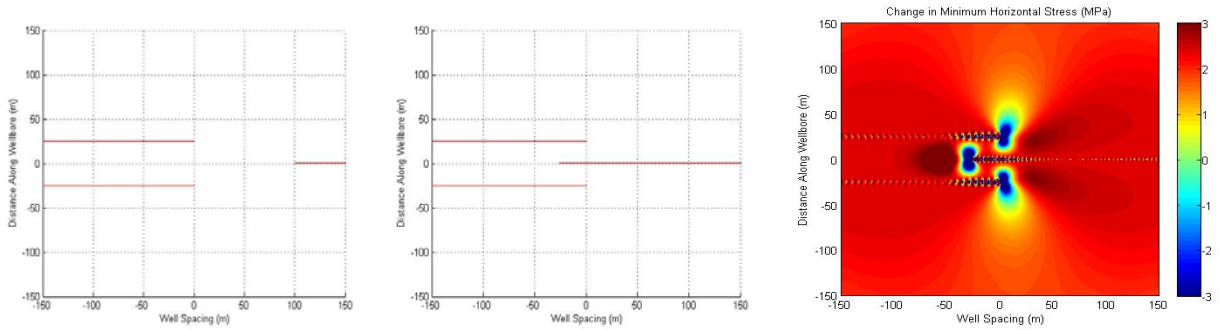




Modified Zipper Frac (MZF), Non-Symmetric

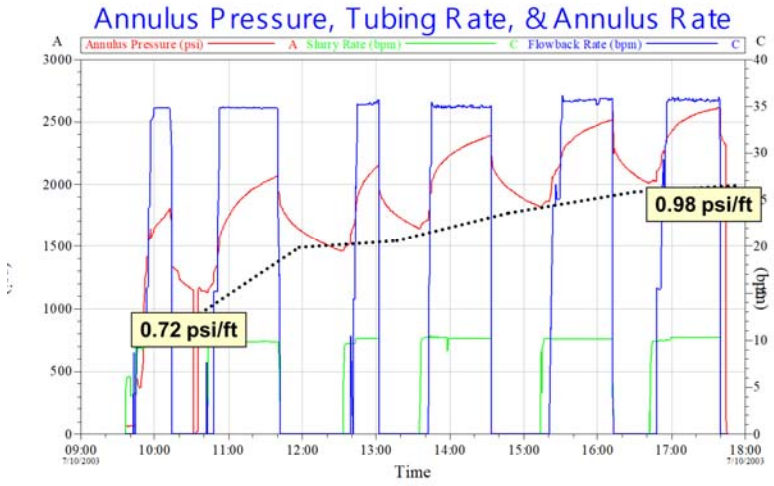


Modified Zipper Frac, Symmetric



Rezaei, et al 2015
ARMA-2015-449

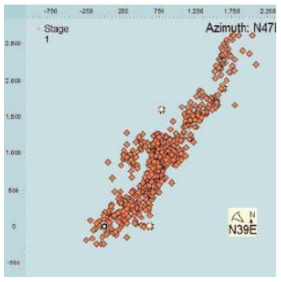
Six SurgiFrac Waterfracs performed consecutively for an Openhole Chert horizontal wellbore



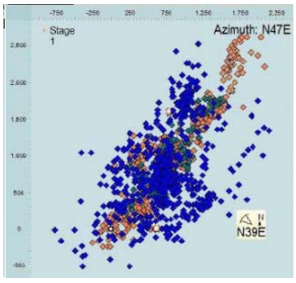
Re-Fracturing and Infill Fracturing

- Purpose
- Vertical wells: re-fracturing
- Horizontal wells: re-fracturing, infill well fracturing
- Geomechanical considerations

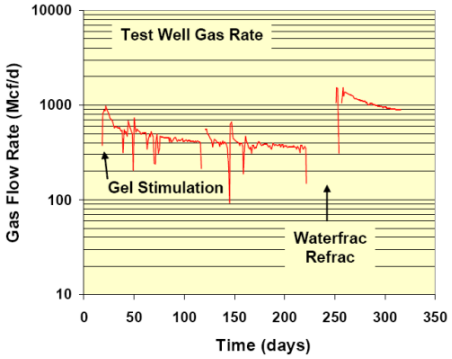
Why is Re-fracturing Needed?



Original

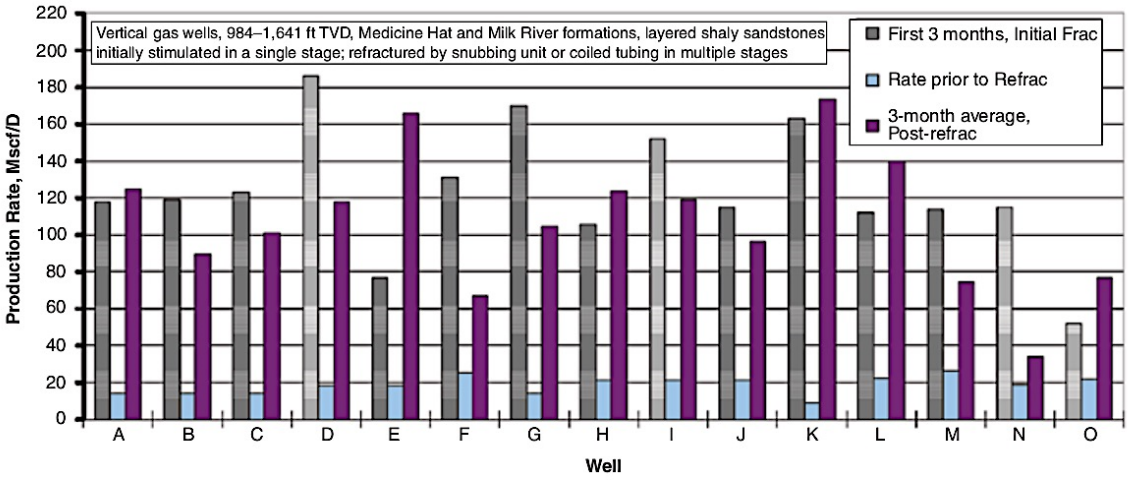


Original + re-fracturing



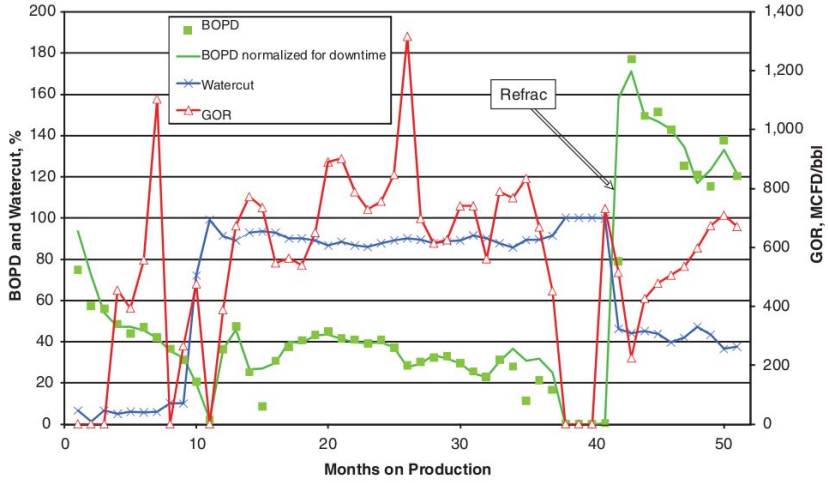
SPE 134330

Effect of Re-Fracturing on Flow Rate



SPE 136757

Example of a Successful Re-Fracturing



Horizontal oil well, 5,200 ft TVD, Middle Bakken in Saskatchewan. Fine-grained dolomitic sandstone formation 5–30 m gross Bakken thickness with 5–12% porosity and 0.01 to 0.5 mD permeability.

Frac gradient 0.68 psi/ft. Temperature of 150°F.

SPE 136757

Re-fracturing

- In Early 80's
- Multiple fractures in different orientations from a vertical well
  - Perpendicular Fractures from late 80's
  - Testing and refrac of a vertical well
  - Multiple fractures/application to drill cuttings injections

Vertical Well Re-fracturing

- Proposed for
  - Low perm formation
  - Declining fracture productivity
- Improves reservoir access
- Restore production
- Reorientation is desirable
  - Stress reversal helps
- Usually one fracture exist in the wellbore

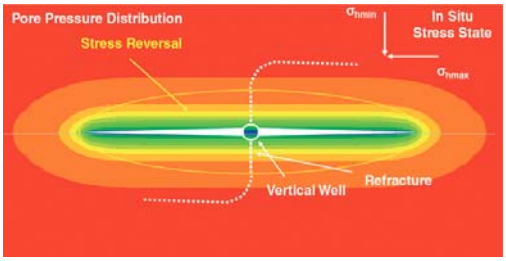
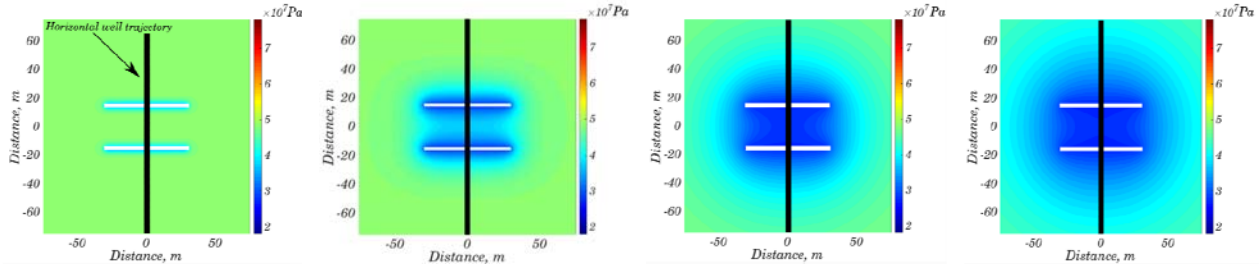


Figure Source:
American Oil and Gas Reporter

Issues with Refrac of Horizontal Wells

- Plug existing fracs
  - Natural loss of conductivity with time
  - Use plugging agent –chemical
  - Multiple proppant sizes
  - Perforate newer areas
- Drill Infill wells (Child Wells)
- Intra-Well Interaction (frac-hits)
- Inter-Well Interactions
- Stress Shadowing and reversal

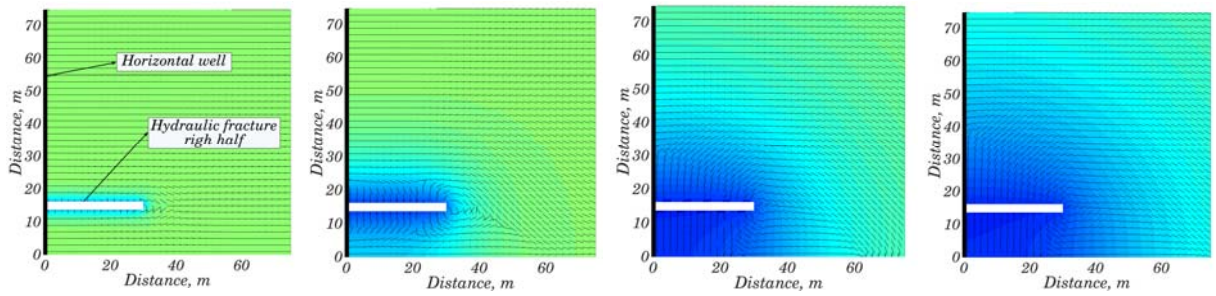
Pore Pressure Depletion



1 day | 1 month | 1 year | 3 years

Rezaei et al (doi: nag.2792)

Changes of Magnitude and Direction of Stresses with Time

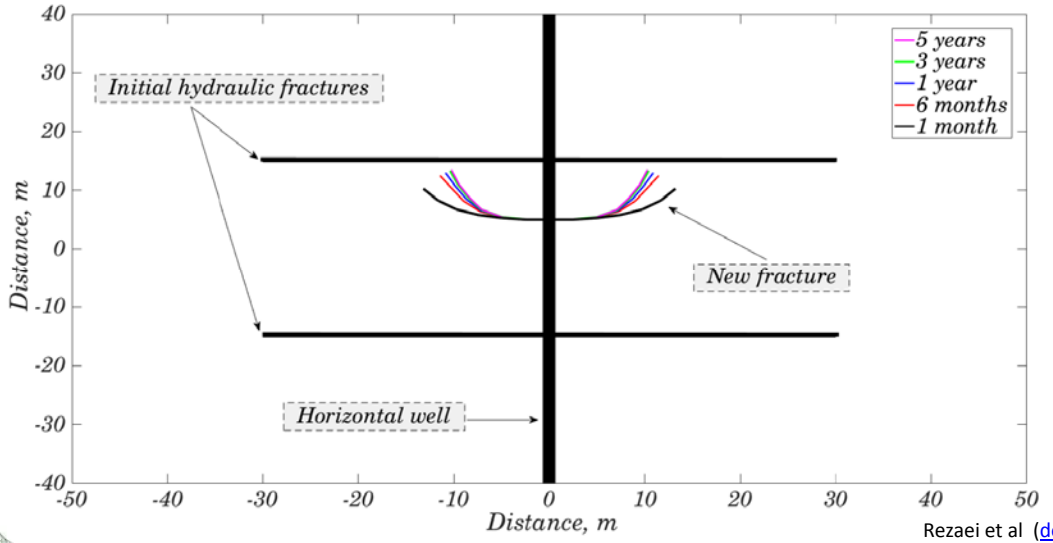


1 day | 1 month | 1 year | 3 years

Black lines are the σ_{max} direction on top of pore pressure depletion

Rezaei et al (doi: nag.2792)

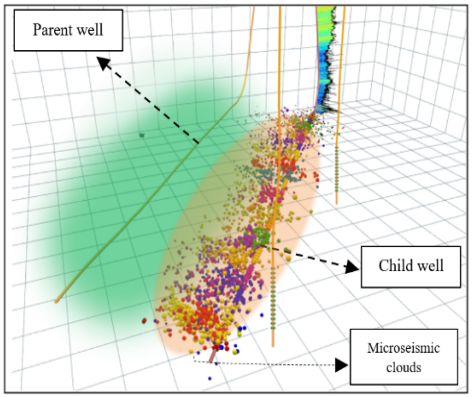
Effect of the Pore Pressure Depletion on Refarc Propagation



Rezaei et al (doi: nag.2792)

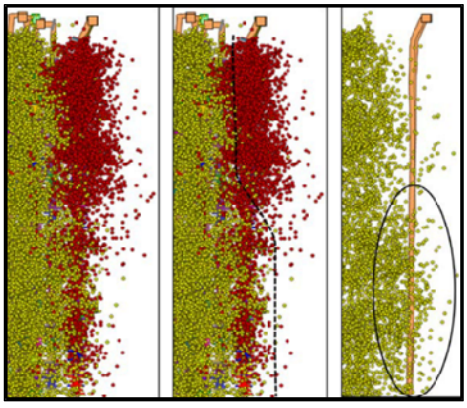
Infill Well Fracturing

Parent well attracts the fractures that are initiated in the infill well



SPE-181656-MS

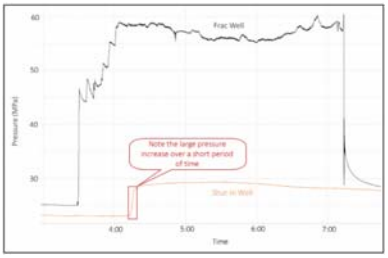
Microseismic activity around parent well



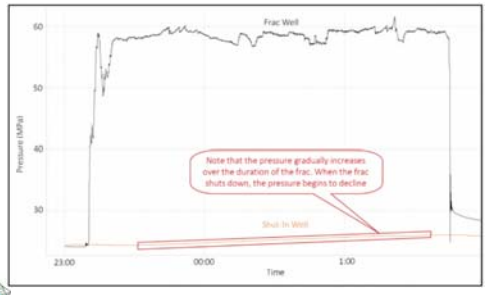
SPE-181767-MS

Infill Well Fracturing Problems

Direct hit

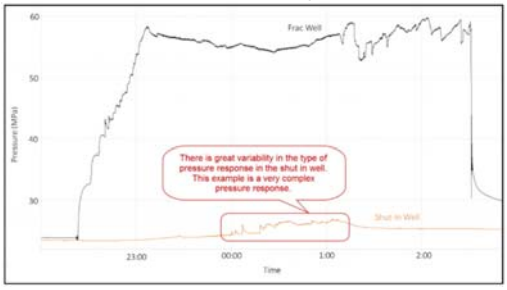


Fracture shadow

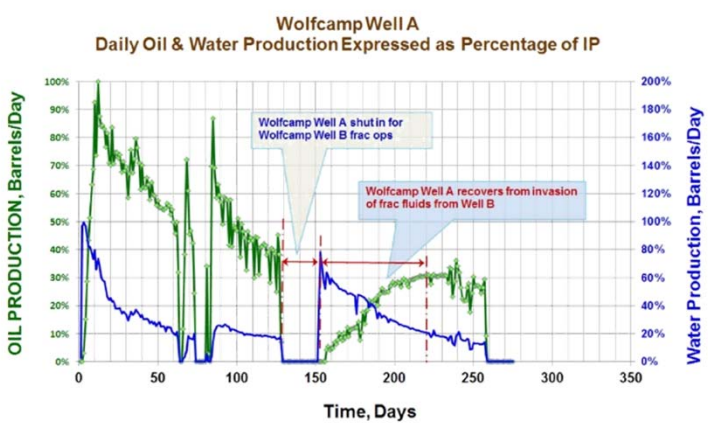


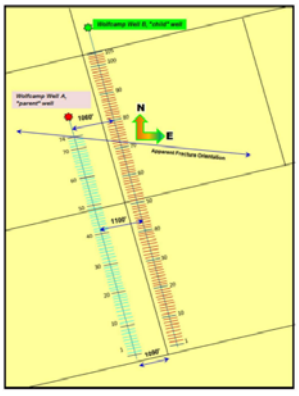
SPE 171628

Variable pressure hit



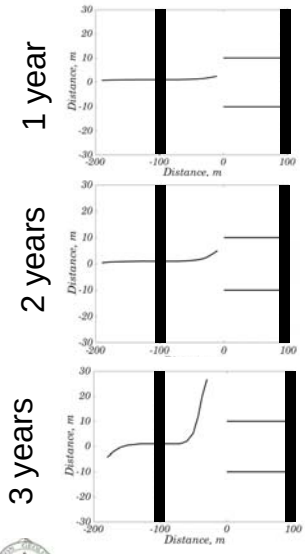
Consequences of Frac-Hit

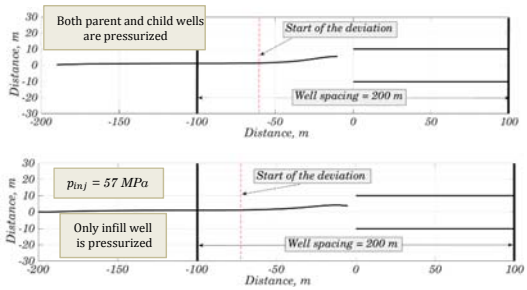




SPE 189853

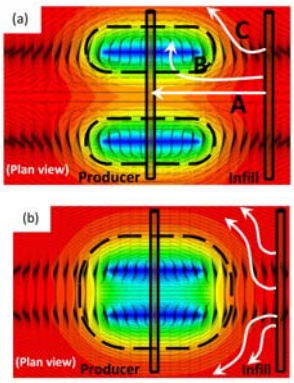
Propagation Path for Infill Well Fracture





Rezaei et al, 2019

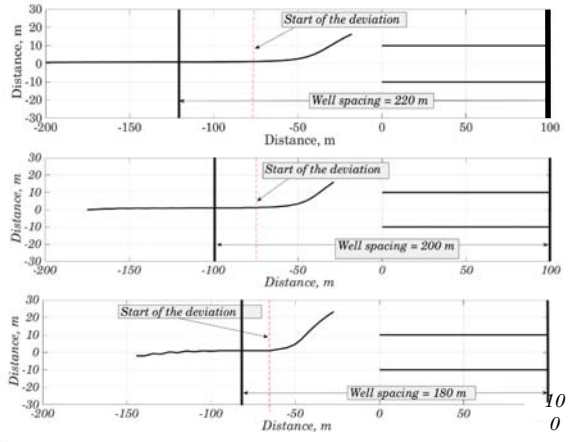
URTeC 2667433



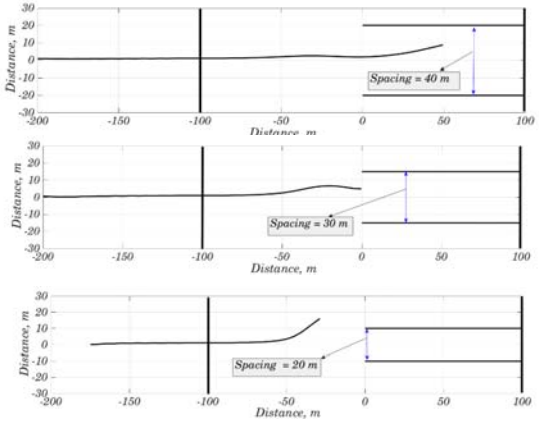
Safari et al, SPE 178513

Other Factors Affecting Propagation of Infill Well Fracture

Well spacing

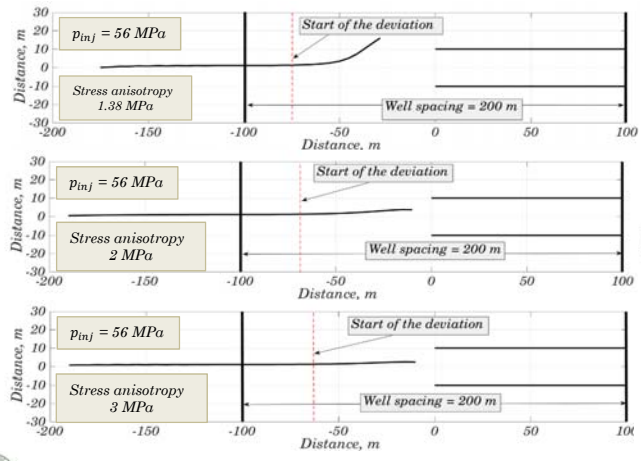


Parent well fracture spacing

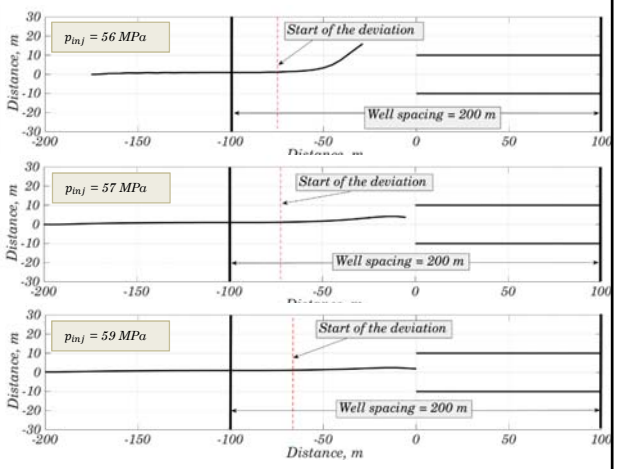


Other Factors Affecting Propagation of Infill Well Fracture. Cont.'s

Stress anisotropy



Pump pressure



Summary

- Hydraulic fracturing is an integrated part of field development
- Behavior of a hydraulic fractures are affected by:
  - Induced mechanical changes in stress regime (stress shadow)
  - Pore pressure depletion that causes redistribution of stress (stress reversal)
- Stress shadow affects the fracture behavior in multi-fracture systems
- Stress reversal:
  - Helps re-fracturing vertical wells
  - Not desirable for horizontal wells
- Both stress shadow and reversal affect the final recovery from reservoir by influencing hydraulic fractures behavior.

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