# Hydraulic Fracture and Natural Fracture Simulation for Improved Shale Gas Development*

**William Dershowitz[1], Ray Ambrose[2], Doo-Hyun Lim[1], and Mark Cottrell[3]**

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[1]FracMan Technology Group, Golder Associates Inc, Redmond, WA (dersh@golder.com)
[2]Devon Energy, Oklahoma City, OK
[3]Golder Associates UK Ltd, Belfast, United Kingdom

## Abstract

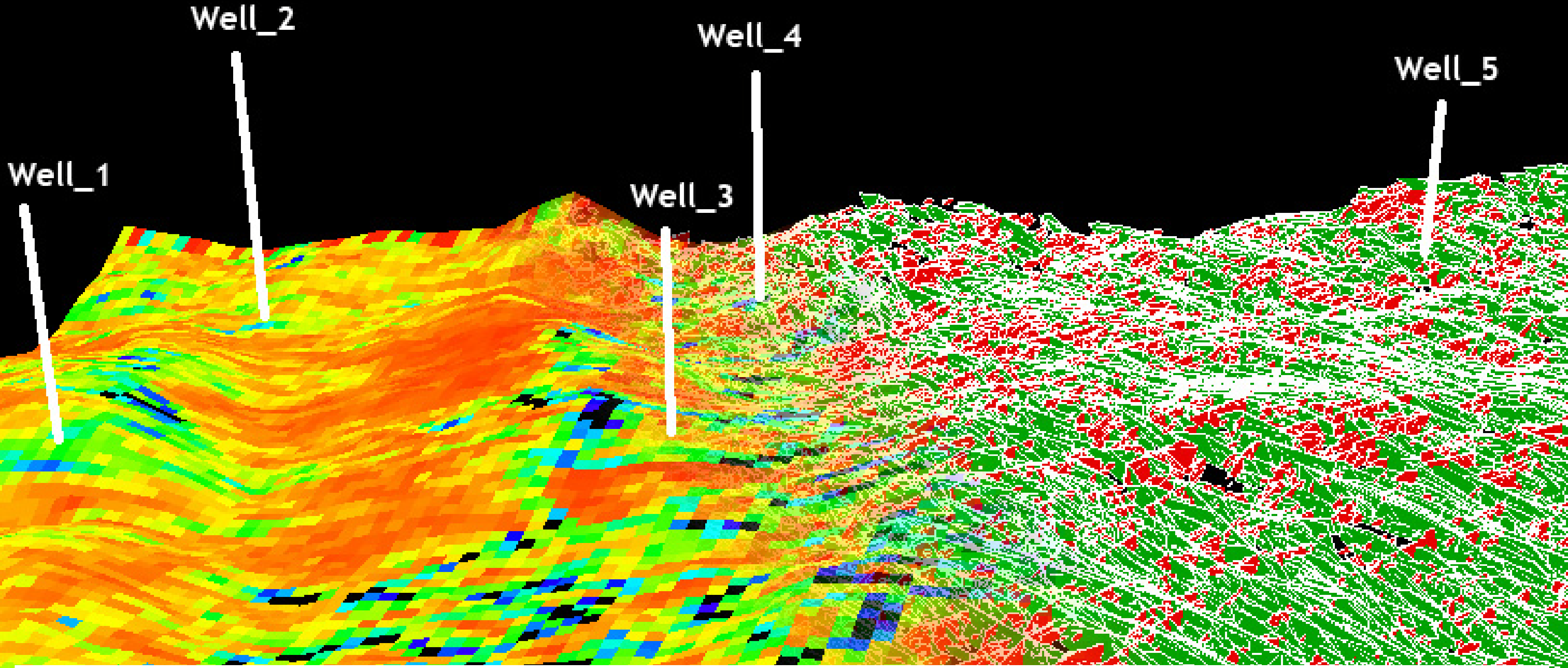
This paper describes a discrete fracture approach for assessment and exploitation of unconventional gas plays. The strategy depends on the evaluation of a localized, well trajectory specific tributary drainage volume, which considers the combined effect of hydraulic and natural fractures. The developed methodology includes (1) the prediction of the in situ stress, (2) geomechanical modeling of hydraulic fracture stimulation, and (3) a scalable DFN approach enabling rapid assessment of large numbers of hydraulic fracture configurations.

Using a geomechanical FE/DE technique, a prediction of the in situ stress conditions in locations where exploration wells may not exist has been made. The models have utilized a stepped approach and have considered specific geometry (major faults and stratigraphic boundaries) and rock properties surrounding the reservoir. The models have allowed local variations in stress and strain across faults to be assessed, and have provided a means for assessing data between wells to unexplored locations.

Reservoir-scale assessment of the in situ stress has provided initial conditions for a range of well-scale models investigating hydraulic fracture stimulation. These geomechanical hydraulic fracture configurations have been supplemented using a scalable DFN-based simulation approach. This has permitted several thousand hydraulic fracture configurations to be rapidly assessed for varying configurations. Both of these approaches use key physical representations, including intact rock strength, natural fracture response, the in situ stress, and the fluid injection conditions.

The result obtained from these simulations allows better understanding of different injection strategies and insight into how the physical quantities of stress, displacement, and fluid pressure inter-relate. Unconventional gas is present at many locations around the globe. These sources exist in a variety of forms, including shale gas, coal bed methane and tight gas. Prediction and understanding of hydraulic fracture stimulation is critical to facilitating enhanced unconventional gas production.

# Hydraulic Fracture and Natural Fracture Simulation for Improved Shale Gas Development



**Bill Dershowitz[1] • Ray Ambrose[2] • D-H Lim[1], Mark Cottrell[1]**

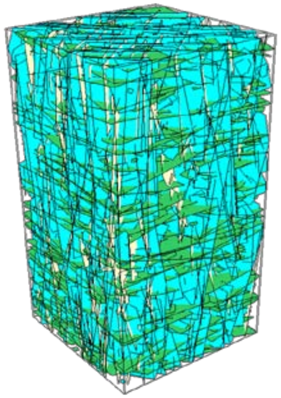
**1 - Golder Associates, Redmond, US; 2 – Devon Energy, Oklahoma City, US**

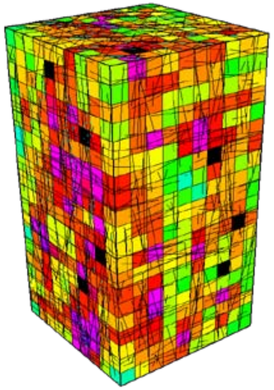
AAPG Annual Conference and Exhibition

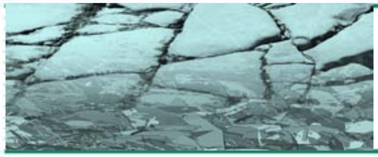
10-13 April 2011 • Houston

# Presentation Overview

- **Hydraulic Fracture and Natural Fracture Simulation for Improved Shale Gas Development**
- Presentation describes a discrete fracture approach and workflow for assessment and exploitation of unconventional plays;
- The developed workflow includes:
  1. Derivation of in-situ properties; fractures, stress, strength;
  2. Geomechanical modelling of hydraulic fracture stimulation; and
  3. A scalable DFN approach enabling rapid assessment of large number of hydraulic fracture configurations.
- The results obtained from these simulations allow for an improved understanding of different injection strategies and insight into how the physical quantities of stress, displacement and fluid pressure inter-relate.



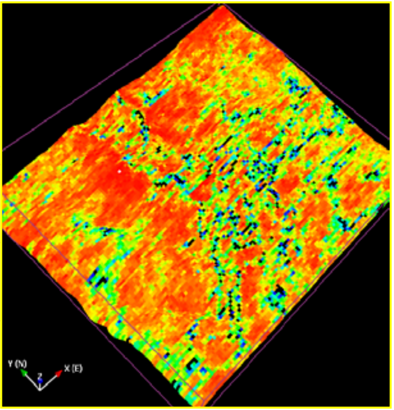




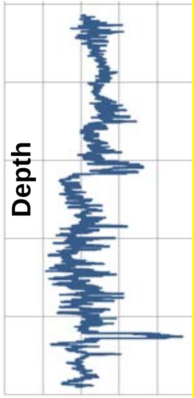
# Derivation of Rock Properties

- Rock mass strength (Mohr-Coulomb, Hoek-Brown, Barton Bandis);
- Rock mass deformability (Elastic modulus & Poisson’s ratio);
- Essential for defining frac-height → Hydraulic fractures propagate vertically until they reach distinct elasticity contrasts (i.e. quenching layer of softer materials);
  - Fractures proceed in dolomite until they reach shale
  - Fractures proceed in shale until they reach a softer shale…
- Rock property grids are generally derived from seismic velocities or wireline geophysics (Sonic, Gamma, etc).

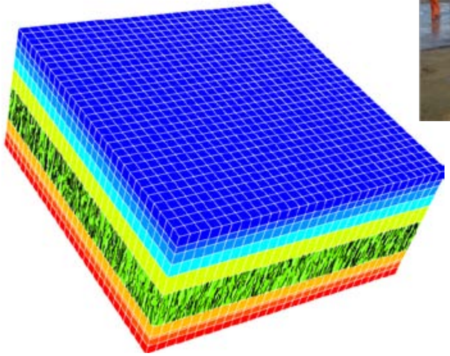
**Seismic Attribute**

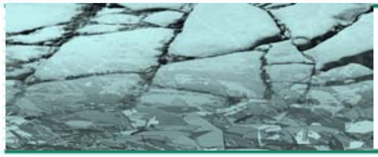


**Core**



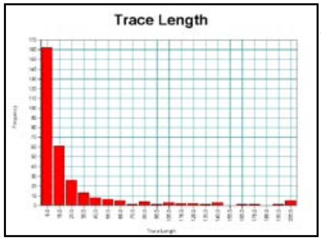
**In situ testing**



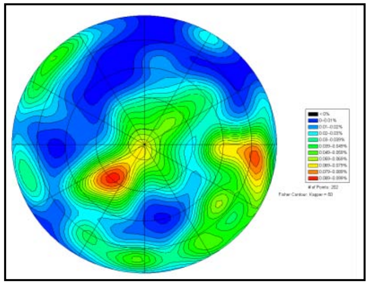


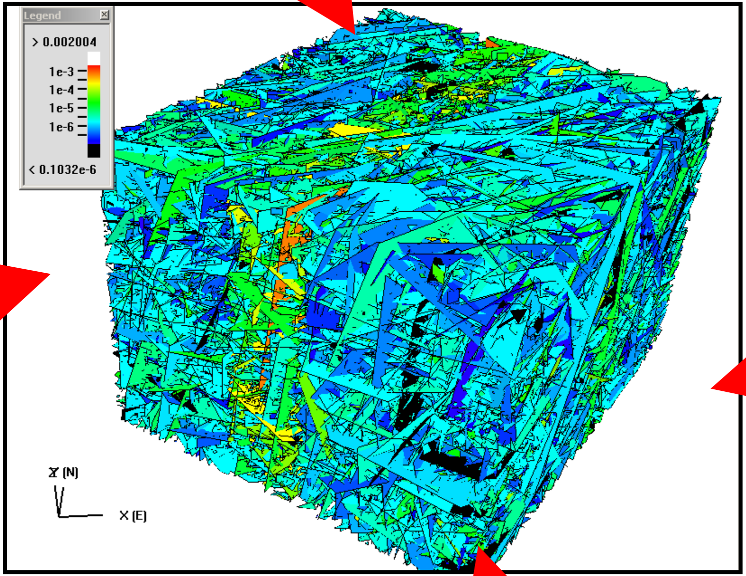
# Natural Fracture Data Analysis Workflow

**Fracture Length Distribution**



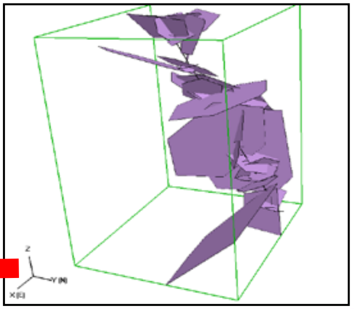
**Orientation Distribution**

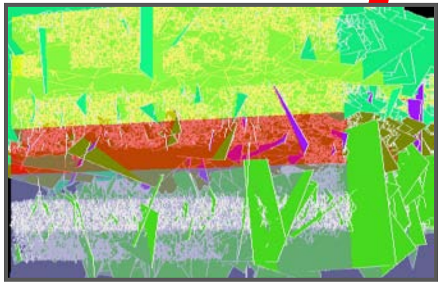




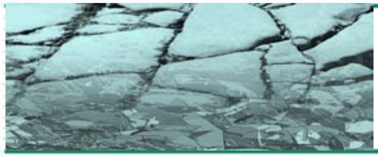
***Defining the fracture system as a network of discrete elements.***

**Fracture intensity**





**Layering, Variability and Lateral Trends**



# Derivation of In-situ Stress

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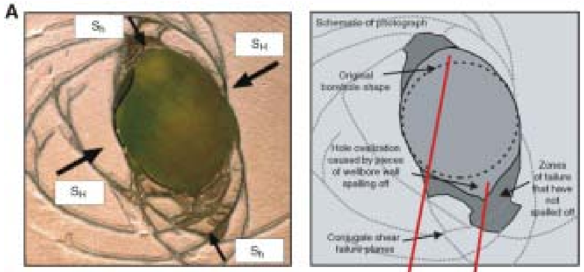
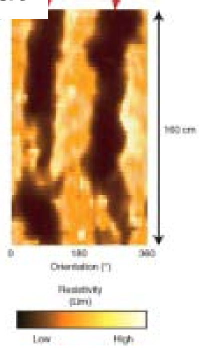
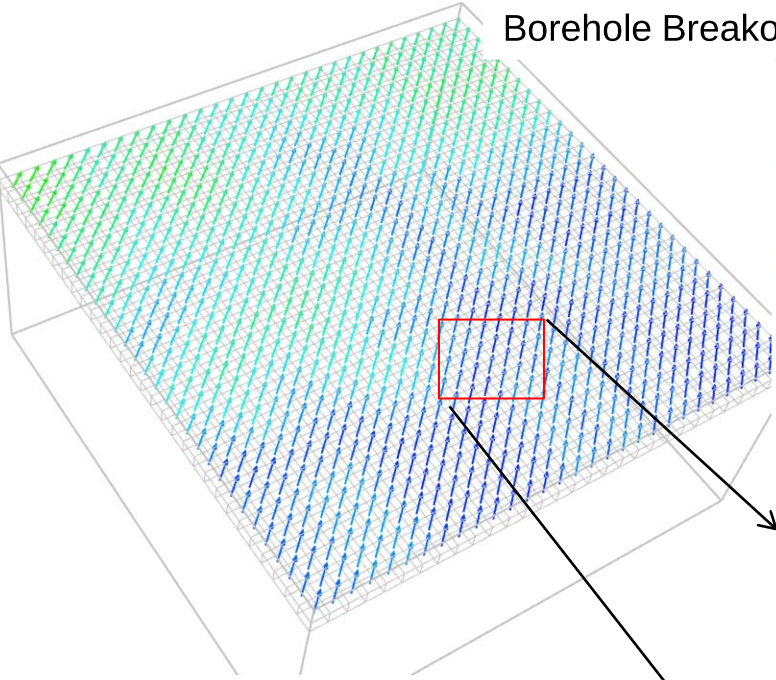
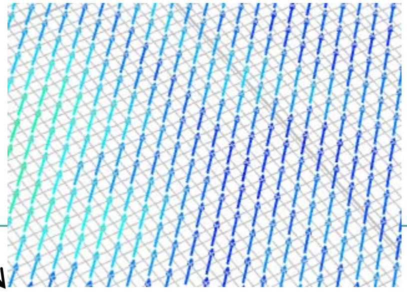


Borehole Breakout

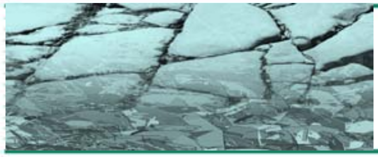






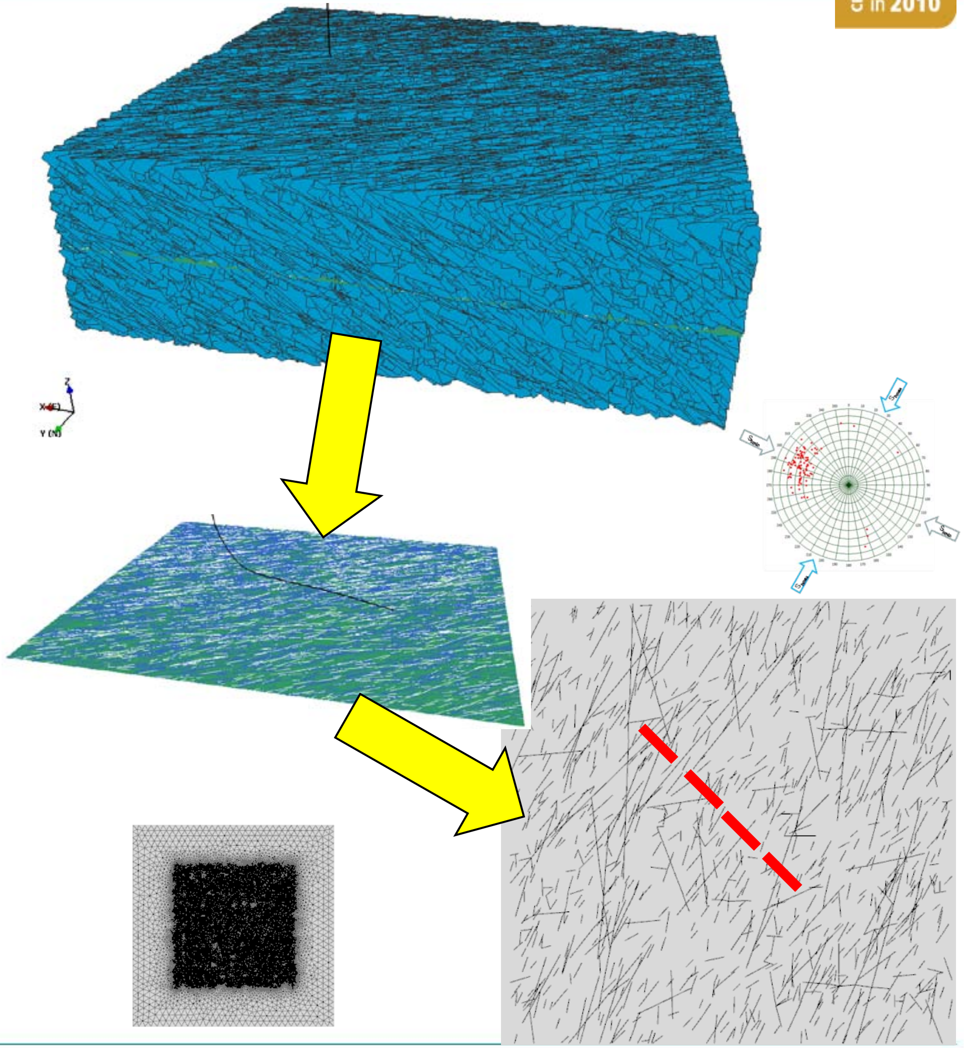
Maximum Horizontal Stress

- Regional tectonic stresses
- Local stresses from borehole breakouts, tension fracs
- Local stresses from ISIP (frac records)
- Vertical stress variation from Sonic logs
- Essential for frac propagation and critical stress analysis of natural fractures



# Hydrofrac Propagation with Natural Fractures – *GEOMECHANICAL SIMULATION*

- **Geomechanical Simulation**
- Geomechanical hydraulic fracture analysis relies on:
  - Natural fracture system of DFN;
  - Accurate reflection of in-situ stress conditions; and
  - Description of rock and fluid properties and injection parameters.
- Natural fracture reactivation is accounted through pressurisation/dilation of existing fractures from the fluid network;
- New (hydraulic) fractures are created when fluid pressure exceeds sum of tensile strength and minor stress state;
- New (hydraulic) fractures are orientated perpendicular to minor stress



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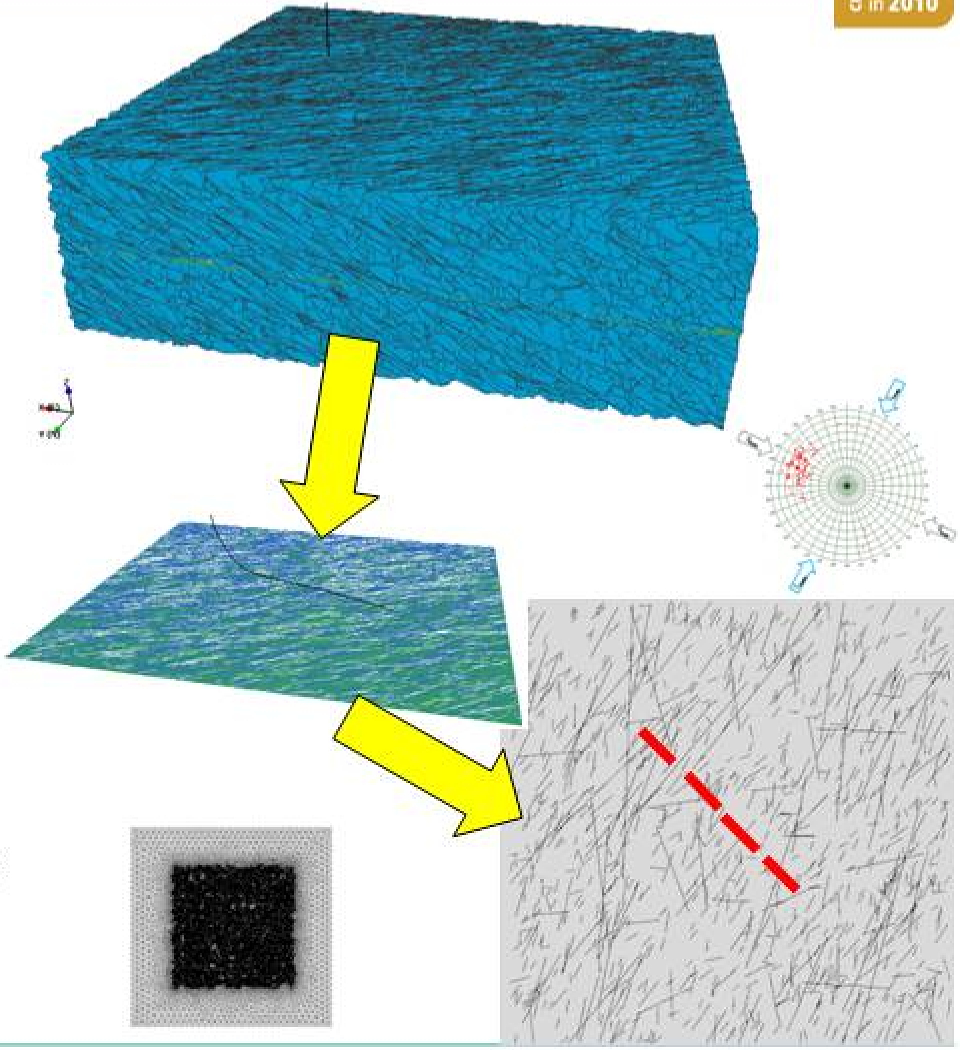
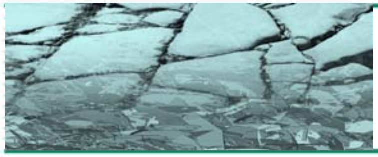
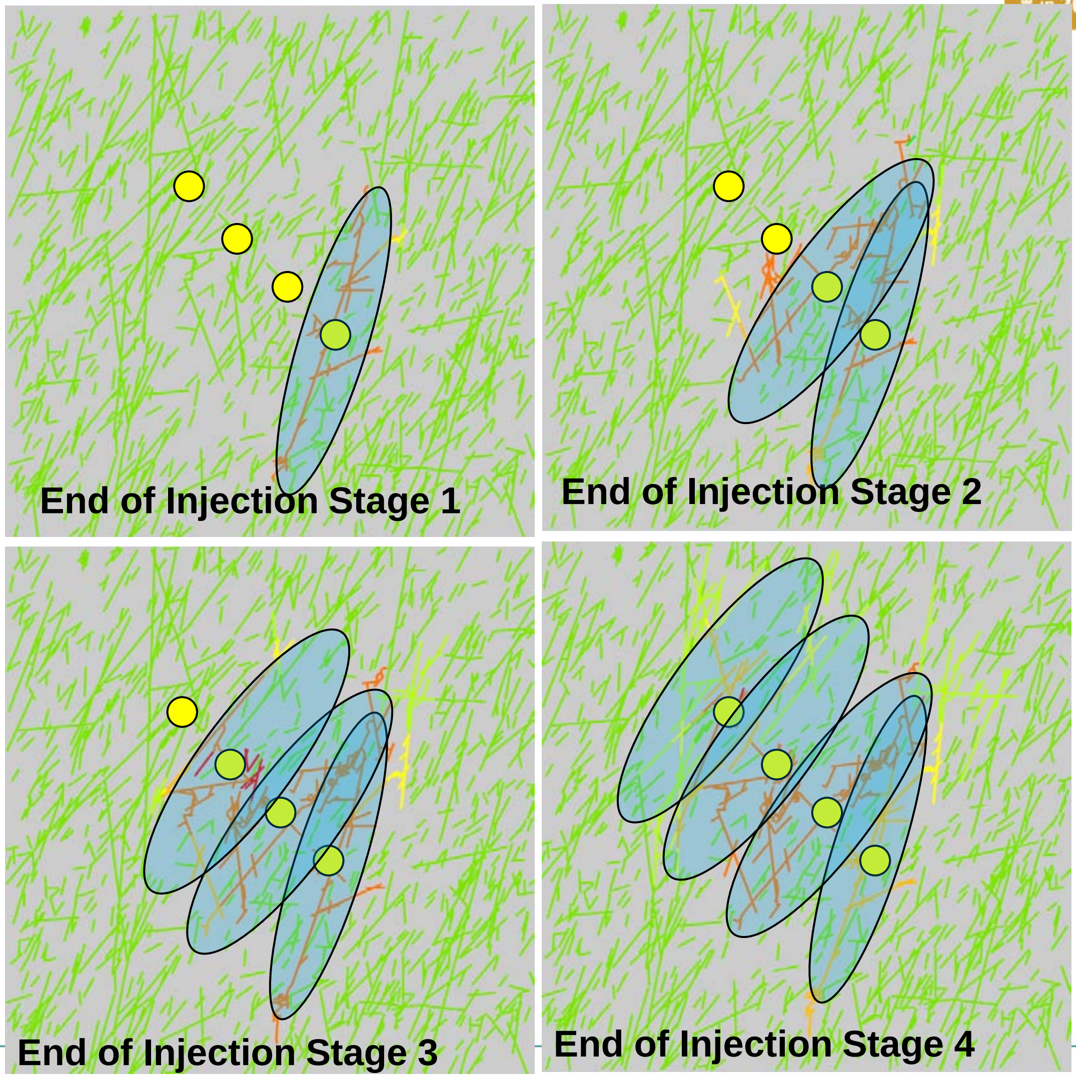
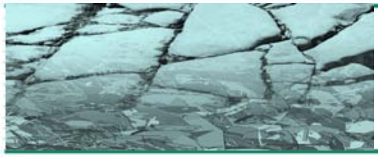




# Hydrofrac Propagation with Natural Fractures – *GEOMECHANICAL SIMULATION*

- **Geomechanical Simulation**
- Multiple perforations are included in the model geometry with correct injection properties;
- Sequential injections at perf locations leads to reactivation of existing and creation of new fractures;
- The response can be used to help design and optimise hydraulic fracture strategies





# Workflow for Discrete Fracture Network (DFN) Hydraulic Fracture Simulation

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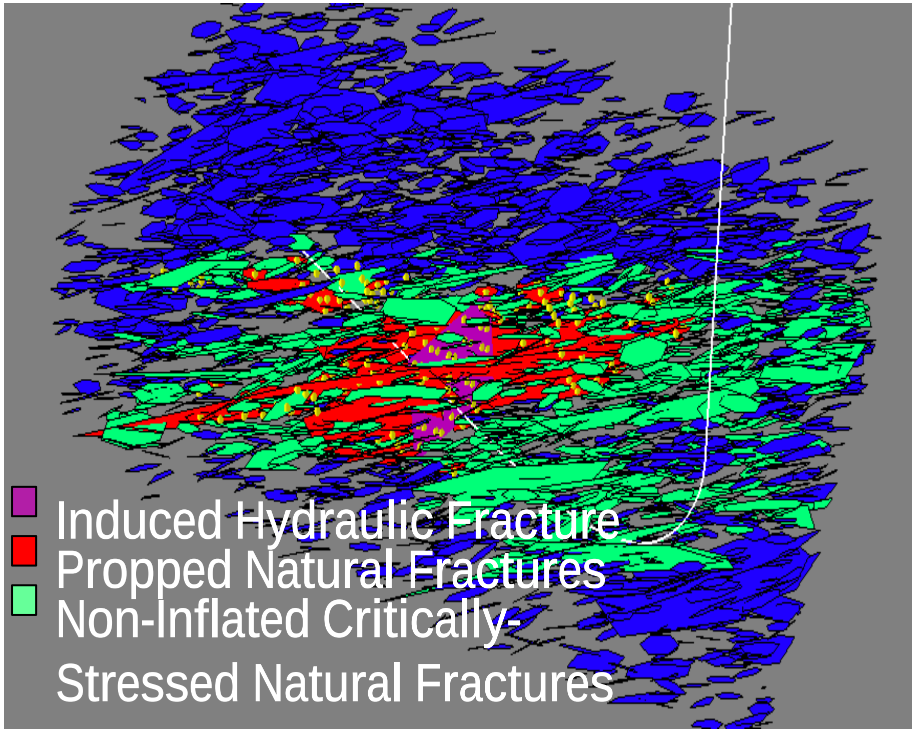
1. Analyze **Rock Properties**→ Create Grid of rock strength and elastic properties
2. Analyze **Natural Fracture** Geometry → Create Natural Fracture Network
3. Analyze ***In Situ* Stress** → Create Grid of stress tensors
4. Simulate **Discrete Fracture Network**
5. **Grow Hydrofracture**
   - Sneddon (PKN) elastic crack solution
   - Balance Injection and Hydrofrac Volumes
   - Leakoff to **Connected Natural Fractures**
6. Evaluate Critical Stress in Connected Natural Fractures → Microseismic Response
7. **Update Hydraulic Properties** of Natural Fractures taking Frac Fluid
8. **Evaluate Drainage** from Combined Natural Fracture & Hydraulic Fracture Network



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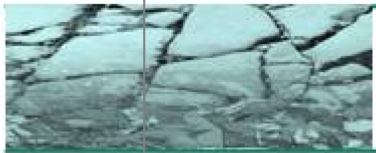

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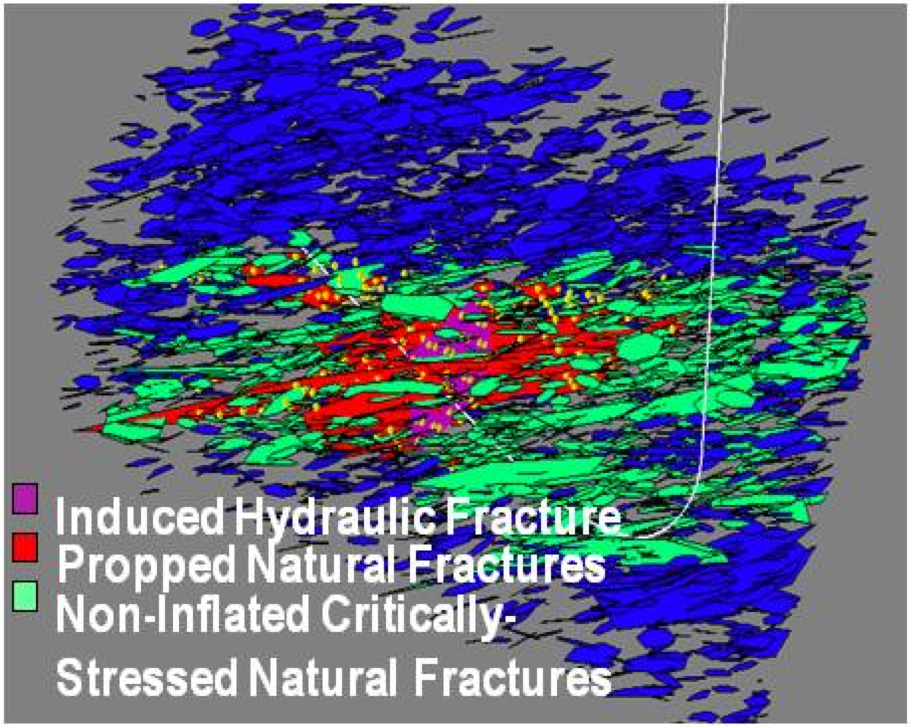
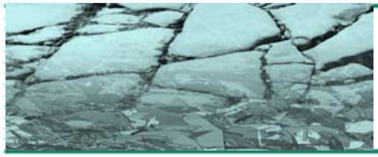
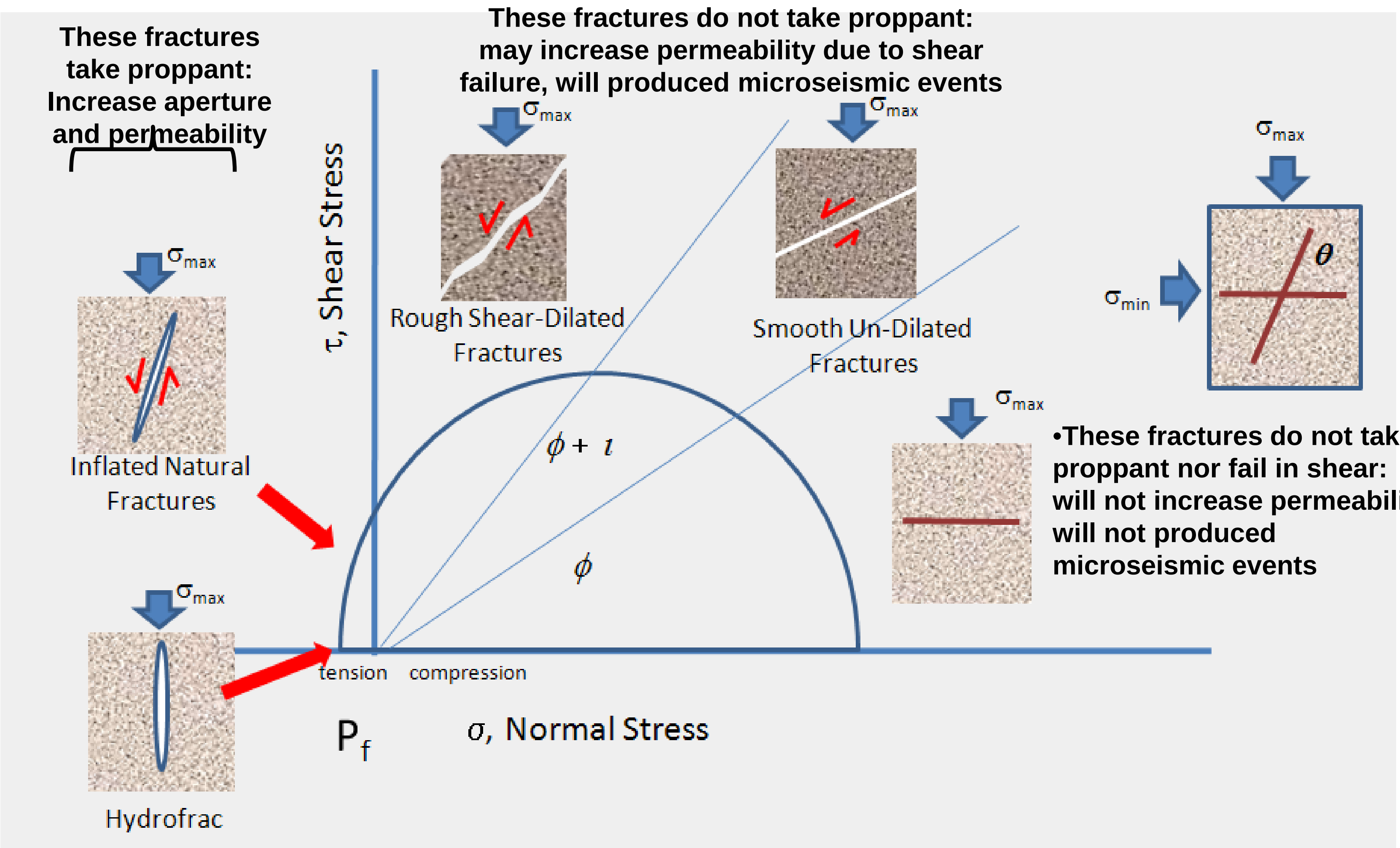




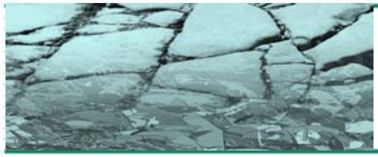
# Update to Natural Fracture Properties from Proppant and Critical Effective Stress Analysis



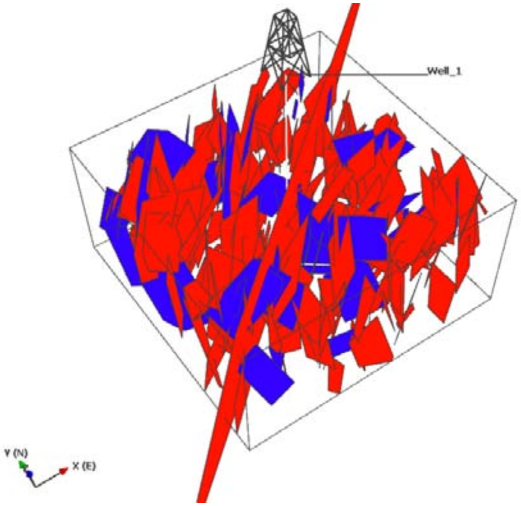
**These fractures take proppant: Increase aperture and permeability**

**These fractures do not take proppant: may increase permeability due to shear failure, will produced microseismic events**

- **These fractures do not take proppant nor fail in shear: will not increase permeability will not produced microseismic events**



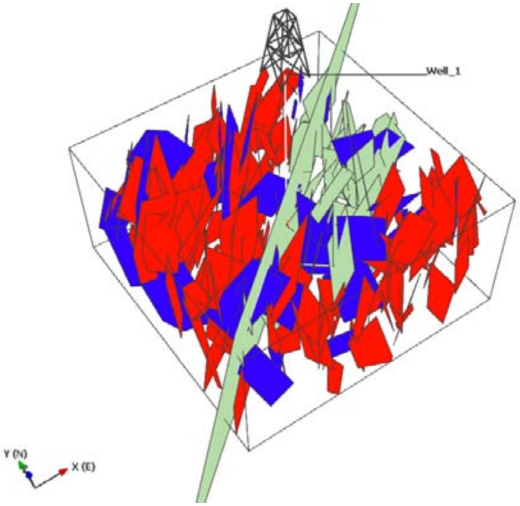
# Hydrofrac Propagation with Natural Fractures – *Leakoff, Reactivation, and Drainage*



PRE-FRAC

Red: Critically Stressed Fractures

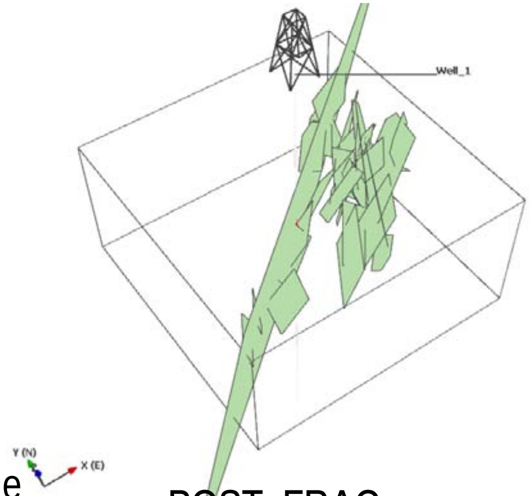
Blue: Unstressed Fractures



FRAC

Networks Connected to Frac and Frac Stage

Potential Leakoff and Reactivation

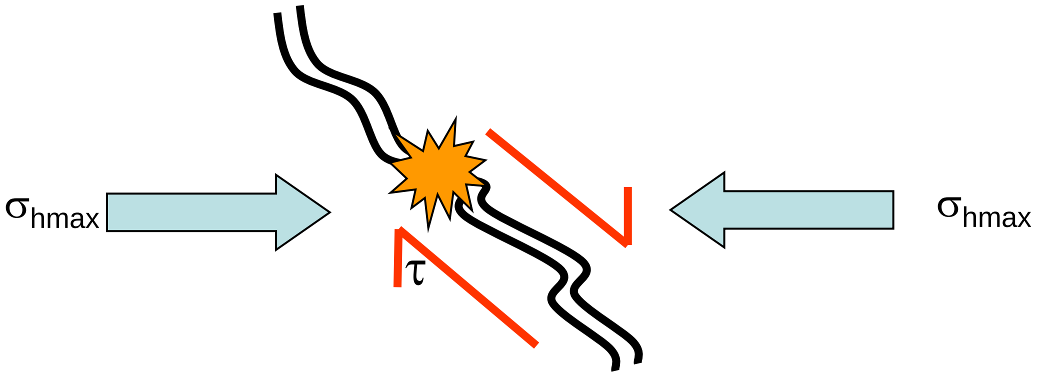


POST- FRAC

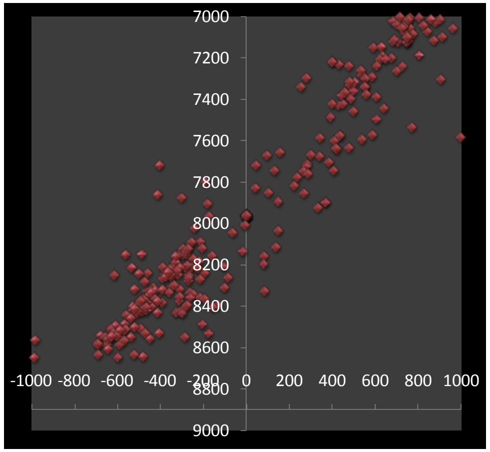
Hydrofrac and Reactivated

Natural Fractures Providing Drainage

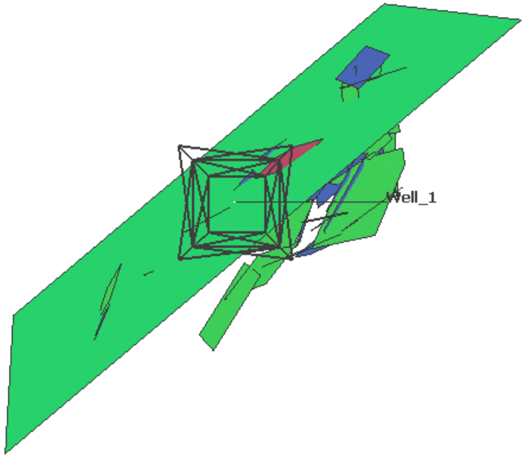
# Critical Stress Analysis and Simulated Microseismic Response

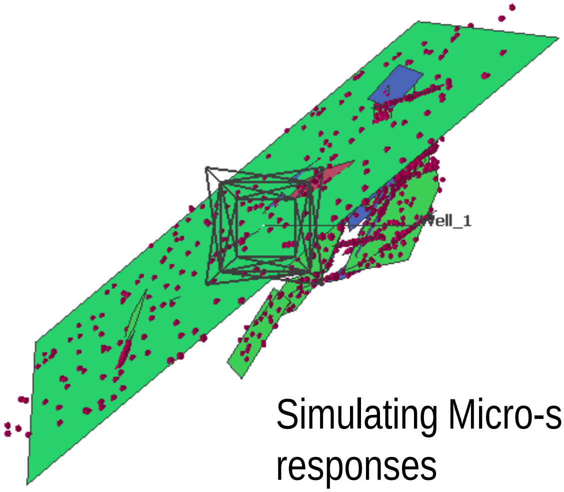


Field Microseismics

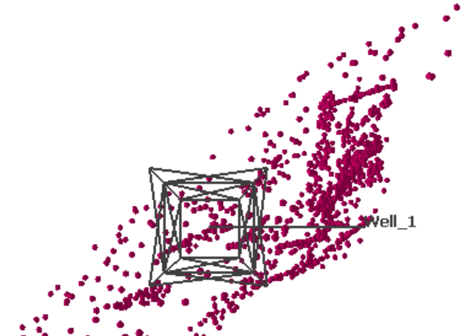


Critically Stressed
Connected Fractures





Simulating Micro-seismic responses



Simulated Microseismics

# Hydraulic Fractures and Natural Fractures

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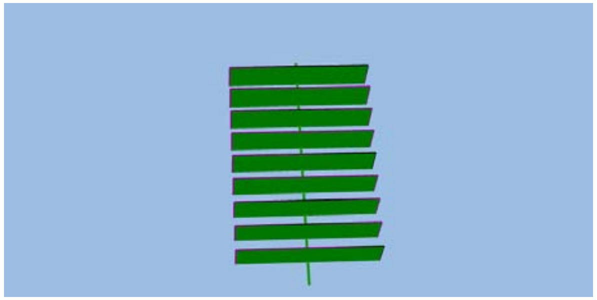
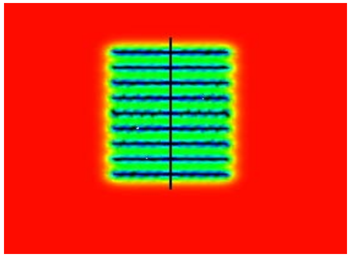
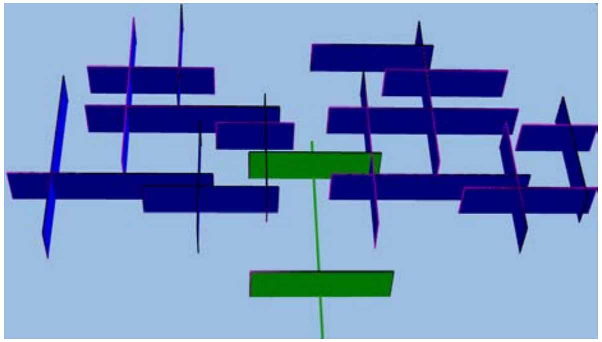
**Fracture Network**

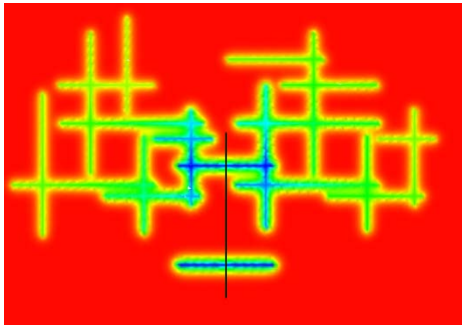
**Pressure Response**



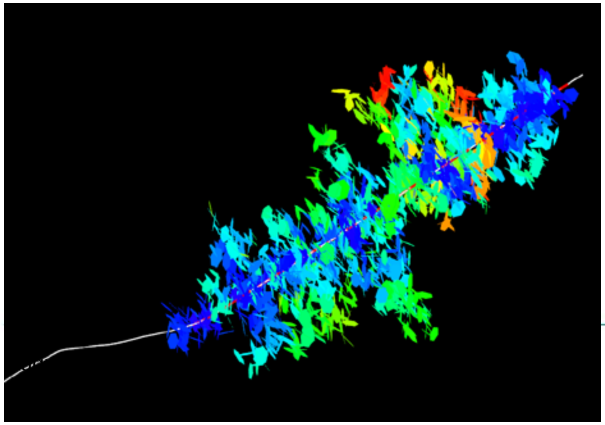


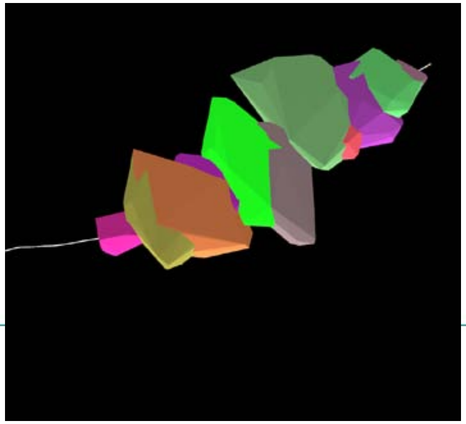
“Type A”





“Type B”





“Type C”

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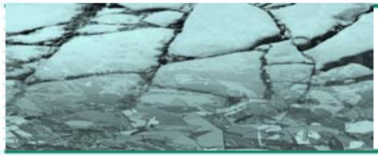
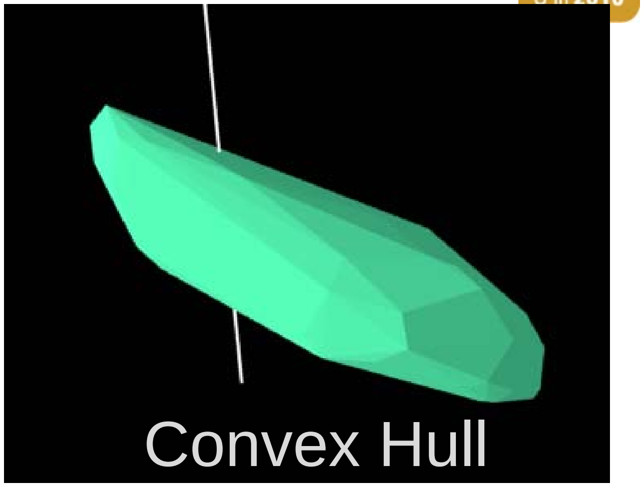
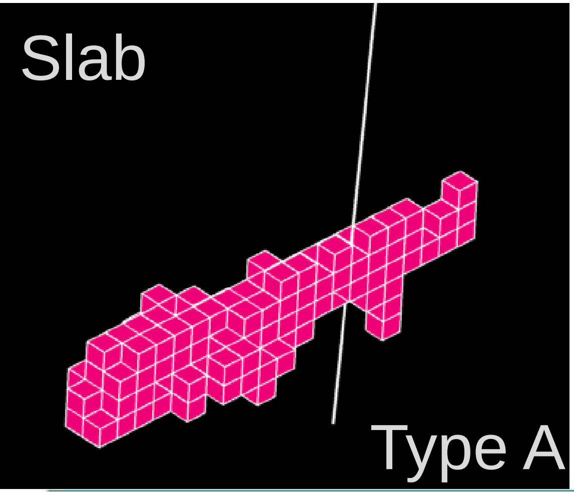
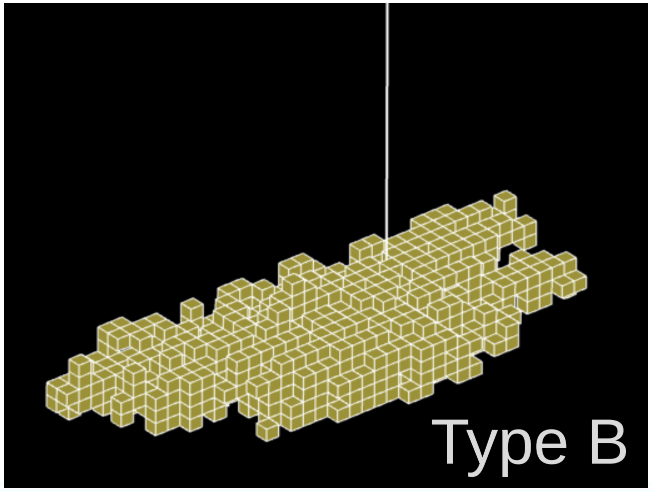


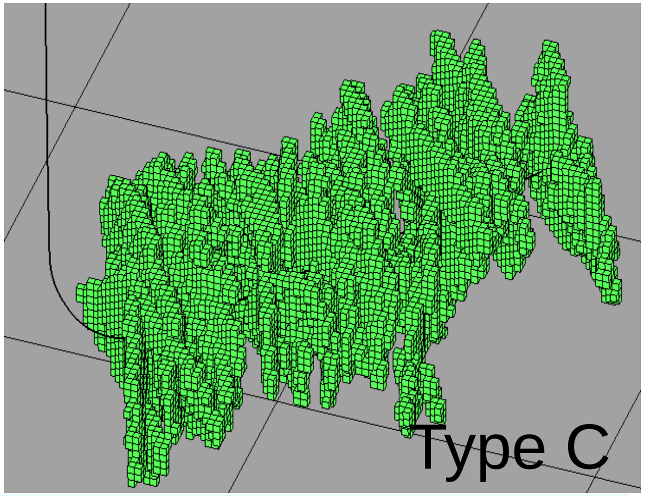
# Tributary Drainage Volumes

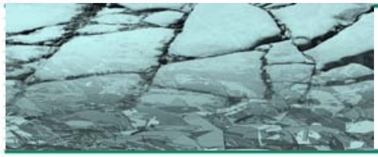
- Tributary Drainage Volume (TDV) in the rock mass volume delivering fluids to the well
- TDV depends on frac geometry and (propped) properties
- TDV also depends on natural fractures contribution – to storage and to flow networks (esp. critically stressed)
- TDV can be used to predict to decline and EUR, and for layout of frac stages and infill programs











# Summary

The DFN approach to modeling fracturing in unconventional reservoirs:

- Is based on an understanding of both the natural fracture system and in-situ stress conditions;
- Accounts for contributions from both induced and natural fractures;
- Allows for rapid hypothesis testing in support of frac design and follow-up;
- Accounts for uncertainty through the modeling of multiple design / natural alternatives;

Caveats

- Understanding the type of reservoir (A, B, C) is crucial to performance
- In-situ stresses can strongly affect both induced AND natural fractures
- FMI logs are a good start, but an understanding of which fractures **are** contributing or **will**, contribute to flow is key.