Induced and Natural Fractures in Shales - A Geomechanical Perspective*

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Abstract

Shales can serve as pressure barriers in basins, as top seals, and as reservoirs in shale gas plays. This paper emphasises the role of geomechanics in governing shale fracturing. In many basins, the fluid pressure of the aqueous system becomes significantly elevated, leading to the formation of a hydrofracture, and fluid bleed-off. Natural hydrofracture is an unlikely process in the circumstances that exist in most basins.

The ideas that underpin hydrofracture thinking are briefly summarised as: a given state of stress such that two in-plane (normally a 2D analysis) principal stresses are almost equal in magnitude; an existing flaw in the material contains a highly pressurised fluid, and a stress concentration develops at the sharp tip of the flaw (which is normally assumed to be slit-like); the stress concentration locally causes a tensile stress to develop in a small region (on the order of mm) in front of the crack tip, causing the material to fail, and hence lengthening the crack; in the elastic equations, the stress concentration depends on the crack length, so the process can continue by feedback.

In a P-Q diagram, the hydrofracture conditions plot in a tiny region near the origin. Those states can be reached in Nature, but only by peculiar paths. It seems likely that the conditions of fluid-related yielding (in low effective stresses) are not those of hydrofracture, but instead are associated with dilational, shear-related deformations. This type of deformation increases the pore volume of the material, and, locally, the fluid pressures will be decreased (at least temporarily) as a result. Fluids will flow into the dilated region, and may leave evidence in the form of veins or sand-filled intrusion swarms. Such physical features are widely observed, but usually attributed to hydrofracture. My analysis suggests that they may be better interpreted as dilational yielding of basin geomaterials. Shale gas plays require the manufacture of the reservoir by inducing hydraulic fractures within the shale. Experience suggests that the outcome can be

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a classical bi-wing, single hydraulic fracture or the creation of a fracture network. Geomechanical simulations, involving approaches that are based on discontinuum methods, help to understand these processes.

Reference

Maxwell, S.C., C. Cipolla, and M. Mack, 2010, Microseismic imaging of hydraulic fracture complexity in shale gas reservoirs: EAGE 2nd Shale Workshop, 26-28 April 2010, Nice France. CD-Rom. http://www.earthdoc.org Web accessed 12/6/2011.

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Gary D Couples

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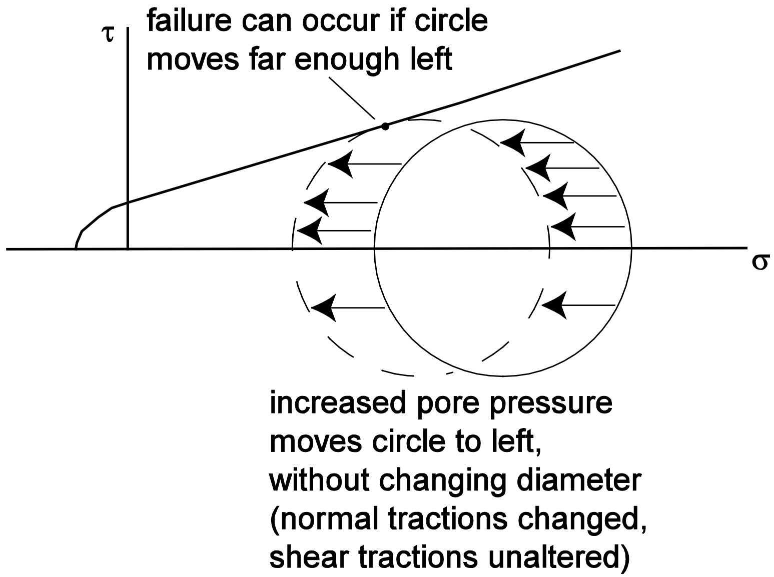
In Practical Terms...

- What is the mechanical response, and the consequences for fluid flow, when a seal interval experiences very high pore pressures?



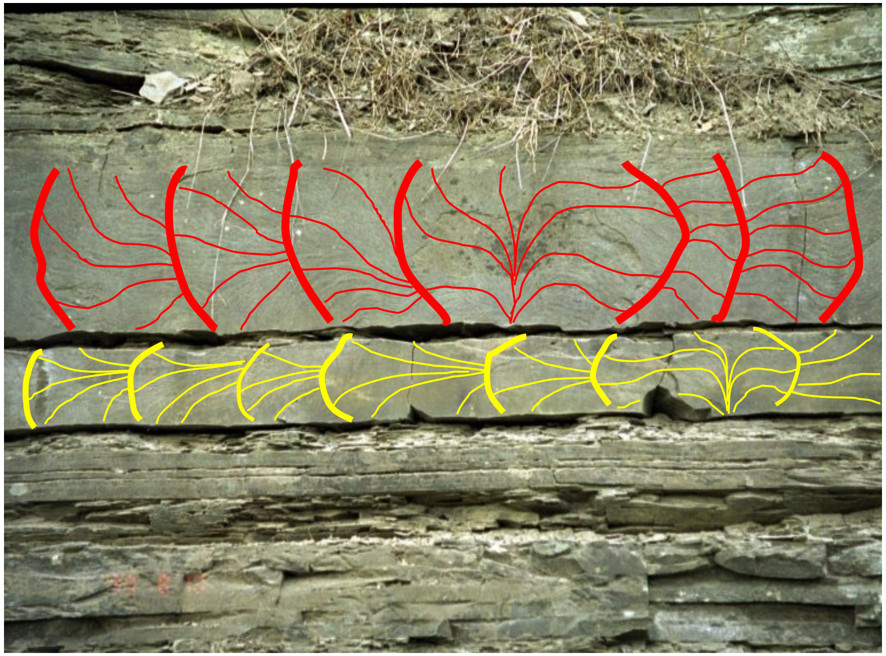
The classical view on this topic

Main Points of this Talk

- Hydrofracture is not the typical response to natural increases in pore pressure
- The normal outcome (in nature) is the generation of fracture networks
- Induced fracture treatments (well stimulation) in pre-fractured shales may be able to exploit the discontinuum/blocky characteristics of suitable shales

Natural Mode I Fractures Exist

J-P Petit



T Engelder

$$P_{cr} = \left(\frac{K_{ic}}{\left(Yc^{1/2} \right)} \right) - \frac{\nu}{(1-\nu)} S_v + \frac{(1-2\nu)}{(1-\nu)} \alpha P_p$$

If one assumes a hydraulic drive, that the material is elastic until failure, and a particular stress state, this equation defines the fluid pressure needed for fracture propagation

The Crux of the Matter

- It is not about whether natural hydraulic fractures exist (they do), but about whether the conditions for their formation are normally achieved
- To gain an understanding of this issue, we have to look a bit further into geomechanics

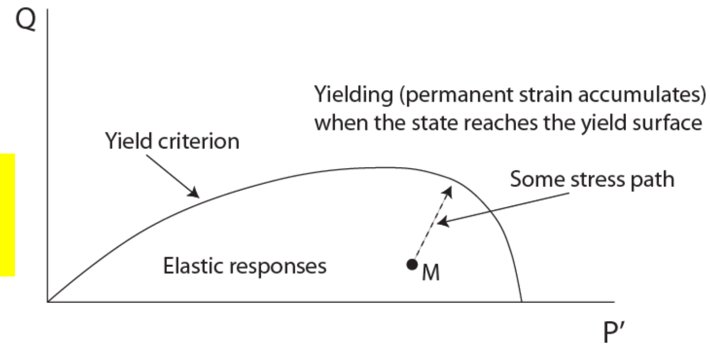
Geomaterials

- ...can be characterised by a yield surface that is dependent on the mean stress, may exhibit post-yield hardening or softening, and strains may be localised after yield
- ALL rocks, plus concrete, soils, snow...
- Conveniently represented in a poro-plastic framework

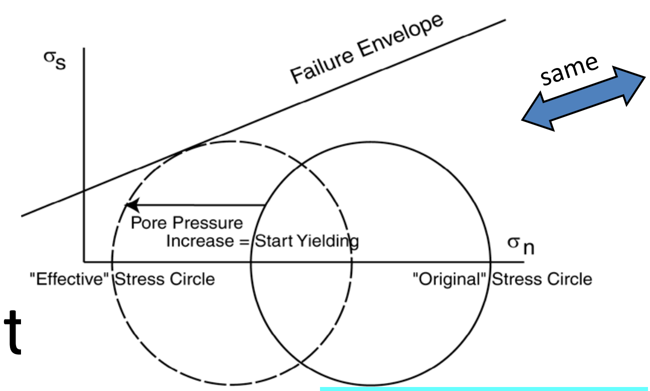
Poro-Plastic Depiction

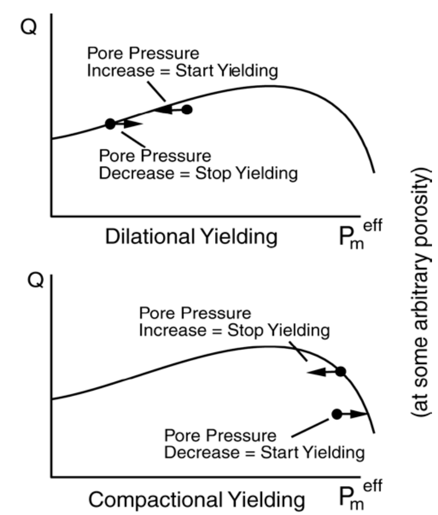
- Often depicted in a P-Q diagram
- Stress state is a single point
- Conditions for yielding
- Classical Mohr-Coulomb is a sub-set

P is effective mean stress
Q is “differential” stress



Role of pore pressure





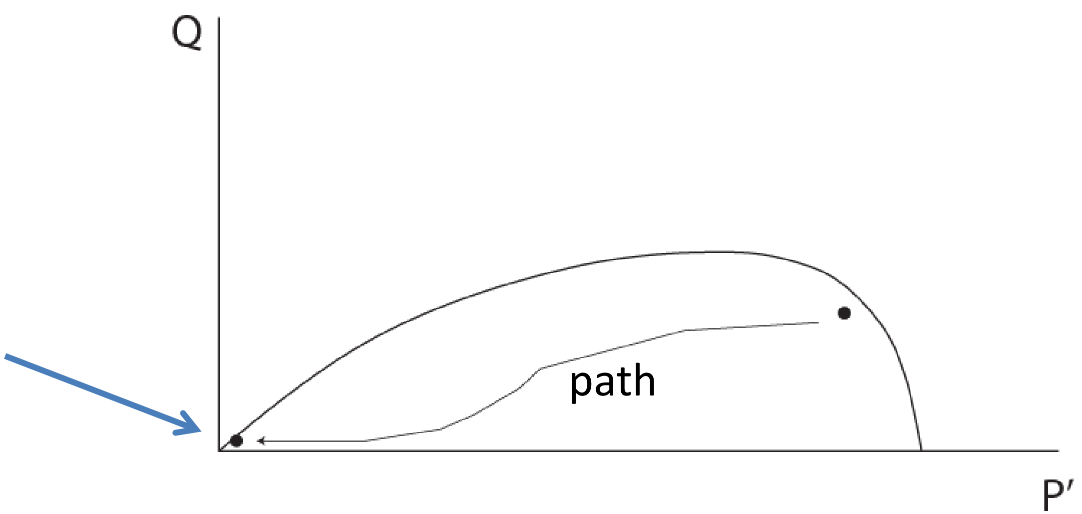
Pure effective stress (α = 1)

Classical Mohr-Coulomb

Poro-plastic

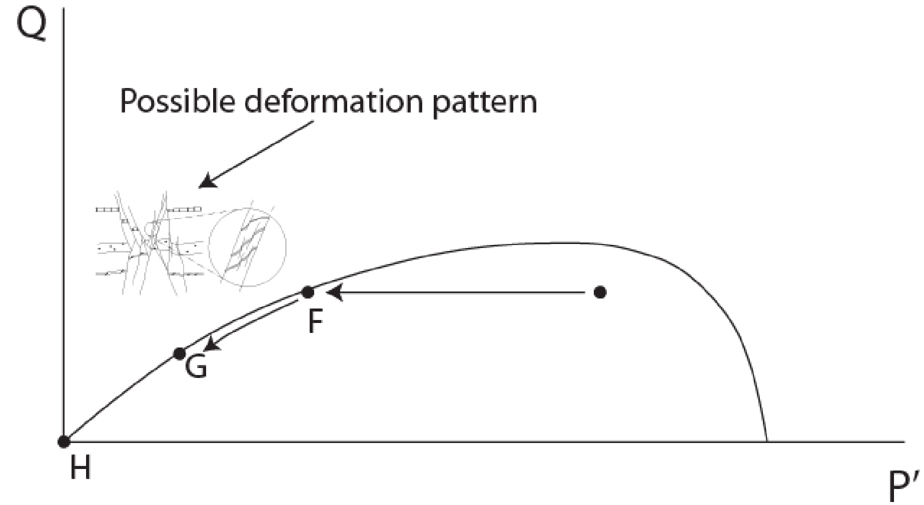
Hydraulic Fracture

- Conditions: low mean stress (high pore pressure, small P’) AND low differential stress (low Q)
- What stress paths can lead to these conditions?



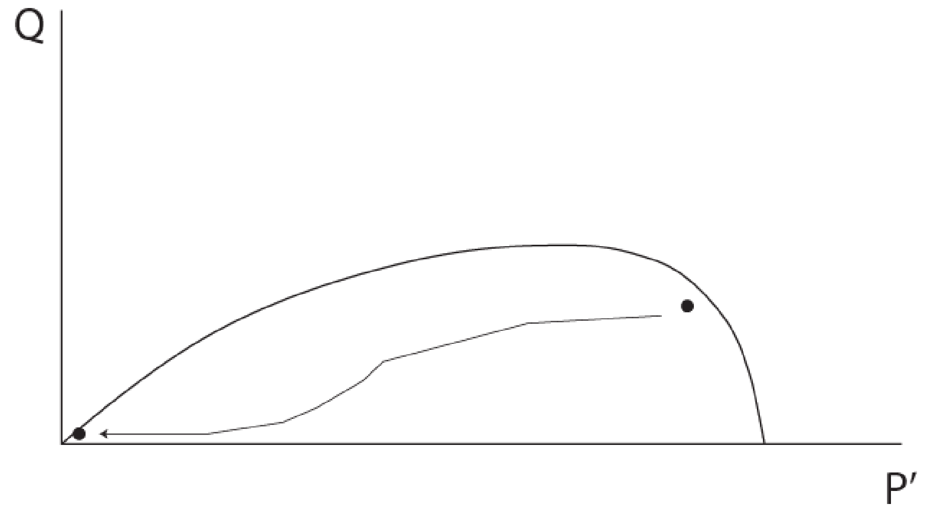
Simple Pore Pressure Increase

- If the only process is pore pressure increase, the stress path reaches the yield surface in conditions which lead to creation of fracture arrays



Tectonic Strains

- In order to attain low Q values, strains must occur so as to change the stresses



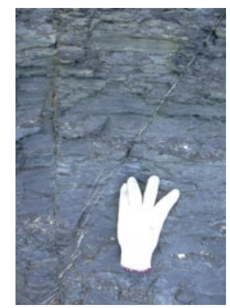
Such paths CAN exist (see previous slides with outcrop evidence!), but the more common paths are likely to lead to fracture arrays

What are the Implications for Flow?

- Need models that capture both the depositional architecture and the superposed fractures

Observed Dilational Deformations

- Can have sand/silt injected
- Fractures can have partial vein filling
- Vast majority have limited vertical extent
- Densities are modest (or sparse)



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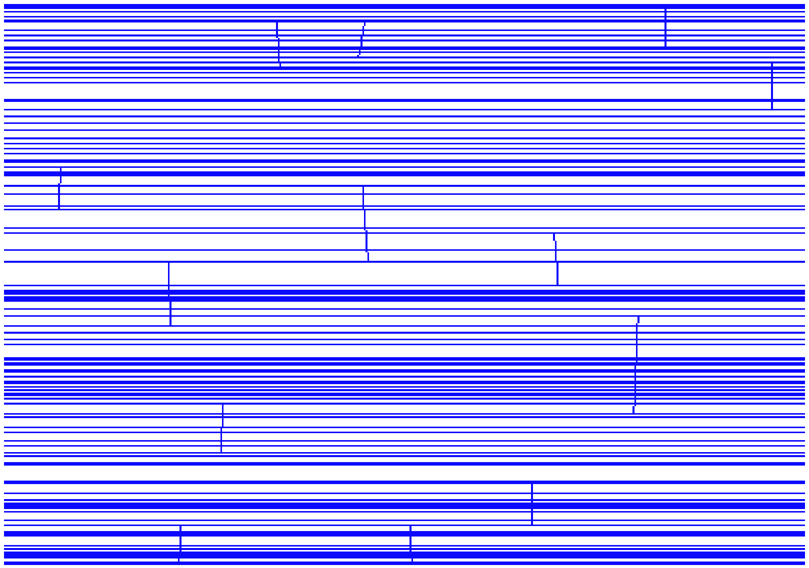
Models to Derive Upscaled Perms

- This example shows a part of a model of a well-layered hemipelagite with mud (white) and sand/silt layers (blue)
- Overprinted with distributions of vertical connection features (blue), which could be injections or fractures

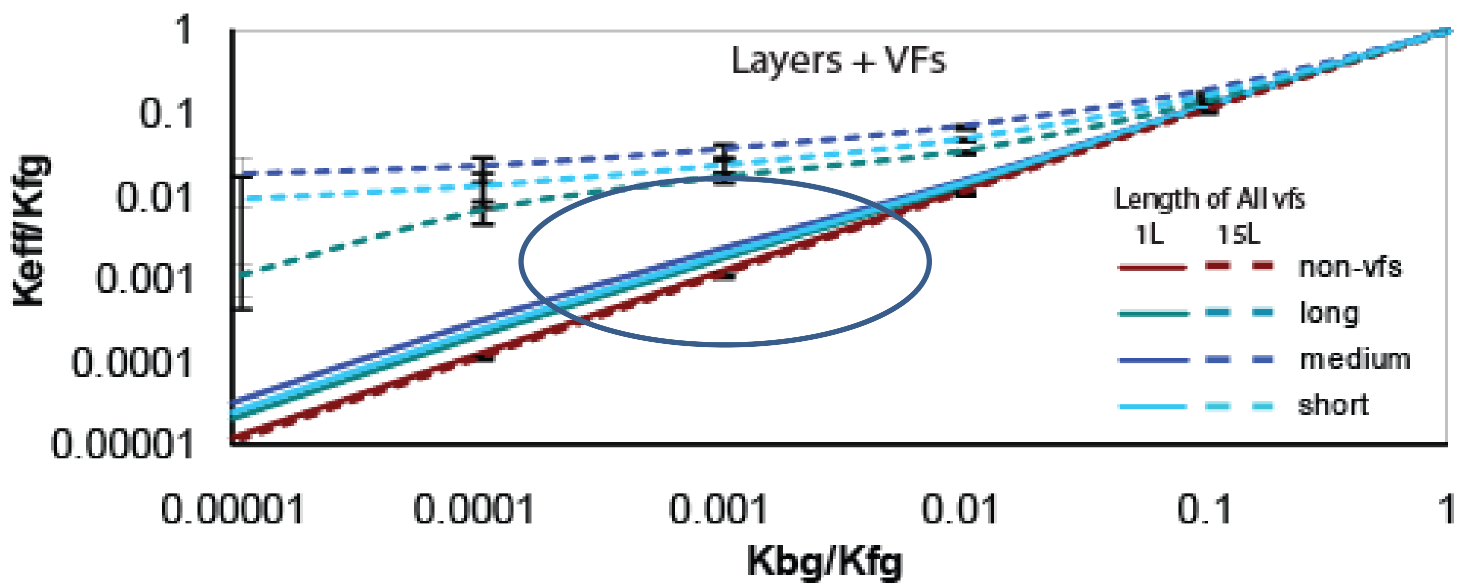


Vertical scale ~10m
Horizontal size of model ~ 500m
(only a portion shown here)

Thanks to Jingsheng Ma

Modest Flow Impacts

- Summary of large suite of simulation cases
- Bottom line: for most seals, fracture arrays increase effective perm by about one order of magnitude



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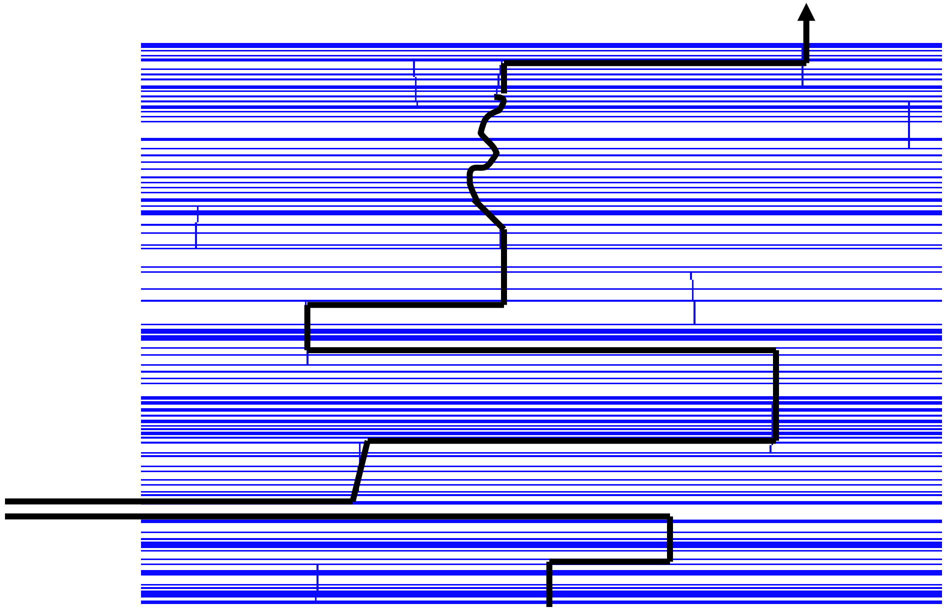
Why Are Impacts So Small?

- Flow paths are long – mainly along layers
- Darcy law:



- $Q = K \frac{\Delta P}{L}$

Unless the deformation features are very numerous, their impacts are modest

One through-going fracture has a limited impact on total flux

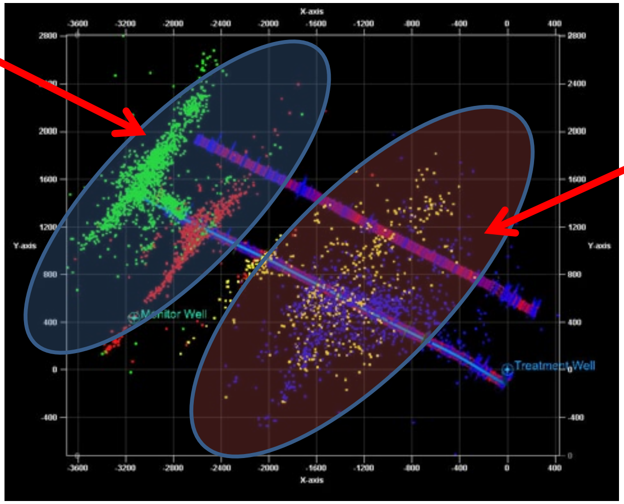
So, seal "failure" not likely to be catastrophic

What About Stimulation?

Image shows microseismic events recorded (map view) for several fracture stage treatments in a well. The well penetrated two volumes which had differing stress states (previously interpreted from reflection seismic data). One volume generated simple bi-wing fractures, while the other developed (reactivated) fracture networks.

Classical bi-wing fractures

Local stress differences of ~0.8 MPa in blue and red regions, derived from seismic attributes



Network-type fractures

After Maxwell et al 2010 EAGE Shale Workshop

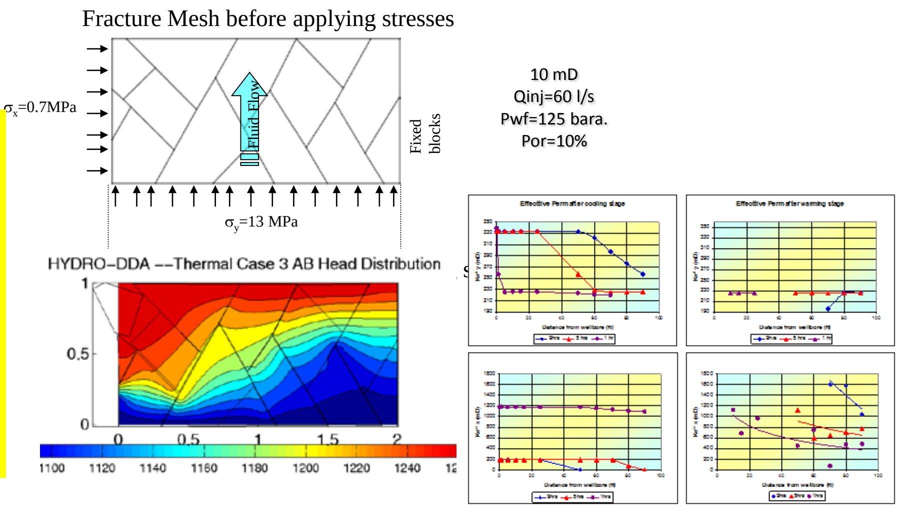
Pre-fractured shale, with multi-stage stimulation treatment in horizontal well

Geomechanical Simulations

- Using a discontinuum approach that represents blocky materials

Thermo-Hydro-Mechanical Models

Model at right shows simulation to calculate effective perms of a fractured geothermal rock mass stimulated by cold-water injection and then allowed to re-equilibrate. Note permanent changes in perms.



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Summary

- Basic principles provide a framework for thinking about the deformation process, and about how states might change
- Major hydrofracturing in natural settings requires very special conditions
- More common response is likely to be the creation of fracture arrays, with modest flow impact
- Same ideas can be used in well stimulation