Modeling Fracture Geometry

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In this session …

- What are the dominant processes of modeling?
- What are the requirements of a good design model?
- What models are available?
- What are their assumptions?
- How should you select an appropriate model?

Which Model & Why

If you are taking the time to 'design' or evaluate a frac job, shouldn't you make it worthwhile?

Simplistic Models:

- Easy to use
- Require minimal input data
- Take little or no time

Sophisticated Models:

- Require input to describe the reservoir
- Accurately describe the fracture
- Allow for making informed decisions

Fracture Design:
Understanding & Modeling Dominant Processes

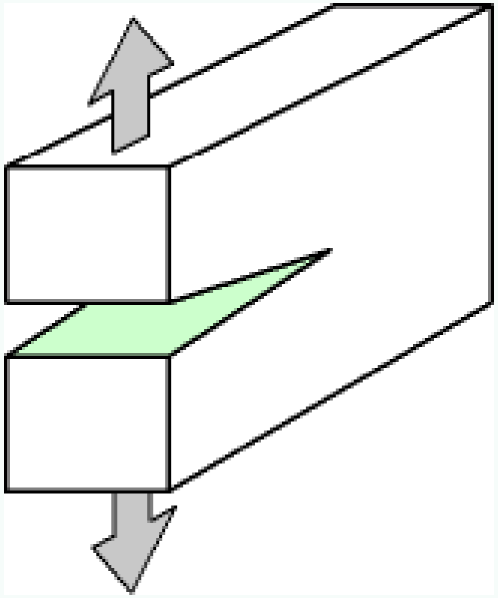
- Fracture geometry creation
  - elastic properties, plasticity, pore pressure
  - model assumptions, rock shear and slip
- Fluid leakoff
  - pressure dependence, whole gel
- Fluid rheology
- Proppant transport
  - rheology, localized leakoff
  - causes & remedies for screenouts

Design Model Requirements

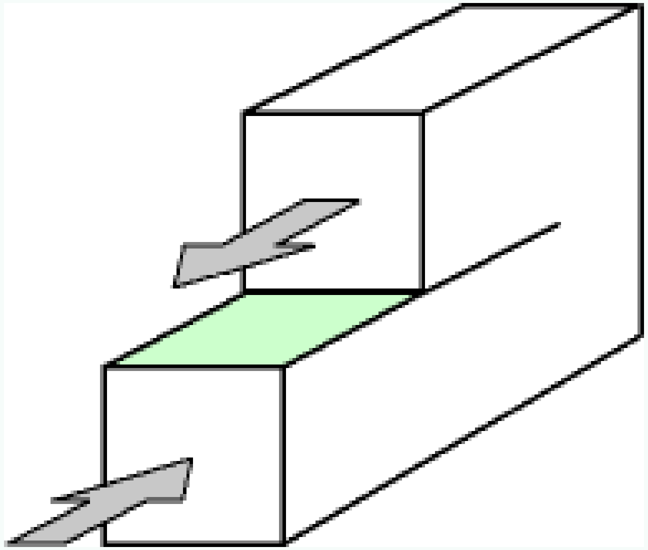
- Describe/Include the basic physics of all important processes
- Ability to predict (not just mimic) job results
- Provide decision making capability
  - Understand what happened
  - Isolate causes of problems
  - Change necessary inputs
  - Predict results

If your model can't do this, why run it?

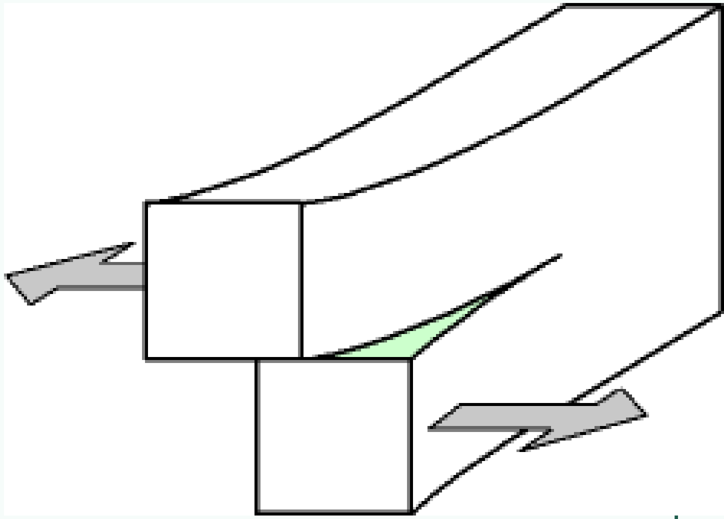
Modes of Fracture



Mode I: Tension



Mode II: Sliding Shear



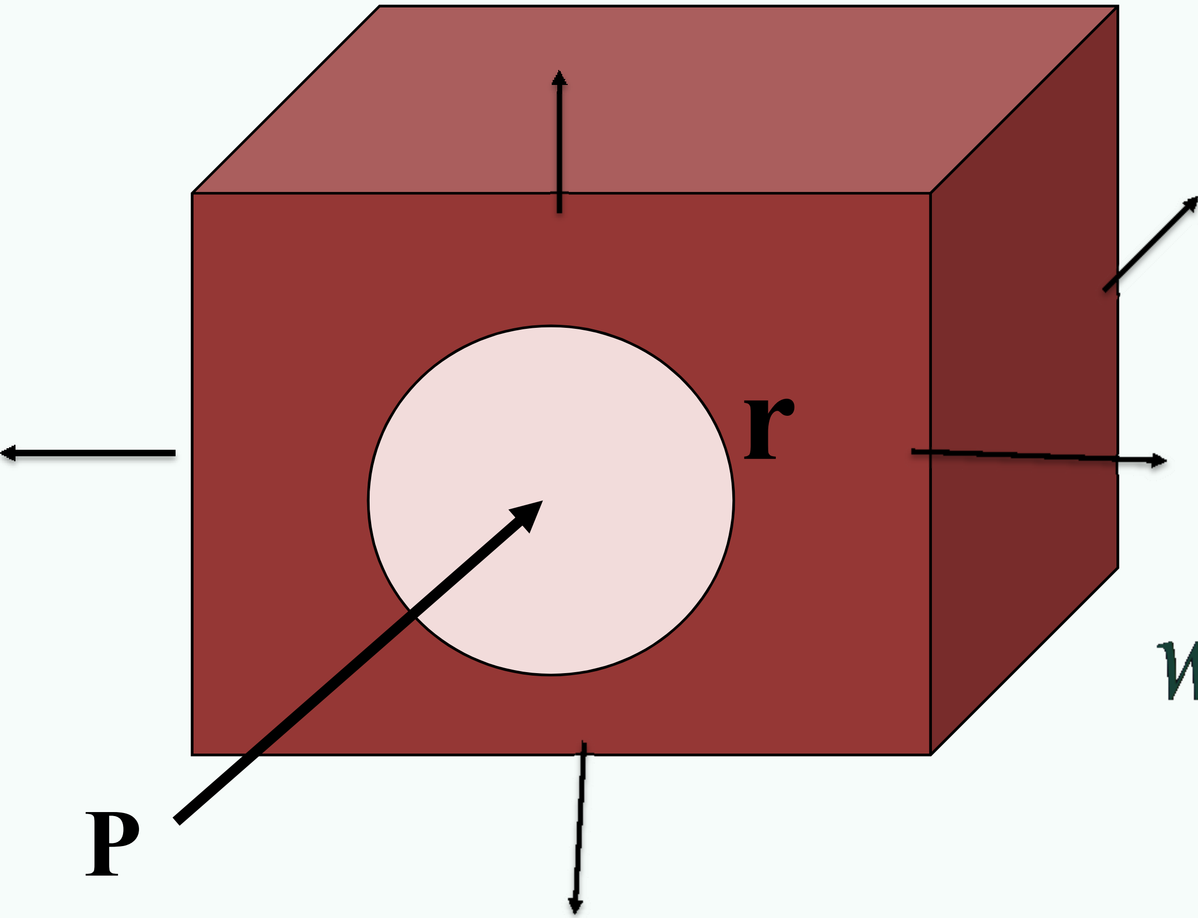
Mode III: Tearing Shear

Conventional frac models only assume Mode I

Available Frac Models

- 2D Models
  - Perkins-Kern Nordgren (PKN)
  - Khristianovich-Geertsma-DeKlerk (KGD)
  - Penny-Frac
- Pseudo-3D Models
  - MFRAC
  - StimPlan, e-StimPlan
  - FracCade
- Lumped Parameter Models
  - FracPro
  - FracPro-PT
- 3D Models
  - GOHFER
  - N-StimPlan
  - Terra-Frac

All Frac Models Start With A Width Equation



Consider the displacement caused by a point load on the surface of a semi-infinite half space:

The displacement of the surface is given by:

$$w = \frac{P_{net}\left(1-\upsilon^2\right)}{\pi E r}$$

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Total Width Results from Surface Integration of Distributed Pressure

The deflection of the surface of a semi-infinite half-space acted on by a distributed pressure is:

$$u = \iint \frac{\left(1-\upsilon^2\right) P_{net}\, d\psi\, ds}{\pi E}$$

This solution was developed by J. Boussinesq in 1885

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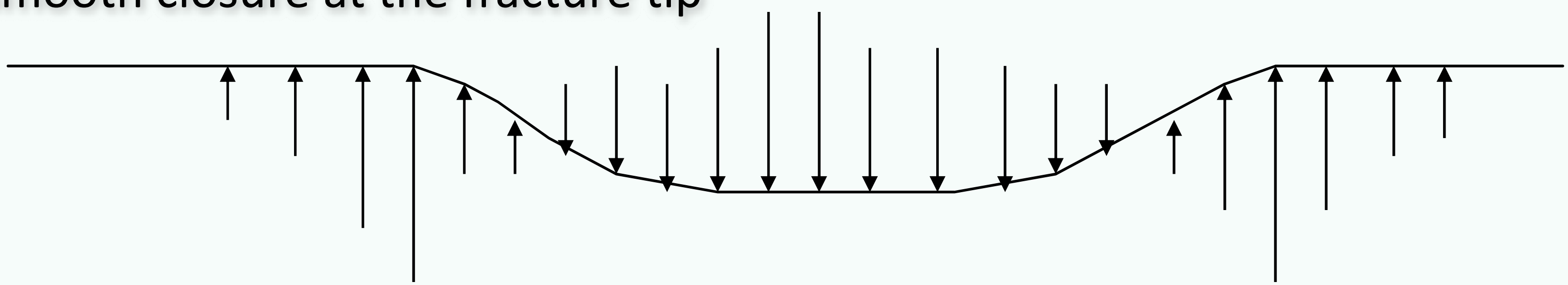
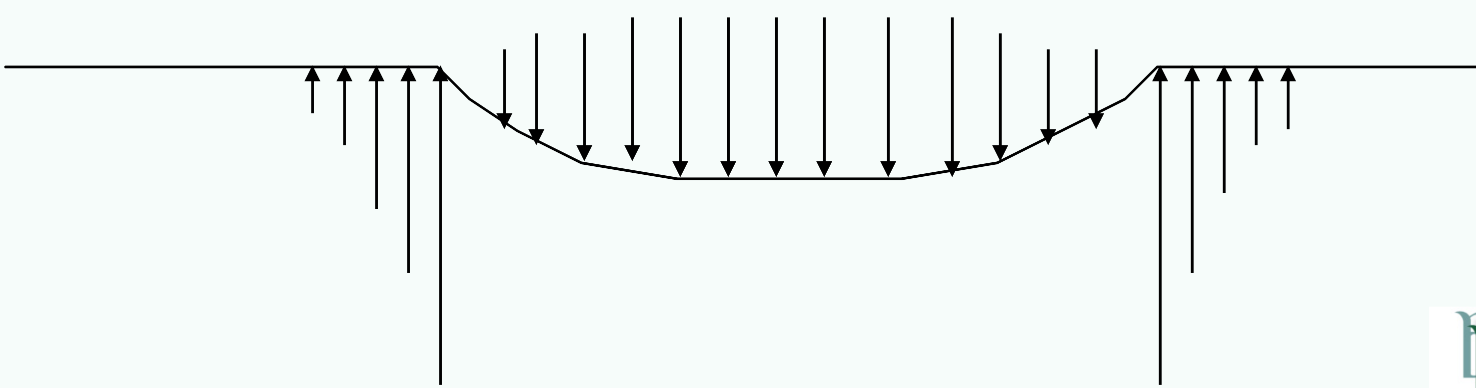
Distributions of “Tensile” Stress at the Frac Tips

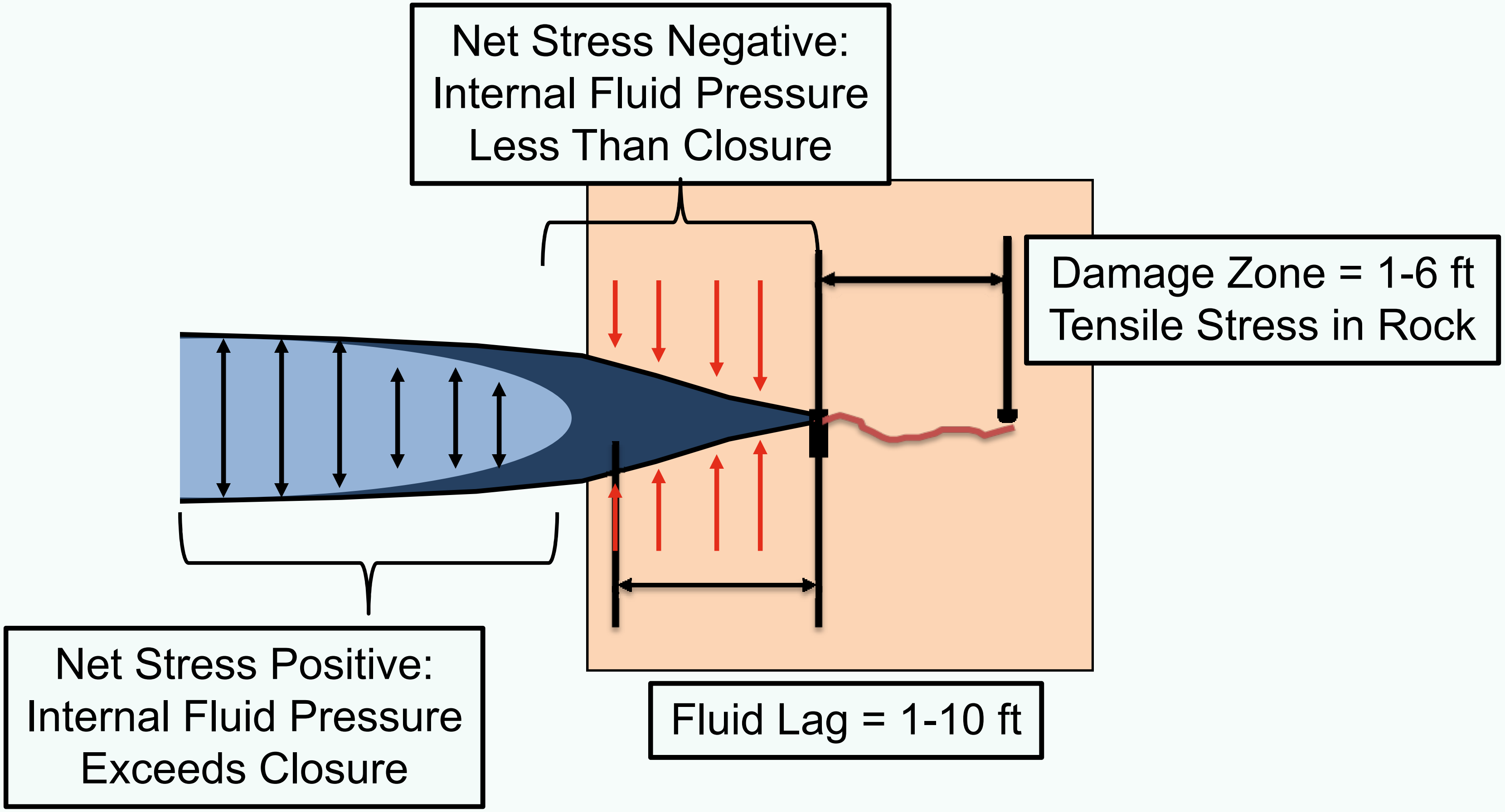
Distributed stress allowing
smooth closure at the fracture tip



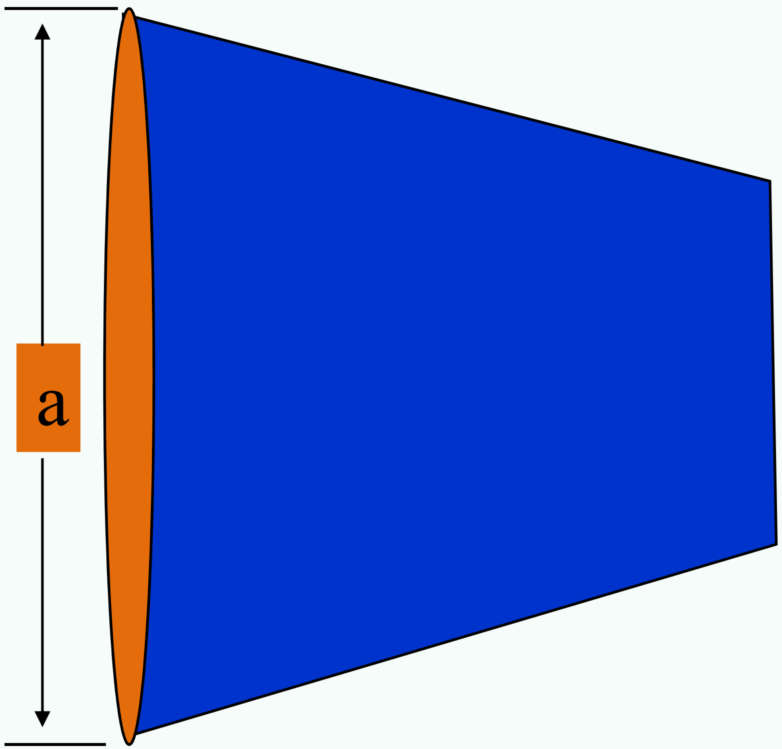
Concentrated stress approaching
a singularity at the fracture tip



Composite Process Zone Modeled by Apparent Stress Concept



Plane-Strain Solution



- Applies for cracks of large aspect ratio
- Width is a function of net pressure and characteristic length
- Width is constant along frac length

Sneddon's Equation

for Width of a Plane-Strain Linear Crack

- Sneddon's equation (1945) for an infinite length (plane-strain) crack, with crack tips at +c and –c
- Simplified-geometry solution assumes two-dimensional plane-strain behavior with an implied stress singularity (infinite stress) at the crack tip

$$u = \frac{2\left(1-\upsilon^2\right)p}{E}\sqrt{c^2 - y^2}$$

Most 2D and Pseudo 3D models use a form of this equation

Geometry Assumption in 2D models

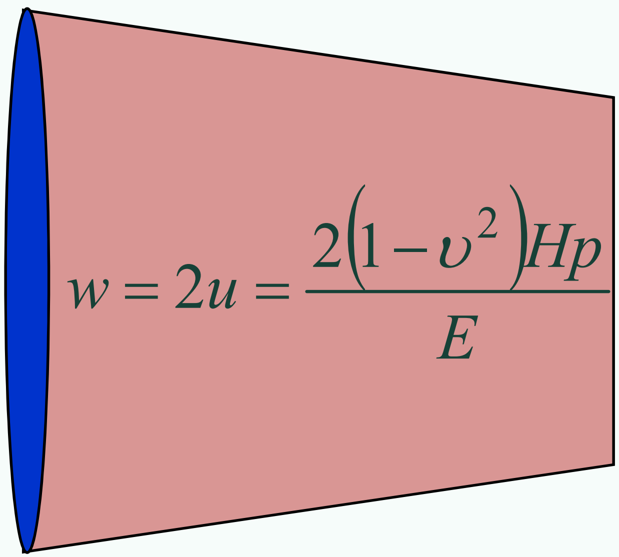
- All 2D models require the user to input constant frac height
- Length and width are calculated from compliance and leakoff
- Called "2D" because only width and length are calculated, while height remains fixed.
- Two 2D models are PKN and KGD
  - Both were published by Royal Dutch Shell researchers in the 1960s.
  - Both use the Sneddon linear crack solution for a plane-strain crack.

Differences in Geometry Assumption for PKN and KGD

Fracture width at the mid-point (y=0) is given by Sneddon's equation for two common 2D models:

PKN

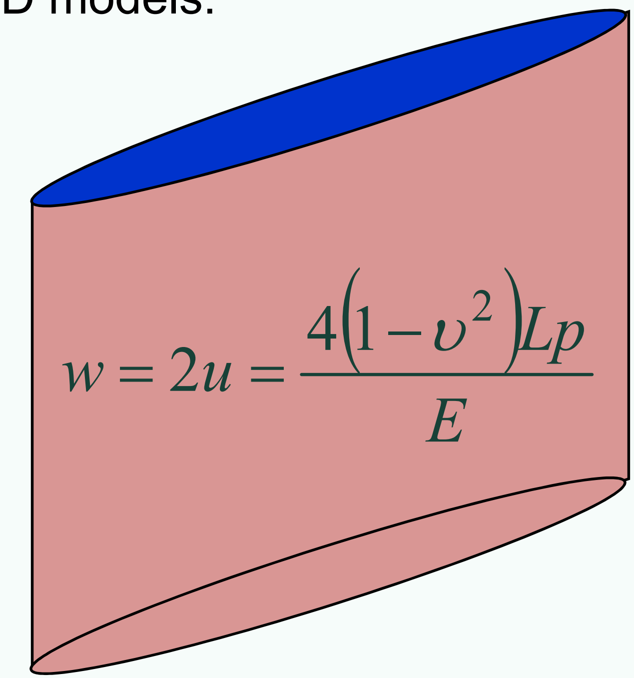
The total fracture height (H) is 2c



$$w = 2u = \frac{2\left(1-\upsilon^2\right)Hp}{E}$$

KGD

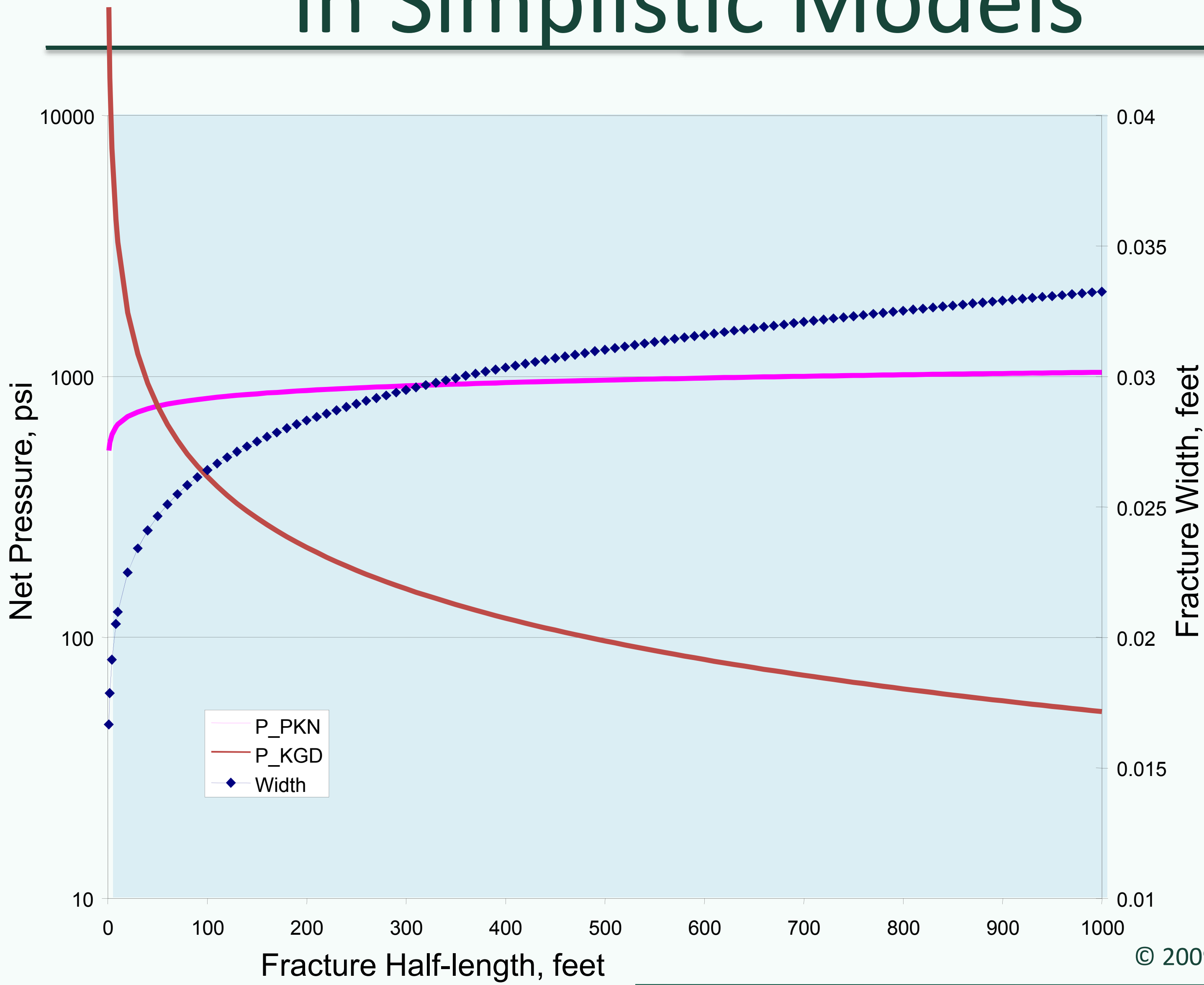
The crack half length (c) is given by L



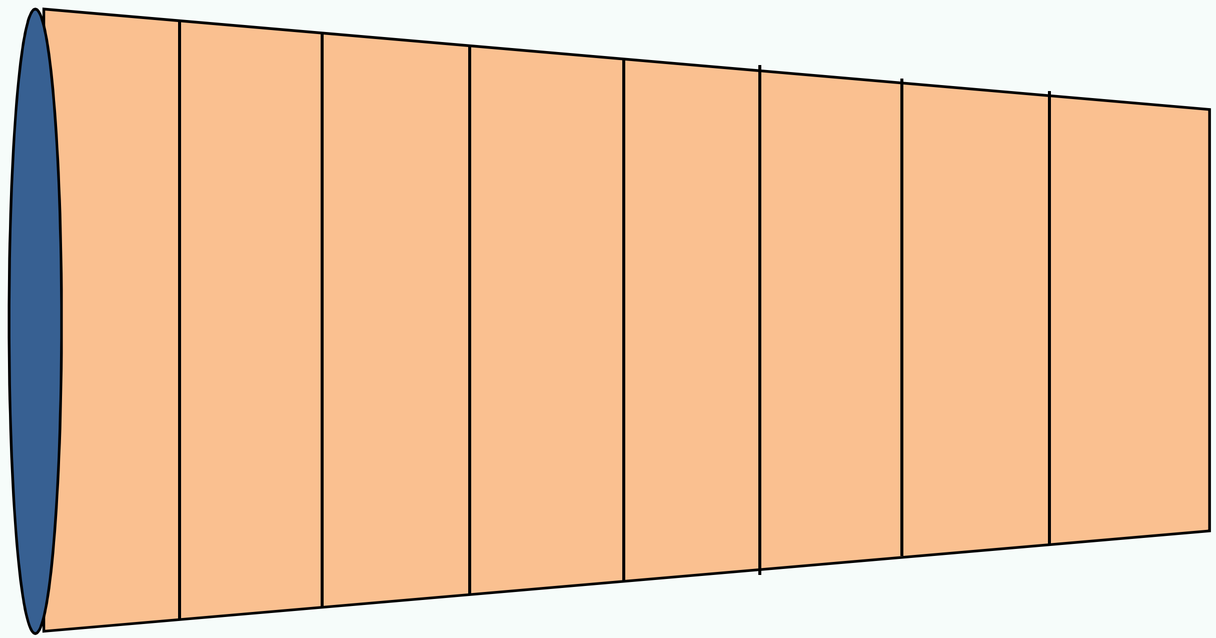
$$w = 2u = \frac{4\left(1-\upsilon^2\right)Lp}{E}$$

Note that these are the same equations solved with different characteristic crack lengths and assume an infinite stress and zero displacement at the crack tips.

Results Controlled by Assumptions in Simplistic Models



Pseudo-3D Models



- Calculate pressure drop along fracture length
- Calculate width and equilibrium height at each segment
- May have proppant transport models run sequentially with geometry

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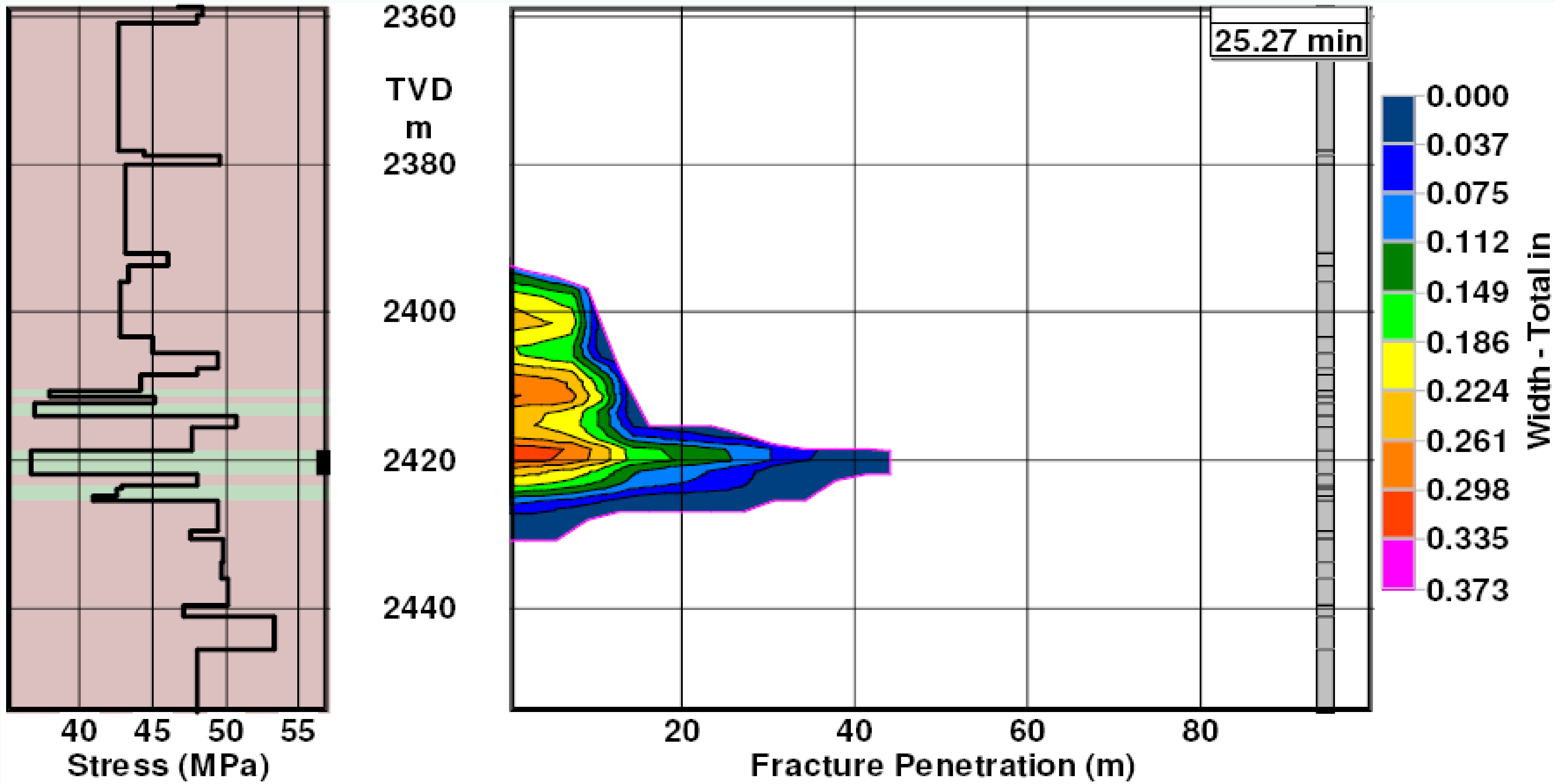
Example of StimPlan Output



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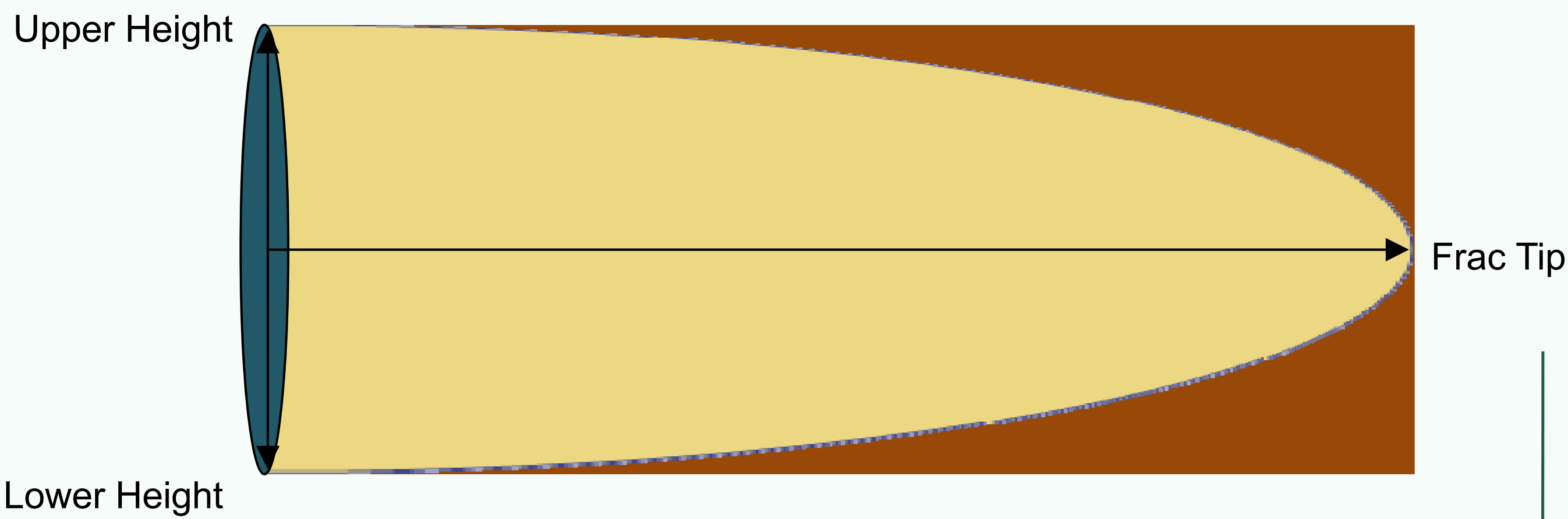
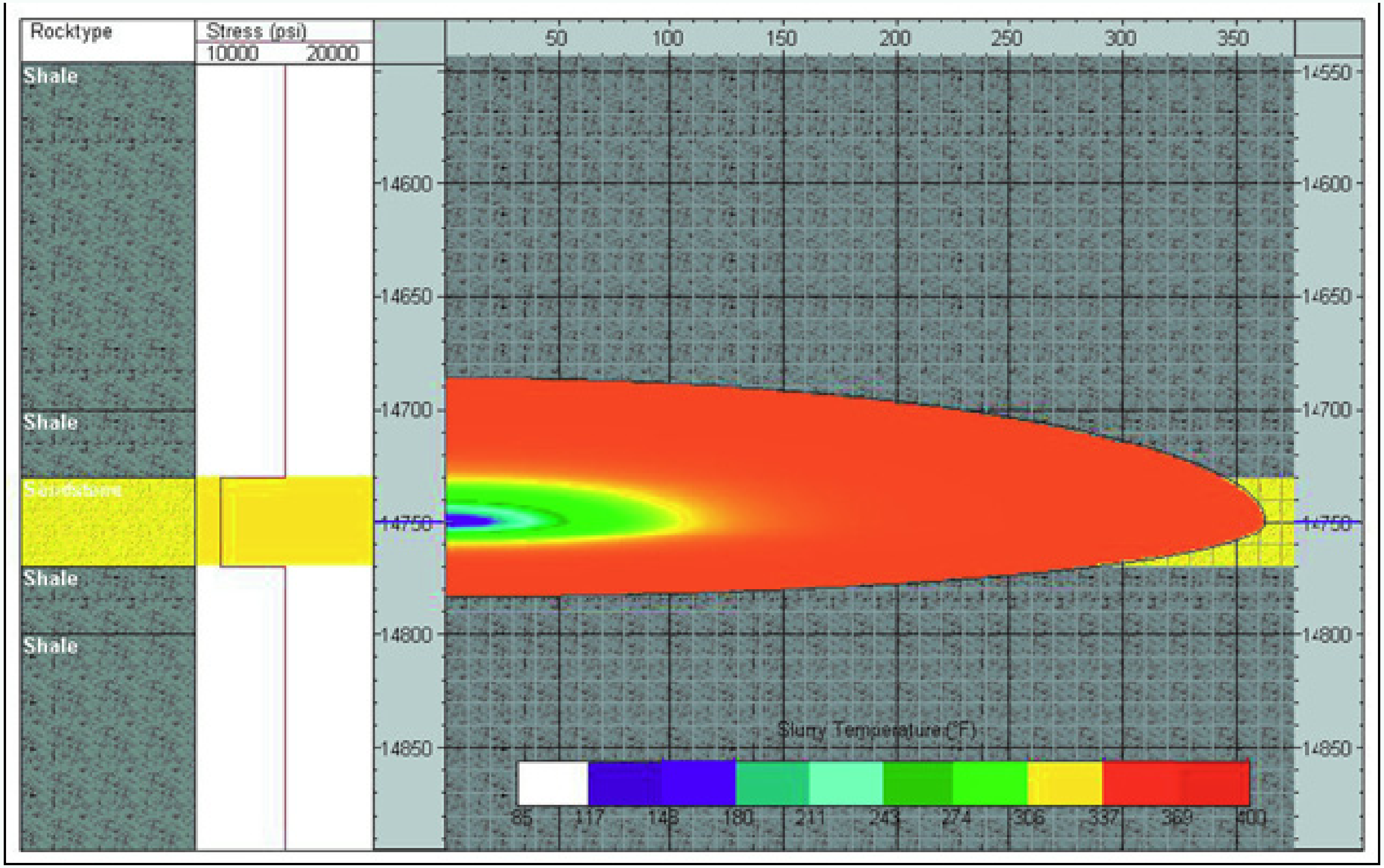
Lumped Parameter Models



- Model gives position of frac at three points only
- Frac growth is driven by vertical and horizontal pressure gradient functions
- Fracture outline is connected with concentric ellipses
- May have separate prop transport models that may or may not interact with geometry development

Example of Fracpro-PT Output



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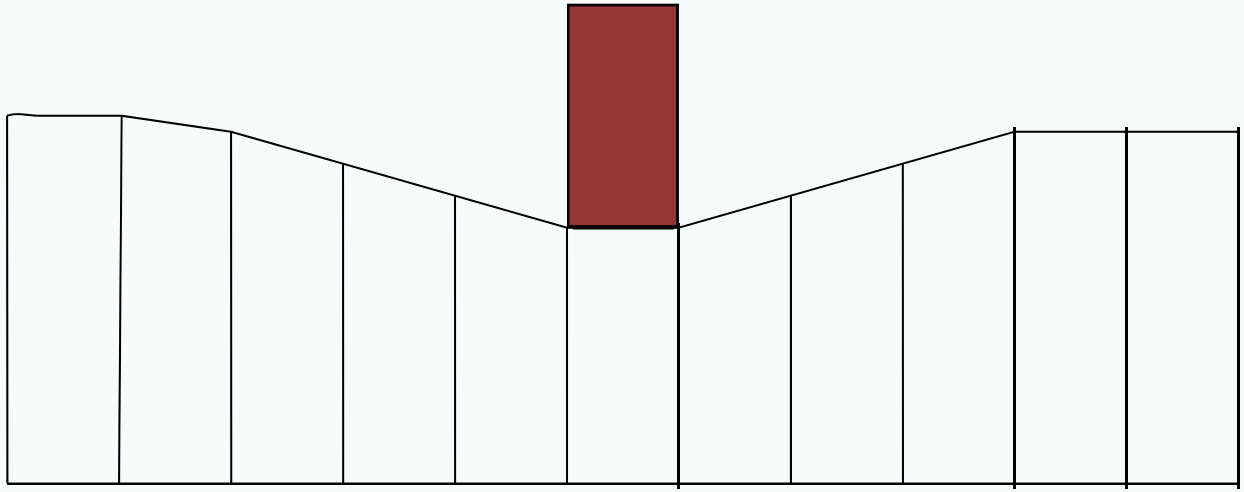
Available 3-D Models

- N-StimPlan
  – Gridded width and flow solution similar to GOHFER™
  – Fully-coupled elastic finite-element width solution
- GOHFER™
  – Gridded deformation and flow solution
  – Shear-decoupled formulation
- Terra-Frac
  – Finite-element solution
  – Requires re-meshing with time
  – Single fluid entry point
  – Linear-elastic solution

Elastically Coupled Displacement

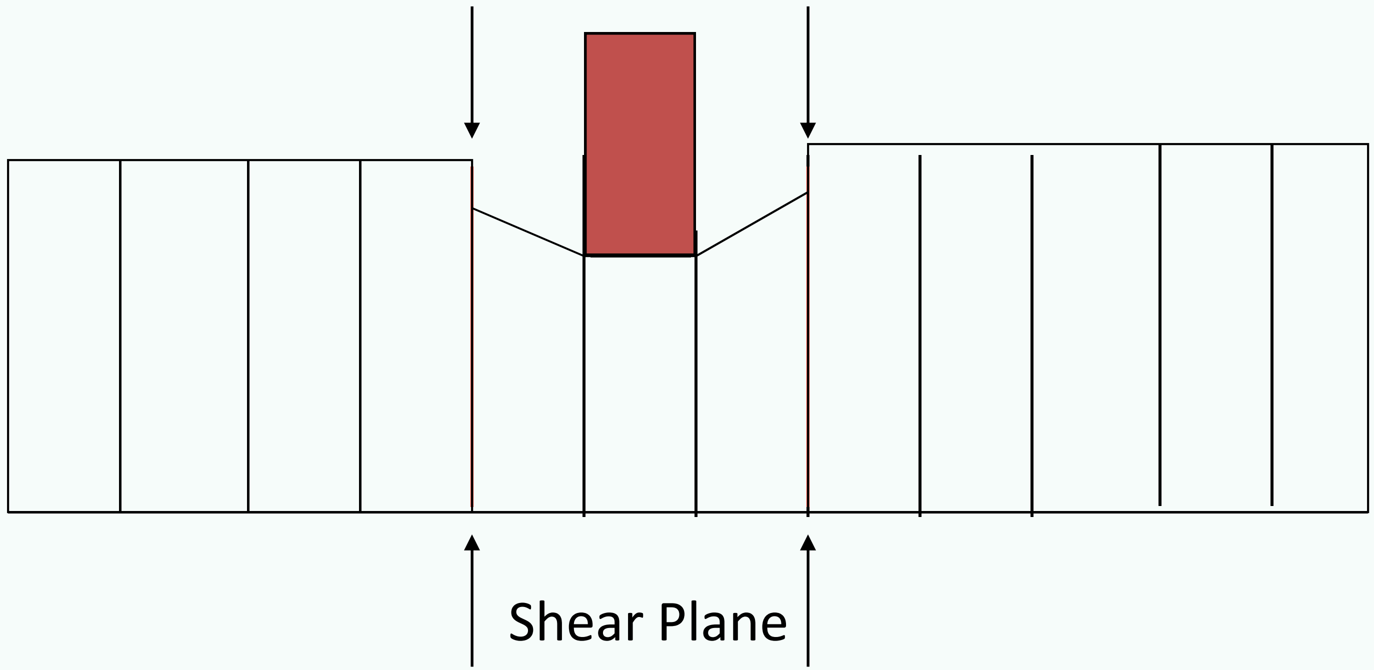


A point-load causes deformation of the entire surface

What is actually Observed in the Field?

- Fracture widths are often less than predicted
- High net treating pressures are common
- Height containment is often better than expected
- Shear failure occurs in the rock mass (microseisms)

Displacement With Shear



Slippage along shear-planes restricts displacement to a limited area

Shear-Slip Model

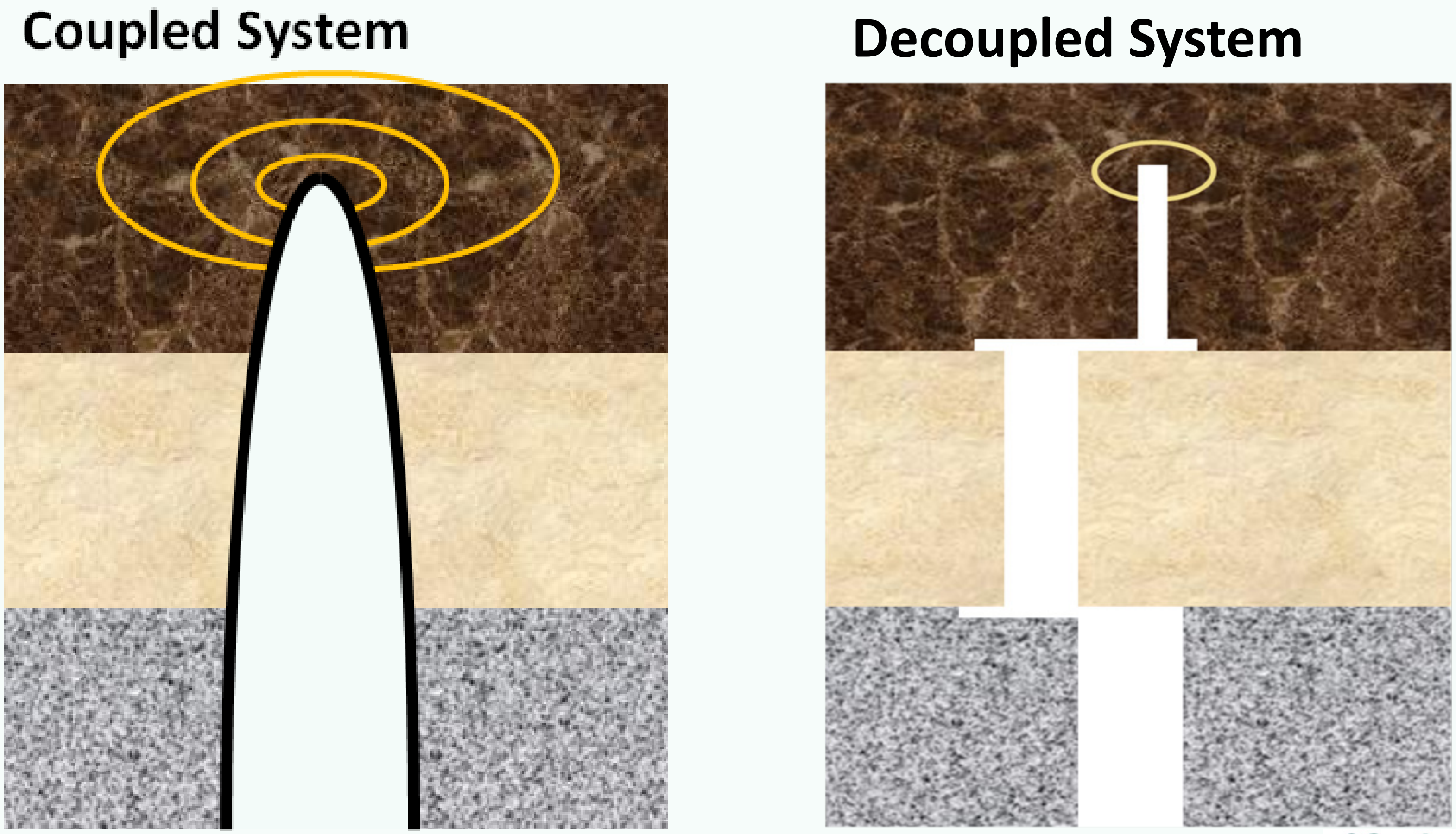
- No displacement transmitted across a freely sliding shear plane
- No influence from any loads applied on opposite side of shear plane
- Integrate applied load over a small area
- No stress concentration at fracture boundary
- Very small fracture widths

Frac Extension with Shear-Slip

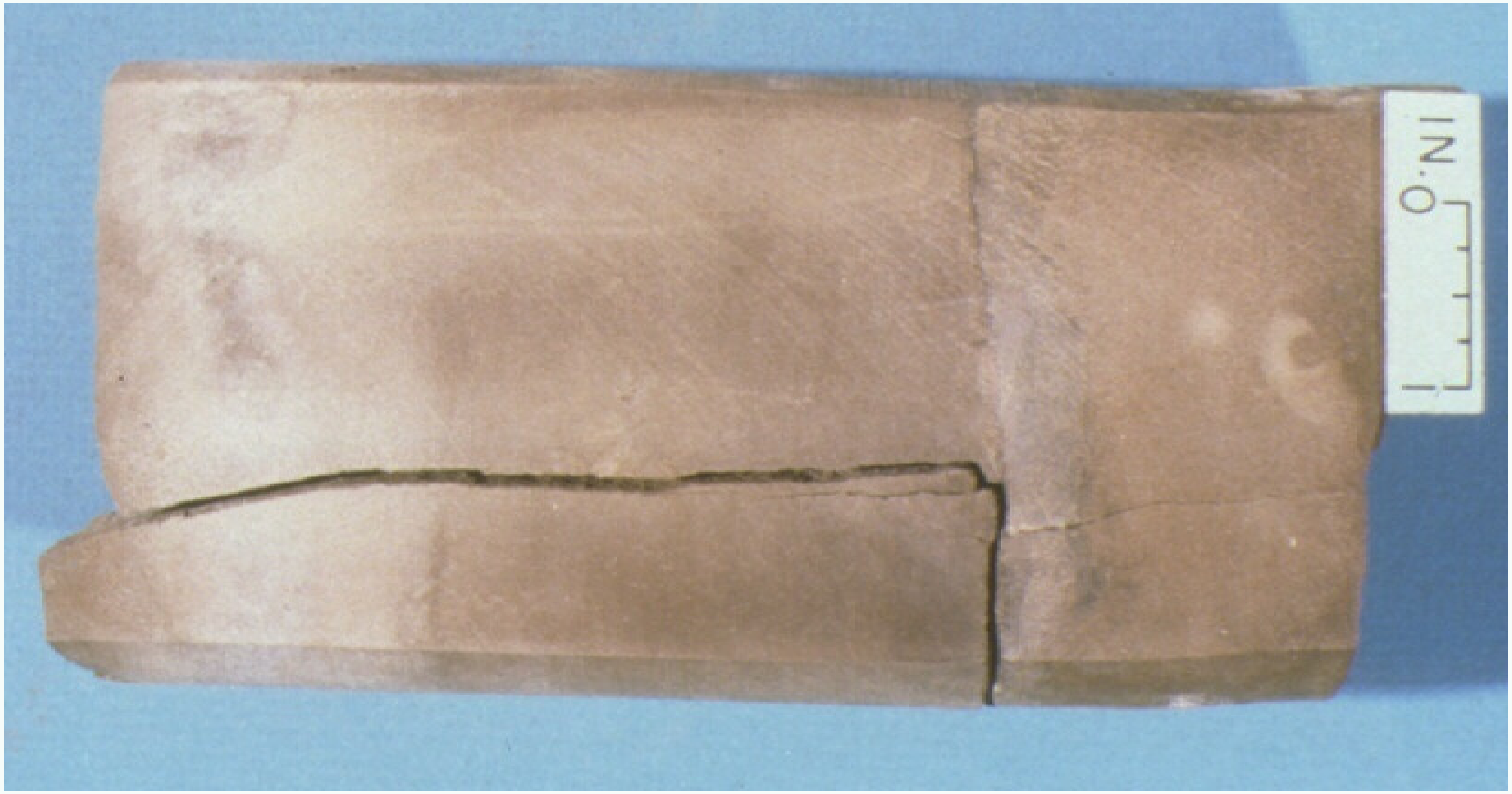
Fluid pressure must penetrate rock and exceed closure stress

Fluid pressure enters existing crack and generates a stress concentration

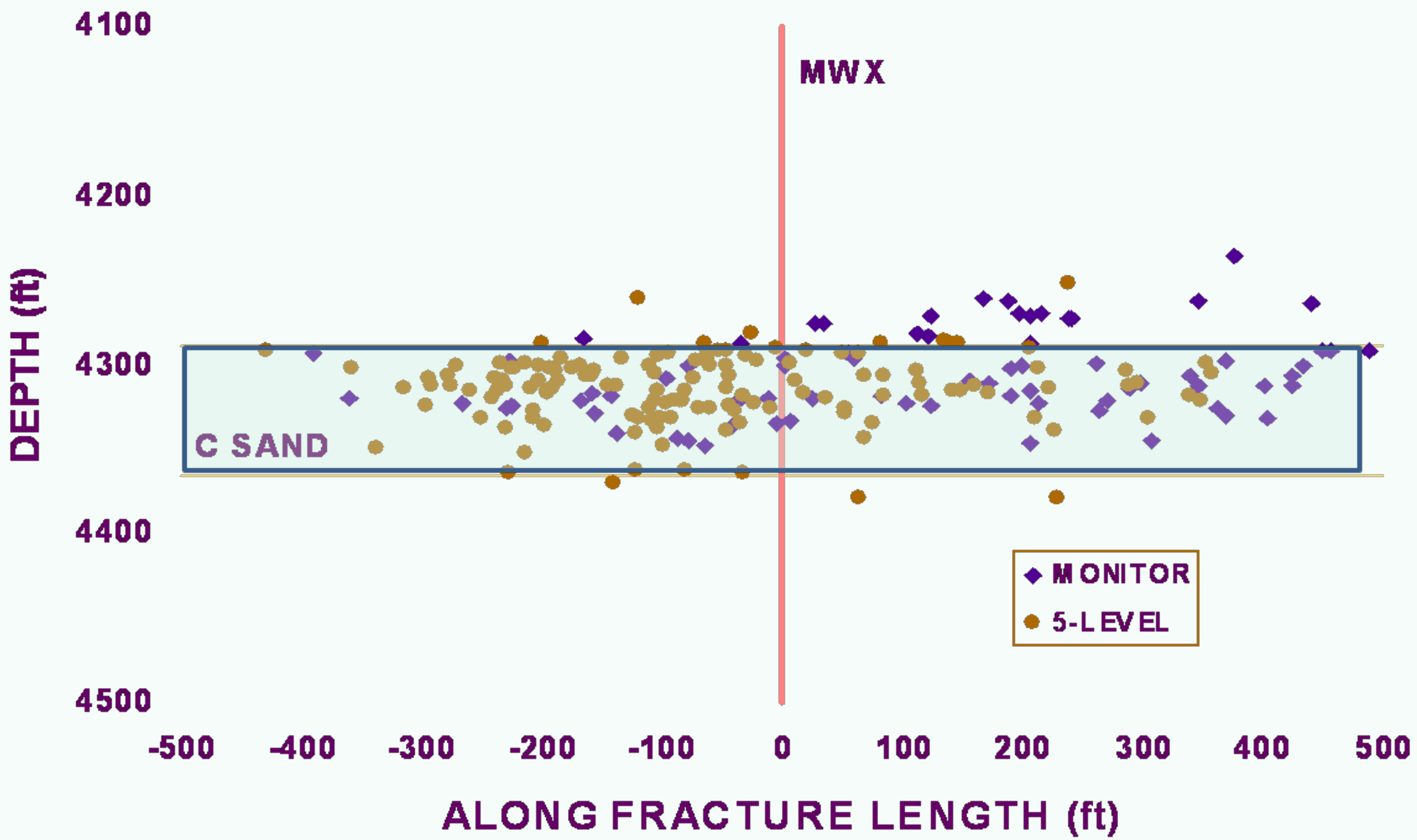
Containment



Actual Fracture in Core Section



Microseisms After Water Injection



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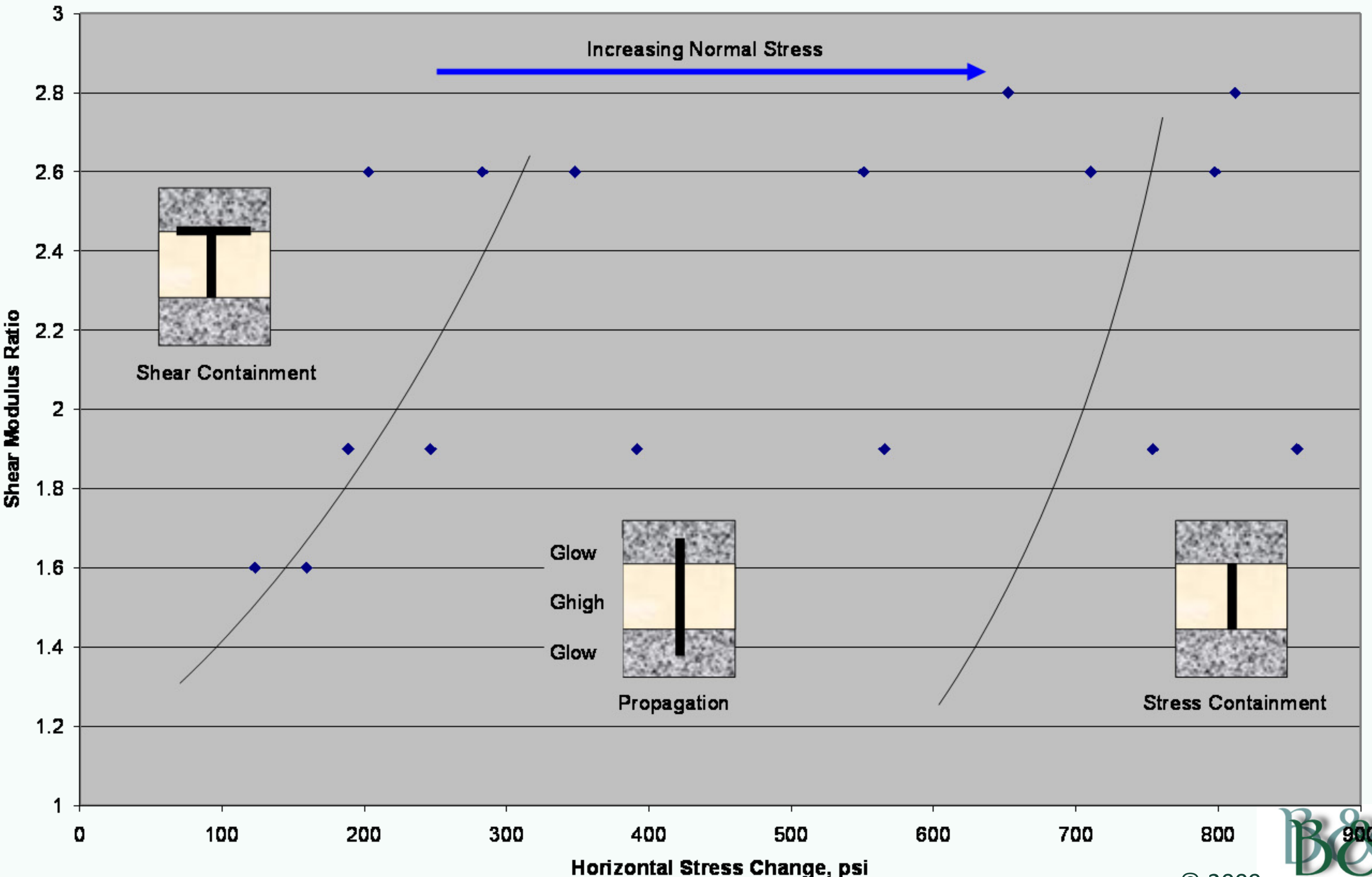
Fracture Height Containment Through Shear Slip at Bed Boundaries



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