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*L a f a y e t t e*

# Particle Size Distribution (PSD) for Wellbore Strengthening Applications

By

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# Outline

- Two perspectives for PSD

## Geomechanics

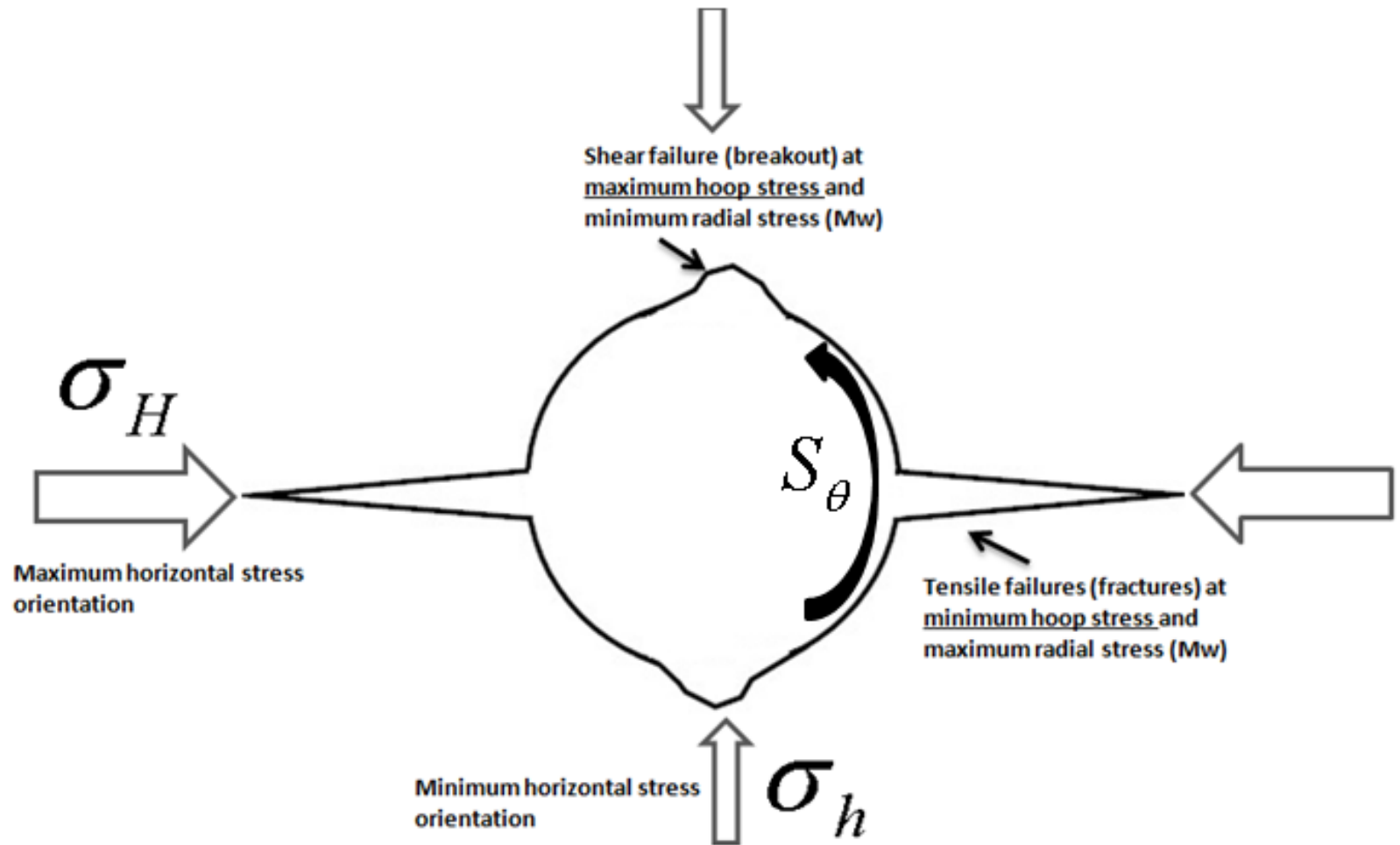
Drilling Fluid's Engineer

- PSD link with Near Wellbore Stresses
- Need to know about fractures to design PSD  
Numerical models vs Analytical Models
- Laboratory experiments
- PSD for Casing while Drilling

# Why two perspectives are different?

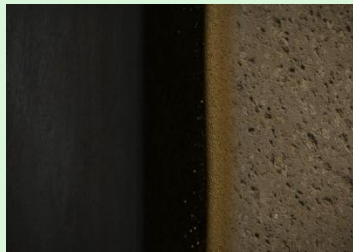
- In-situ and near wellbore stresses are key elements for well integrity
- In-depth knowledge of fracture (initiation, propagation and sealing) is required
- Different loss mechanisms need different treatments

# Why wellbore stresses matter for PSD design?

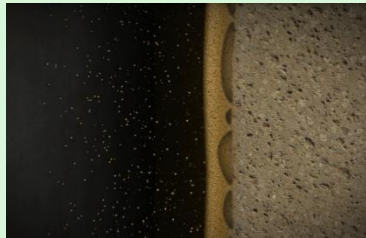


# Fracture pressure strongly depends on near wellbore permeability (Mud cake quality)

Fracture pressure for a well with a good mud cake (upper limit-non penetrating)



Fracture pressure for a well with a poor mud cake (lower limit-penetrating)



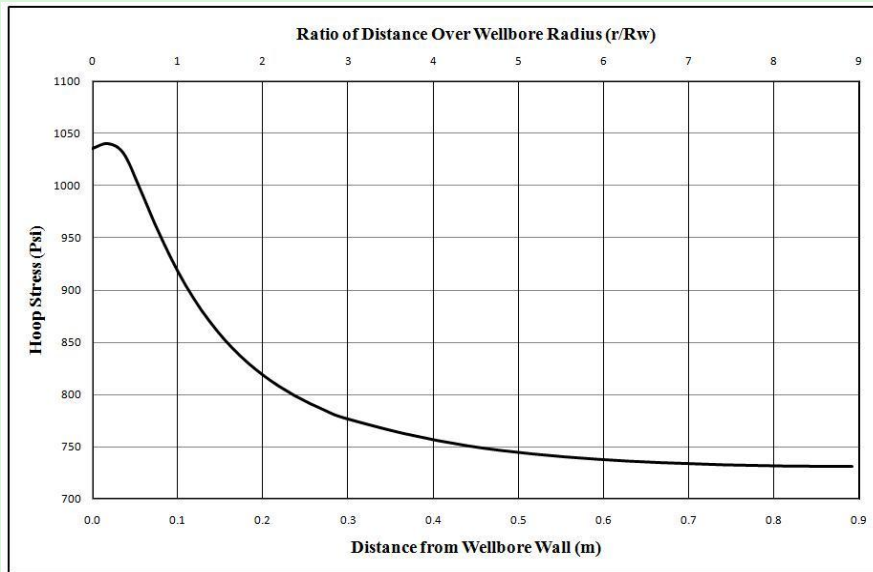
$$P_{frac} = 3\sigma_h - \sigma_H - PP + T_0$$

$$P_{frac} = S_\theta - PP + T_0$$

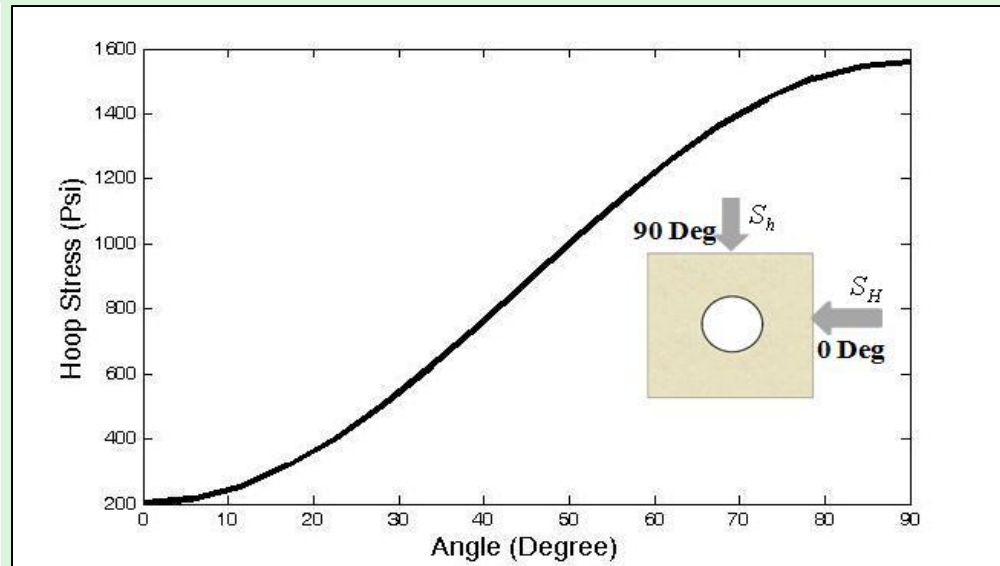
$$P_{frac, penetrating} = \frac{3\sigma_h - \sigma_H - \frac{\alpha(1-2\nu)}{(1-\nu)} PP + T_0}{2 - \frac{\alpha(1-2\nu)}{(1-\nu)}}$$

# Why wellbore stresses matter for PSD design?

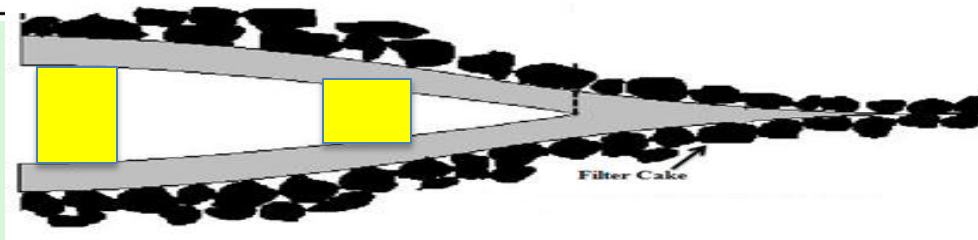
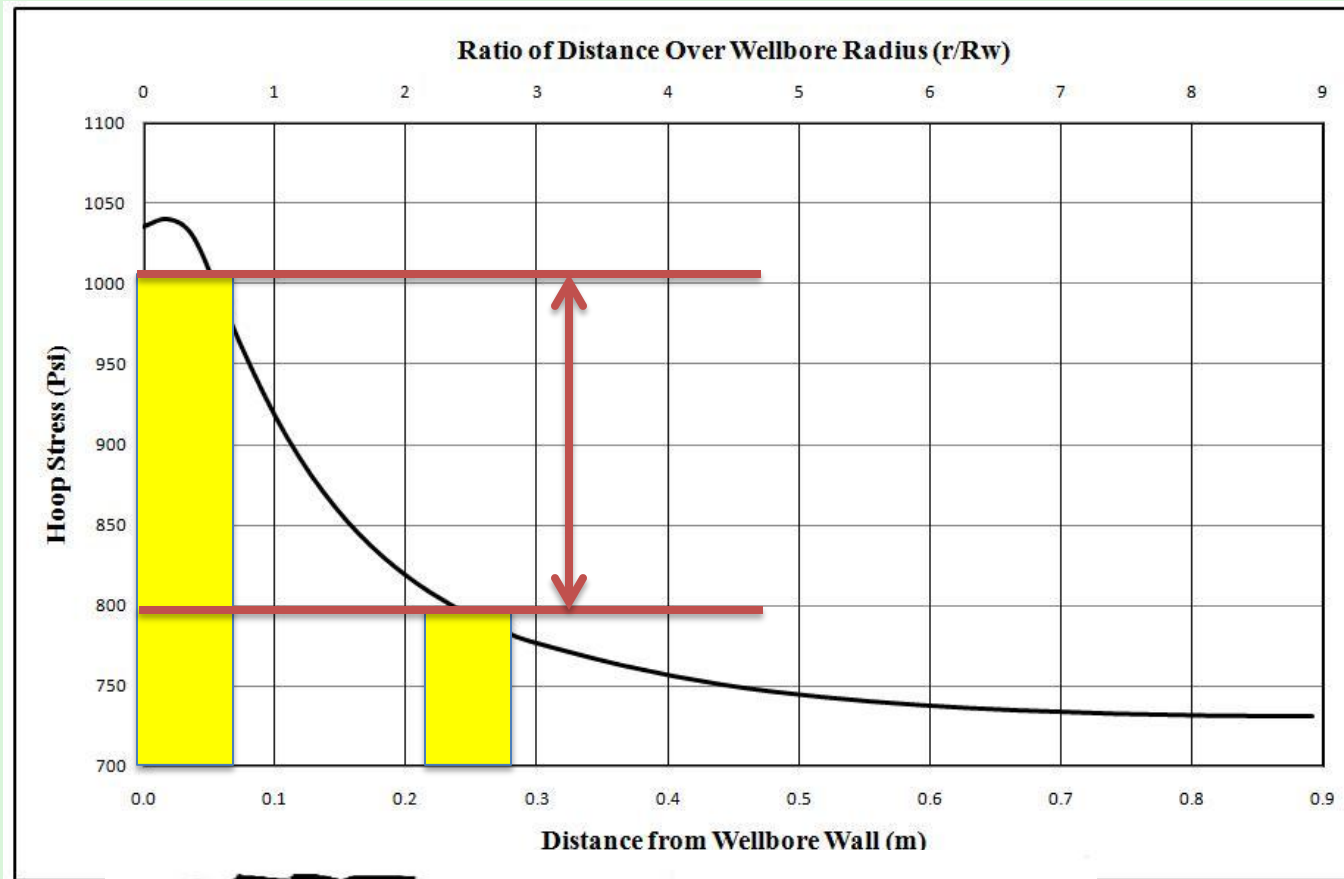
## Hoop stress by distance from the wellbore



## Hoop stress around the wellbore well



# Right PSD design can get the most benefit from near wellbore stresses

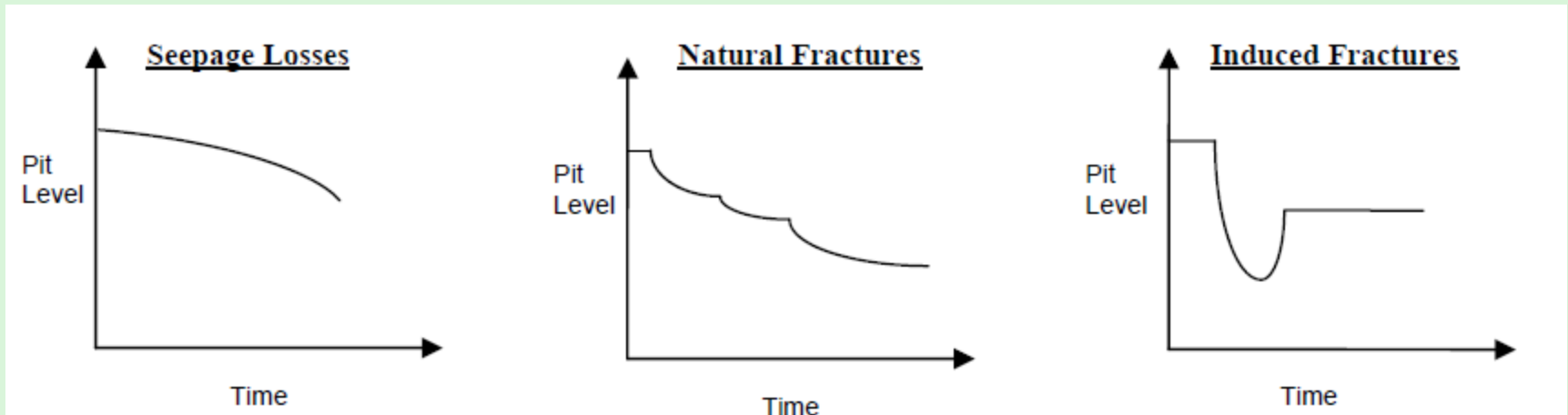


Salehi , 2012

# Why type of fracture matters?

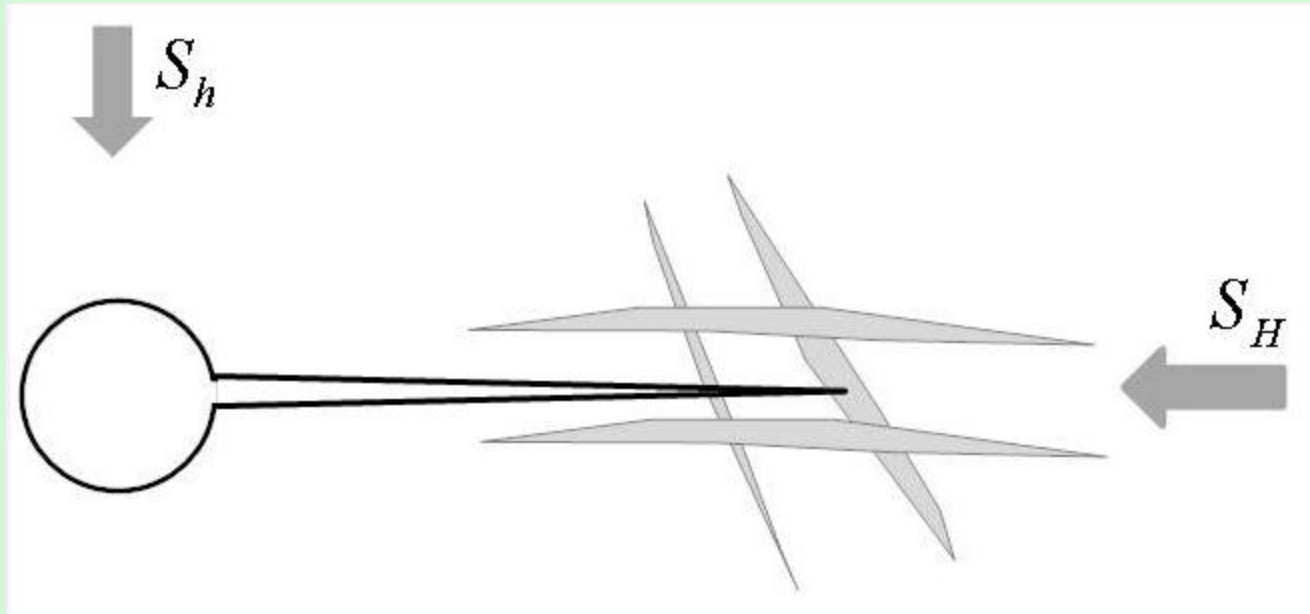
- Type of lost circulation will depend on type of the fracture

-Induced fracture versus Natural Fractures  
(Vugs)-Combination of both





# Loss Mechanism-Mechanically open vs Hydraulically open fractures

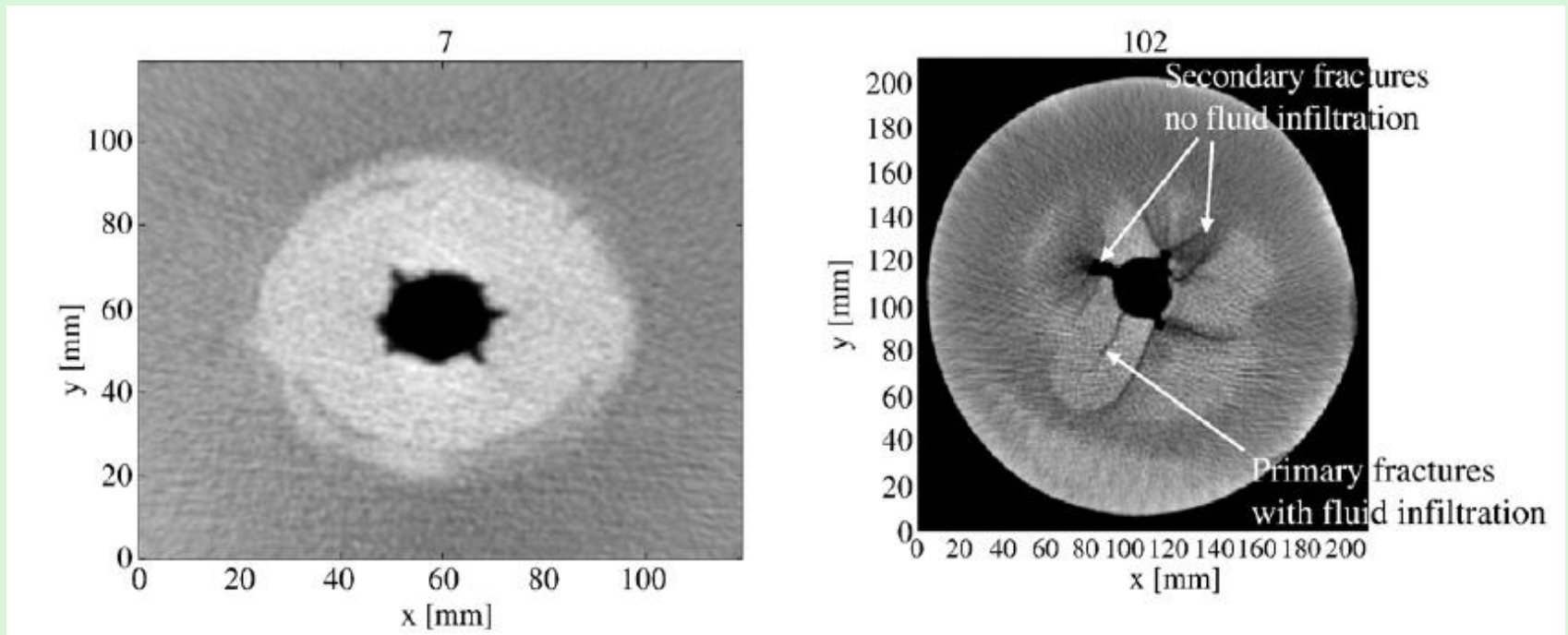


When experiencing losses in hydraulically open fractures losses will continue until the fracture volume is filled up. Adding LCM won't help much.

Nygaard and Salehi, 2011

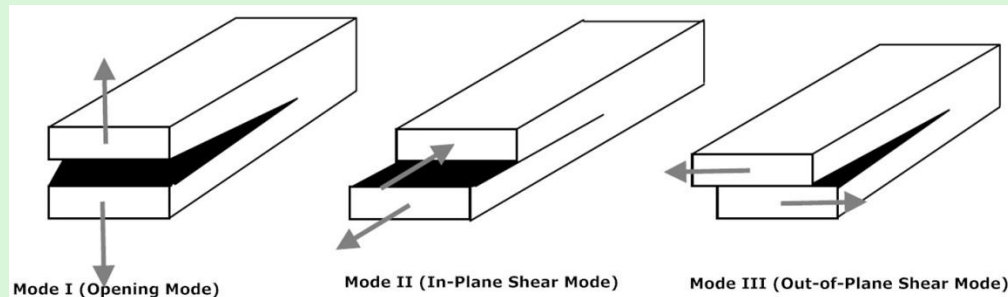
$$\frac{80.75 UCS^{0.55}}{\sigma_v - Pp} > 2.5$$

# Fracture types change based on Rock Material Behavior

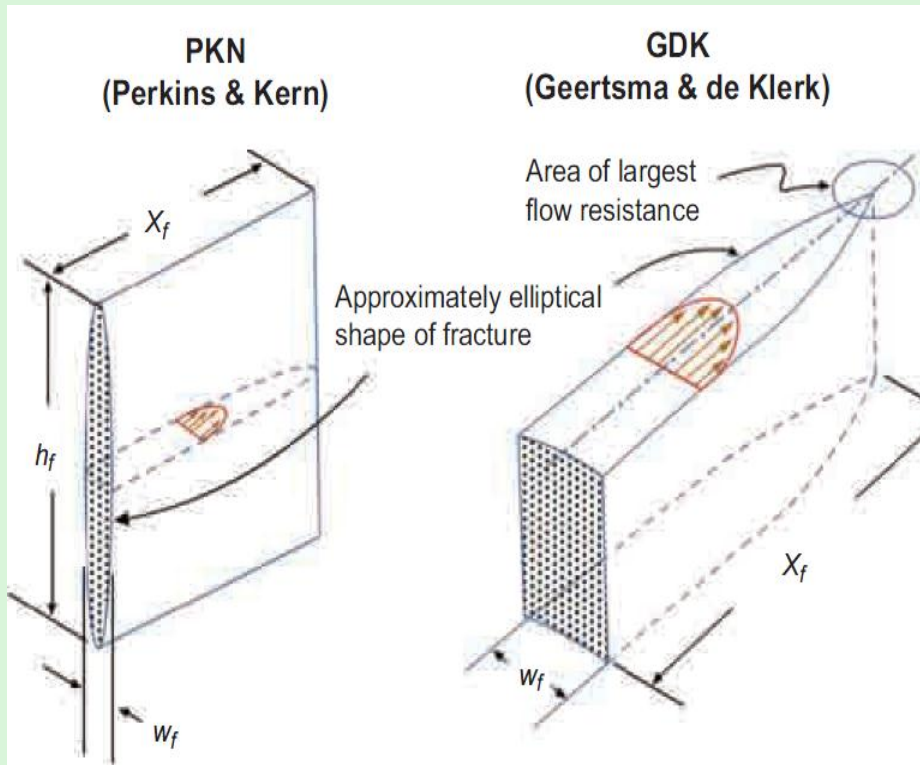


## CT scan of Fractures in soft rock

Bohloli and Pater, 2006



# Predicting Fracture Width-Analytical Models?!



Adachi et al., 2007

$$w_m = \frac{2(1-\nu^2)Hp_n}{E}$$

$$w_m = \frac{4(1-\nu^2)Lp_n}{E}$$

# Three Key Steps for Wellbore Strengthening PSD Design

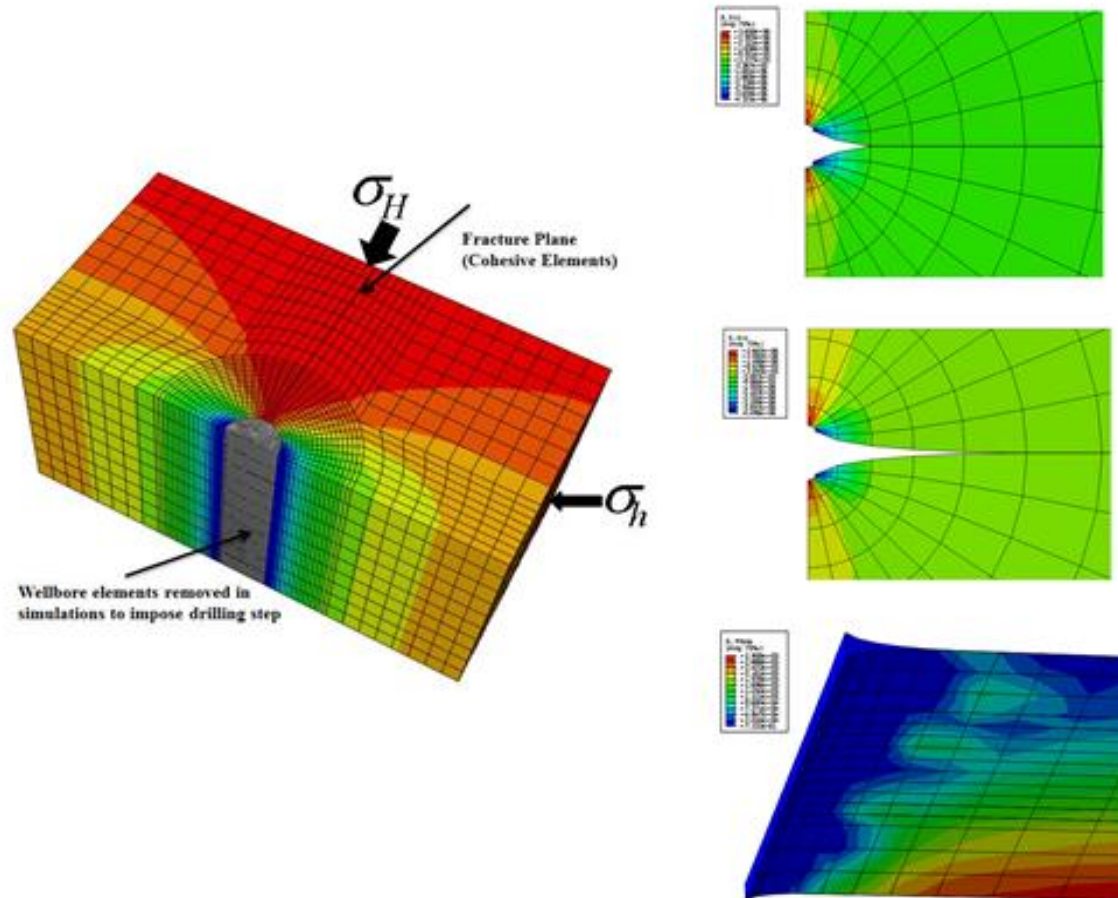
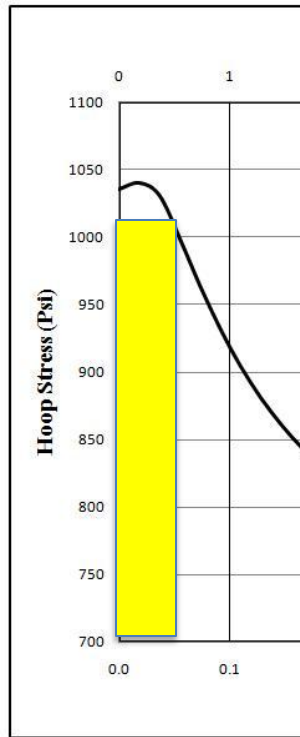
**Step 1.** wellbore condition and loss mechanism  
(By understanding your leak off test (or XLOT, FIT),

**Step 2.** Design PSD to Maximize Hoop Stress

**Step 3.** Verify your PSD in Lab

## Step 2.

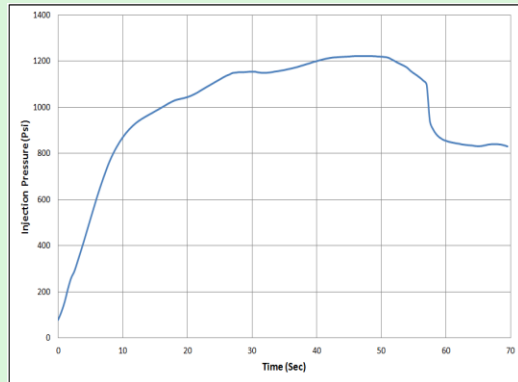
### Design PSD to Maximize Hoop Stress



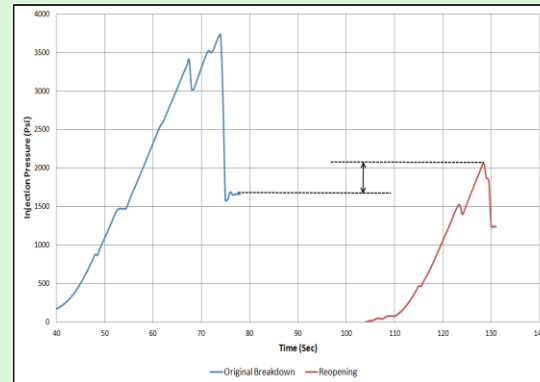
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Advanced Numerical Models can optimize PSD design for maximized hoop stress restoration

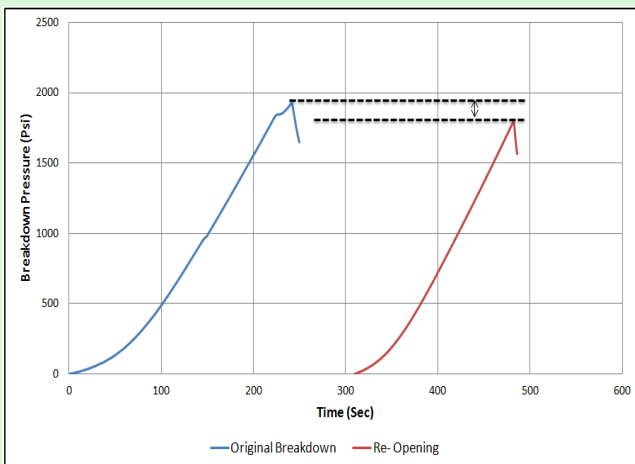
# Near Wellbore Fracture Experiment-Evaluating Frac Breakdown and Reopening Pressures



**Very low fracture breakdown pressure on samples with pre-existing fractures**



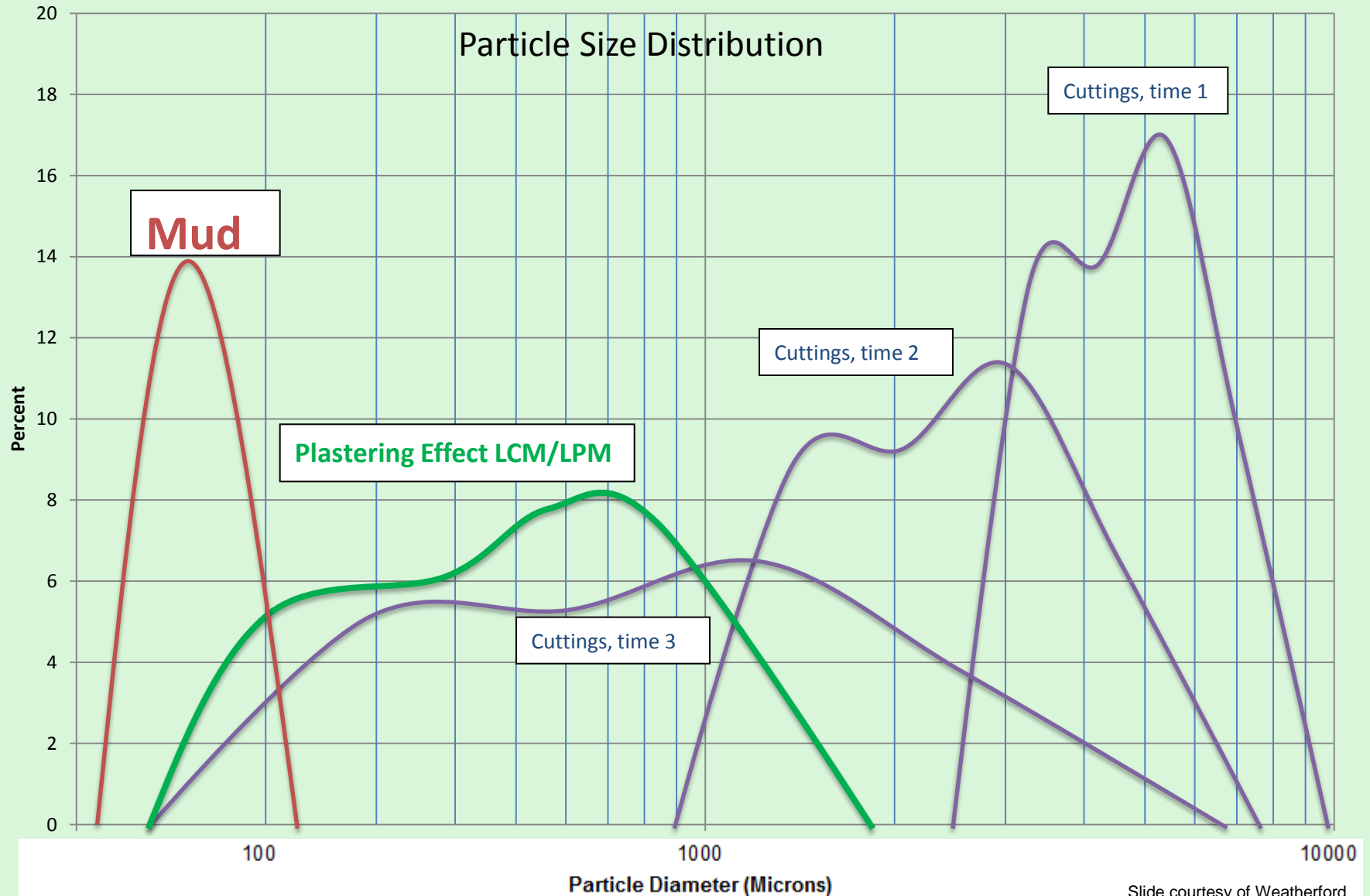
**Very high breakdown pressure on Dolomite samples**



**Lower breakdown pressure on Sandstone cores-Fracture healing effects**



# PSD in CwD



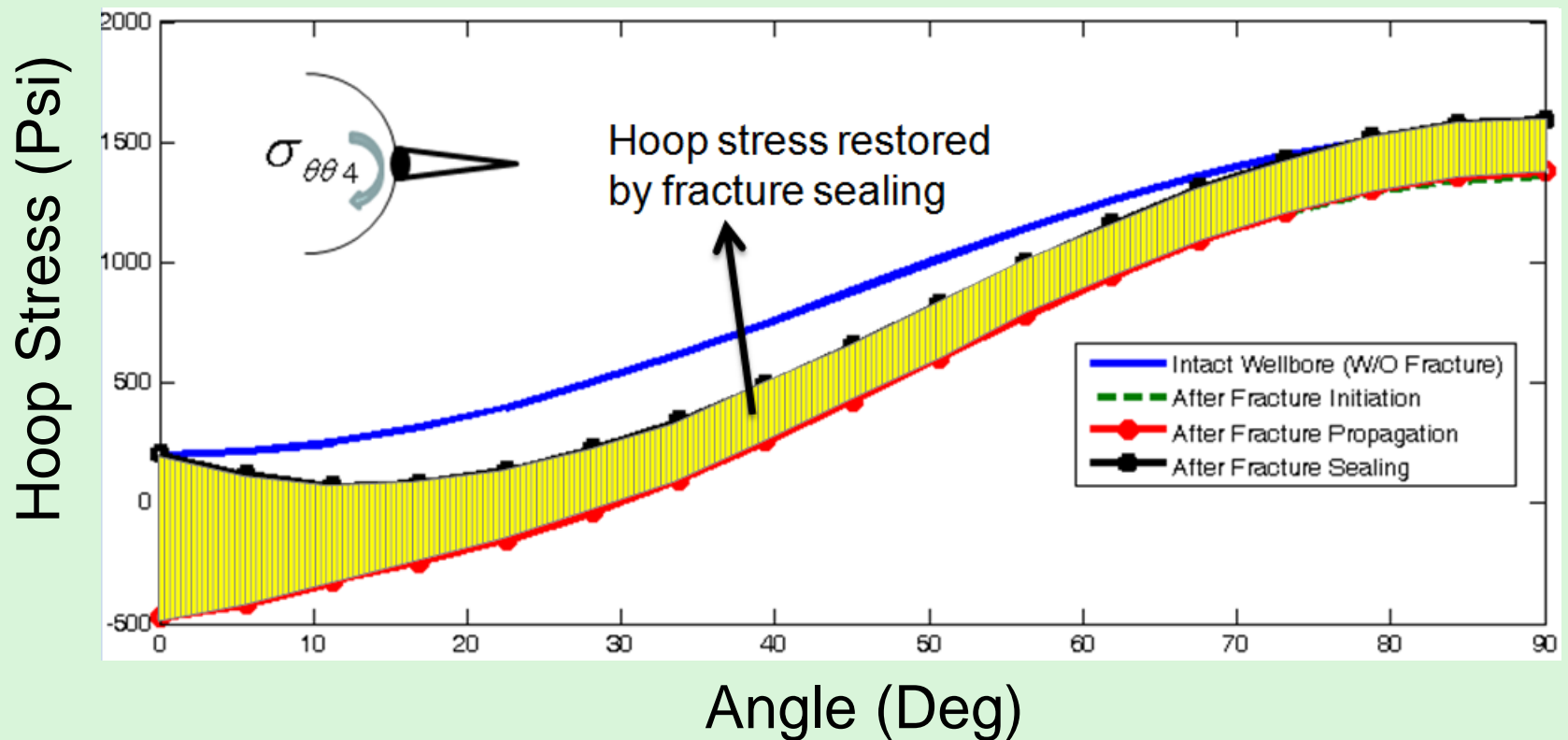
# Question?



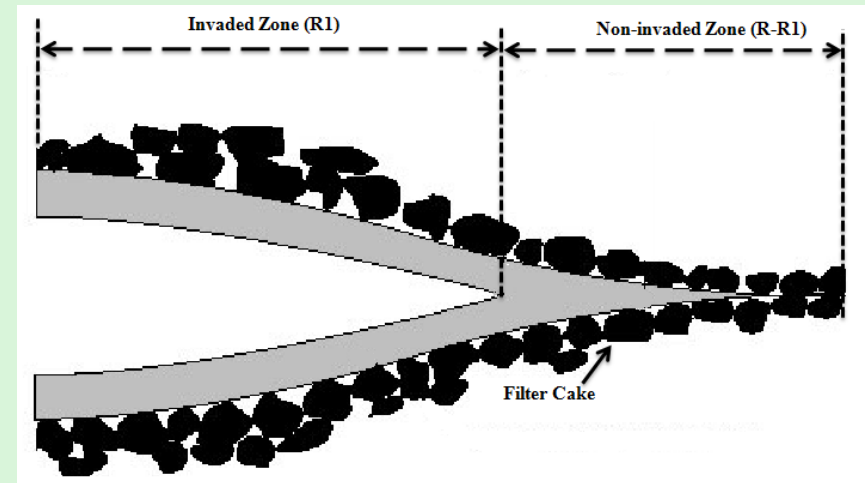




# Simulations of fracture initiation, propagation and sealing (Results)



# Fracture Healing Effects- WBM



$$P_{fp} = (\lambda + 1)\sigma_h - \lambda P_p$$

$$\lambda = \frac{1}{1 - \sqrt{1 - \left(\frac{R_1}{R}\right)^2}} \times \sqrt{1 - \left(\frac{R_1}{R}\right)^2}$$

Modified From Abe et al, 1976

