OilFieldGeomechanics

# OilField Geomechanics LLC

# On The Geomechanics Of Zipper Fracs

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October 2014

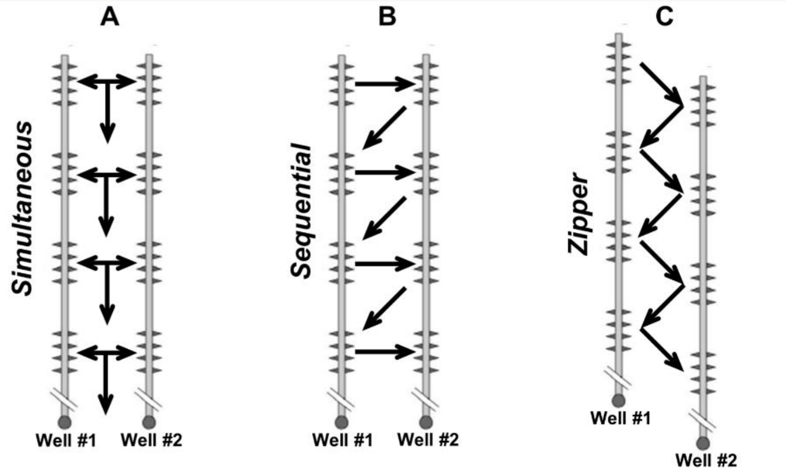


## What Is The Goal Of Multi-Well Completions?

Because of the low (ultra-low) permeability in many of the Unconventional plays, operators are investigating all manner of mechanisms to improve well productivity at the same or lower costs. Multi-well completions, like Zipper Fracs, are viewed as another mechanism to achieve this goal. Key issues:

- An important goal of many completion operations in Unconventionals is to increase 'complexity' – wherein a complex fracture pattern is stimulated (rock failure) within the reservoir formation (providing a large, enhanced drainage volume) as opposed to vertical, bi-planar hydraulic fractures.
- In a multi-well completion scheme, the intent is that the operational timing of hydraulic fractures, well placement, and placement of the hydraulic fractures themselves will further increase the size and/or permeability of the enhanced drainage area from a single well alone.
- Note that some operators report using multi-well completions solely for operational efficiency (mostly pad operations) rather than production improvement.

# Multi-Well Completion Concepts




In multi-well completions, the operational timing of injections, the well spacing, and the injection locations (stages) are used in an attempt to increase the overall 'complexity' generated and increase production.



# Geomechanics 101

**Every geomechanics evaluation consists of four primary components and these components must be understood in order to evaluate a given geomechanical response:**

1. **Stress and stress changes – a stress increase tends to lead to rock failure.**
2. **Formation pressure – a pressure increase tends to reduce the effective stress, which tends to increase rock failure.**
3. **Mechanical properties – changes in stress and pressure are resisted by the properties (e.g., strength) of the rock.**
4. **Geometry – the orientation of a structure or feature (e.g., natural fracture) within the stress and pressure fields.**

# Critical Fundamental Concepts

**The effects from multi-well configurations must build upon critical, fundamental, geomechanics concepts:**

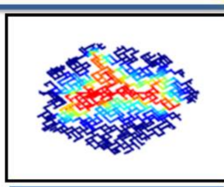
- **Hydraulic fractures induce the Stress Shadow effect – which increases the total normal stress on ALL natural fractures around it.**
- **The Stress Shadow effect can be offset by increasing natural fracture pressure.**
- **HF tip shear is a key driver for (common?) shale formations with closed/cemented or partially cemented weakness planes or natural fractures in order to open them for a fluid pressure change.**

***<u>The punchline:</u> In order to understand (and design) Zipper Fracs, we must understand the changes in stress and pressure on the rock mass, natural fractures, and weakness planes from hydraulic fractures.***



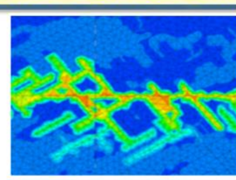
# Hydraulic Fracturing Scenarios in Unconventionals

**Highly Fractured Rock Mass**



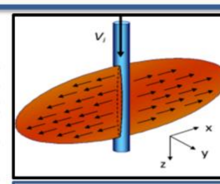
- Limited or no HF is created.
- Characterize NF sets for differences.
- Optimize Operational Parameters.

**Cemented Natural Fractures: Weak or Partially Open**



- Interaction of HF with NFs & discontinuities is critical.
- Design: How to fail and open the NFs to create flow area.
- Characterization of NF sets and stress and pressure is key.

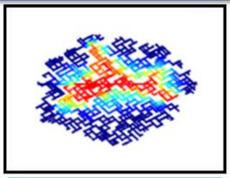
**No Natural Fractures or Fractures with Strong Cementation**

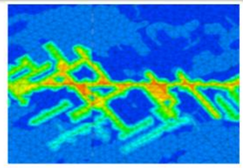


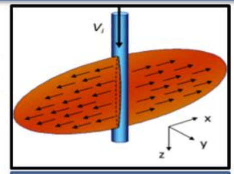
- Treat as conventional HF.
- Economics of multiple stages.
- Optimization of length/area in pay.

***The key starting point for hydraulic fracture design in Unconventionals is to understand the rock mass…which may vary within the play or even along the wellbore…***

# Hydraulic Fracturing Scenarios in Unconventionals








...ured Rock Mass

- Limited or no HF is created.

...Parameters.

...tural Fractures: ...artially Open

- Interaction of HF with NFs &

...NF sets and stress and pressure is key.

...l Fractures or ...Strong Cementation

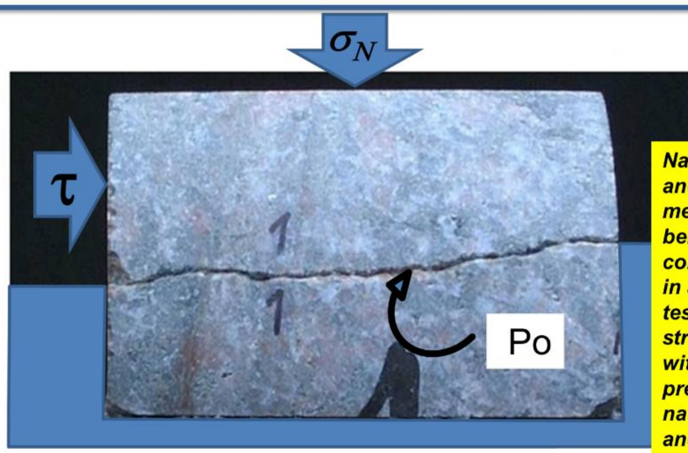
- Treat as conventional HF

**KEY: These do NOT stimulate the same – whether in a single well or multi-well configuration!**

***The reason the rock mass is the key starting point for hydraulic fracture design is that these different rock mass types do not stimulate the same!***



# Natural Fracture Mechanical Behavior

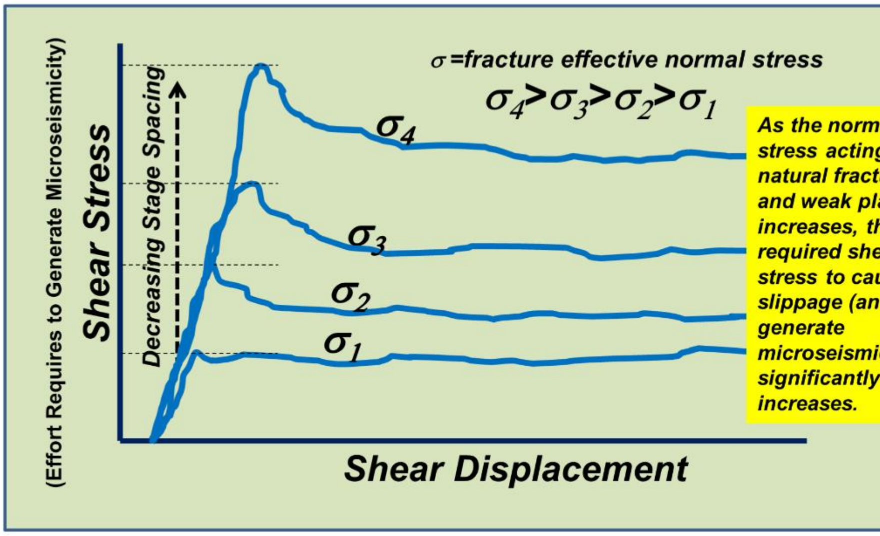



***Natural fracture and weak plane mechanical behavior is commonly tested in a direct shear test. A total normal stress is applied, with a given pressure in the natural fracture, and a shear stress is applied until the natural fracture or weakness plane slips.***

Effective stress=$\sigma'$
Total stress=$\sigma_N$
Pore pressure=Po

$$\sigma' = \sigma_N - p_o$$

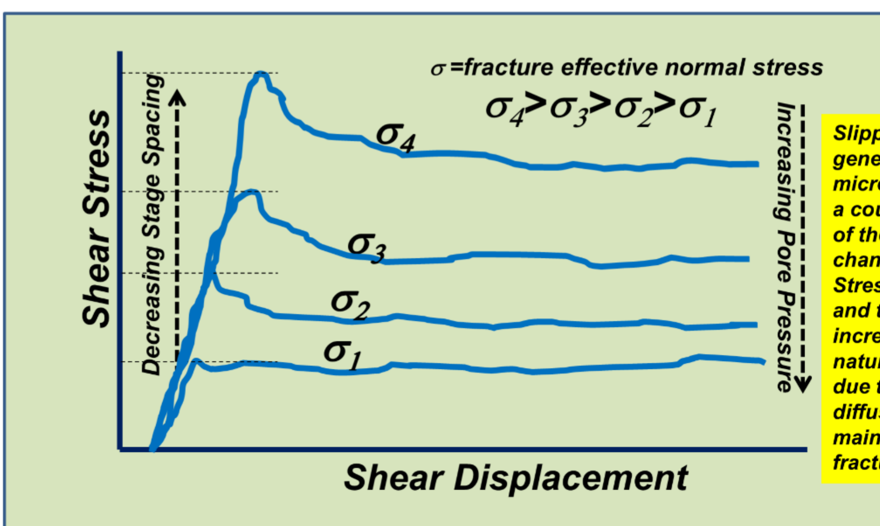
# Natural Fracture Mechanical Behavior




As the normal stress acting on natural fractures and weak planes increases, the required shear stress to cause slippage (and generate microseismicity) significantly increases.

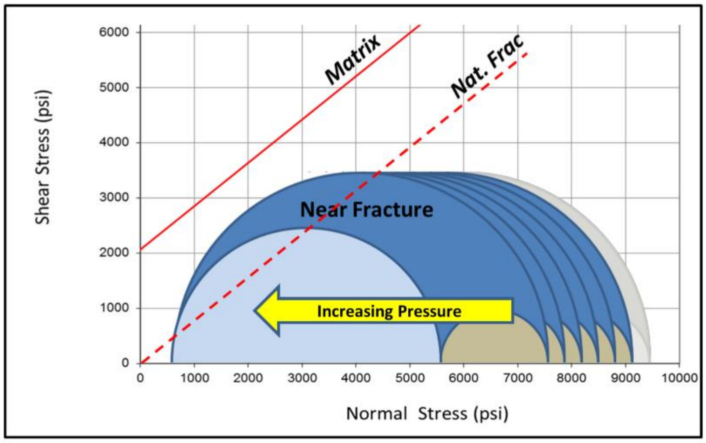


# Natural Fracture Mechanical Behavior




Slippage (and generated microseismicity) is a coupled function of the stress change due to Stress Shadows and the pressure increase in the natural fractures due to pressure diffusion from the main hydraulic fracture.

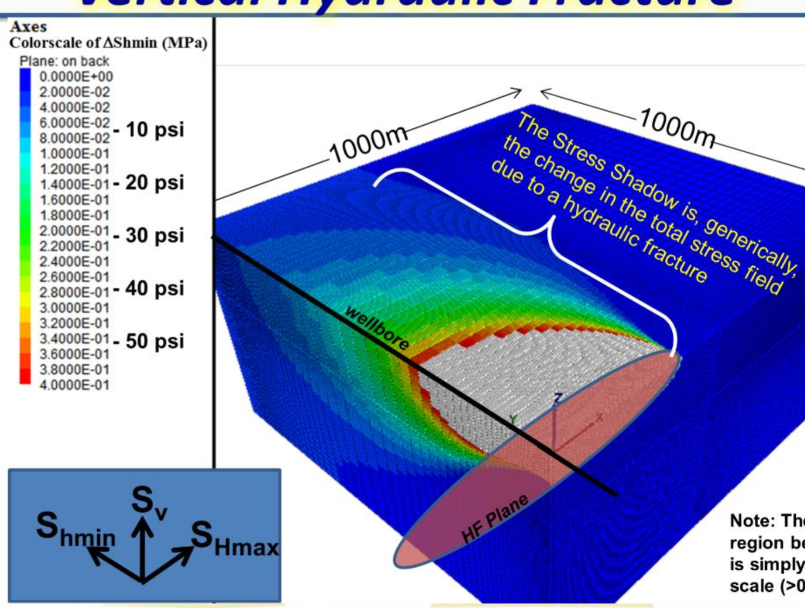
# Stress Change Due to Increasing Pressure in Natural Fractures




**A key (the key?) to understanding natural fracture and weakness plane shear ('complexity') is the influence of pressure on reducing the effective normal stress.**

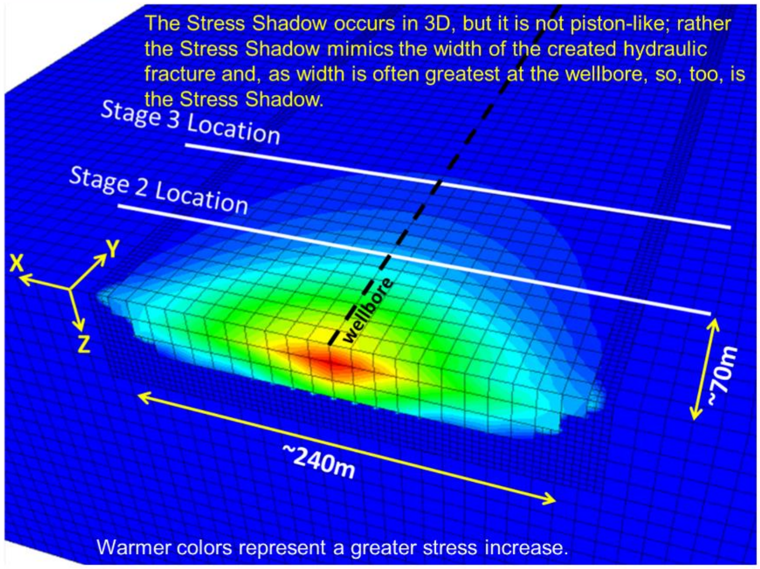


# Stress Changes From A Bi-Planar, Vertical Hydraulic Fracture



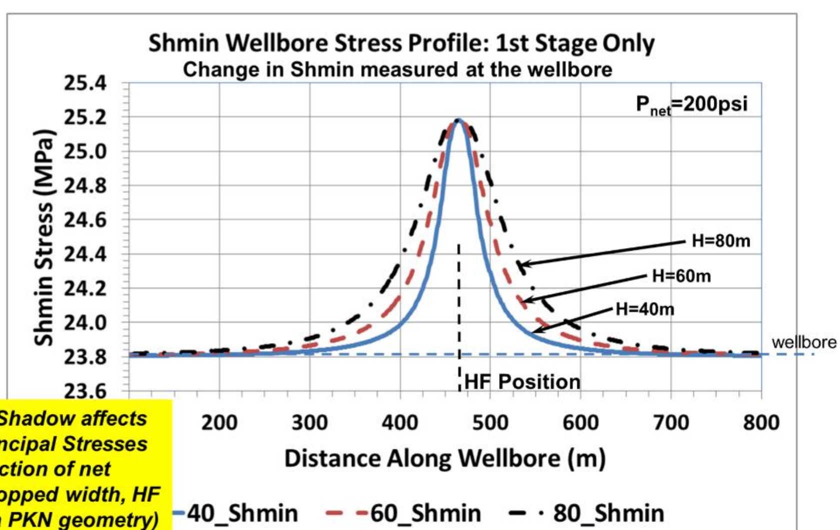

**Note: The white region behind the HF is simply off the color scale (>0.4 MPa)**

# Single Stage Stress Shadow



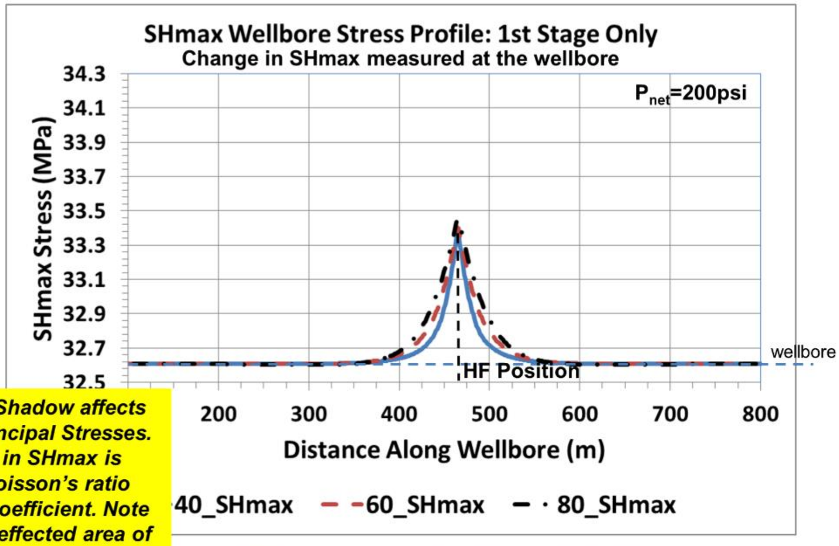



# Shmin ~f(height) – Single Stage




***The Stress Shadow affects all three Principal Stresses and is a function of net pressure/propped width, HF height (for a PKN geometry) and distance.***

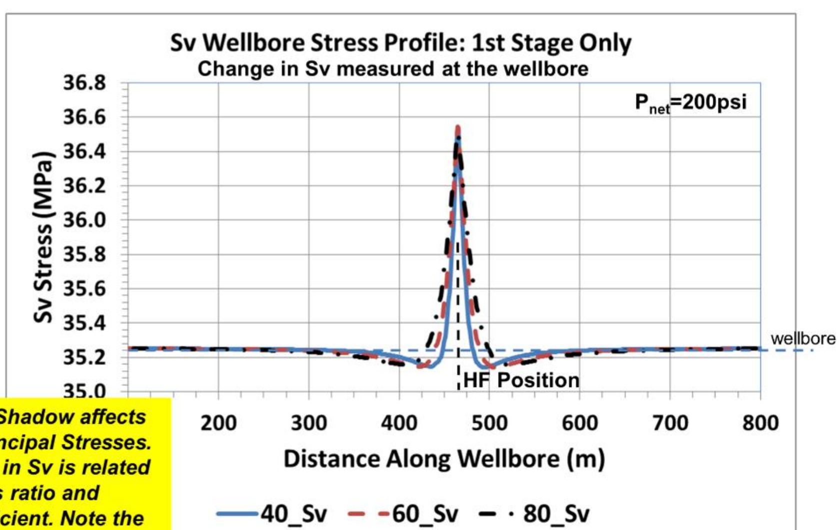
# SHmax ~f(height) – Single Stage




***The Stress Shadow affects all three Principal Stresses. The change in SHmax is related to Poisson's ratio and Biot's coefficient. Note the smaller effected area of SHmax.***

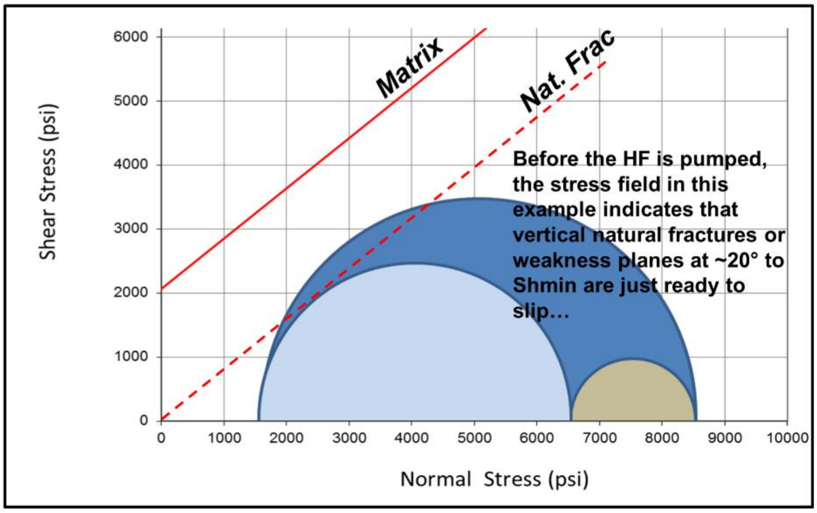


# Sv ~f(height) – Single Stage



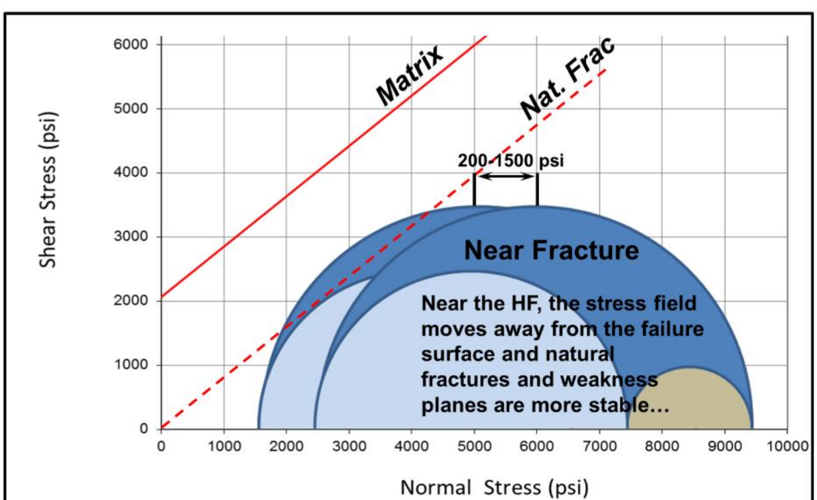

***The Stress Shadow affects all three Principal Stresses. The change in Sv is related to Poisson's ratio and Biot's coefficient. Note the smaller effected area of Sv.***

# Stress Before Hydraulic Fracturing

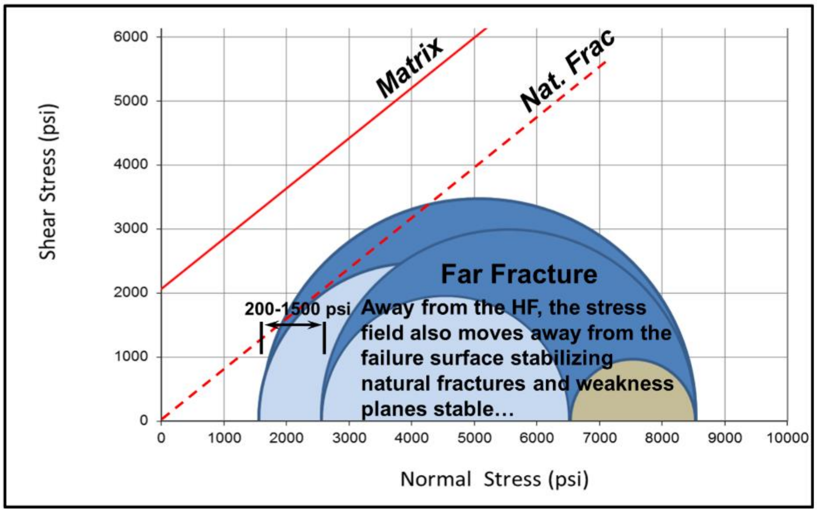





# Stress Change Due To Hydr. Fracture-Induced Stress Shadow

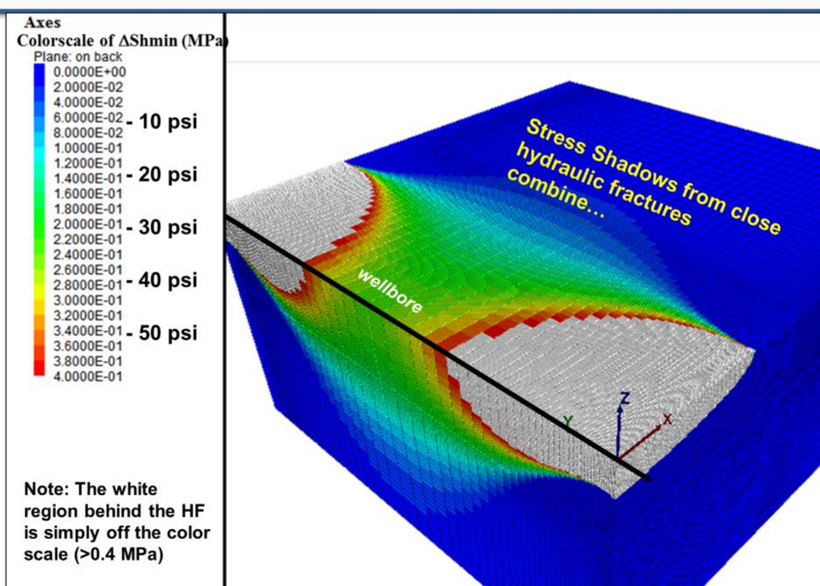


# Stress Change Due To Hydr. Fracture-Induced Stress Shadow

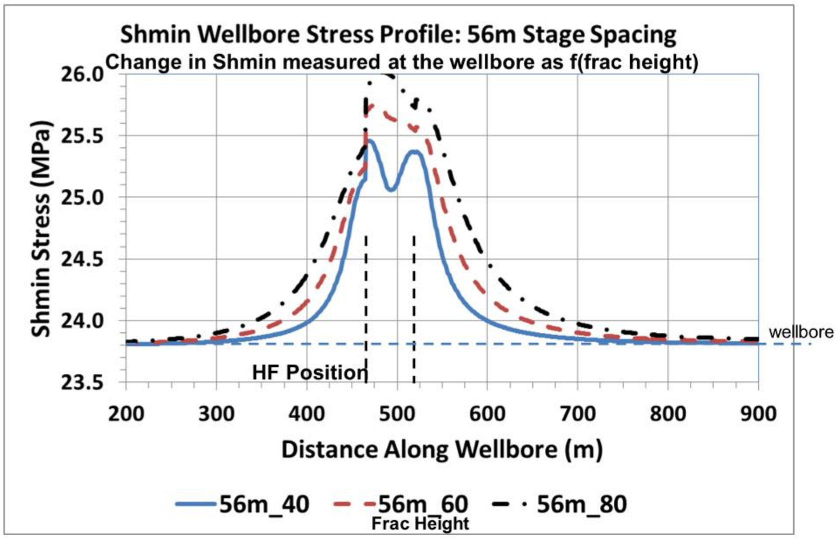





# Two Frac Stress Shadows

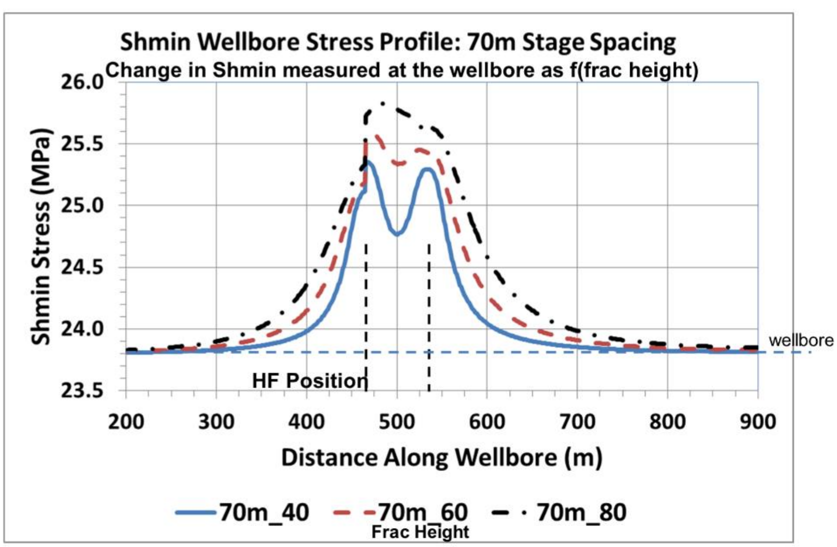


# ΔShmin – Dual Frac, Sp=56m

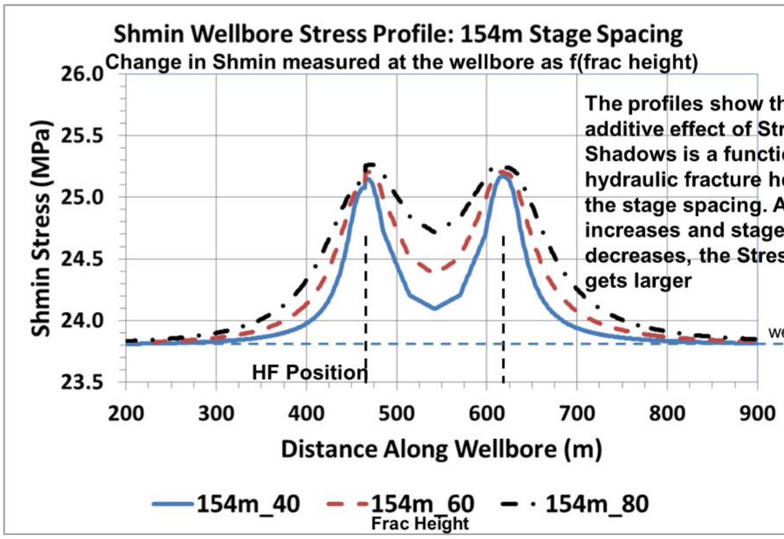





# ΔShmin – Dual Frac, Sp=70m

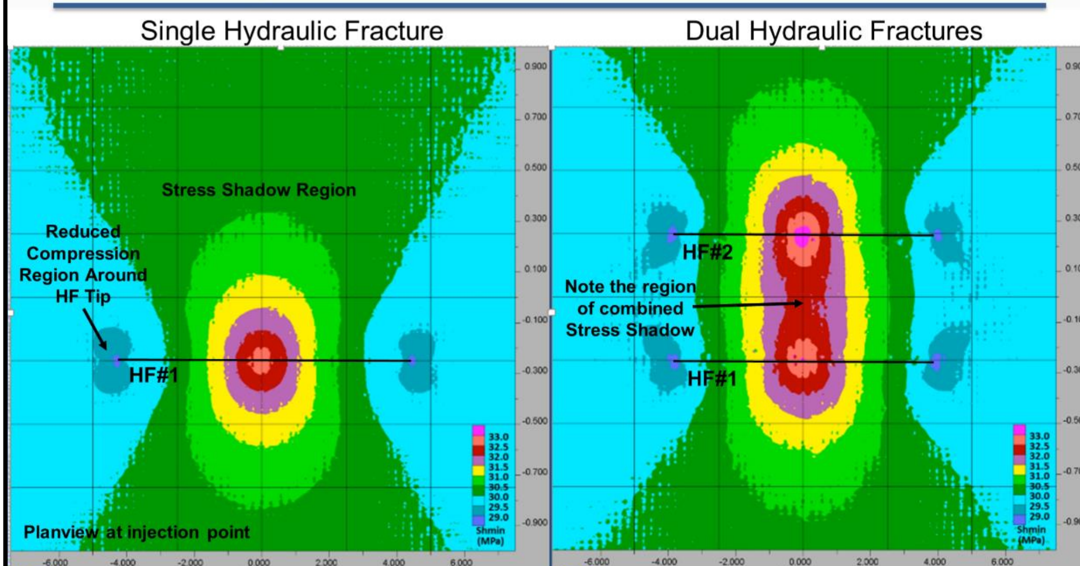


# ΔShmin – Dual Frac, Sp=154m



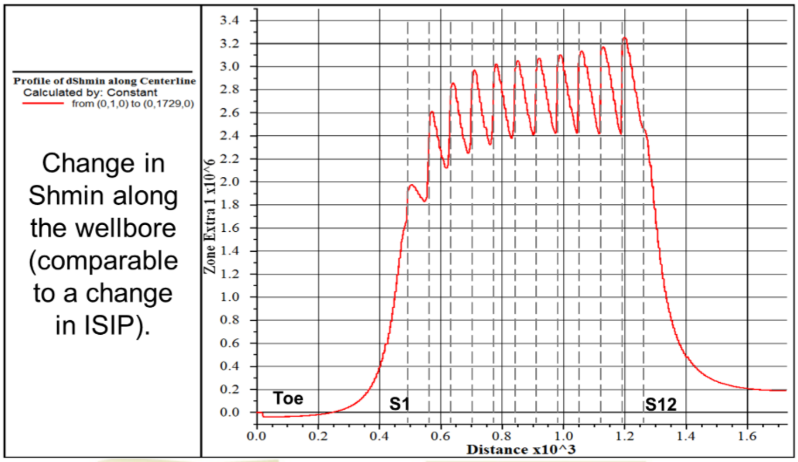



# Dynamic Stress Shadows



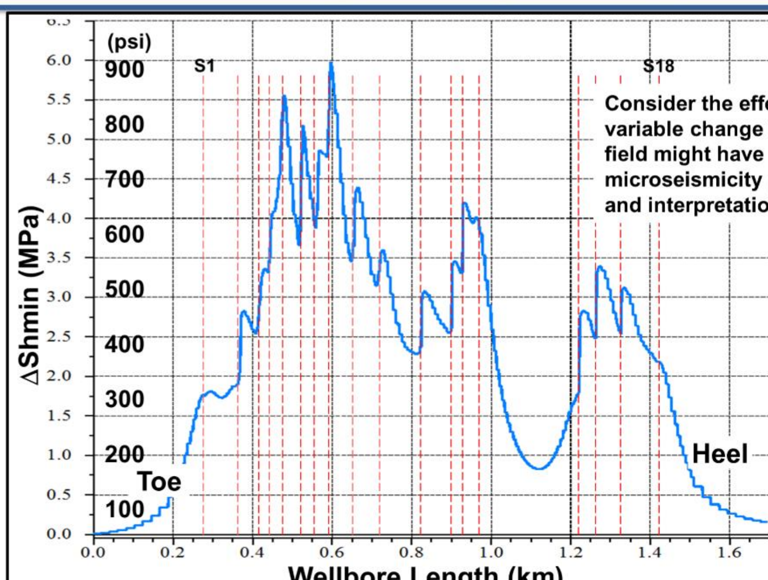
# Stress Shadows Along the Wellbore

**Multi-stage fracturing causes a rise in inter-frac stress, which stabilizes natural fractures!**

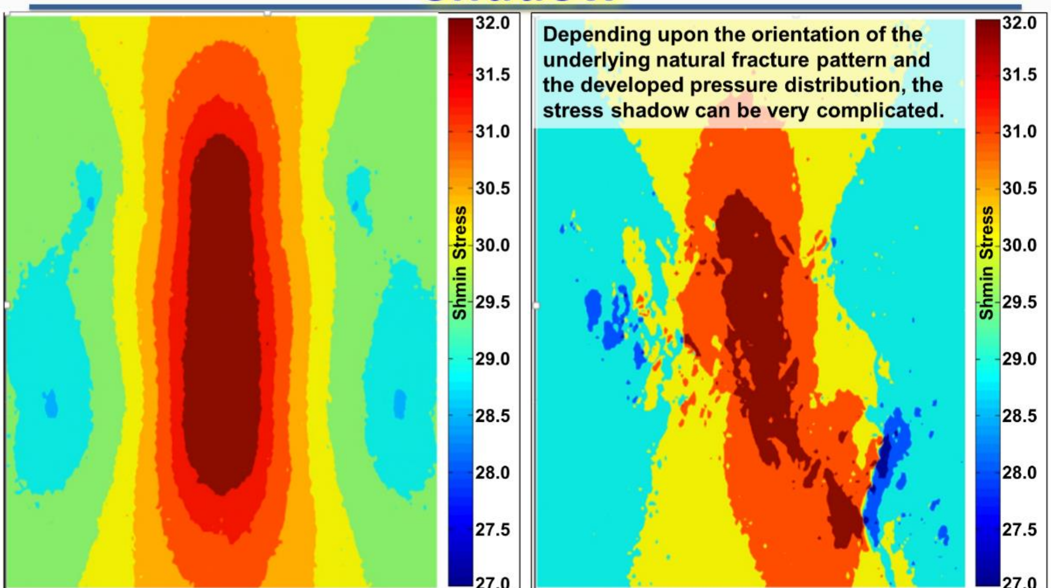





# ΔShmin: 18 Stage Irregular Spacing

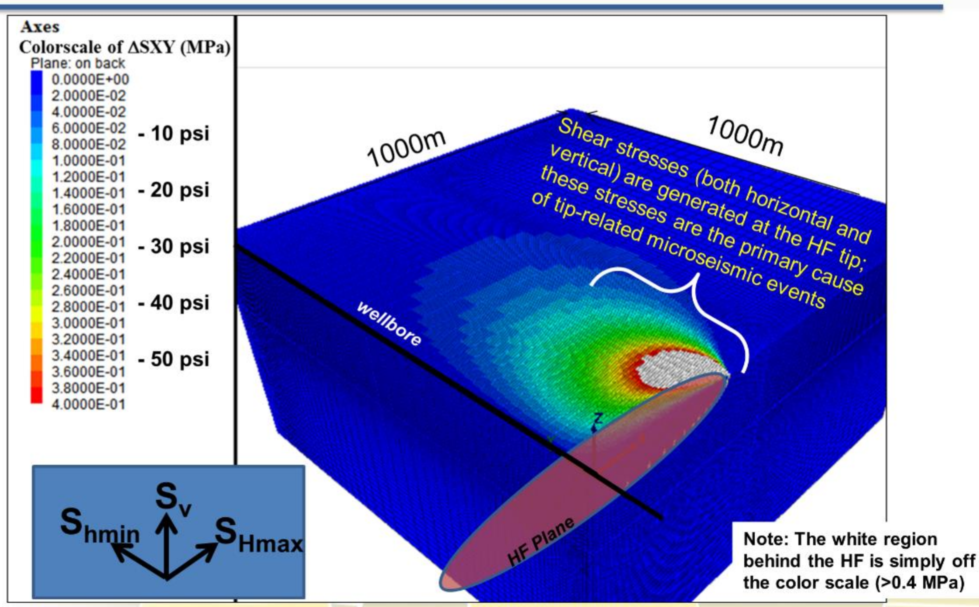


# Influence of DFN Orientation on Stress Shadow

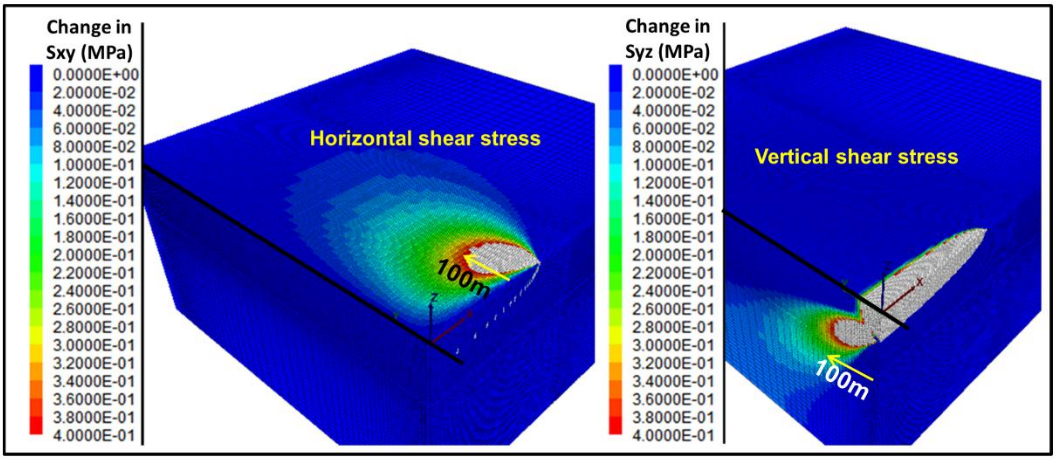





# Stress Shadows: Tip Shear Stresses



# Stress Shadows: Tip Shear Stresses

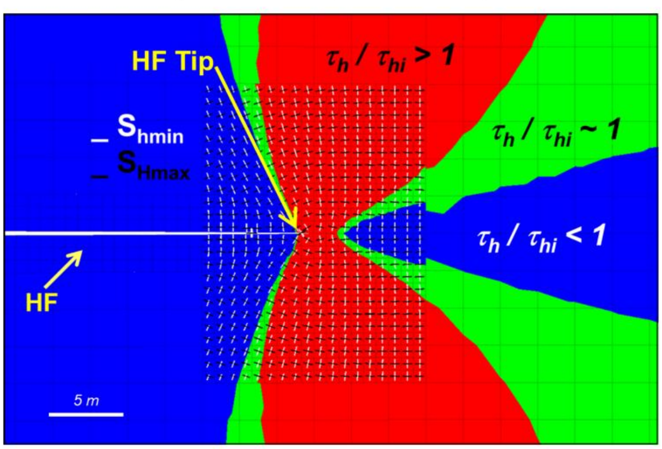



Note: The white region behind the HF is simply off the color scale (>0.4 MPa)



# Shear Stress at a Hydraulic Fracture Tip

**Horizontal plane crossing fracture origin at z = 0**



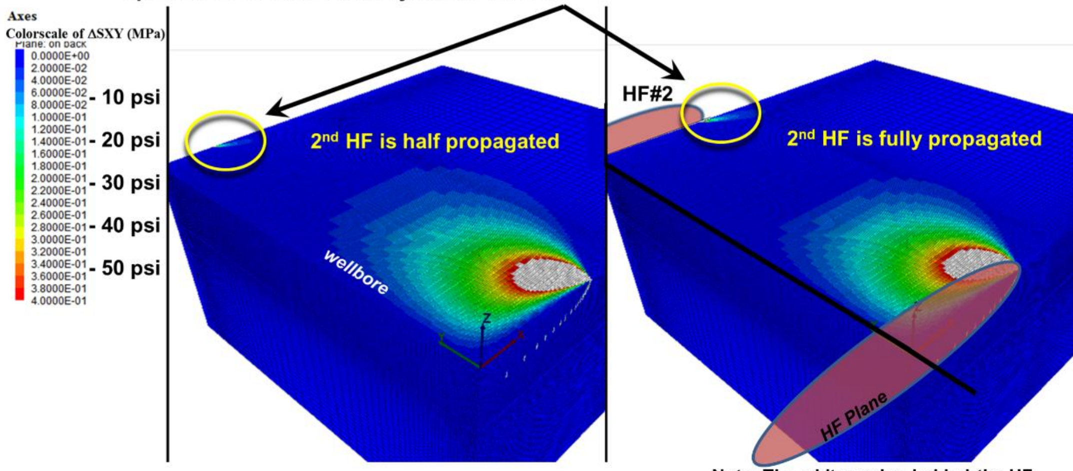

**The region in red exhibits an increase in horizontal shear stress, while the green region is largely unchanged. The blue region represents areas where the shear stress is reduced. The reduction behind the HF tip is caused by the Stress Shadow.**

**Shear stresses at the tip may play a critical role in opening closed/cemented natural fractures so that they can accept fluid.**

**Note the rotation in principal stresses immediately at the HF tip.**

# Dual Hydr. Fractures: Horizontal Shear Stress Development

**The Stress Shadow from the first hydraulic fracture greatly reduces the horizontal tip shear from the second hydraulic fracture.**

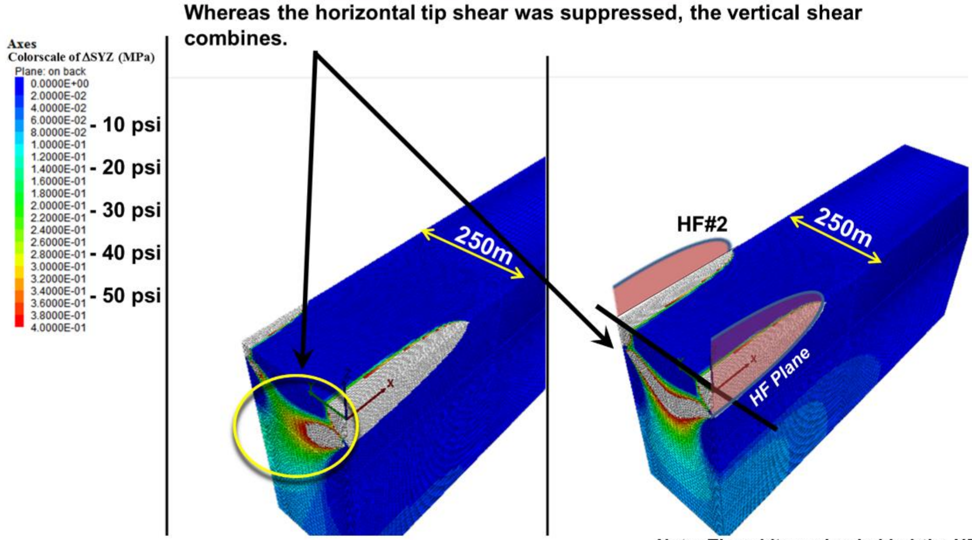



Note: The white region behind the HF is simply off the color scale (>0.4 MPa)



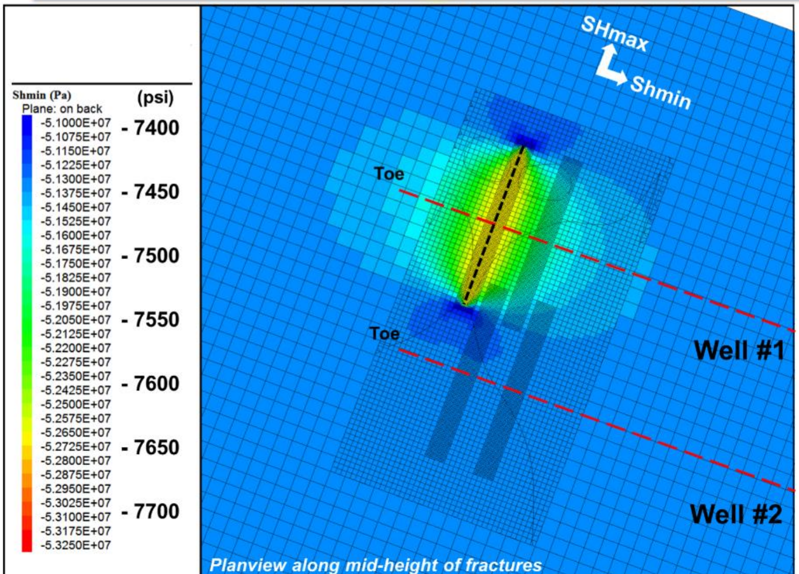
# Dual Hydr. Fractures: Vertical Shear Stress Development

**Whereas the horizontal tip shear was suppressed, the vertical shear combines.**




Note: The white region behind the HF is simply off the color scale (>0.4 MPa)

# Static Zipper Frac Stress Shadows: Stg#1-Shmin

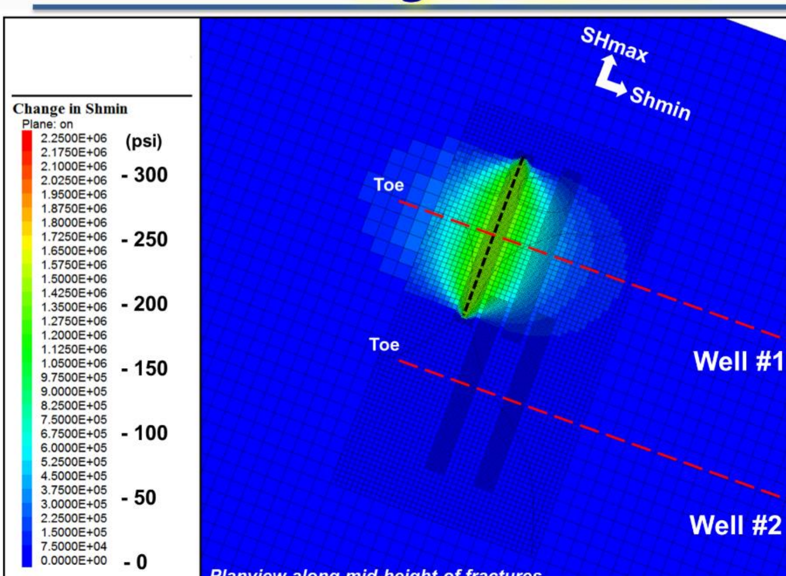



A four stage Zipper frac is shown. The first frac has been pumped.

Shmin has increased both towards the Toe (left) and the Heel (right)



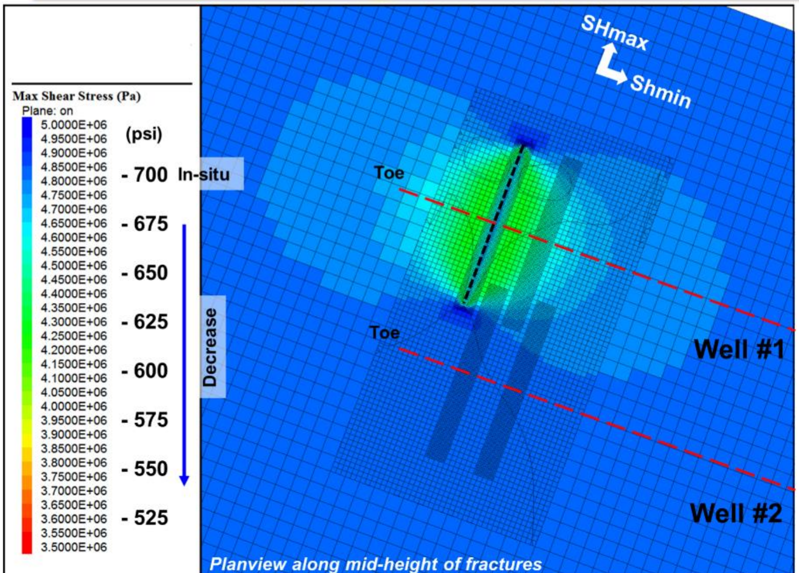
# Static Zipper Frac Stress Shadows: Stg#1-∆Shmin




A four stage Zipper frac is shown. The first frac has been pumped.

Around the hydraulic fracture, the stress field has increased in magnitude.

# Static Zipper Frac Stress Shadows: Stg#1-Max Shear

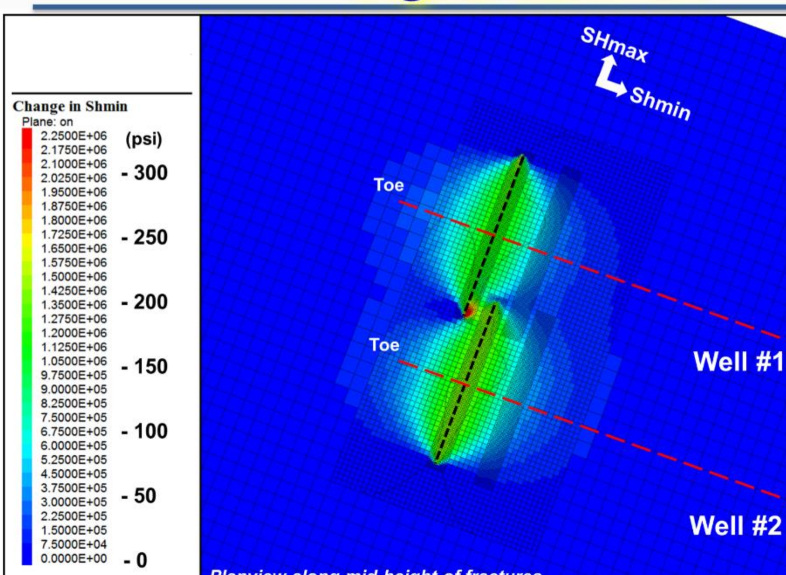



A four stage Zipper frac is shown. The first frac has been pumped.

Max Shear is the maximum shear stress within the region. There is no higher shear stress. As shown, Max Shear decreases significantly (~5MPa) around a hydraulic fracture.



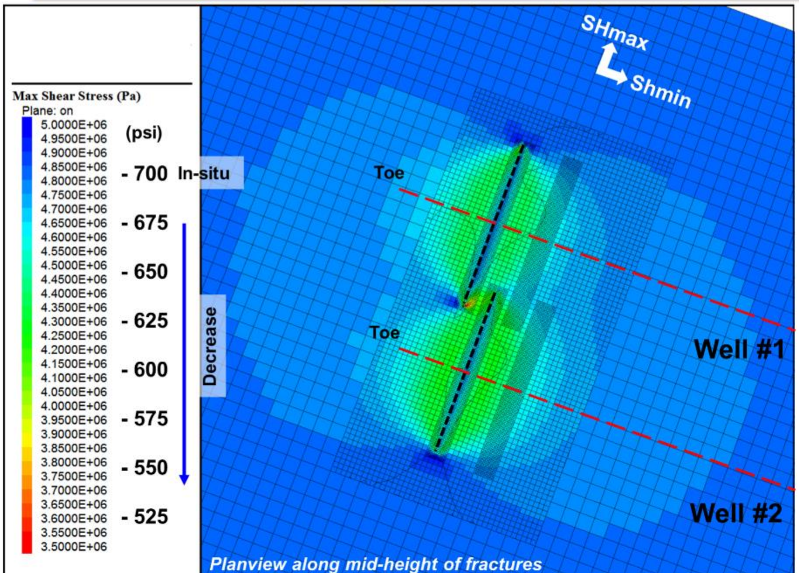
# Static Zipper Frac Stress Shadows: Stg#2-ΔShmin




A four stage Zipper frac is shown. The second frac has been pumped.

dShmin has increased both towards the Toe (left) and the Heel (right) of both wells. dShmin is higher in the overlap region of the fractures, but there is little effect of the combined fractures..

# Static Zipper Frac Stress Shadows: Stg#2-Max Shear

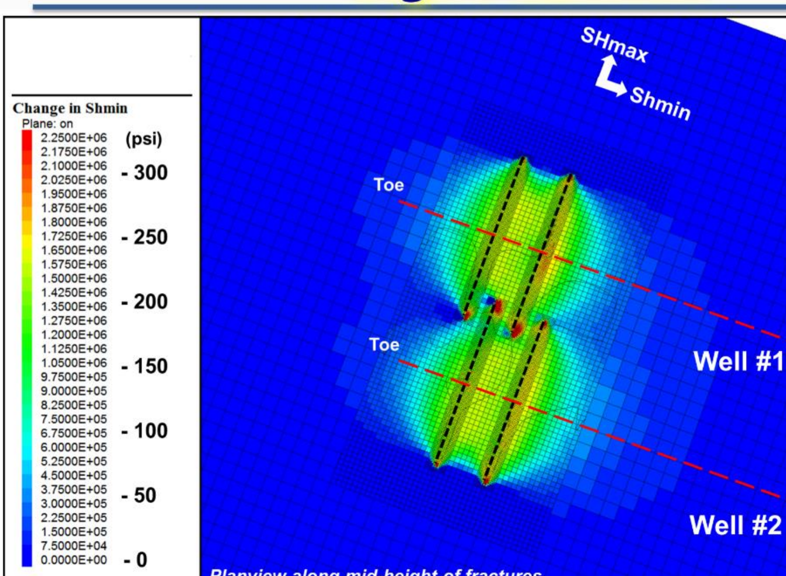



A four stage Zipper frac is shown. The second frac has been pumped.

With regard to the Max Shear, there is a combining effect of two wells – as shown, the reduced Max Shear region is now significantly larger.



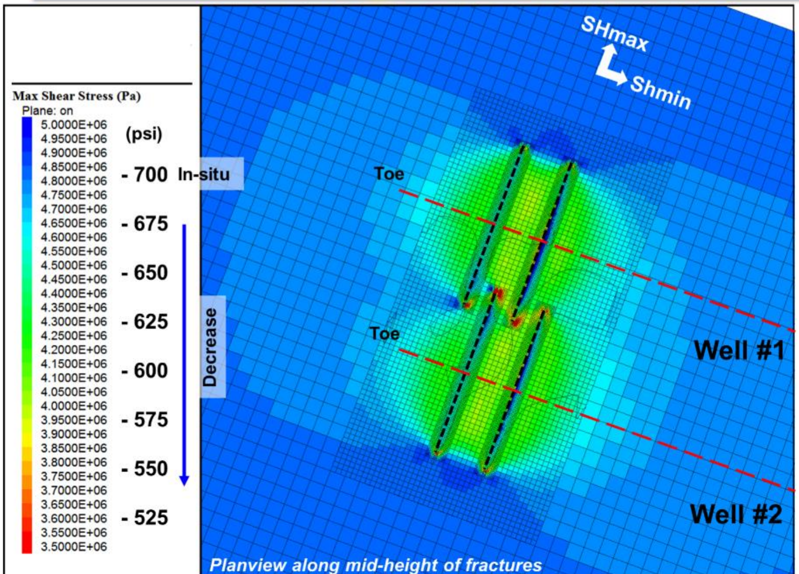
# Static Zipper Frac Stress Shadows: Stg#4-ΔShmin




A four stage Zipper frac is shown. The fourth frac has been pumped.

dShmin has increased both towards the Toe (left) and the Heel (right) of both wells. dShmin is higher in the overlap region of the fractures, but there is little effect of the combined wells.

# Static Zipper Frac Stress Shadows: Stg#4-Max Shear




A four stage Zipper frac is shown. The fourth frac has been pumped.

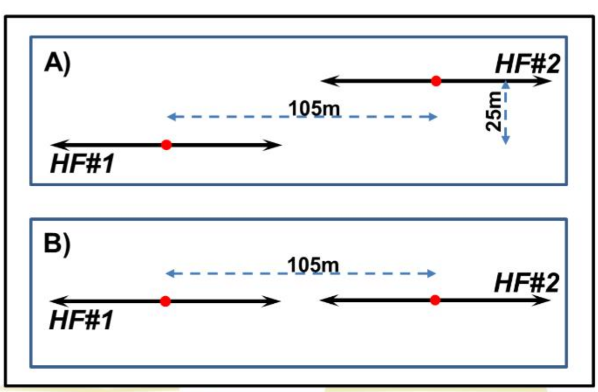
With the exception of minor, very near fracture effects, the Max Shear stress is significantly reduced throughout the region of the two wells.



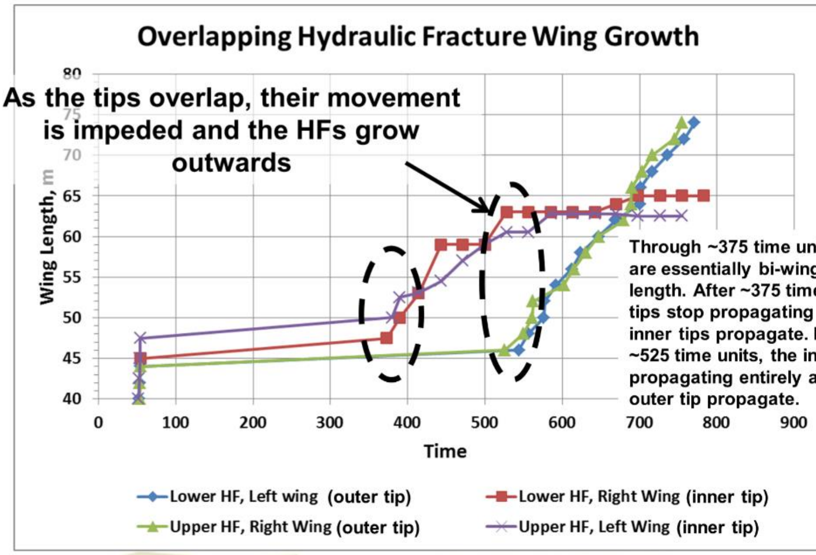
# When Hydraulic Fractures Interact

There are two basic forms of HF interaction: overlapping tips (A) or direct communication (B).

The basic behavior of these needs to be considered before considering the impact on natural fractures or weakness planes in a multi-well completion (e.g., Zipper Fracs).

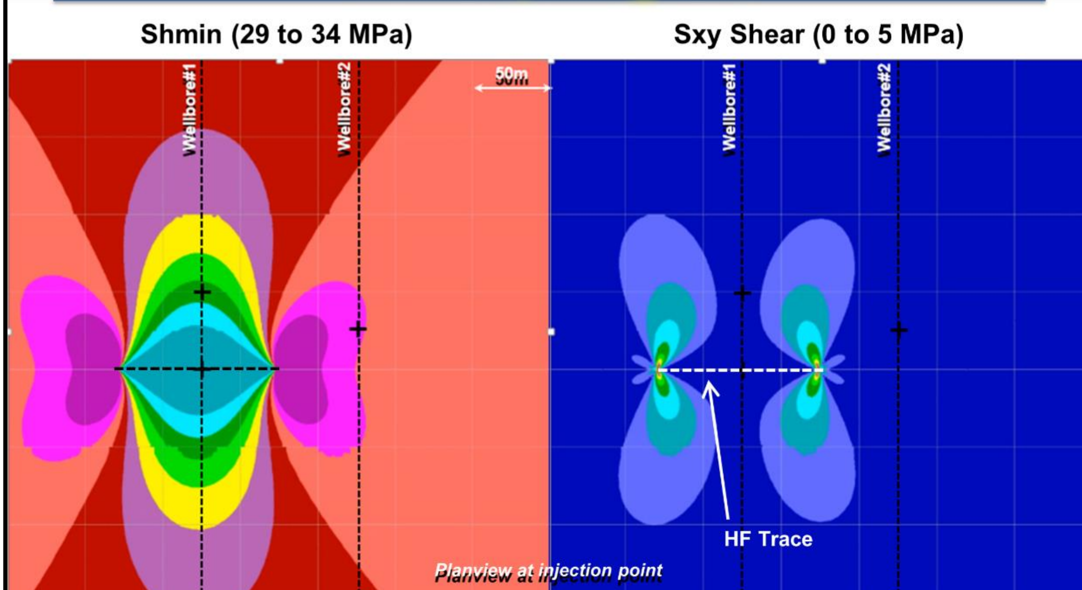


# Tip Movement for Overlapping HFs



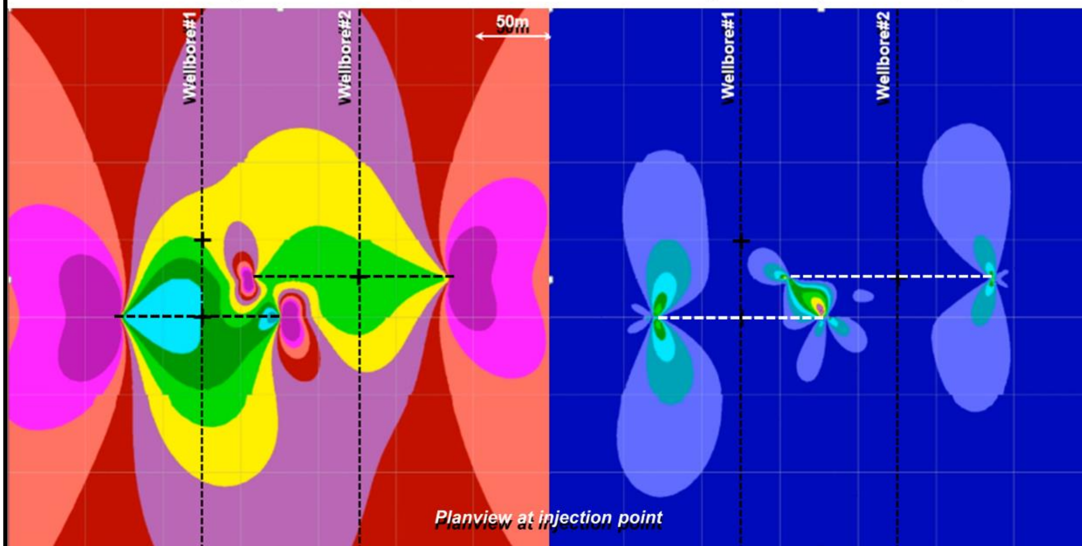



# Dynamic Zipper Frac Stress Shadows: Well#1, Stage#1



# Dynamic Zipper Frac Stress Shadows: Well#2, Stage#1

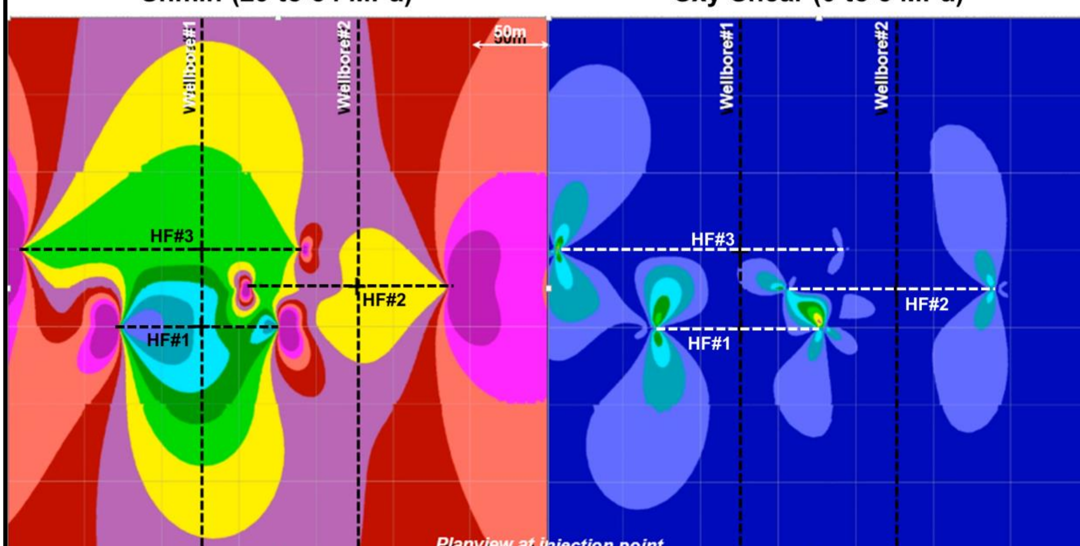
**Shmin (29 to 34 MPa)** | **Sxy Shear (0 to 5 MPa)**






# Dynamic Zipper Frac Stress Shadows: Well#1, Stage#2

**Shmin (29 to 34 MPa)** | **Sxy Shear (0 to 5 MPa)**



# Summary of Dynamic Stress Shadows

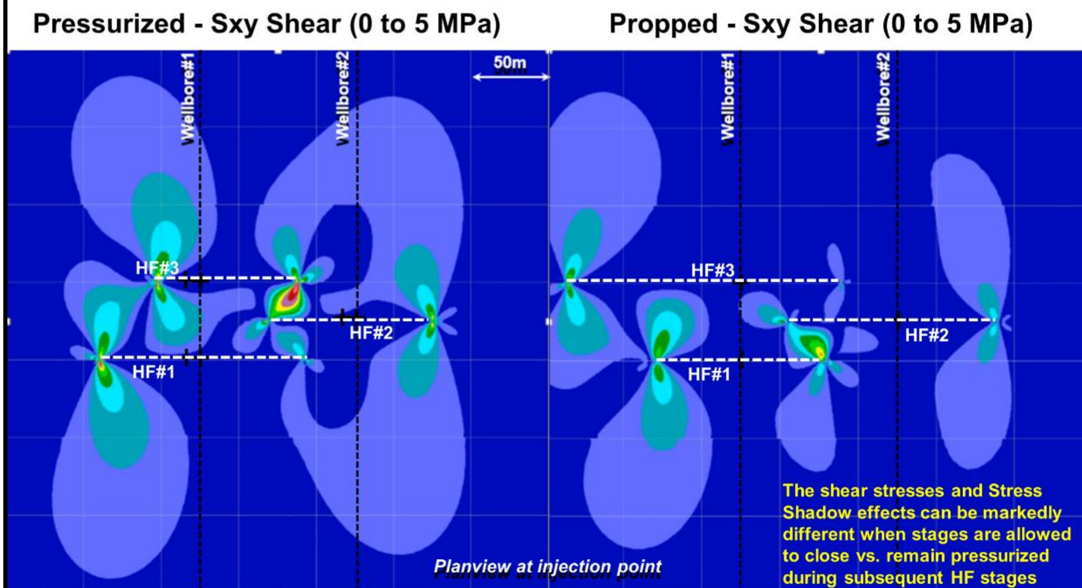
- The first frac stage on Well#1 shows clear bi-wing grow, a significant, symmetric Stress Shadow, and significant, deep shear stress from the hydraulic fracture tips.
- The first frac stage on Well#2 is bi-wing, but the inner wing is slightly longer than the outer wing. Further, for the same fluid injection, the hydraulic fracture is ~27% longer.
- The stress shadow effect (Shmin) from the first frac stage on Well#2 (HF#2) is now a bit more complicated and asymmetric. The shear stresses are markedly different: 1) the overall area of shear stress from the inner tips is significantly reduced; and 2) the magnitude of the shear stress near the tip of the Well#1 HF has increased notably.



# Summary of Dynamic Stress Shadows

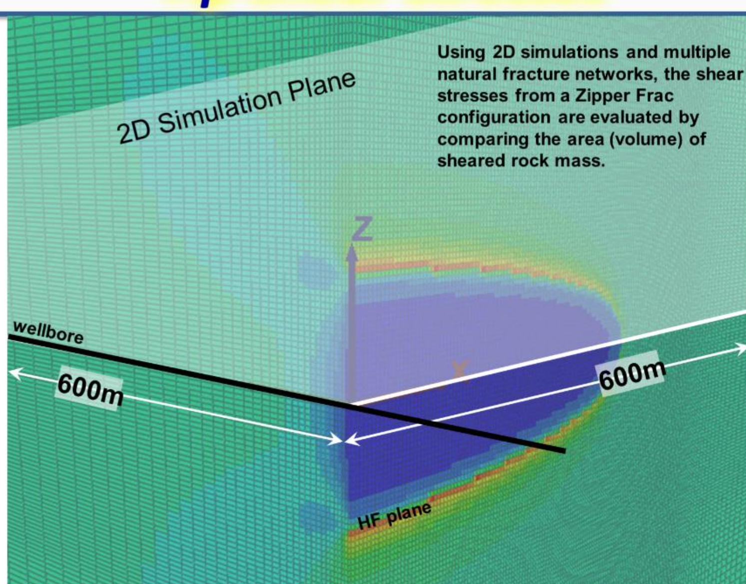
- The second frac stage on Well#1 (HF#3) shows a longer inner wing than on the first Well#1 frac stage (for the same injection volume); however, the outer wing length is significantly increased (the second HF on Well#1 is ~74% longer than the first HF stage).
- The shear stress from the inner tip of the second stage on Well#1 is almost completely gone; however, there is significant shear stress from the outer tip – likely because it has extended so far beyond the limits of the first frac stage on Well #1.

# Dynamic Zipper Frac Stress Shadows: Propped vs. Pressurized Shear Behavior

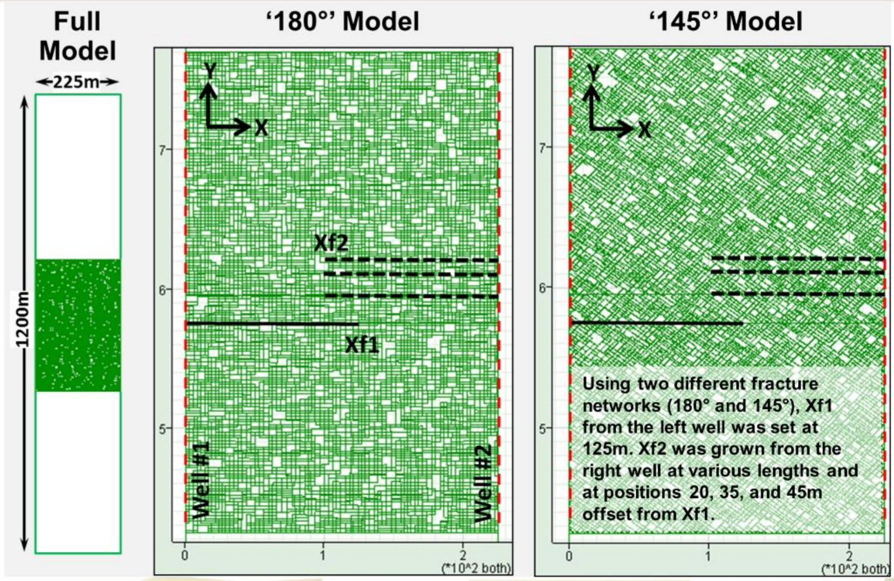





# Quantify Zipper Frac Hydr. Fracture Tip Shear Stresses

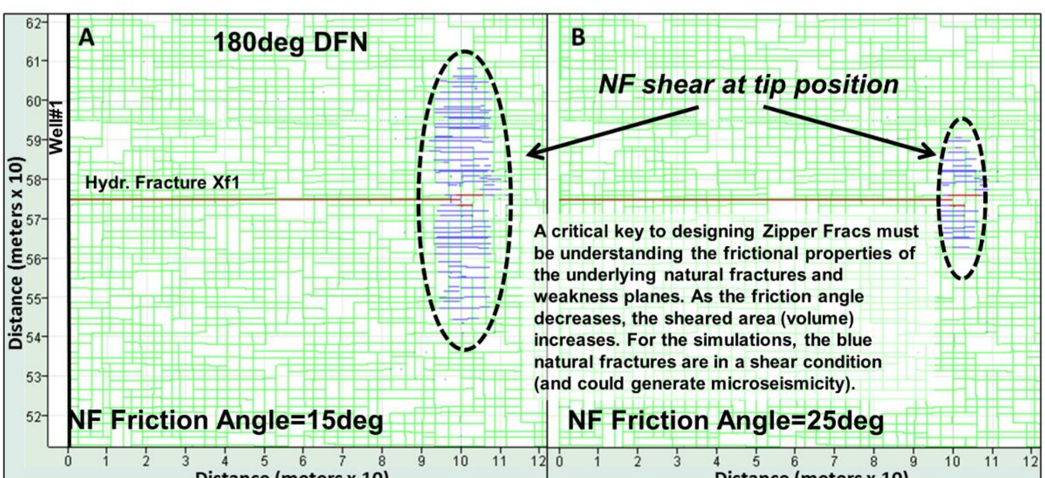


# Model Schematics

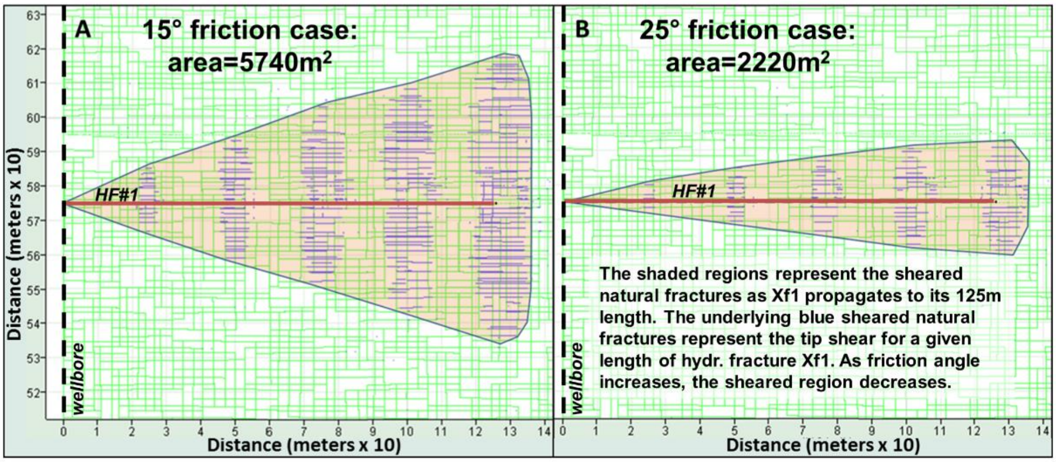





# Nat. Fracture Shear f(Friction Angle)

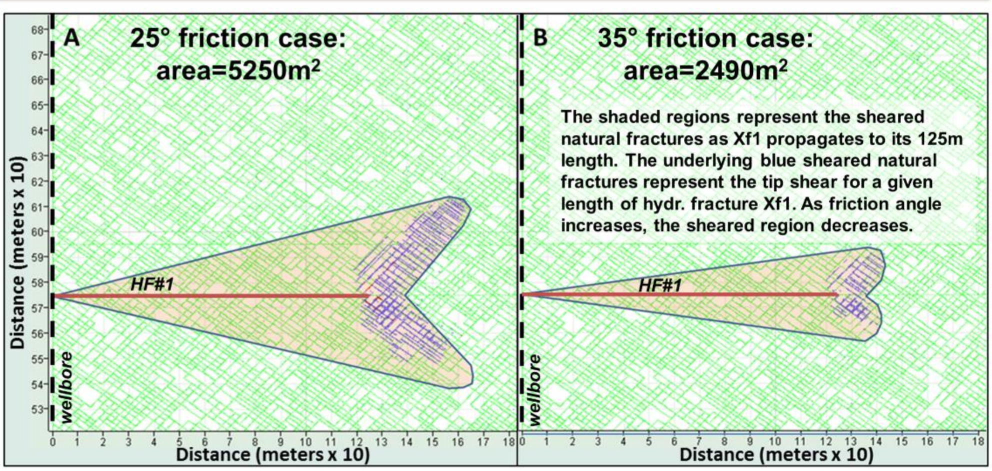


# Shear Region vs. Friction Angle





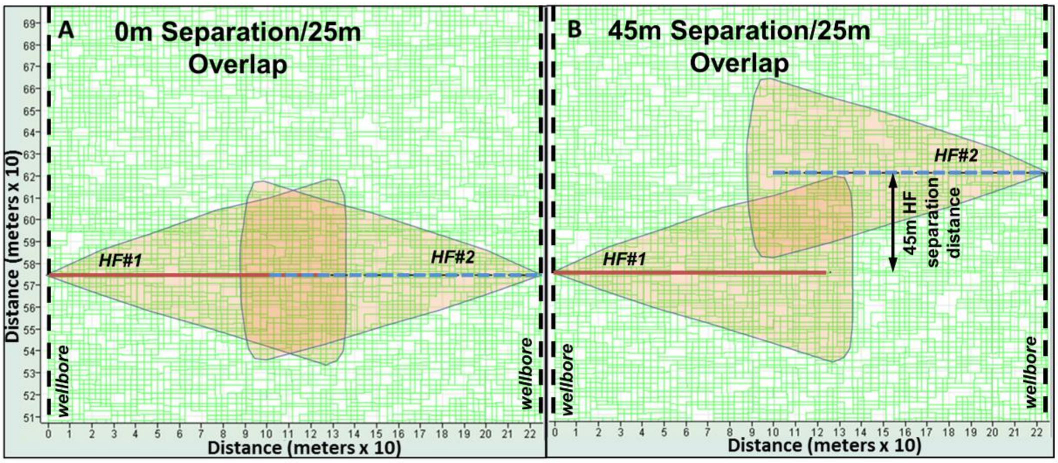

# Shear Region vs. Friction Angle




***Importance of natural fracture network orientation:***

**The area (and by default the volume) of formation sheared (5740m2) for the 15° FA for the '180°' model was similar to the 25° case of the '145°' DFN (5250m2)**

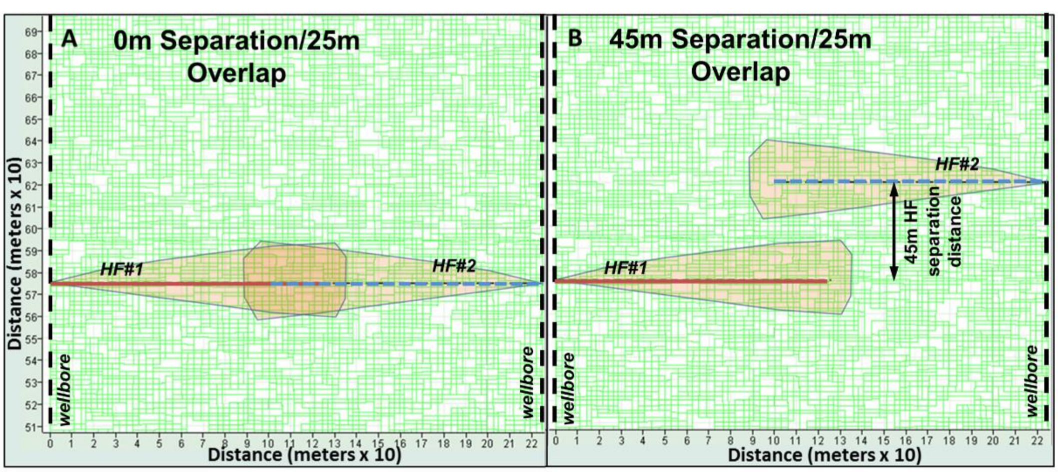
# Shear Region Overlap in Multi-Well Configuration – 15° Friction




When sheared regions overlap, it is assumed that this a neutral or negative effect on production. Consequently, a Zipper Frac design should limit overlap.

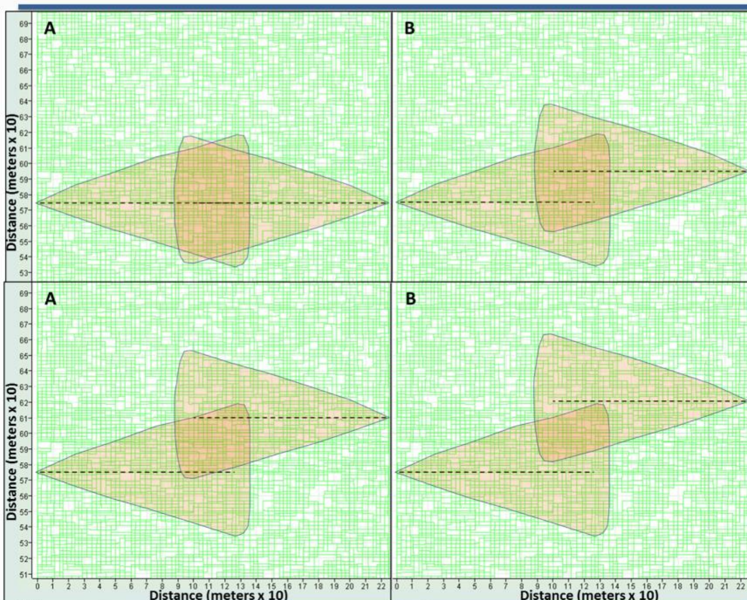


# Shear Region Overlap in Multi-Well Configuration – 25° Friction




When the friction angle is greater, less overlap occurs for a given separation distance. Again, this means that the shear strength of the natural fractures and weakness planes needs to be considered in Zipper Frac design.

## Possible Multi-Well NF Shear

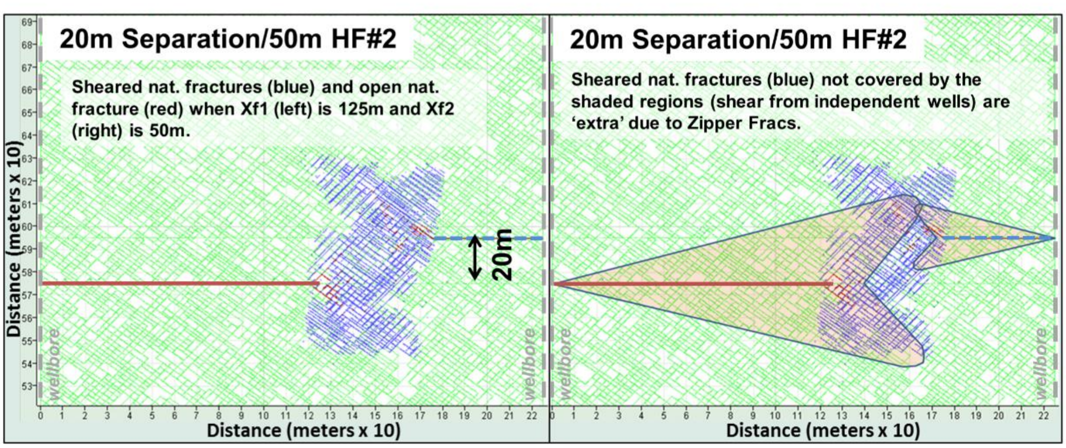



**Question: In overlapping regions, do we simply re-shear the same fractures (neutral or negative) or increase the sheared volume?**



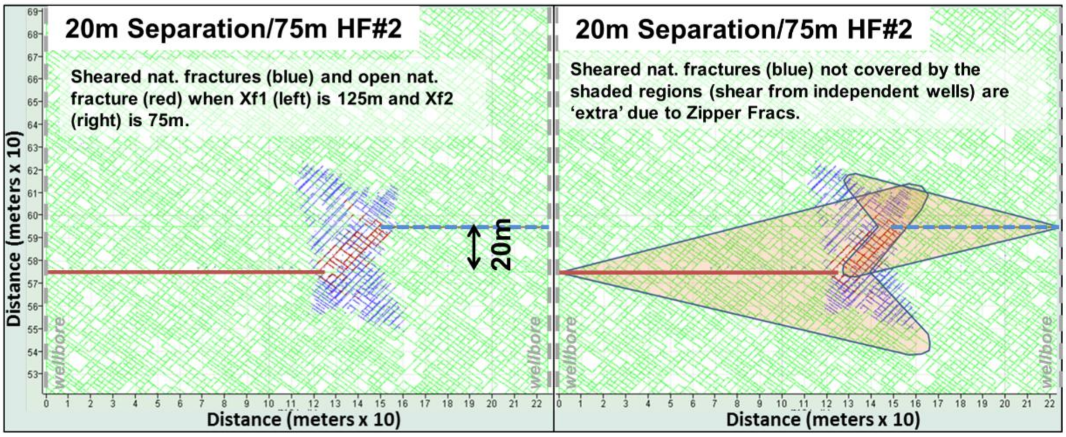
## Multi-Well Shear, 25° FA: f(Length)

**'145°' Model / 20m Separation / 50m HF#2**



# Multi-Well Shear, 25° FA: f(Length)

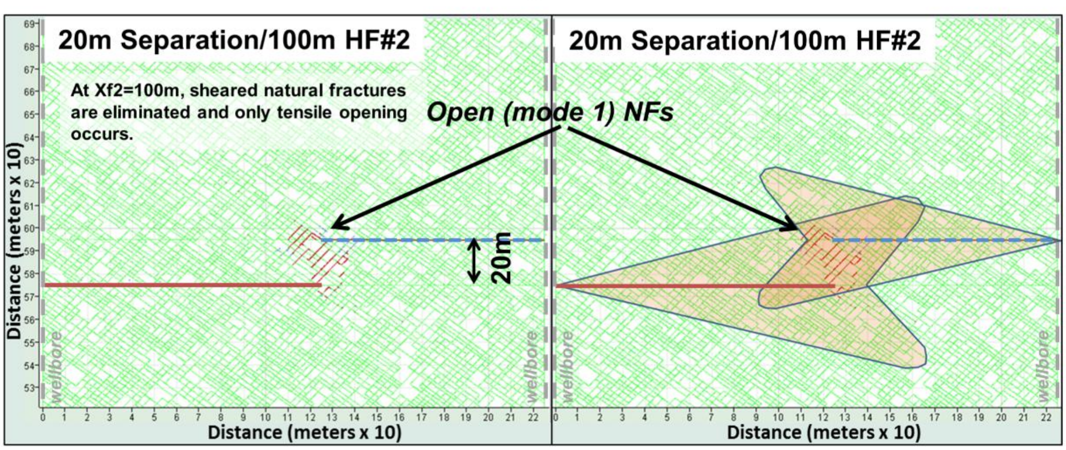
## '145°' Model / 20m Separation / 75m HF#2





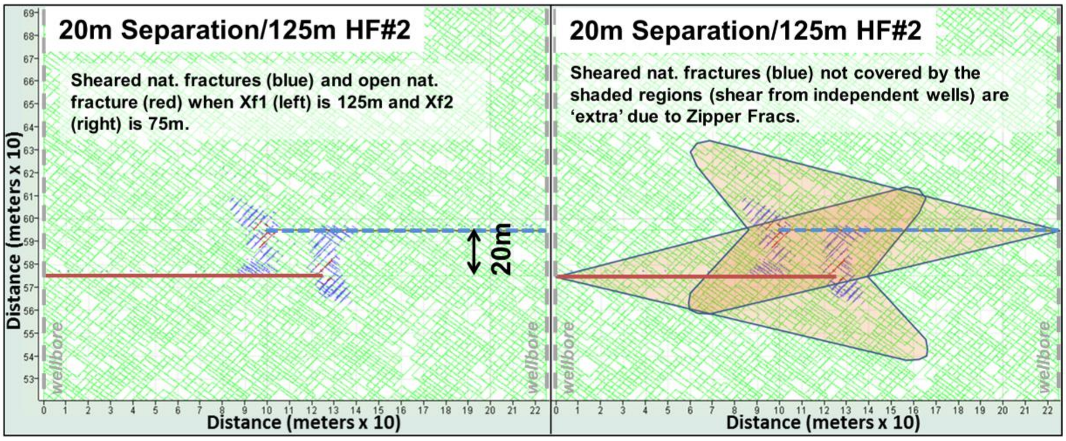

# Multi-Well Shear, 25° FA: f(Length)

## '145°' Model / 20m Separation / 100m HF#2



# Multi-Well Shear, 25° FA: f(Length)

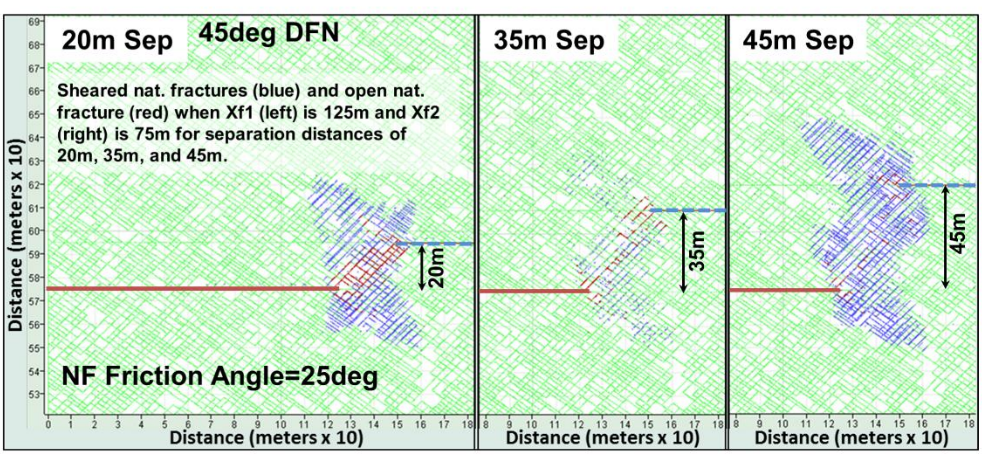
## '145°' Model / 20m Separation / 125m HF#2





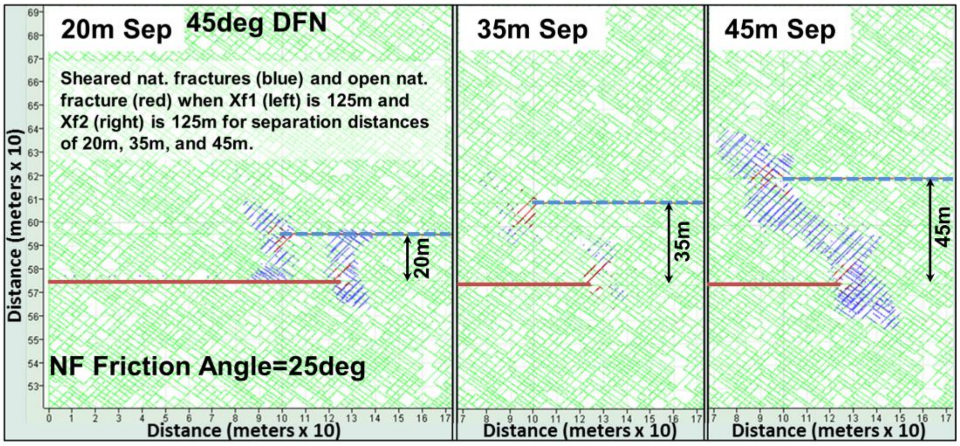

# Multi-Well Shear, 25° FA: f(Separation)

## '145°' Model / 75m HF#2



# Multi-Well Shear, 25° FA: f(Separation)

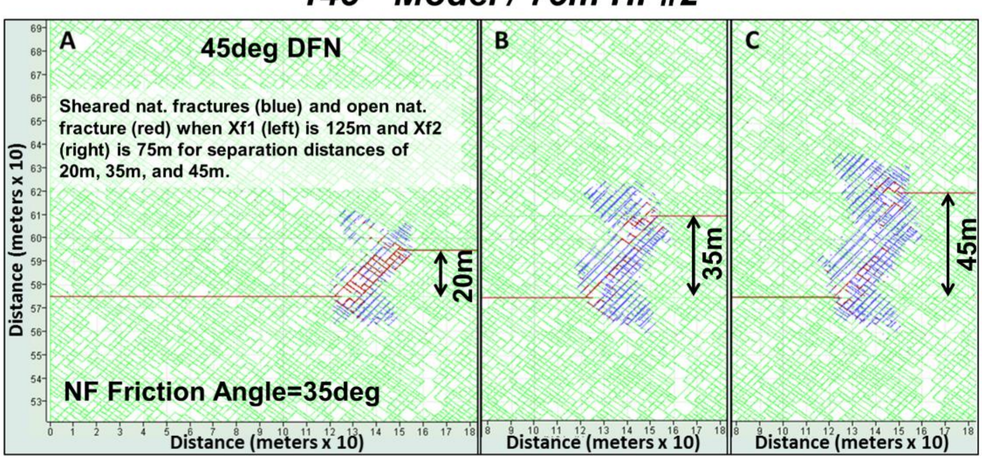
## '145°' Model / 125m HF#2





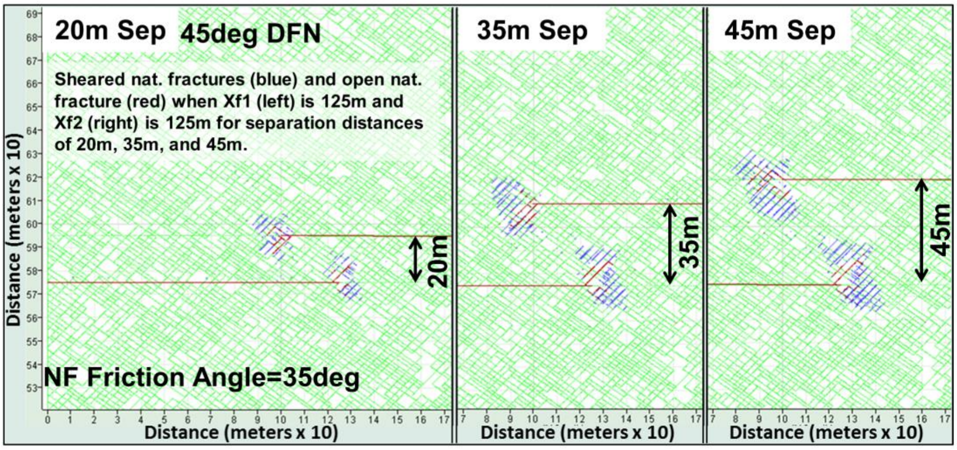

# Multi-Well Shear, 35° FA: f(Separation)

## '145°' Model / 75m HF#2



# Multi-Well Shear, 35° FA: f(Separation)

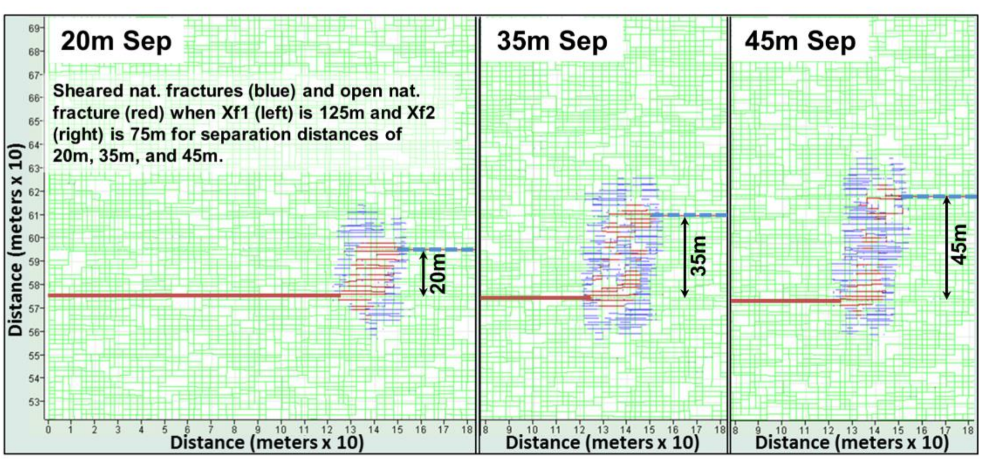
## '145°' Model / 125m HF#2





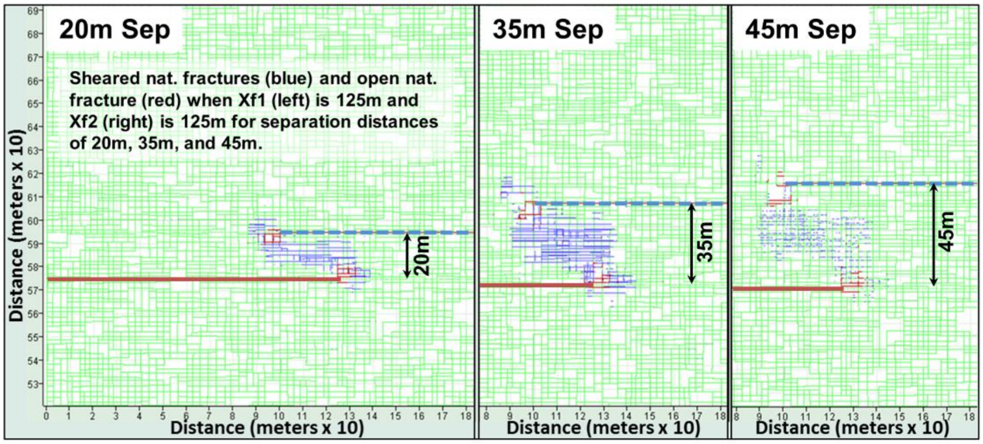

# Multi-Well Shear, 25° FA: f(Separation)

## '180°' Model / 75m HF#2



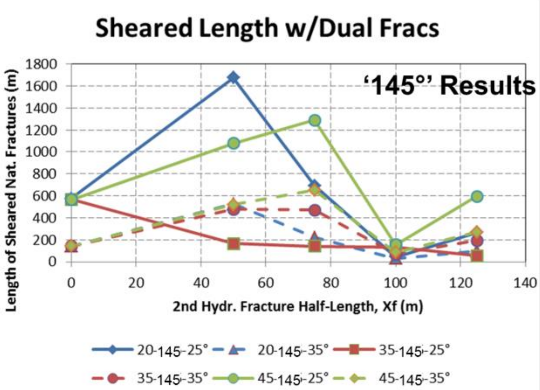
# Multi-Well Shear, 25° FA: f(Separation)

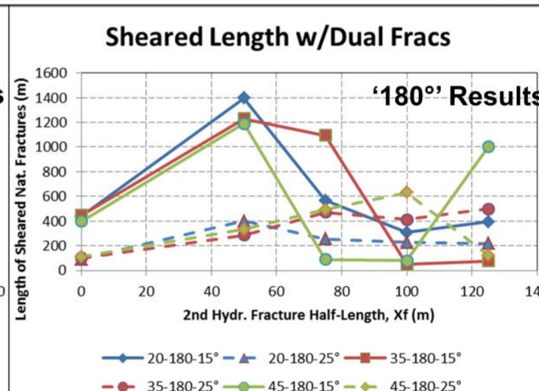
## '180°' Model / 125m HF#2






# Results: Shear From Zipper Fracs

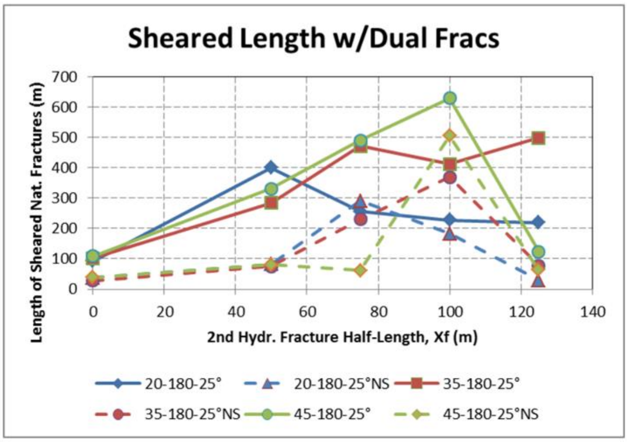



**KEYS:**
- Shear is a function of separation distance, NF orientation, and FA;
- Maximum shear at 50 to 25m tip-to-tip distance;

**KEYS:**
- Minimum shear generally at 100m (tips aligned); and
- For 35m separation & '145°' case, 35° FA was greater shear

# Influence of Stress Field

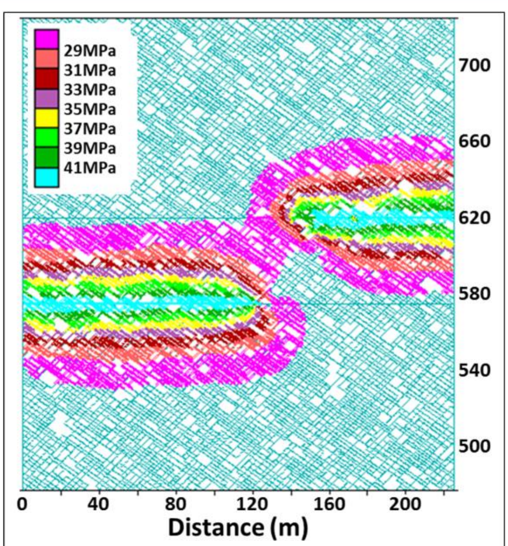



KEYS:

- More isotropic stress greatly reduced shear;
- More isotropic required more overlap to maximize shear;
- Maximum shear occurred at 45m separation; and
- Maximum shear occurred at 100m XF2 (tips aligned)
-

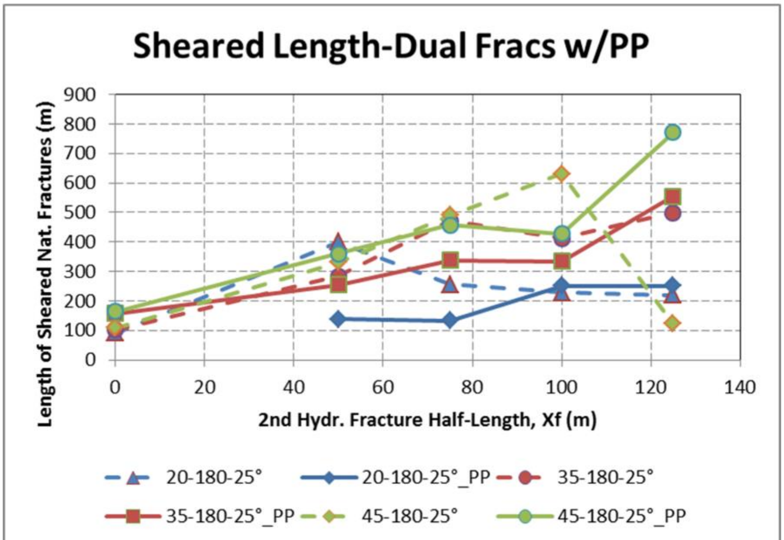


# Zipper Fracs with Pressure Diffusion




In order to investigate the role of pressure change and Zipper Fracs, the simulations were re-run accounting for significant pressure diffusion in association with hydraulic fracture propagation. The picture left shows an example of the magnitude of the pressure change.

# Sheared Length: Zipper Fracs w/PP

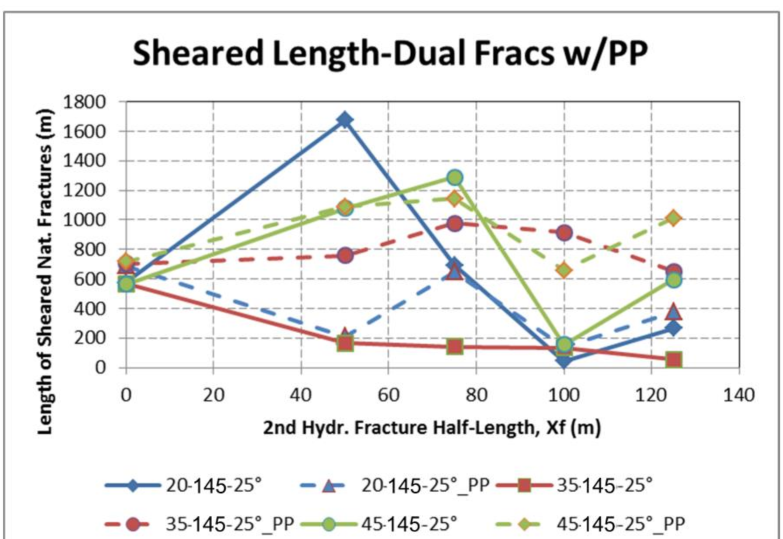



KEYS:

- For the 180° model, the amount of sheared area did not significantly change; however,
- The maximum benefit of a Zipper Frac occurred when hydraulic fractures overlapped.



# Sheared Length: Zipper Fracs w/PP




KEYS:

- For the 145° model, the amount of sheared area also did not significantly change; however,
- The greater benefit of a Zipper Frac occurred when hydraulic fractures overlapped.

## Key Learnings

1. Natural fracture orientation significantly influences the amount and location of natural fracture shear, and multi-well completion optimization must account for this.
2. Natural fracture friction controls the depth and amount of natural fracture shear, and multi-well completion optimization requires the evaluation and consideration of friction properties.
3. The optimum hydraulic fracture separation distance for multi-well completions must also account for the in-situ stress ratio.



## Key Learnings

4. For multi-well completion schemes, the design length of the second hydraulic fracture (Xf2) should be kept less than the point of overlap with the first hydraulic fracture (Xf1) and be optimized in conjunction with the hydraulic fracture separation distance.
5. Overall, the study results suggest that there is the potential for ***only modest improvements in stimulation complexity from the modified zipper-frac completion schemes*** while the potential for well-to-well communication (and possible screenout conditions) increases..

# Summary

**The four key elements of the potential improvement in production from multi-well completions (Zipper Fracs) are: Stress Shadows, Tip Shear, Natural Fracture Pressure Changes, and the underlying Fracture Network Connectivity.**

- **Stress shadows stabilize natural fractures, reducing their ability to shear.**
- **Tip shear controls the opening of closed or partially closed natural fractures and weakness planes to accept pressure.**
- **Fracture network connectivity affects the depth of pressure diffusion from a hydraulic fracture.**
- **Increasing natural fracture pressure decreases the effective normal stresses increasing the ability to shear natural fractures.**



# Critical Zipper Frac Design Issues

***Some Critical Optimization Issues:***

- **Correctly predicting the horizontal overlap of HFs;**
- **Correctly predicting HF spacing (from separate wells) at the location of overlap;**
- **Maximizing tip shear stresses (relative to the HF spacing);**
- **Knowing the underlying natural fracture (weakness plane) pattern;**
- **Knowing natural fracture connectivity/aperture;**
- **Understanding in-situ natural fracture pressure changes during the HF; and**
- **Knowing the in-situ stress ratio**

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