

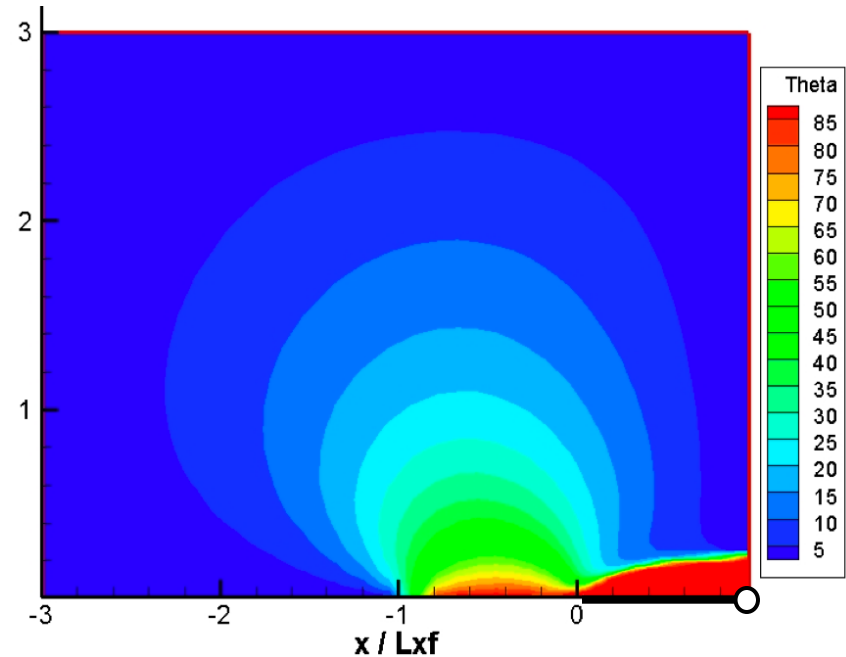
# Improved Reservoir Access Through Refracture Treatments In Tight Gas Sands And Gas Shales

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**Students: Nicholas Roussel,  
Kyle Freihauf, Vasudev Singh**

**Mukul M. Sharma**

The University of Texas at Austin  
Petroleum and Geosystems  
Engineering  
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# Outline

- Motivation and objectives
- Project participants, tasks and timing
- Project tasks / deliverables
- Progress to Date
  - ✓ Stress reorientation around producers and injectors: vertical and horizontal wells
  - ✓ Timing of refrac treatments
  - ✓ Multiple fracs in horizontal wells
  - ✓ Proppant placement in refracs
- Summary

# Motivation

- Beating the decline curve in unconventional gas reservoirs requires continuous drilling and fracturing.
- In a low gas price environment re-frac treatments offer a low cost alternative to drilling new wells.
- Multiple fracs in horizontal wells are becoming the norm and the placement and geometry of these is impacted by stress reorientation.
- Performance of re-fracs and multi-fracs is highly variable and must be made more reliable and predictable.

# Project Objectives

- Quantify the role played by stress reorientation on re-frac productivity improvement.
- Improve our ability to predict refrac and multi-frac production enhancement,
  - ✓ Candidate well selection
  - ✓ Timing of refracs
  - ✓ Interaction of multiple fracs
- Improve refrac and multi-frac design based on findings.
- Calibrate the findings with field data.

# Project Participants

## University of Texas at Austin

### Contact

Mukul M. Sharma  
Professor of Petroleum &  
Geosystems Engineering

## Noble Energy

### Contact

Michael Zoll  
Completions Manager  
Denver, CO

## Anadarko Petroleum Corp.

### Contact

Jon David Caron  
Project Engineering Advisor

## BJ Services

### Contact

Satya Gupta  
Senior Research Leader  
Tomball Technology Center

## Pinnacle Technologies

### Contact

Steve Wolhart  
Region Manager

# Project Tasks

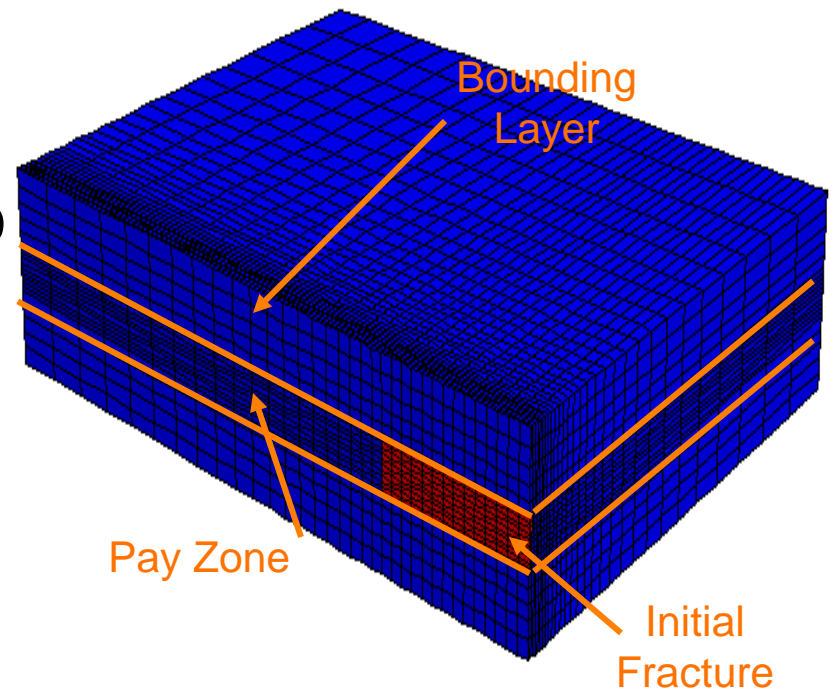
- **Task 4. Stress Reorientation around Fractured Wells: Implications for Re-fracturing**
  - ✓ Subtask 4.1 Data compilation in the Codell formation and the Barnett shale
  - ✓ Subtask 4.2 Stress re-orientation around fractured wells in shales and tight gas sands
  - ✓ Subtask 4.3 Models for stress reorientation in multi- fractured wells
- **Task 5. Selecting Timing and Candidate Wells for Re-fracturing**
- **Task 6. Multi-frac Designs for Deviated and Horizontal Wells**
- **Task 7. Proppant Placement in Re-fracturing Treatments (Vertical and Horizontal Wells)**
- **Task 8. Use of Novel Proppant Placement Strategies in Re-fracturing Operations: Energized Fluids, hybrid fracs.**
- **Task 9. Field Design of Re-Fracture Treatments in the Wattenberg Field**
- **Task 10: Design, Implementation and Evaluation of Field Fracture Designs**

# Project Timing

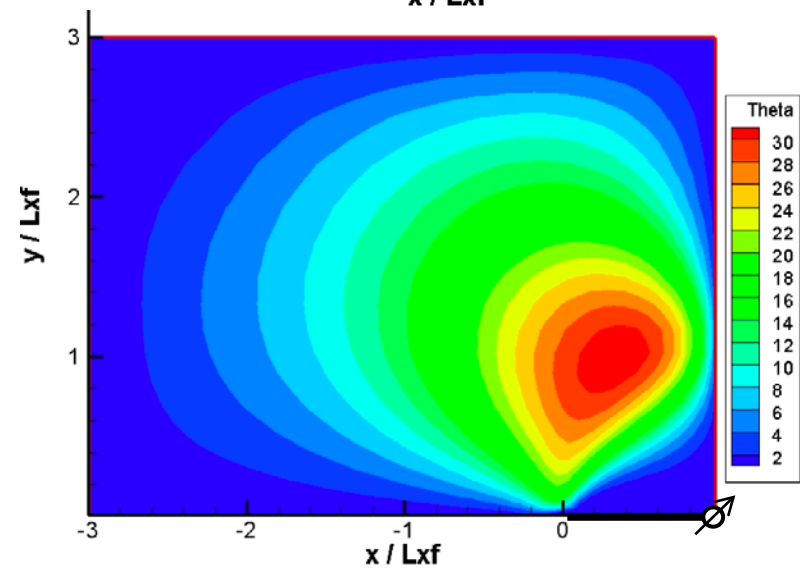
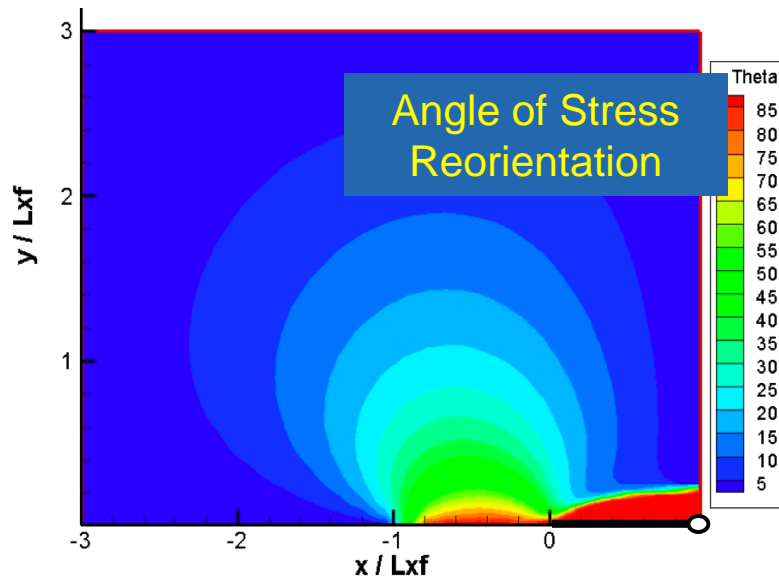
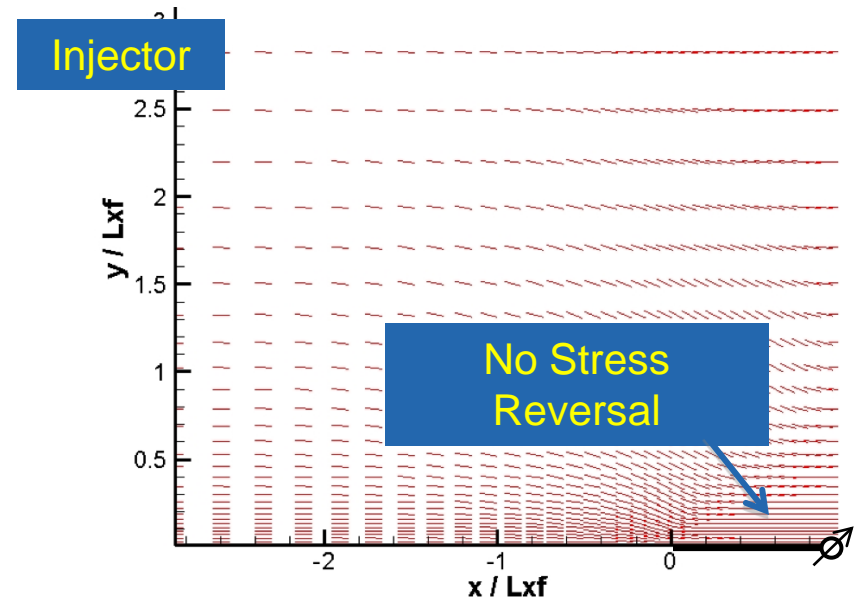
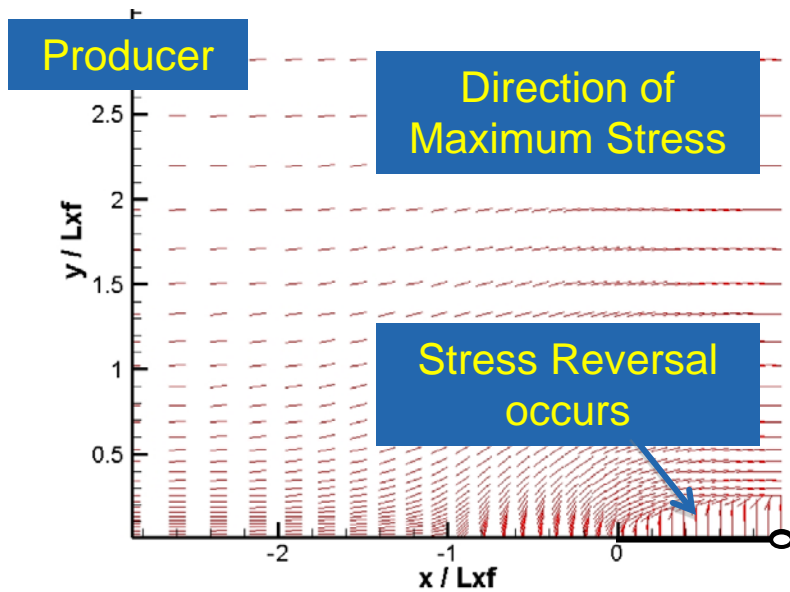
Task	Year 2				Year 3			
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8				█				
9, 10						█		

# Task 4: Stress Reorientation

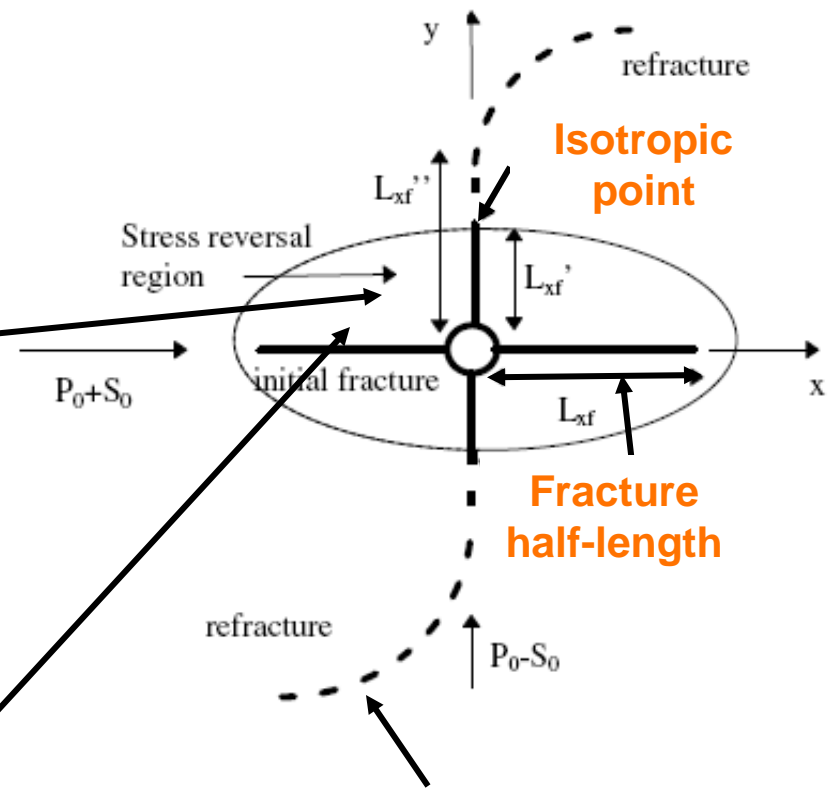
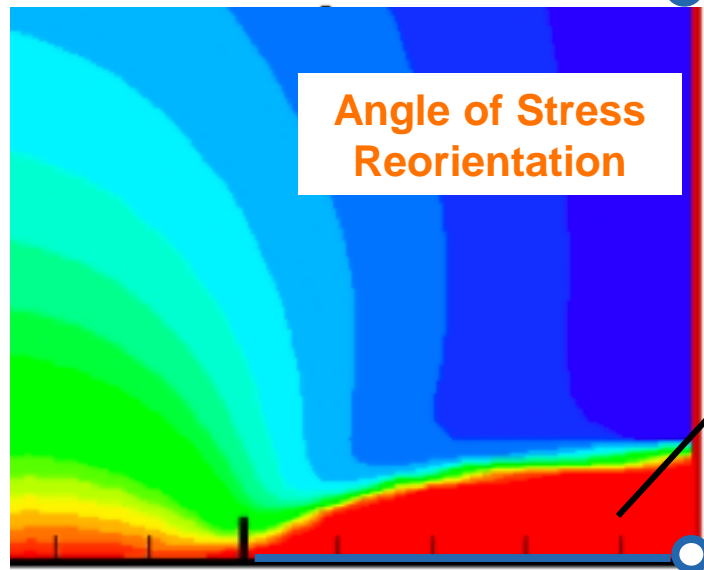
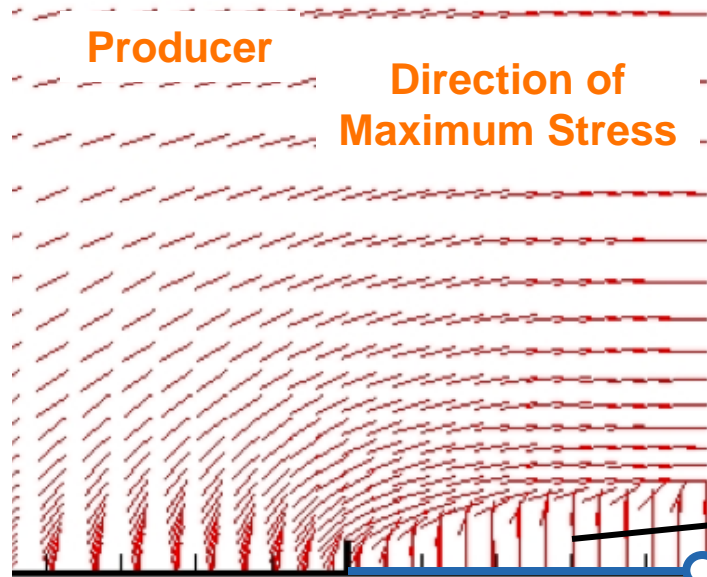
- Model is 3D and capable of handling, heterogeneity elasto-plasticity, multiple layers and anisotropy.
- Stress reorientation due to two factors:
  - Poroelastic effects
  - Fracture opening
- Constant pressure in vertical well and initial fracture.



# Stress Reorientation Around Producers and Injectors

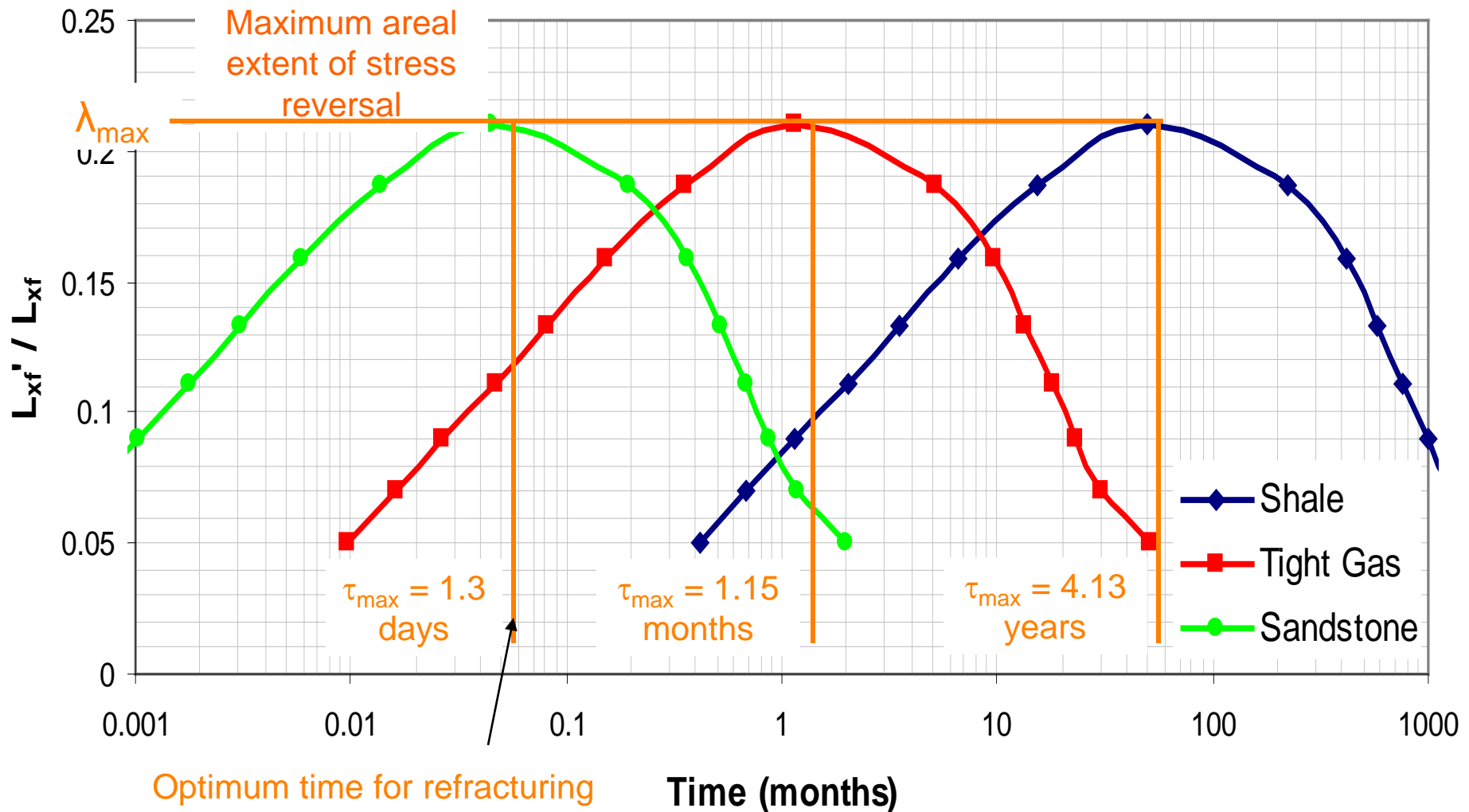


# Stress Reversal Region



Stress reversal region impacts direction of refracture in the field

# Task 5. Selecting Timing and Candidate Wells for Re-fracturing



# Parameters Affecting the Orientation of the Re-frac

- The areal extent and timing of the stress reversal depend on:
  - ✓ Fluid properties
  - ✓ Reservoir characteristics
  - ✓ Stress contrast
  - ✓ Drawdown
  - ✓ Thickness of the reservoir
  - ✓ Mechanical properties of the bounding layers

# Dimensionless Parameters

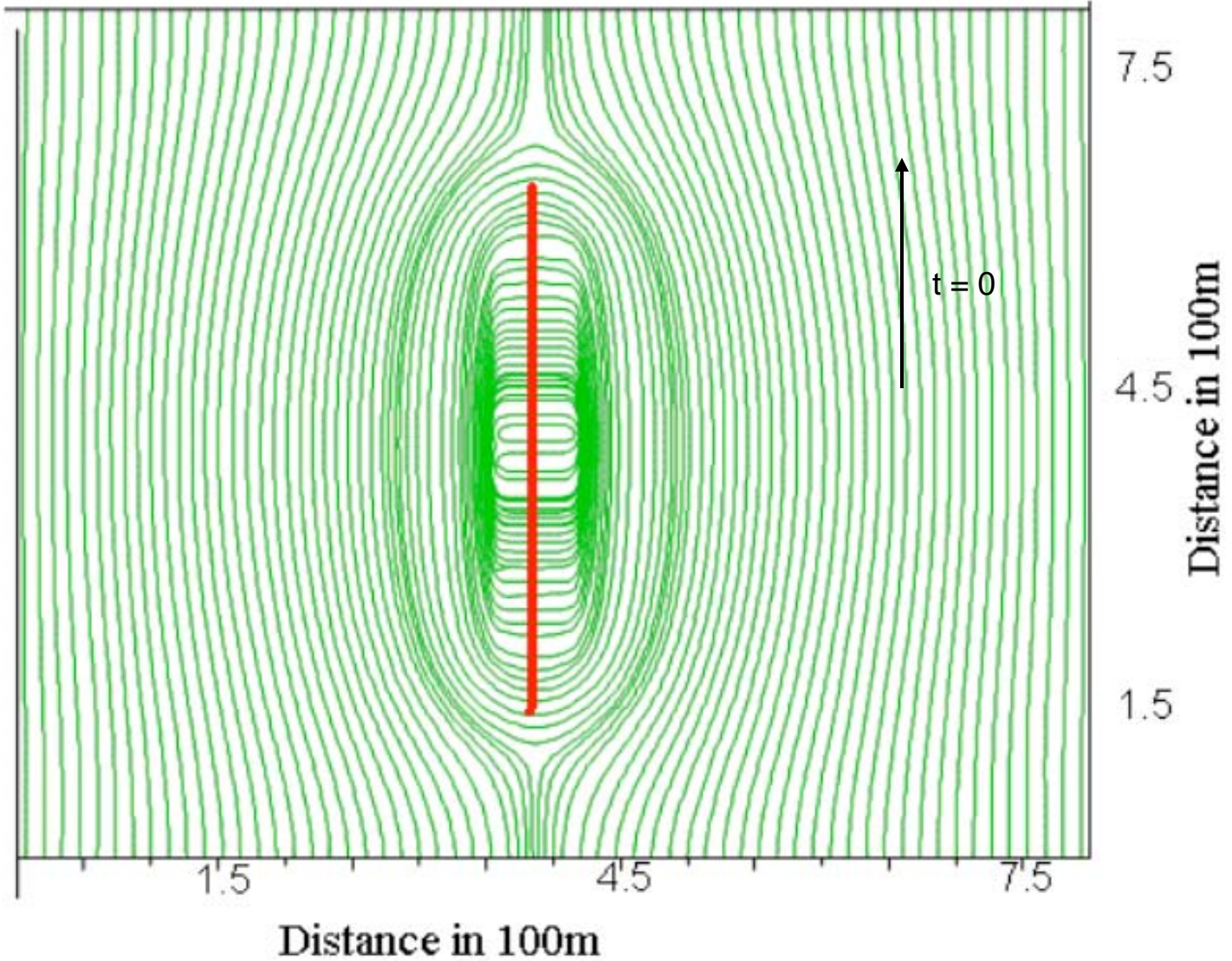
(Berchenko *et al.*, 1997; Siebrits *et al.*, 1998;  
Roussel and Sharma, 2009)

- Dimensionless Time  $\tau = \frac{4ct}{L_{xf}^2} = 4 \frac{\kappa}{S} \frac{t}{L_{xf}^2} = \frac{4kt}{\mu L_{xf}^2 \left( \frac{1}{M} + \frac{\alpha(1+\nu)(1-2\nu)}{(1-\nu)E} \right)}$
- Dimensionless Stress Deviator  $\Pi = \frac{S_0}{\sigma_*} = \frac{S_0}{\eta p_*} = \frac{\sigma_{h \max} - \sigma_{h \min}}{\frac{\alpha(1-2\nu)}{1-\nu} |p_{R_i} - p_{wf}|}$
- Dimensionless Fracture Height Ratio  $\gamma = \frac{H}{L_{xf}}$
- Dimensionless Shear Modulus Ratio  $\beta = \frac{G_b}{G_r}$

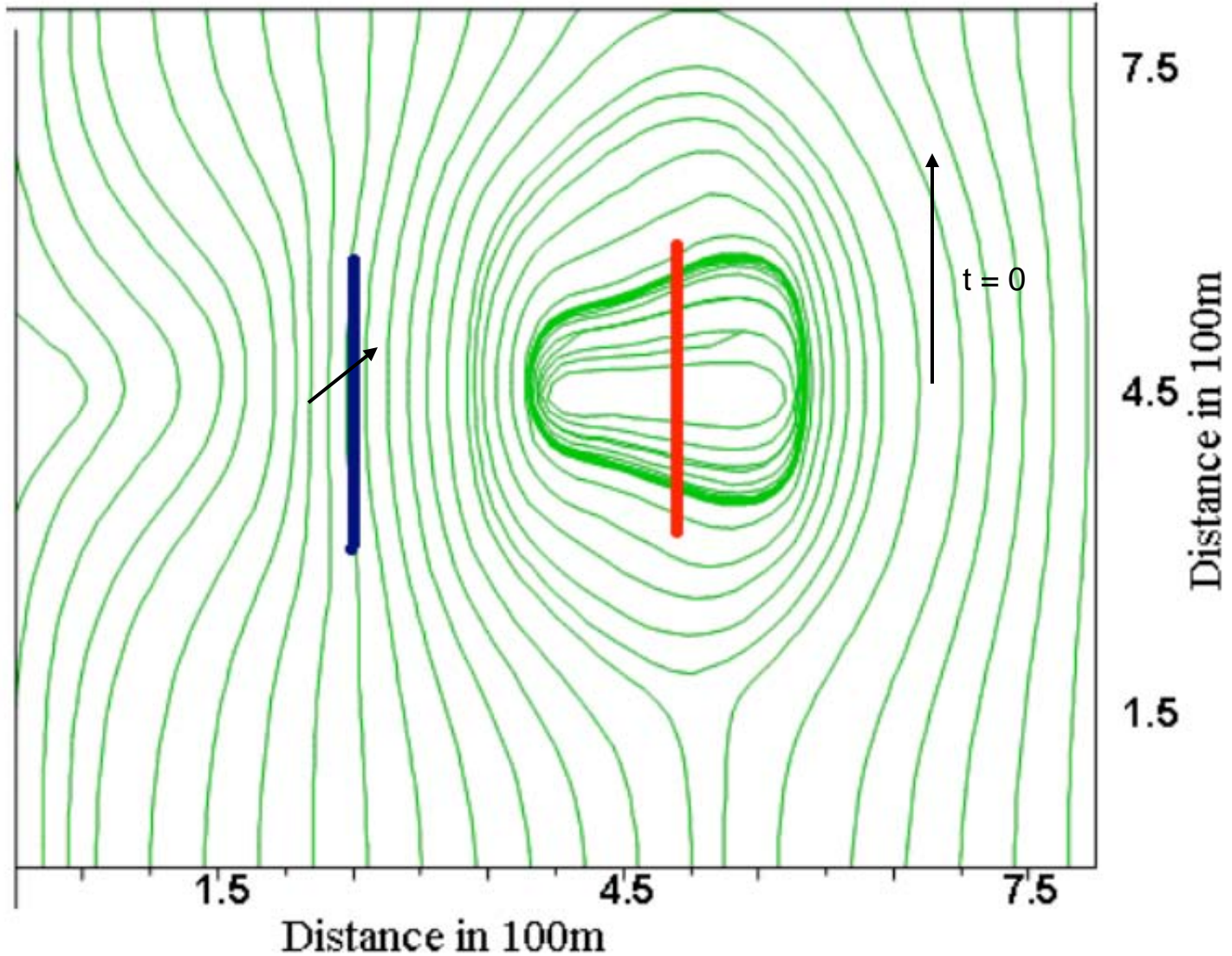
# Task 5. Selecting Timing and Candidate Wells for Re-fracturing

- For a given set of reservoir and well conditions we can now estimate the extent of stress reorientation. This should be one of the primary criteria for re-frac candidate well selection.
- The main results have been published.
  - ✓ *“Quantifying Transient Effects in Altered-Stress Re-fracturing of Vertical Wells”*, SPE 119522, Presented at the SPE Hydraulic Fracturing Meeting, Woodlands, 2009, Nicolas P. Roussel, Mukul M. Sharma.

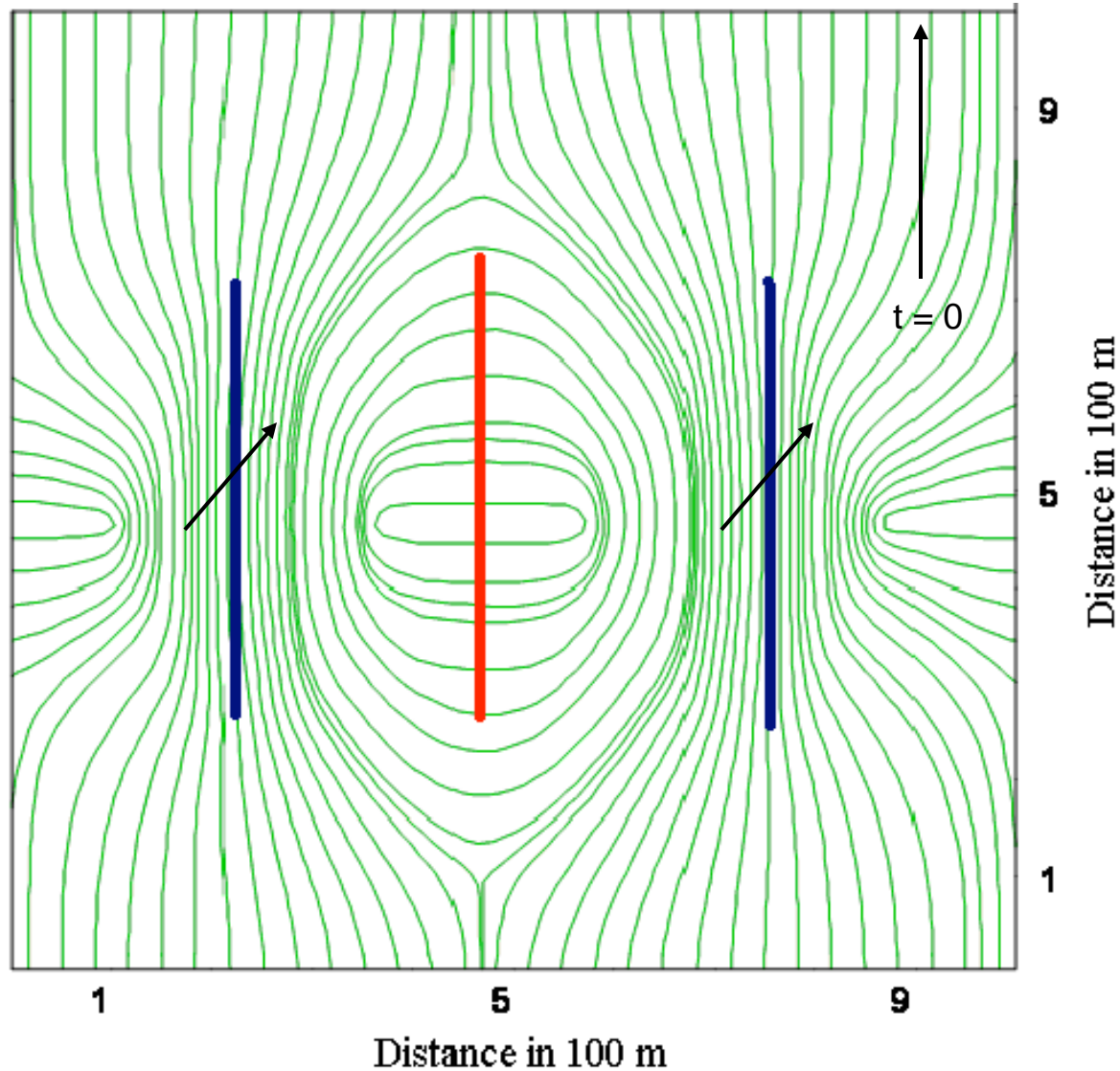
# Task 6. Re-fracture Designs for Deviated and Horizontal Wells



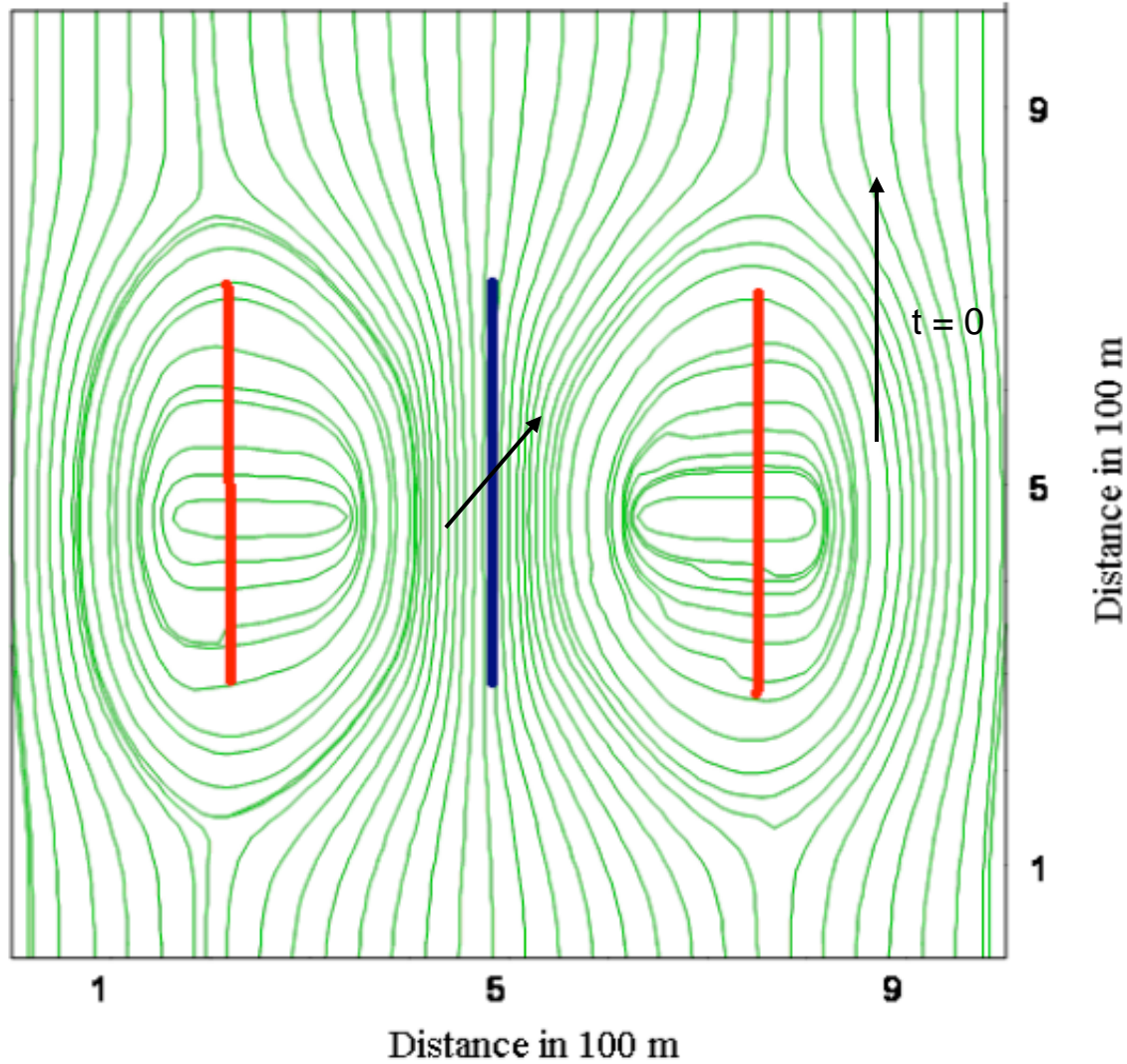
# Stress Reorientation for a Production - Injection Well Pair



# Stress Reorientation for 1 Production, 2 Injection Wells

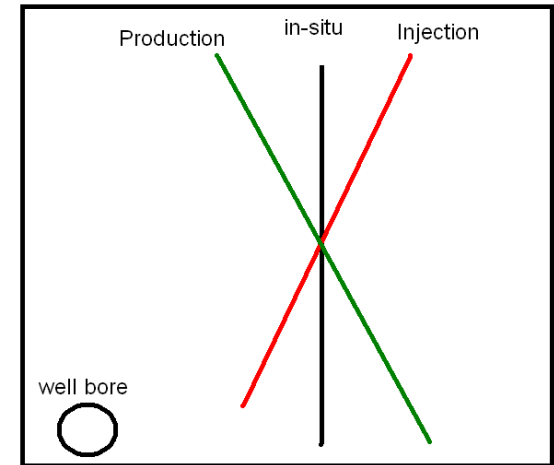


# Stress Reorientation for 2 Production, 1 Injection Well



# Other Findings, Summary

- An approaching fracture will go:
  - ✓ Away from a production well
  - ✓ Toward an injection well
- Stress reorientation depends on:
  - ✓ Drawdown
  - ✓ Stress anisotropy
  - ✓ Moduli of sand and bounding layers
- Stress reversal does occur in fractured producers. For a given set of reservoir / well conditions, we can now compute its,
  - ✓ Spatial extent
  - ✓ Timing

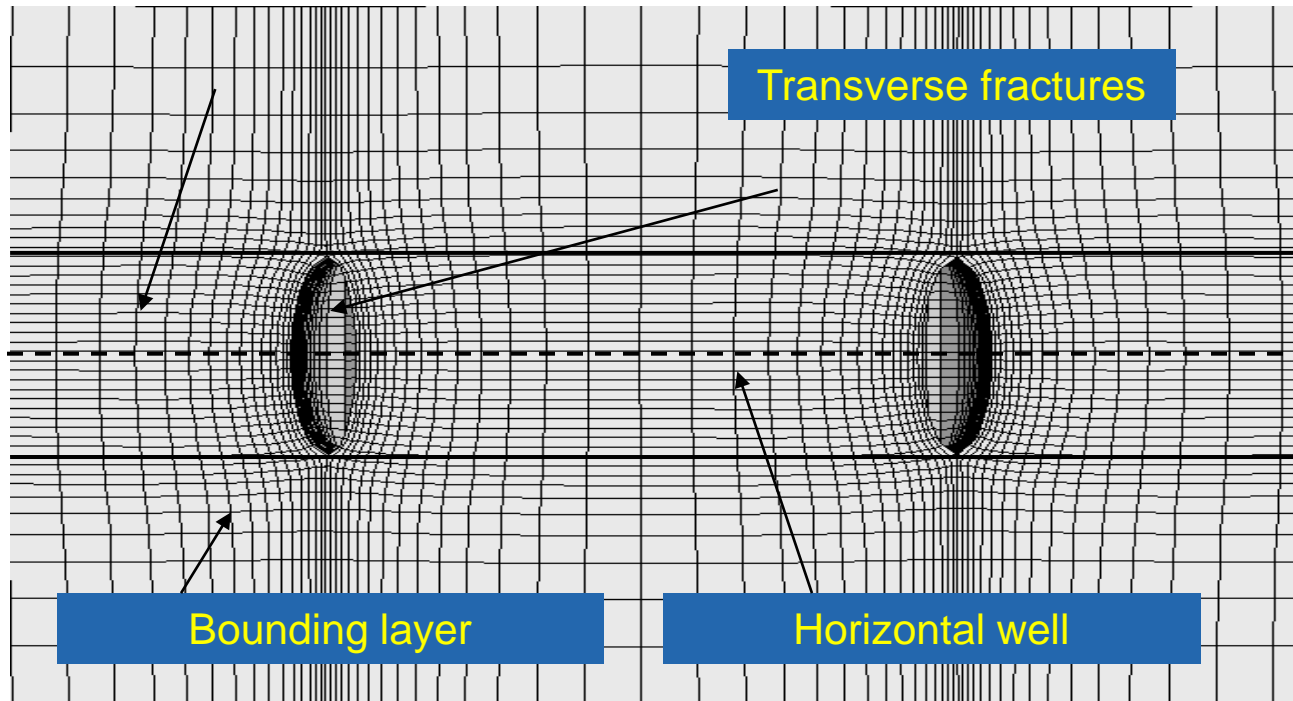


# Field Validation

- We have computed stress reorientation in wells in the Barnett shale and in the Codell formation in the Wattenberg field.
- A complete dataset should include:
  - ✓ Wellbore schematic and data
  - ✓ Base map showing location of wells
  - ✓ Details of frac and re-frac jobs
  - ✓ Logs (dipole sonic)
  - ✓ Microseismic
  - ✓ Gas flow rate before / after re-frac
- Good initial agreement is obtained. Results of this comparison are in the SPE paper.
- Additional work ongoing with partner companies.

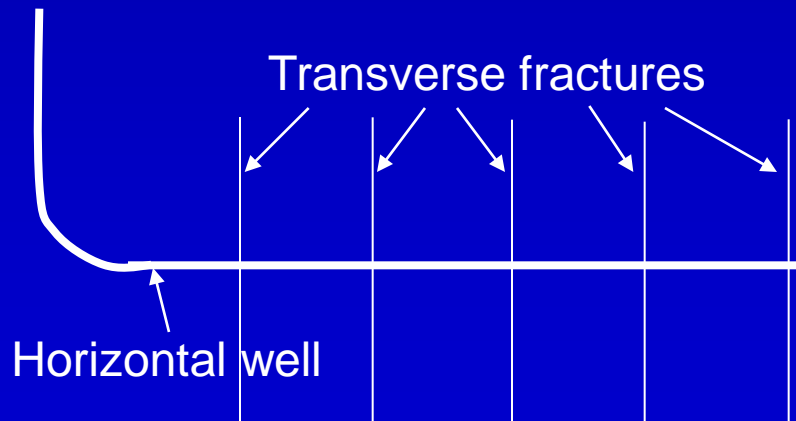
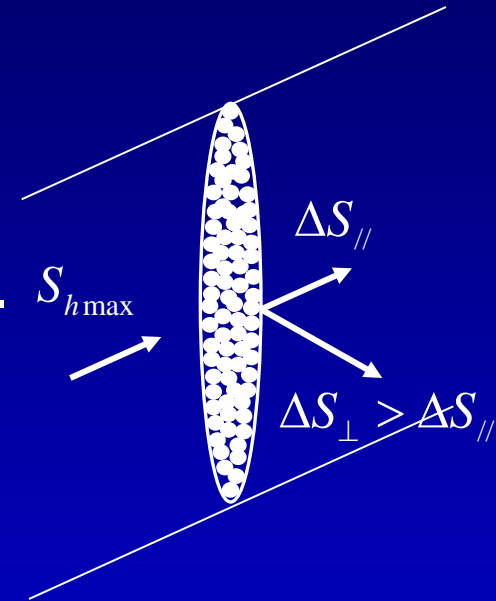
# Stress Reorientation Due to Fracture Opening

- Opening of a fracture increases the stress in the direction of fracture opening i.e. increases the minimum horizontal stress.
- Poro-elastic effects are negligible before production is initiated.

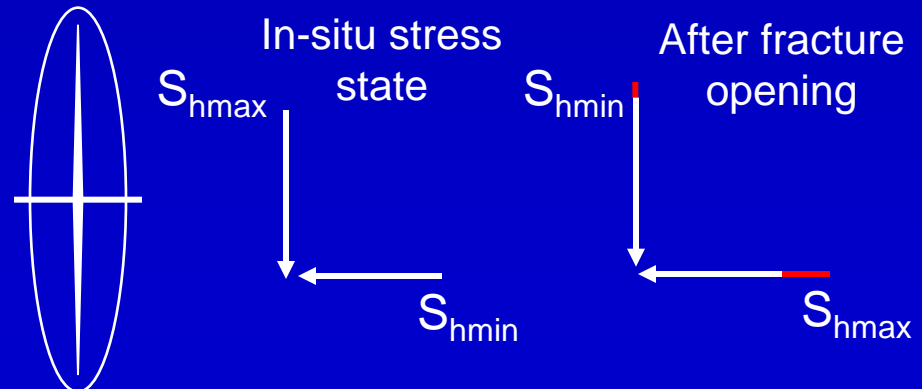


# Stress Reorientation Limits the Number of Transverse Fractures

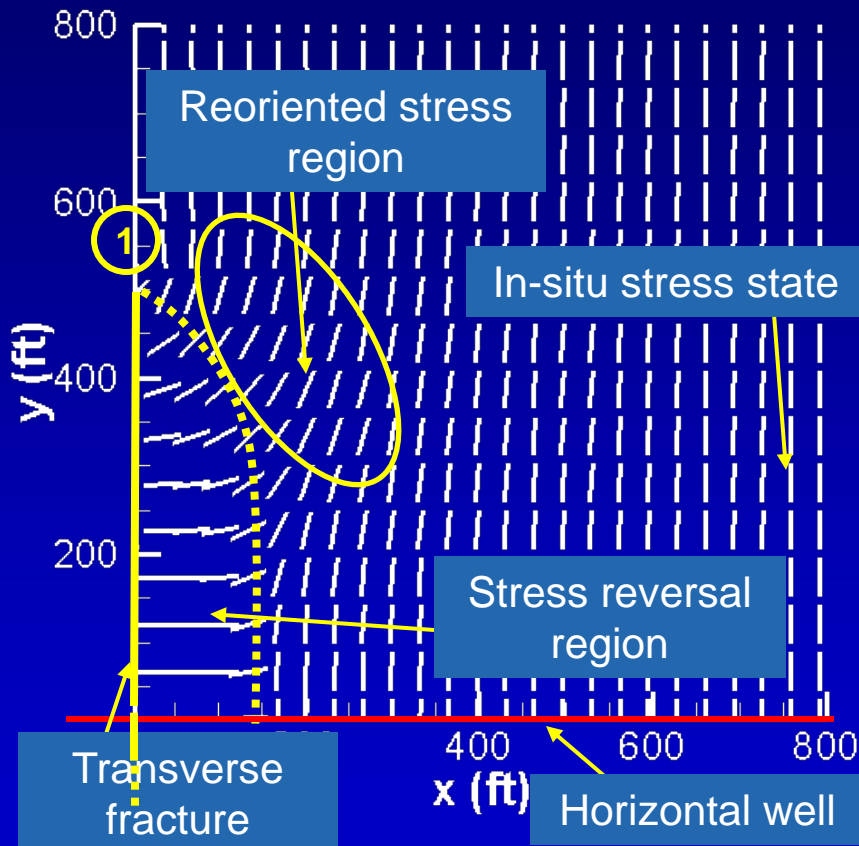
- Every fracture after the first one is affected by the stress reorientation.
- Fractures tend to reorient away from previous fractures in the vertical plane.
- This can lead to TSO or longitudinal fractures.
- We have quantified this effect.



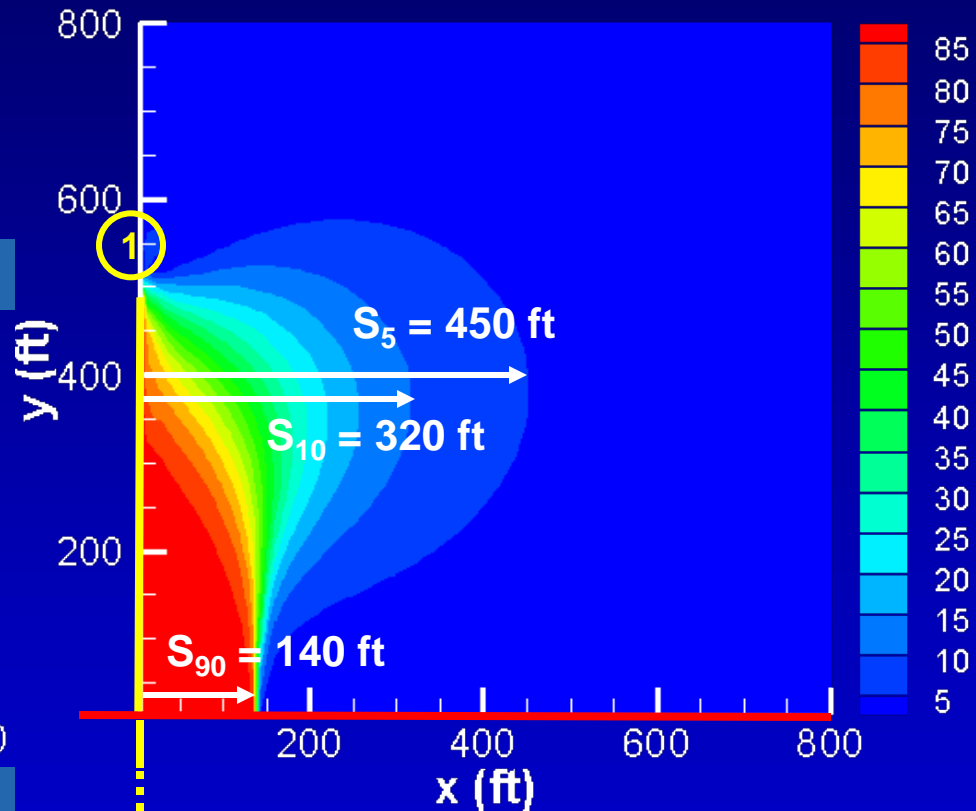
Top view



# Stress Reorientation in Horizontal Well Fracturing



Direction of maximum horizontal stress

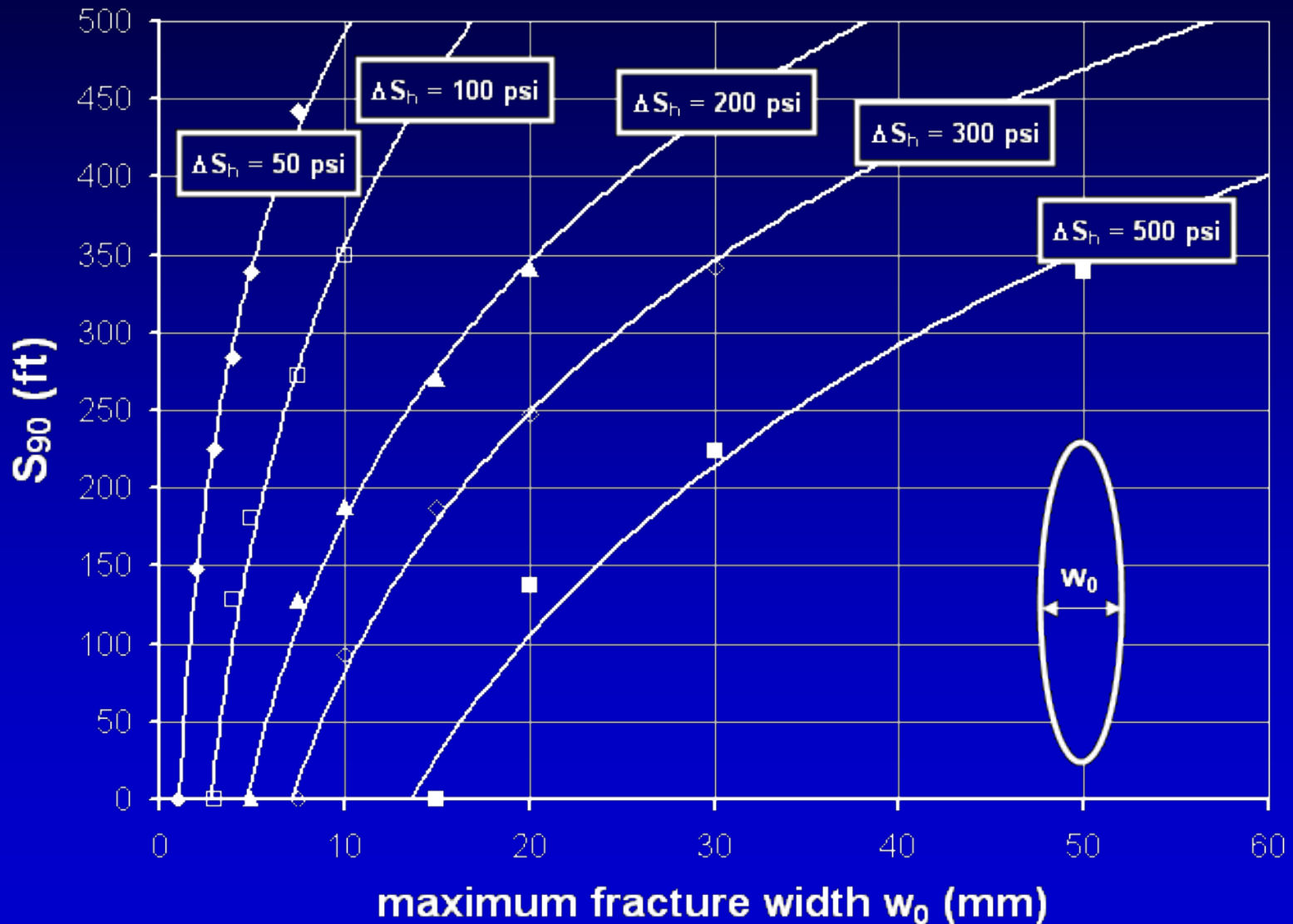


Angle of stress reorientation

# Quantifying the Concept of Minimum Fracture Spacing

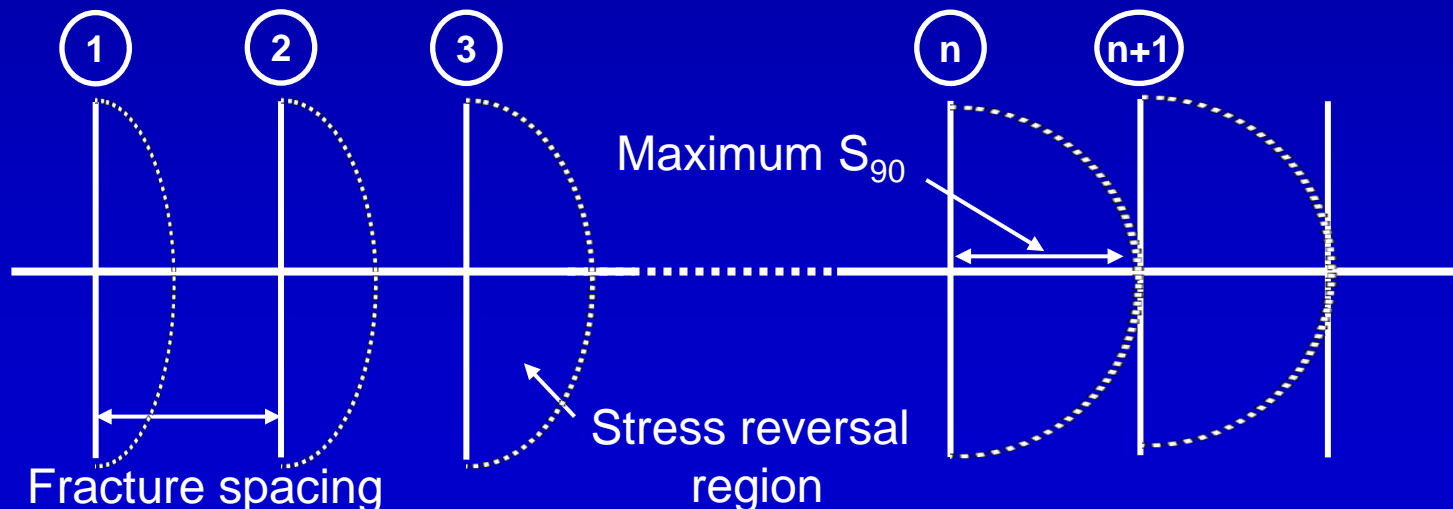
- If the next fracture is initiated inside the stress reversal region, there is a possibility of:
  - ✓ Longitudinal fracture
  - ✓ Risk of screen-out
- To avoid longitudinal fractures, the minimum fracture spacing, should be greater than  $S_{90}$ .
- To maintain transverse fractures the fracture spacing should be greater than  $S_5$ .
- For any spacing between  $S_{90}$  and  $S_5$  fractures will deviate from the transverse plane.
- **Ref: Nicolas P. Roussel, Mukul M. Sharma, SPE 127986, "Optimizing Fracture Spacing and Sequencing in Horizontal Well Fracturing" (2010).**

# Effect of Fracture Width, Stress Contrast on Minimum Fracture Spacing

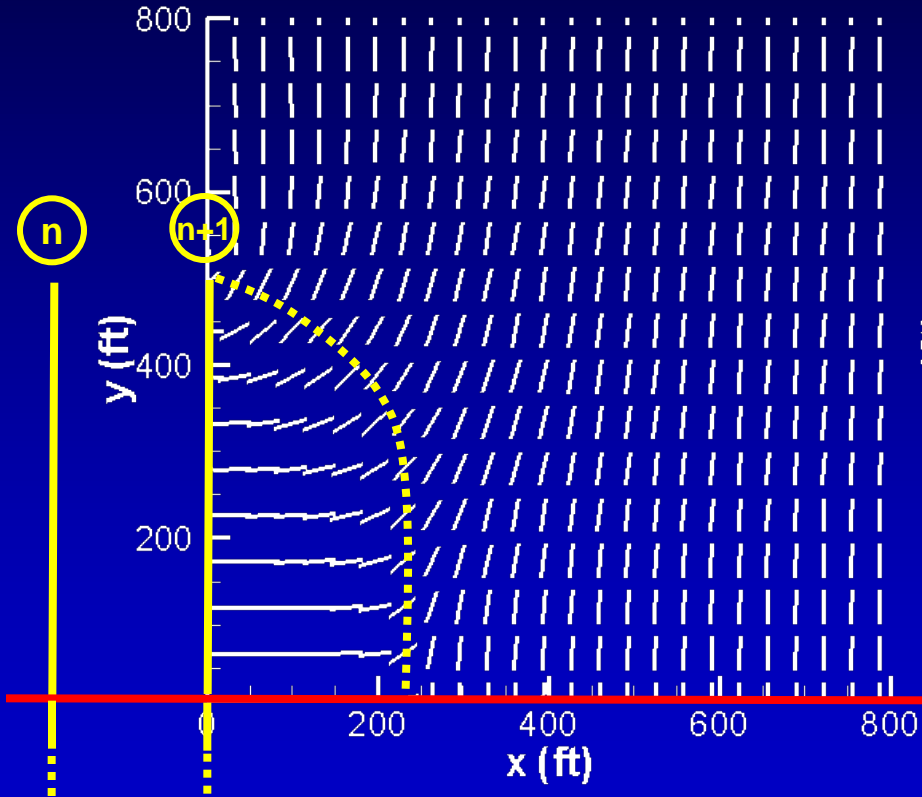


# Fracture Reorientation Because of Multiple Fractures

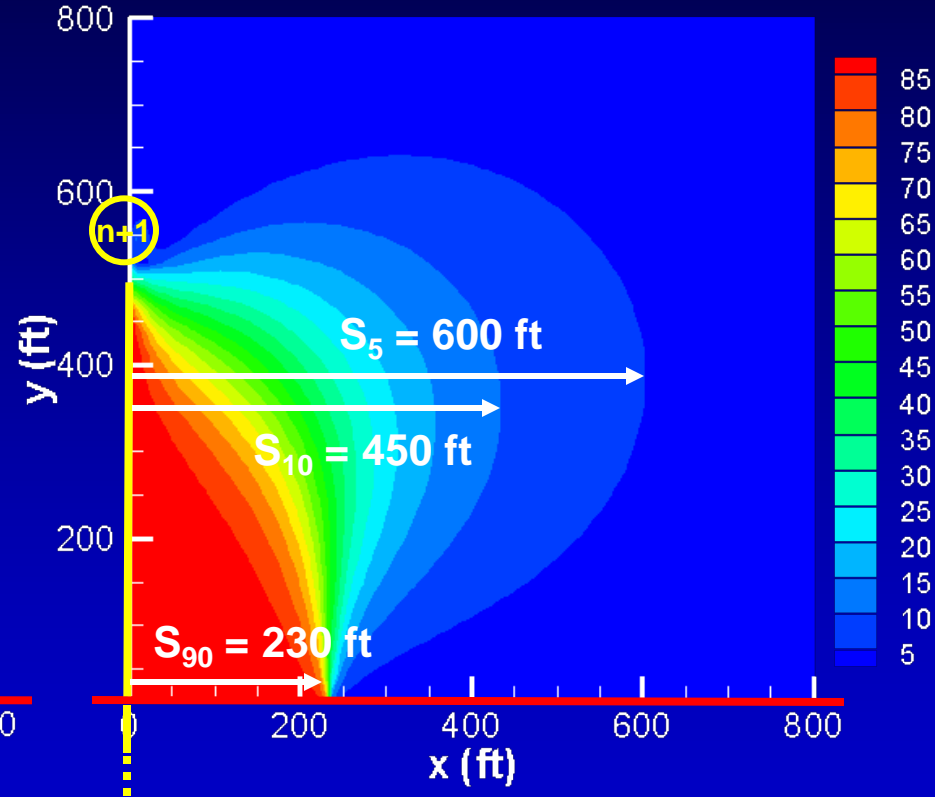
- Stress perturbations are cumulative as more fractures are added
- The stress reversal region grows with each additional fracture
- Fracture spacing should be at least greater than the maximum value of  $S_{90}$



# Estimating Minimum Fracture Spacing, Consecutive Multiple Fractures



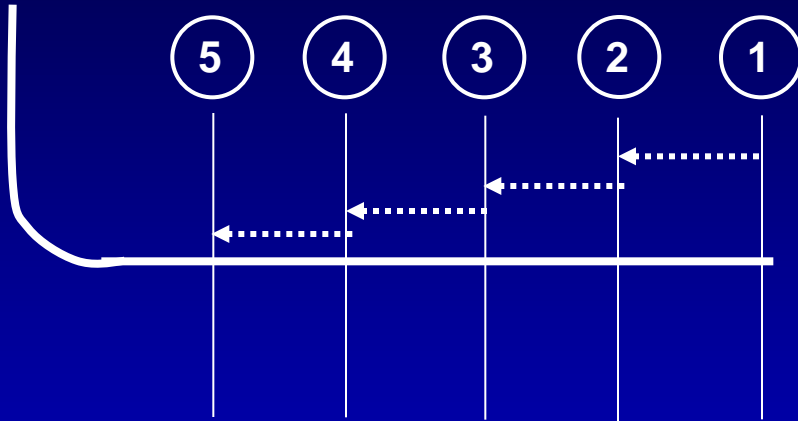
Direction of maximum horizontal stress



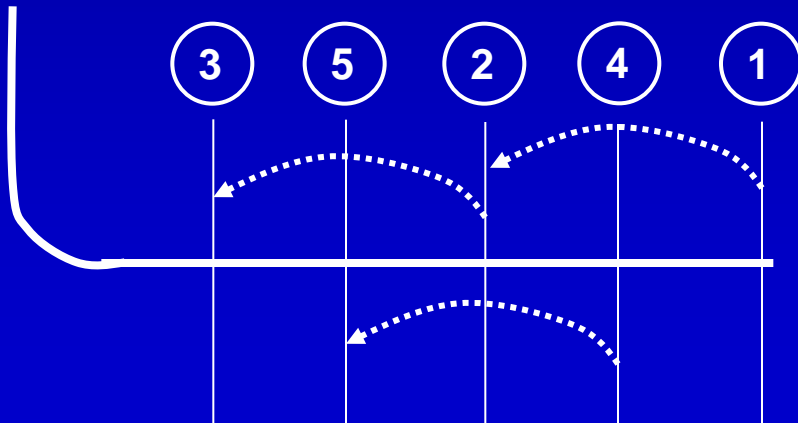
Angle of stress reorientation

# Three Fracturing Sequences

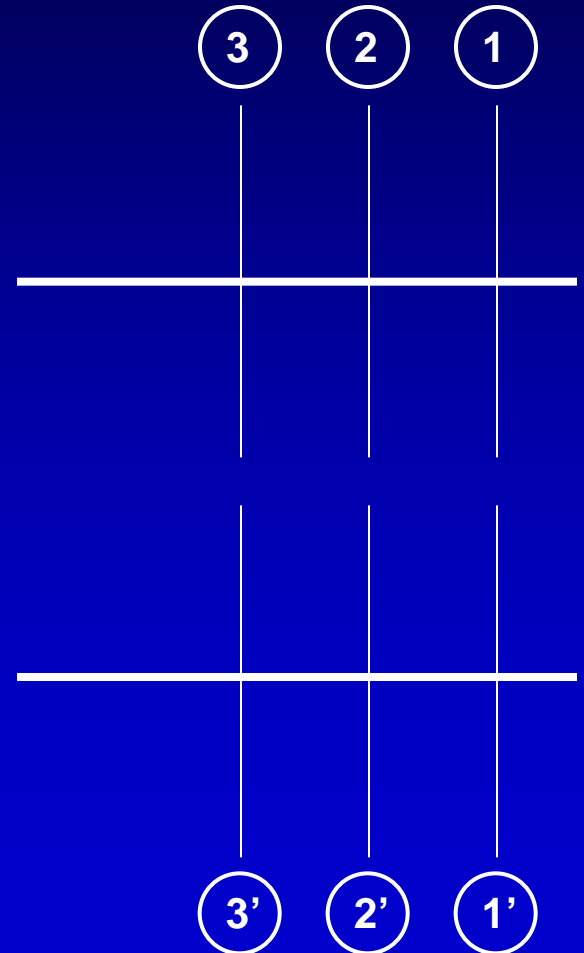
## 1. Consecutive fracturing



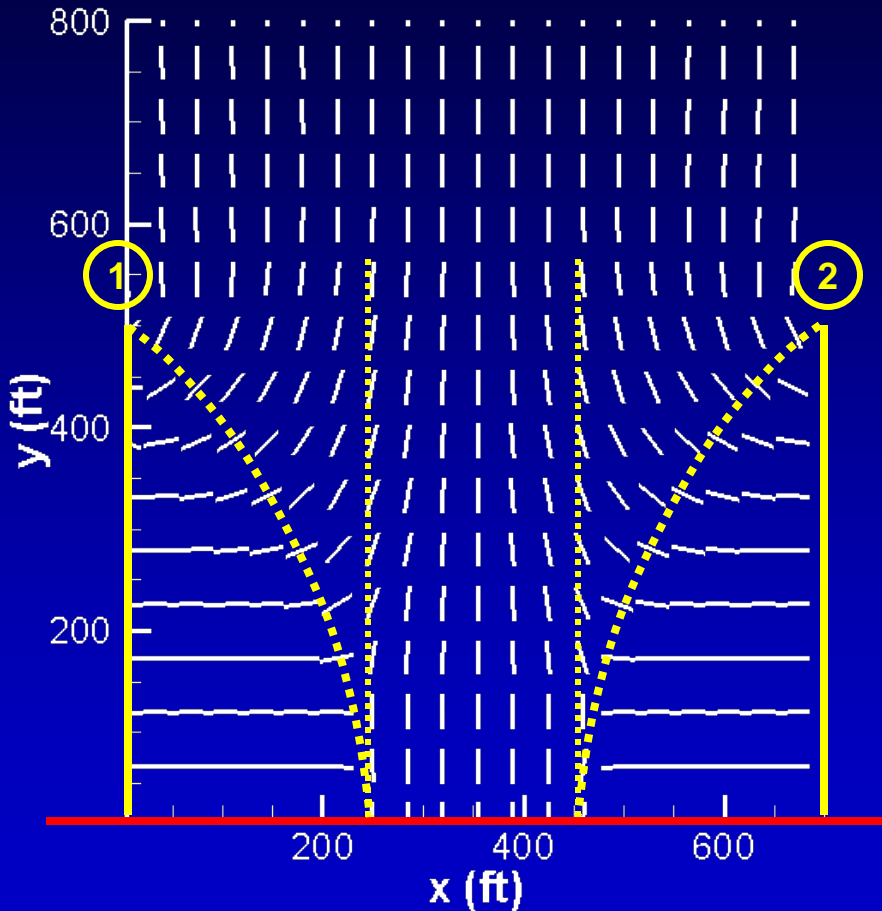
## 2. Alternate fracturing



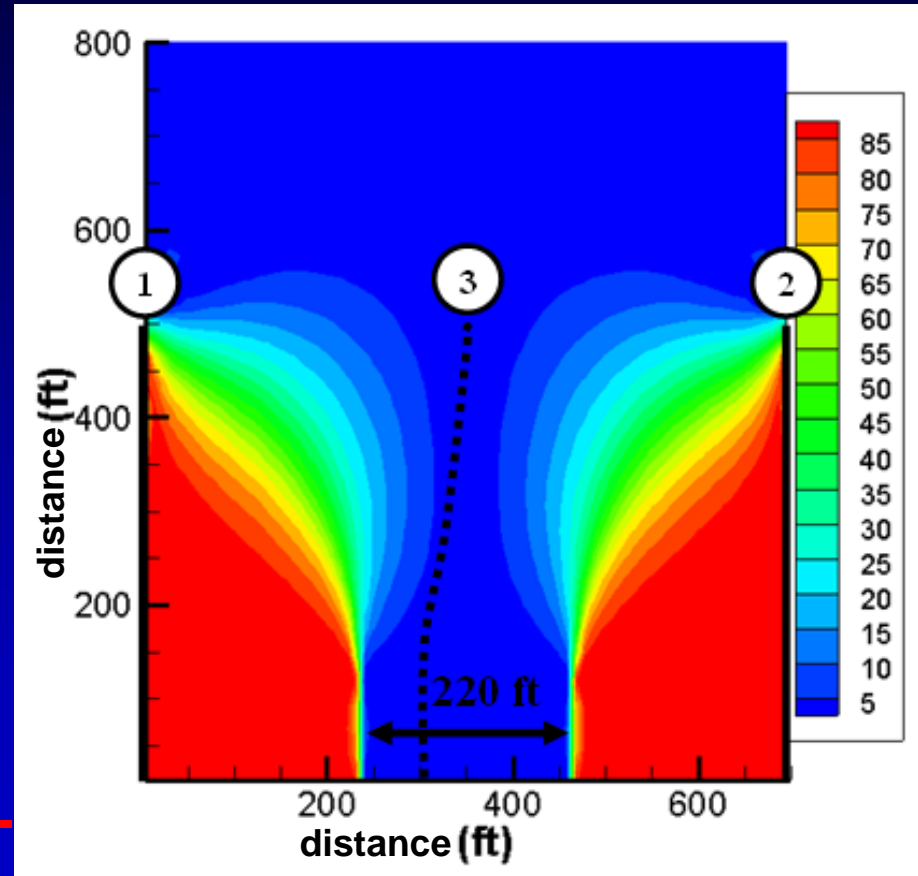
## 3. Zipper frags



# Alternate Fracturing (700-ft spacing)

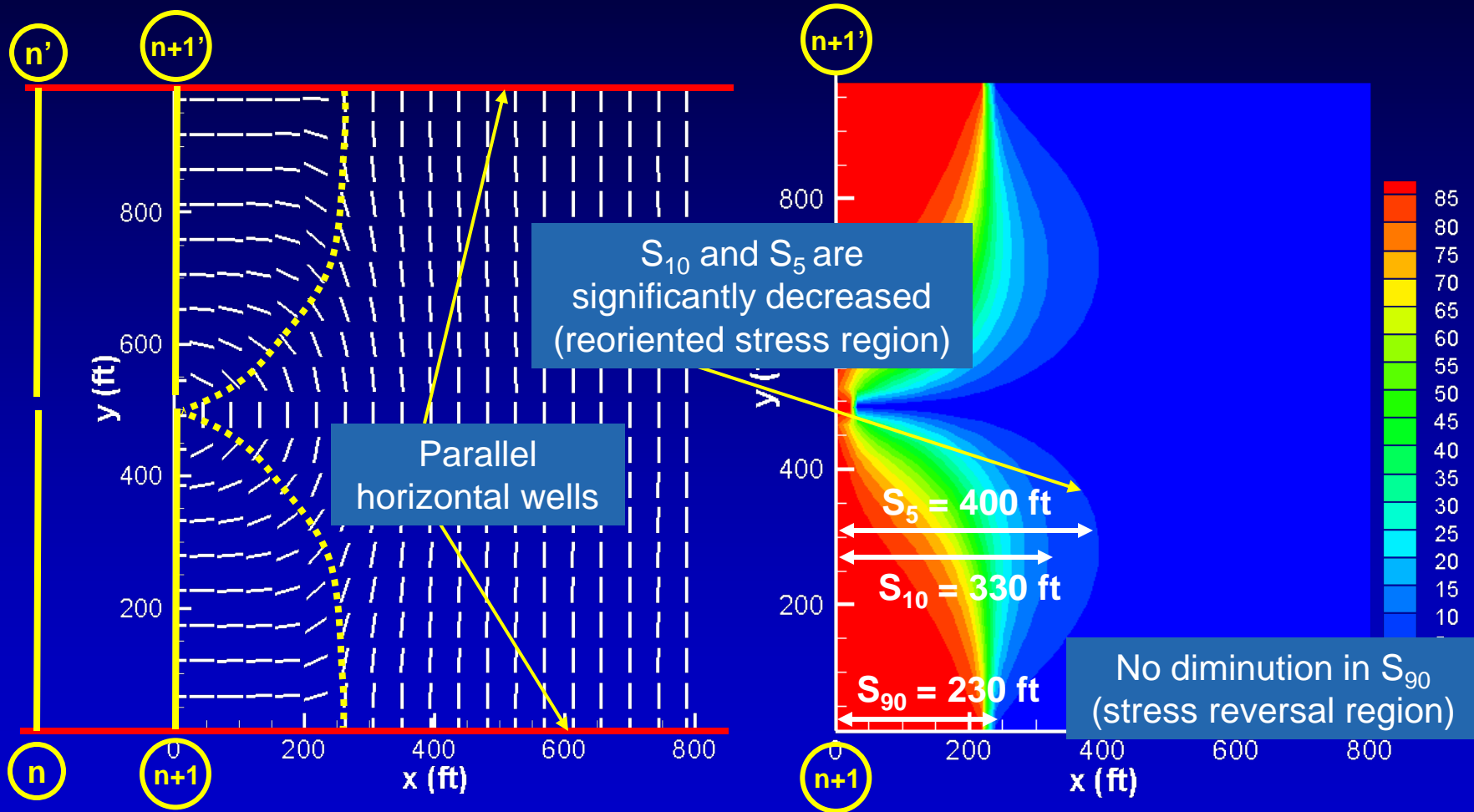


Direction of maximum horizontal stress



Angle of stress reorientation

# Simultaneous Fracturing of Adjacent Wells: Zipper Fracs



Direction of maximum horizontal stress

Angle of stress reorientation

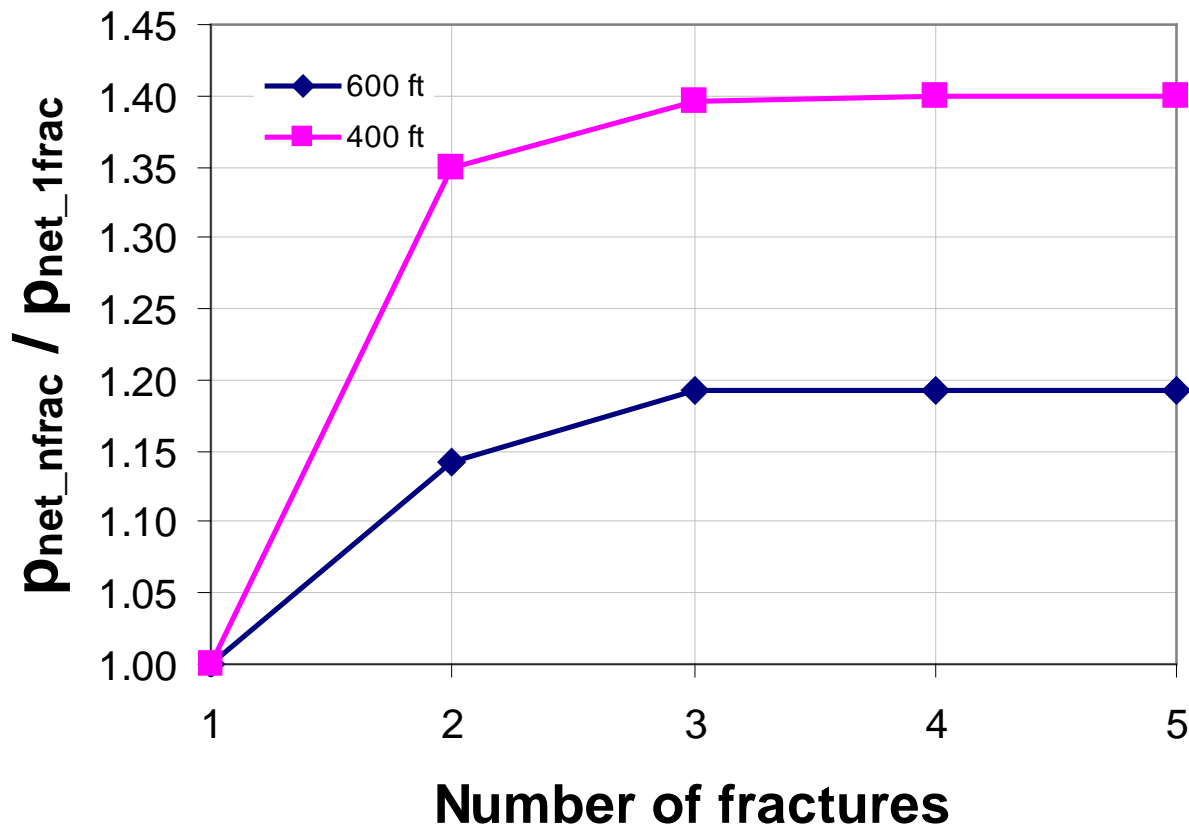
# Alternate Fracturing Sequence Minimizes Fracture Spacing

- Minimum fracture spacing ( $S_{90}$ ): to avoid screen-out or longitudinal fractures
- Recommended fracture spacing ( $S_5$ ): to avoid fracture deviation from orthogonal path

	Consecutive fracturing (1-2-3-4-5...)	Alternate fracturing (1-3-2-5-4...)	Simultaneous fracturing of adjacent wells (well spacing = $2 L_f$ )
Minimum fracture spacing (ft) (= $S_{90}$ or interval for 3 <sup>rd</sup> frac > 0 ft)	230	325	230
Recommended fracture spacing (ft) (= $S_5$ or interval for 3 <sup>rd</sup> frac > 100 ft)	<b>600</b>	<b>340</b>	<b>400</b>

# Effect of Fracture Spacing On Net Pressures – Multiple Fracs

- Net pressure increase from toe to heel indicates stress interference.
- Net pressure change depends on fracture dimensions and mechanical properties

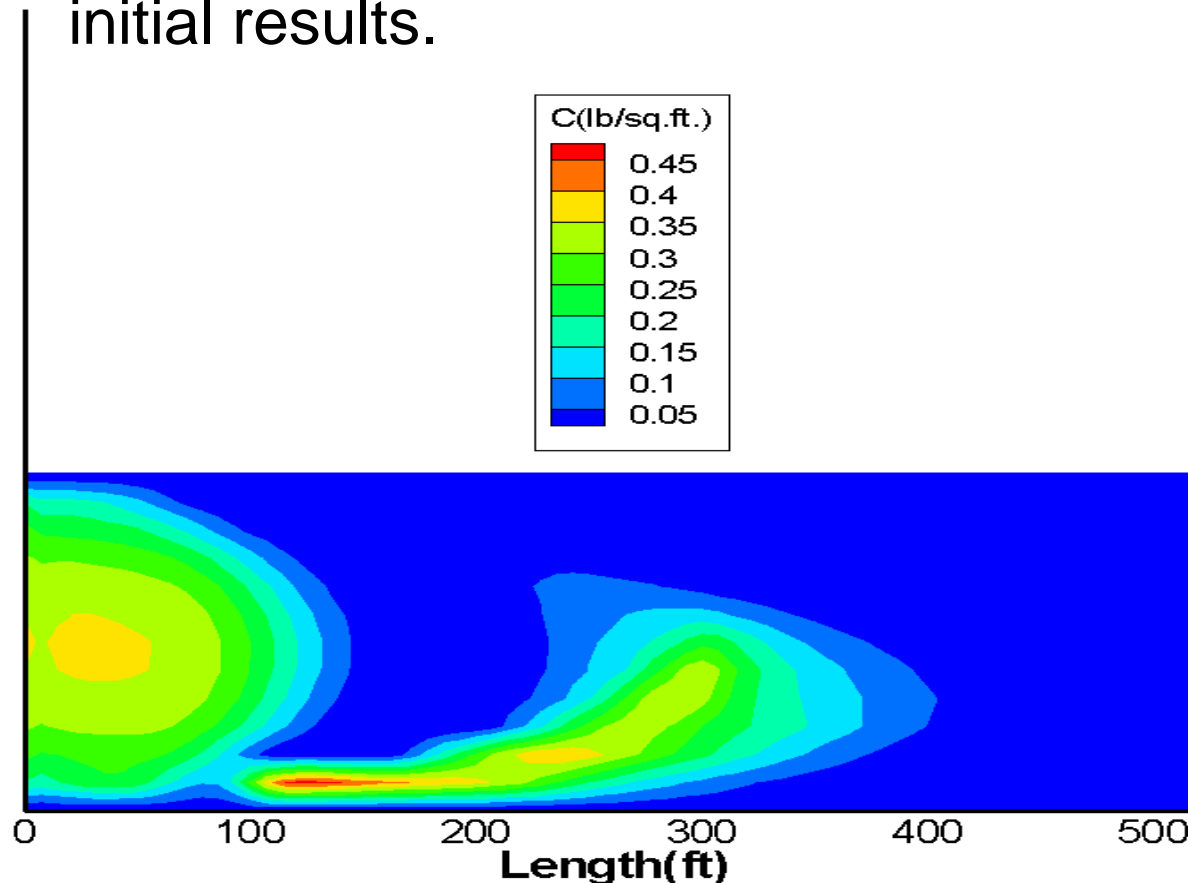


# Summary

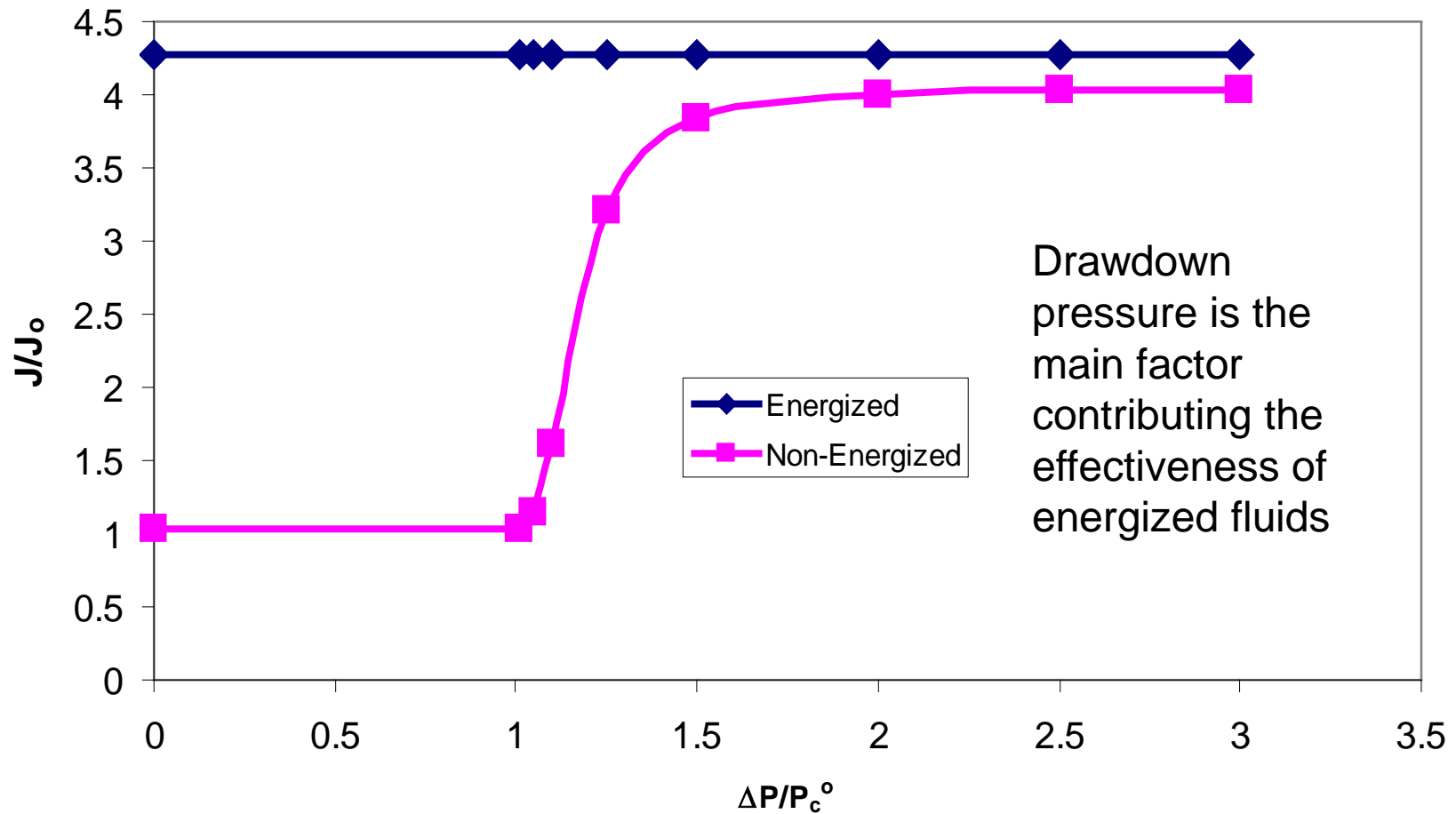
- Stress reorientation is the limiting factor in the spacing of multiple transverse fractures.
- Our numerical model provides estimates of the minimum and recommended fracture spacing for any given set of reservoir, fracture properties.
- The alternate fracturing technique minimizes fracture spacing.
- Significant opportunities for higher production in horizontal well completions may be possible with the alternate fracturing method.

# Task 7, 8. Use of Novel Proppant Placement Strategies in Re-fracturing Operations

Status: Work is underway and we have some initial results.



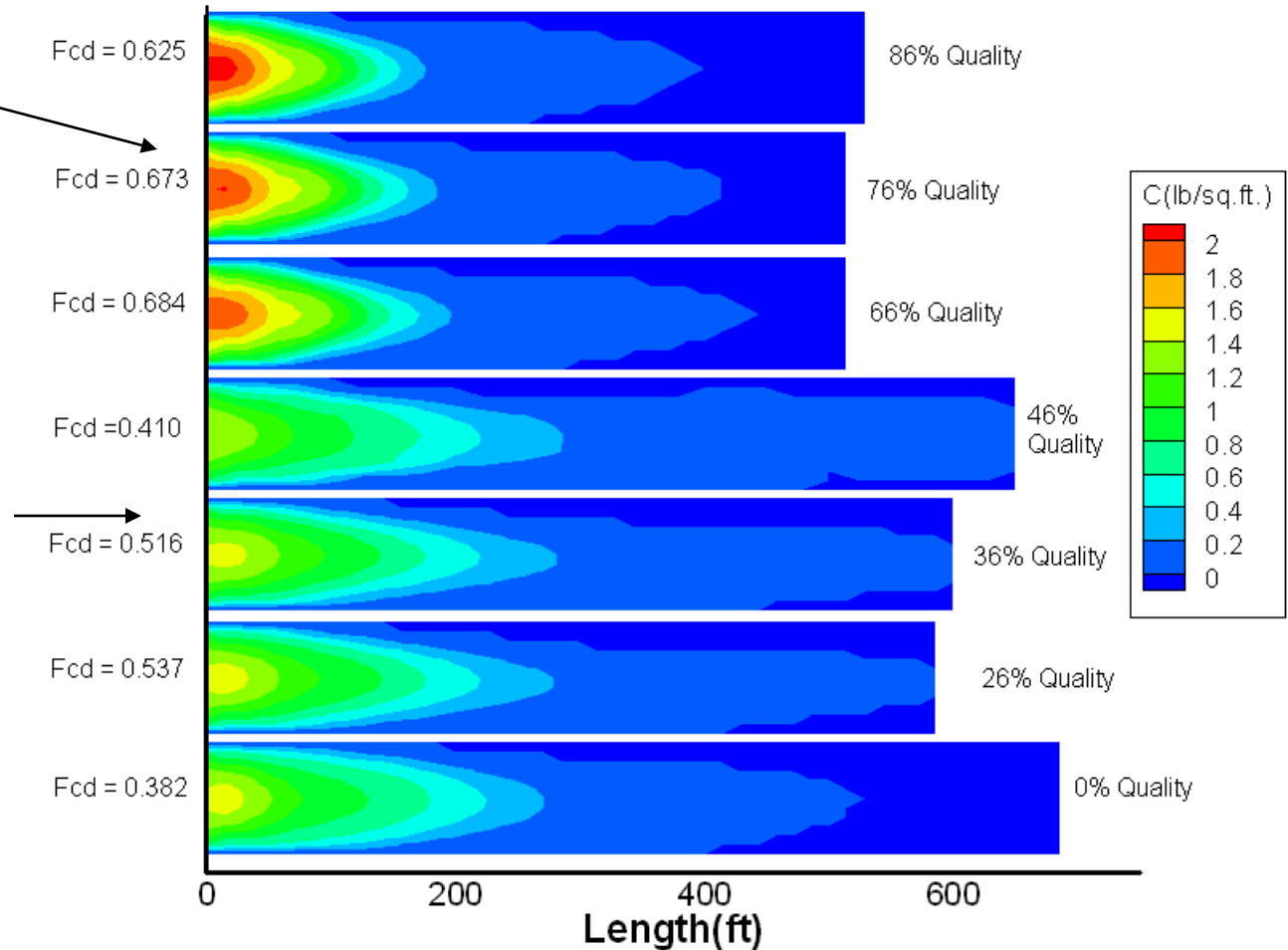
# Effect of Drawdown Pressure: Well A (EFRAC Results)



# Effect of Inlet Foam Quality: Well A (EFRAC Results)

Foams create higher conductivity

Un-foamed fluids create more length



# Summary of Progress to Date

- Stress reorientation due to poroelastic and mechanical effects has been calculated for vertical, fractured and horizontal wells.
- Key parameters and conditions that control this stress reorientation have been identified.
- Re-frac candidate well selection is now possible using stress reorientation as a screening tool.
- The optimum timing of re-frac treatments has been computed for the first time.
- A new strategy for fracturing horizontal wells has been proposed to reduce the spacing between adjacent fractures.

# Future Work

- Further explore strategies for multiple fracturing in horizontal wells.
- Continue to compare fracture reorientation results with well data from the Barnett and Codell formations.
- Simulate different proppant placement strategies in re-fracture treatments.

## **I would like to Acknowledge:**

- ✓ **RPSEA for their support.**
- ✓ **Our partner companies (Anadarko, BJ Services, Noble Energy, Pinnacle) for collaboration and access to data.**
- ✓ **Members of the Fracturing and Sand Control JIP at the University of Texas at Austin (Anadarko, BJ Services, BP, ConocoPhillips, Halliburton, Schlumberger, Shell, Total) for providing the cost sharing for this project.**

**Thank you  
Questions?**

# Application of the Model to Typical Gas Reservoir Types

- Parameter values for sandstone gas, tight gas and shale gas

	Shale gas	Tight gas	Sandstone gas
Permeability $k$ (md)	$10^{-4}$	$10^{-2}$	1
Young's Modulus $E$ (psi)	$5.1 \cdot 10^6$	$1.0 \cdot 10^6$	$2.8 \cdot 10^6$
Poisson's Ratio $\nu$	0.3	0.3	0.3
Porosity $\phi$	0.05	0.05	0.2
Compressibility (1/psi)	$2 \cdot 10^{-4}$	$3 \cdot 10^{-4}$	$3 \cdot 10^{-4}$
Viscosity $\mu$ (cp)	0.02	0.03	0.03
Fracture Length $2 L_{xf}$ (ft)	600	600	600

# Objectives

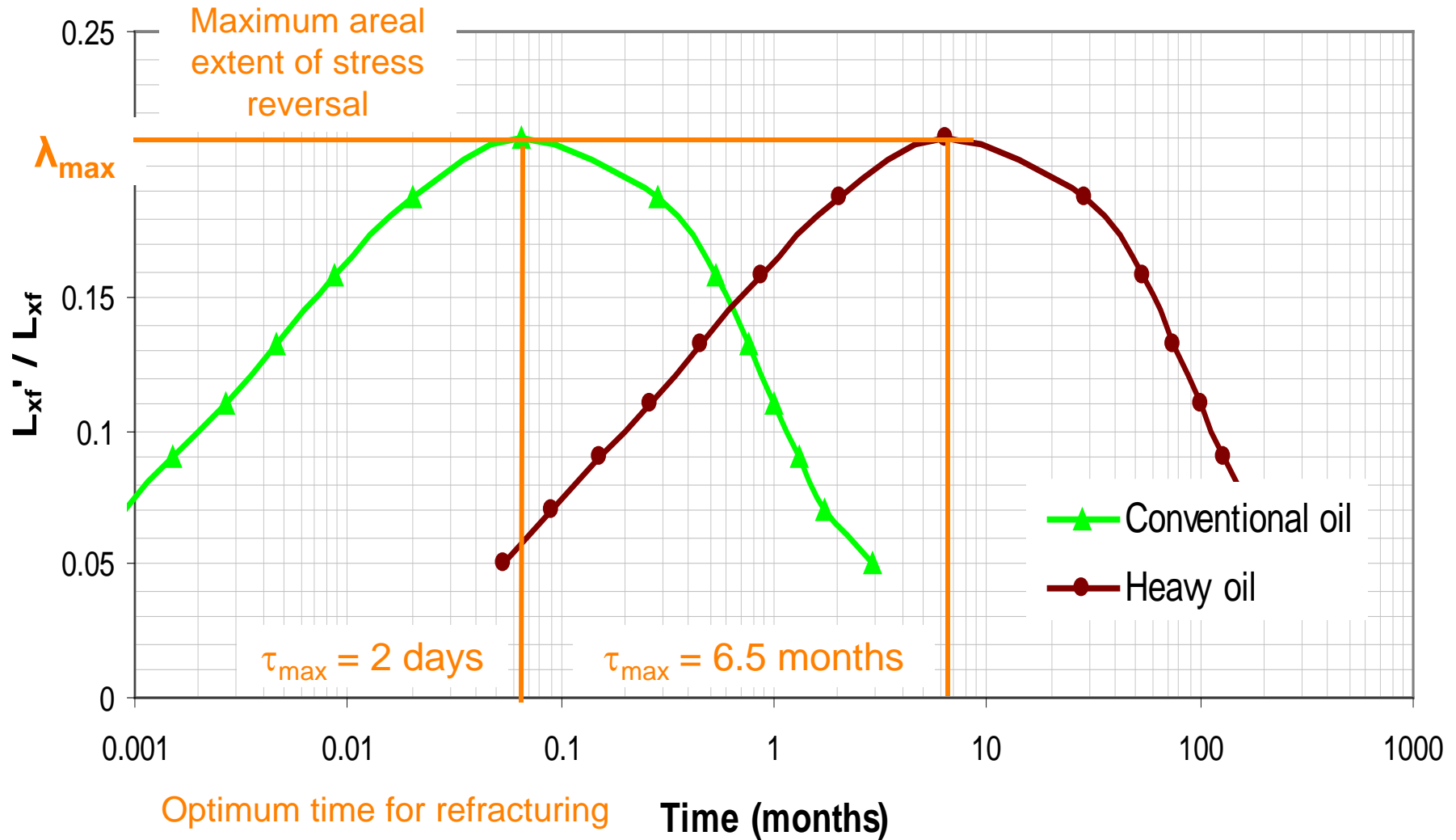
- Use principal component analysis to determine the increase in production rate after a refracture treatment.
- Use stress reorientation models to study the role played by stress reorientation vs other factors such as GOR and depletion.
- Use these findings to recommend timing for refracs
- Create a statistical, predictive model for
  - ✓ Production enhancement
  - ✓ Candidate well selection

# Data Set

- Refracture well data, approx. 4000 wells  
Anadarko, Noble Energy (1999 - 2008)

<b>Groups</b>	<b>Description</b>
Well information	Year
Orig. frac treatment	Volume of gel and proppant during the first fracture
Pre-refrac data	Production information and number of perforations
Refrac design	Gel loading, pad size, surfactant, etc
Refrac treatment	Fluid injection, perforations
Rheology	Viscosity measurements, gel usage
Water quality	Water source, composition
Job comments	Problems during the job
Refrac data	Production increment

# Time-Window for Refracturing: Oil Reservoirs



# Field Data for Validation

- A complete dataset would include:
  - ✓ Gas properties (viscosity, compressibility)
  - ✓ Reservoir parameters ( $k$ ,  $\Phi$ ,  $E$ ,  $\nu$ )
  - ✓ Bounding layer parameters ( $E$ ,  $\nu$ )
  - ✓ Pressures (reservoir, wellbore)
  - ✓ Estimates of stresses (direction and magnitude of maximum and minimum horizontal stresses)!!

# Statistical Analysis

## *Linear Regression*

- Linear regression

$$y_i = \sum_{j=1}^m X_{ij} \beta_j + \varepsilon_i$$

- Linear regression on original data
  - ✓ Scatter plots show weak relationship
  - ✓ Relating 1279 entries to 43 parameters

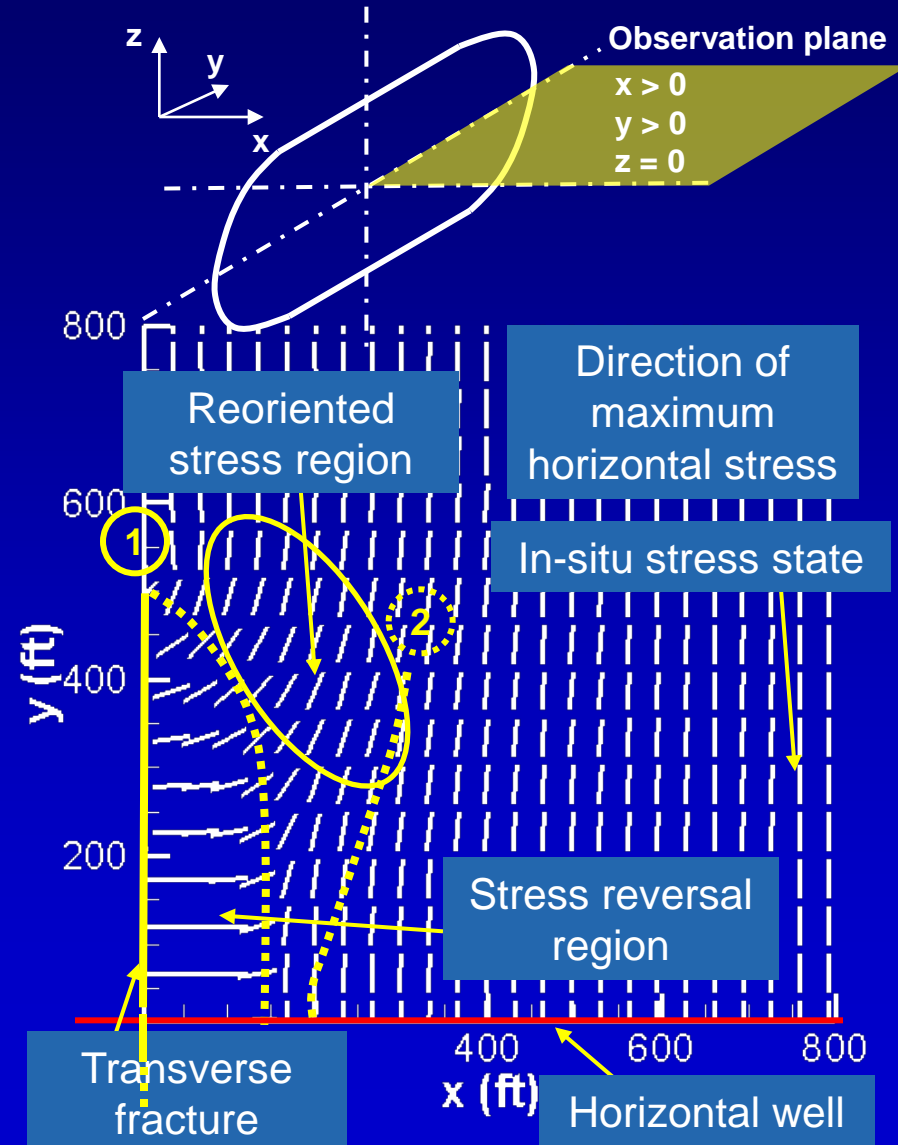
# Milestones

- 1 Research Management Plan**
- 2 Technology Status Assessment**
- 3 Data compilation for the Codell formation**
- 4 Data compilation for the Barnett shale**
- 5 Stress reorientation model implementation and runs for Codell re-fracs**
- 6 Stress reorientation model implementation and runs for Barnett shale re-fracs**
- 7 Evaluation of fractured well performance in the Codell, Barnett and horizontal wells**
- 8 Candidate well selection based on poro-elastic model and field data analysis**
- 9 Design of re-frac treatments in the Codell, and Barnett based on simulations, new fluids and proppants**
- 10 Design of re-frac treatments in horizontal wells based on simulations, new fluids and proppants**
- 11 Implementation of re-frac treatments in the Codell, and Barnett (new designs).**
- 12 Post frac evaluation of re-frac treatments in the Codell, Barnett and horizontal wells**
- 13 Workshop in Houston to discuss results**
- 14 Final report with all the findings from the study**

# Stress Reorientation in Horizontal Well Fracturing

- In the stress reversal region, risk of screen-out or longitudinal fracture.
- Second fracture propagates away if initiated too close to the first fracture.

Ref: **Nicolas P. Roussel**  
**Mukul M. Sharma, SPE 127986,**  
**“Optimizing Fracture Spacing and Sequencing in Horizontal Well Fracturing” (2010).**



# Task 9, 10. Design of Re-Fracture Treatments in the Wattenberg Field

- Wattenberg field, D-J basin
- Codell formation
  - ✓ Thin sandstone layer
  - ✓ Low permeability, requires stimulation
- Refractured since 1998
  - ✓ Observations indicate that refracture performance is dictated by fracture-fluid viscosity profile  
(Ref: Miller, J. et al., 2004, SPE 90194)
  - ✓ Fracture reorientation has been reported (Ref: Wolhart, S. et al., 2007, SPE 110034)

