Welcome!

The program will begin soon.

You will not hear audio until we begin.

Differentiating fracture bypass from intersection using active offset acoustics and pressure

Seismos presenter: Dan Moos

July 7, 21

Webinars

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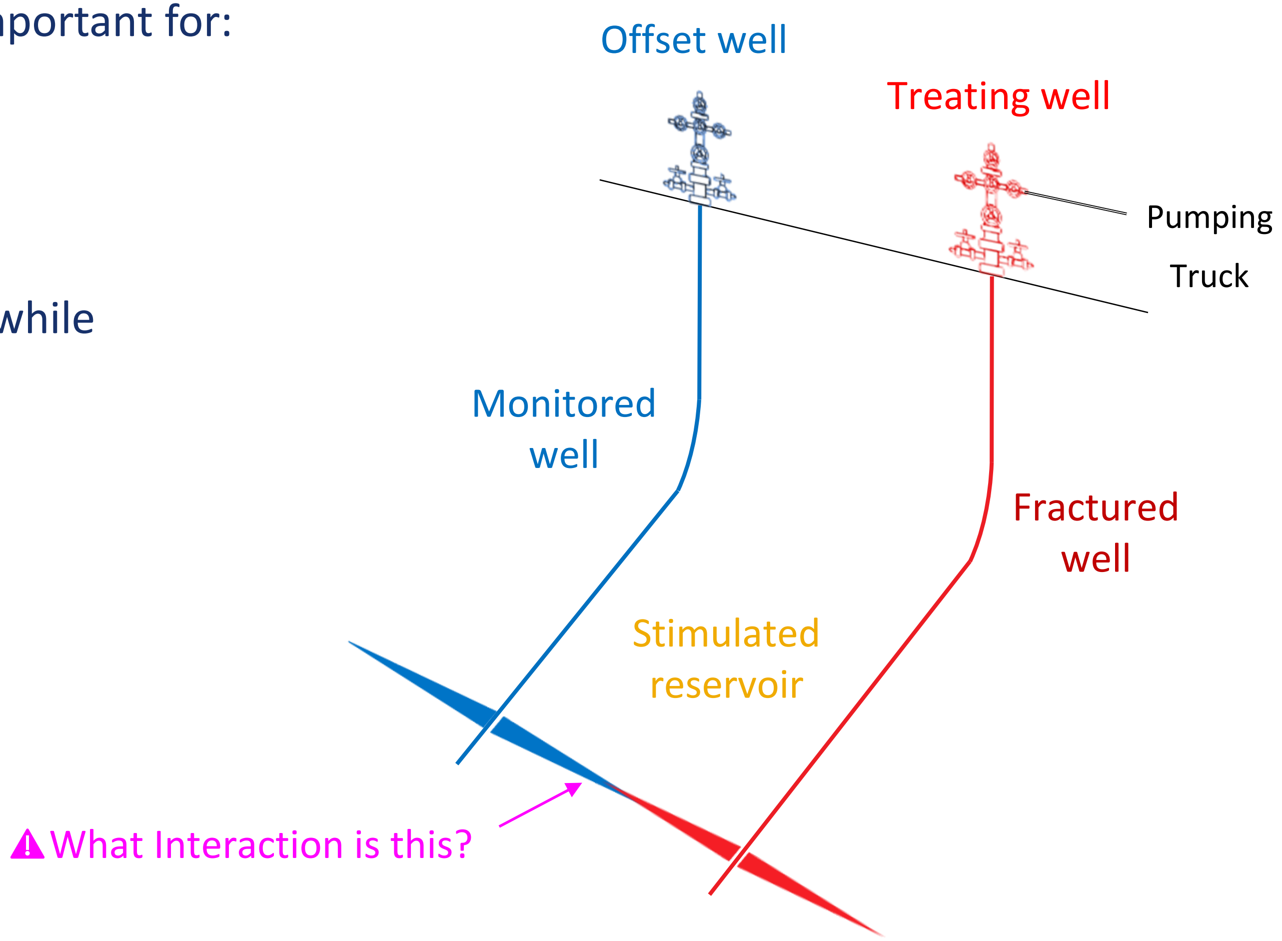
Why monitor for fracture interference?

- Understanding connectivity between wells is important for:
  - Treatment optimization
  - Parent-child interactions
  - Infill well drilling
- This requires monitoring "passive" offset wells while pumping



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Why monitor for fracture interference?

- A new approach is introduced combining:
    1. Offset acoustics: active pulsing (NFCI)
    2. Offset pressure: measured at surface
- The approach has been tested in a number of plays
- Fracture interference examples will be shown from the Haynesville and Eagle Ford

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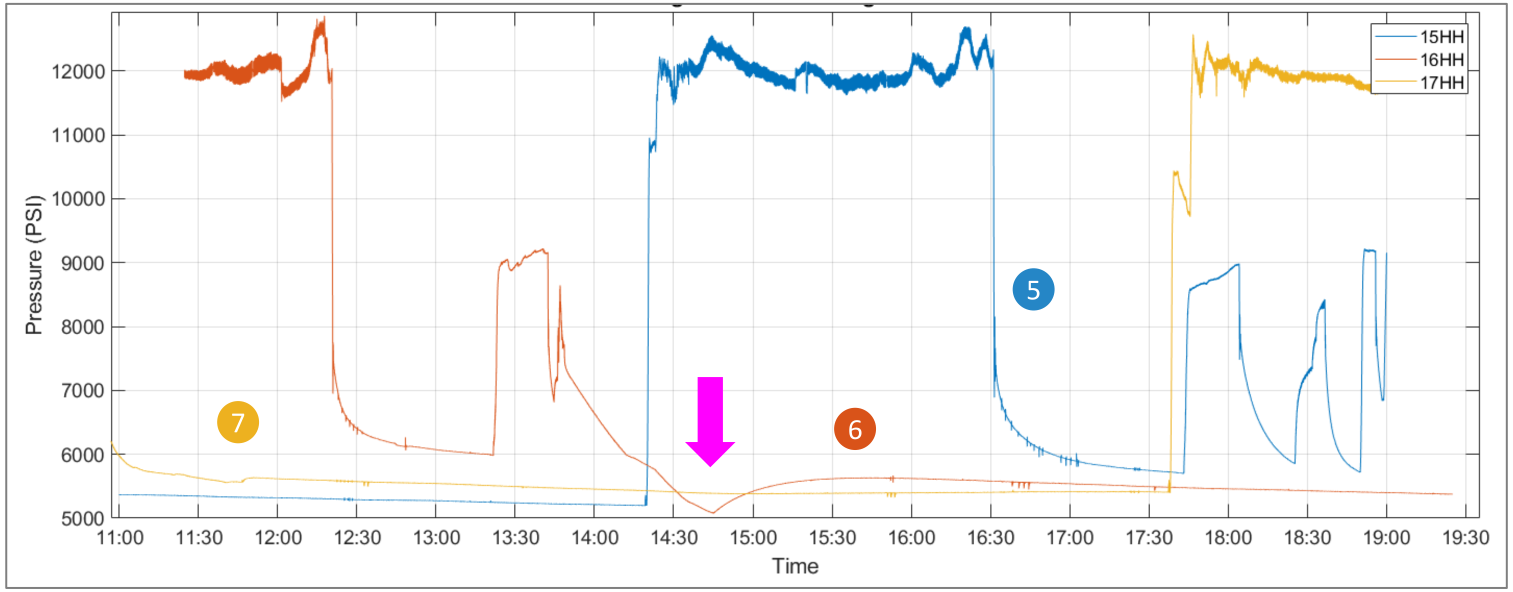
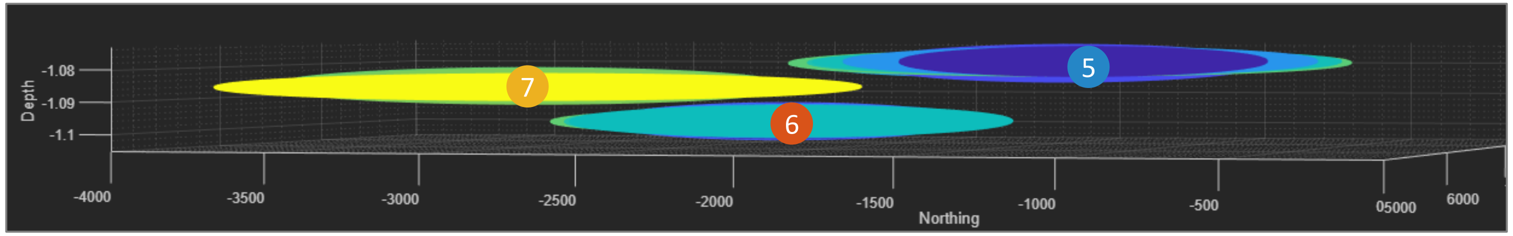
Interference example - Haynesville





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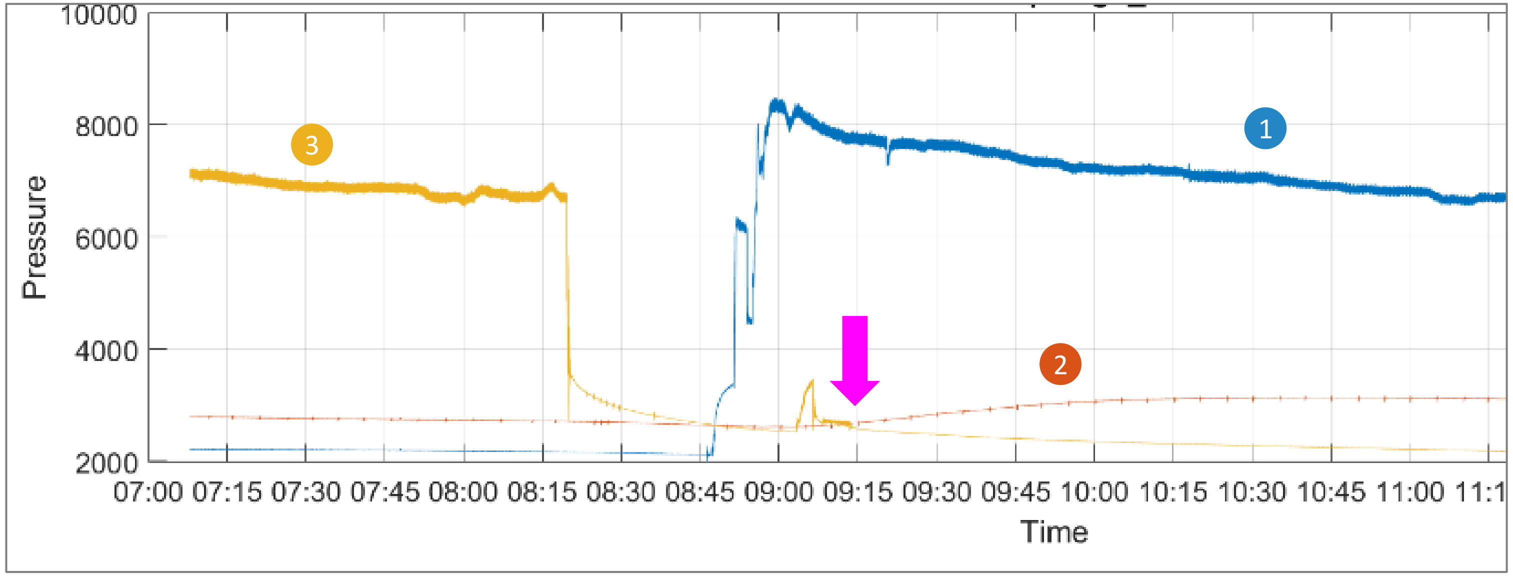
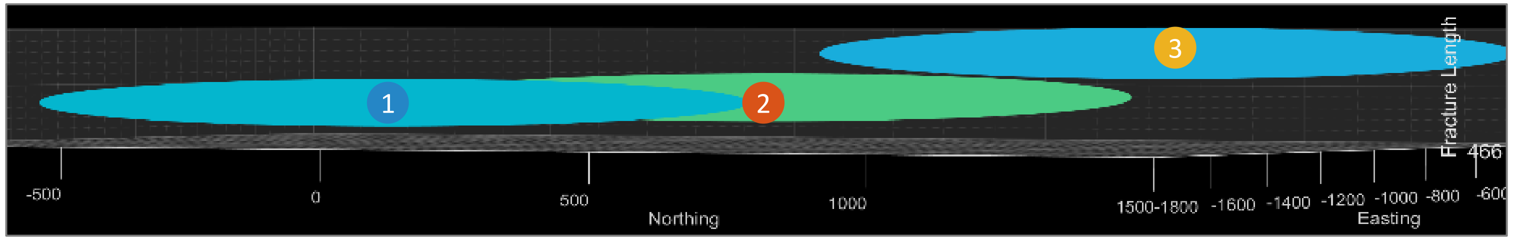
Interference example – Eagle Ford





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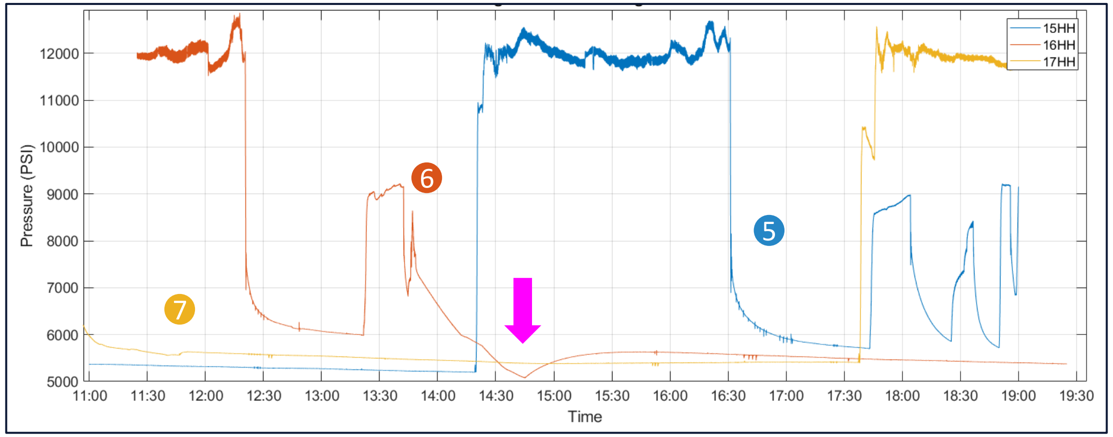
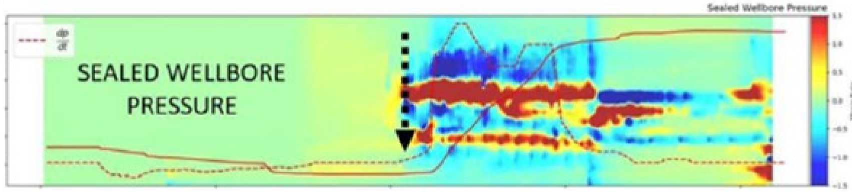
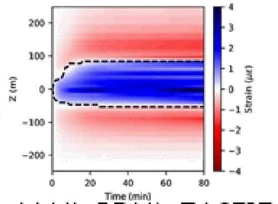
Existing methods: Offset pressure/strain (fiber, sealed wellbore)

- Interference can be detected using
  - Pressure
  - Temperature
  - Strain
  - Tilt
- Above methods often struggle to explain where and how interference occurred
  - Direct connection?
  - Stress shadow?
  - Poro-elastic effects?
  - At what depth?







Fiber

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Pressure and strain alone do not give the full picture

- To differentiate stress shadow from a direct hydraulic connection requires two measurements:
  1. Surface pressure
     - Pressure can increase through a direct hydraulic connection
     - Pressure can increase if stress shadow exerts compression on a closed wellbore / fracture system
  2. Downhole strain
     - Compressive strain can occur through a reduction in fracture pressure
     - Compressive strain can occur through an increase in compressive stress (stress shadow)

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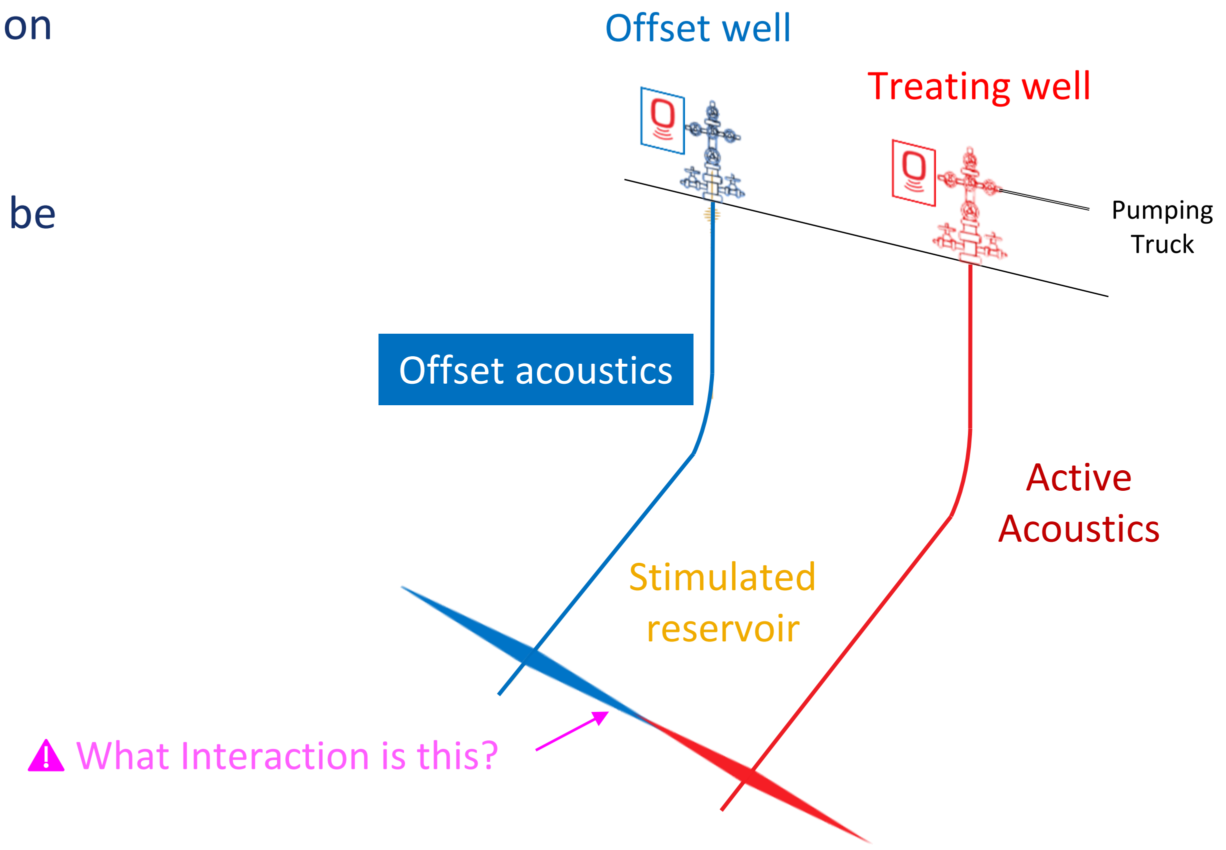
OFFSET ACOUSTICS

Introducing offset acoustics

- Offset Acoustics provide a comprehensive solution through the direct measurement of Near-field Conductivity (NFCI)
  - NFCI is a function of fracture width and can be measured at surface using acoustics
  - The position in the well of the interference object can also be determined
- Seismos-OFFSET™ monitors simultaneously:
  - Offset NFCI (near field conductivity)
  - Offset pressure



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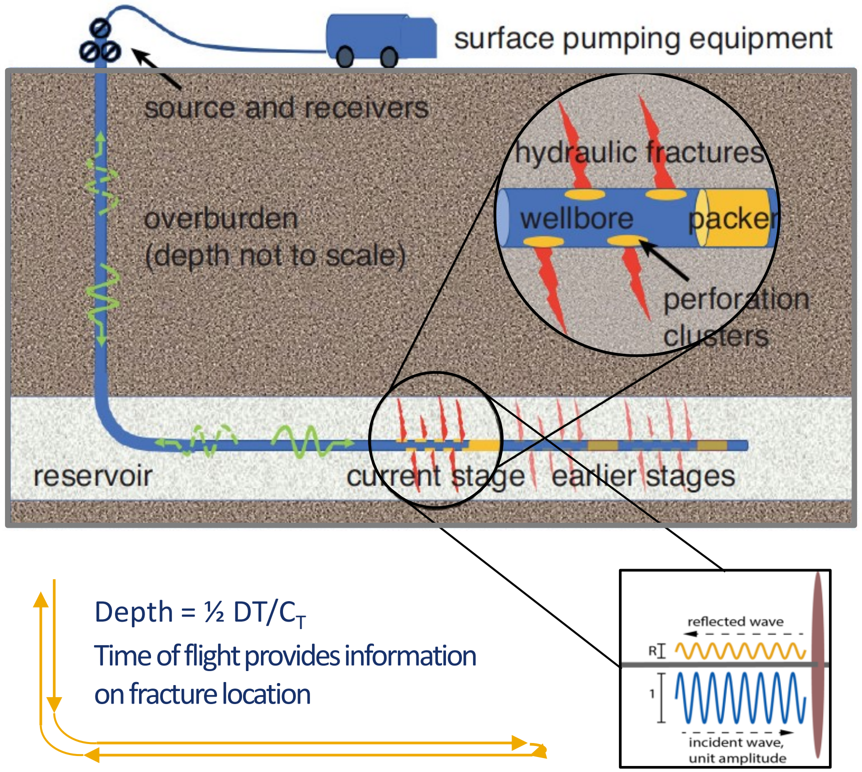
Acoustics measures hydraulic impedance and position



Quantify response in terms of fracture hydraulic impedance:

$$R(\omega) = [Z_f(\omega) - Z_T] \,/\, [Z_f(\omega) + Z_T]$$

$Z_f(\omega)$ = fracture hydraulic impedance

$Z_T = \rho c_T/S$ = tube wave hydraulic impedance

$$Z(\omega) \approx -\frac{\mu}{2\pi k w} \ln\left(\sqrt{\frac{-i\omega}{D}} R\right)$$

Dunham et al., 2017

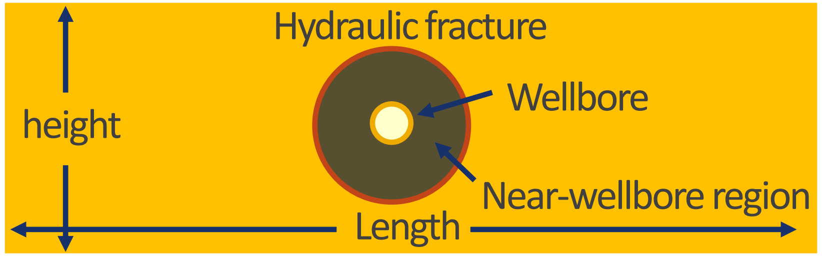
Direct calculation of fracture conductivity (width)

Hydraulic impedance is a function of fracture conductivity (width)

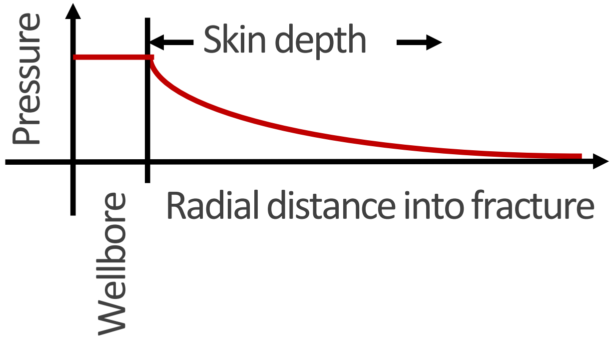
$$Z = \frac{\text{pressure perturbation at fracture mouth}}{\text{volumetric flow rate into/out of fracture}}$$

$$Z(\omega) \approx -\frac{\mu}{2\pi k w} \ln\left(\sqrt{\frac{-i\omega}{D}}R\right) \qquad D = \frac{k}{\mu\beta}$$

ω = angular frequency, μ = fluid viscosity, w = width (aperture), k = permeability,
R = wellbore radius, β = (sum of fluid compressibility and pore compressibility) times porosity



side view, along wellbore axis



Dunham et al., 2017

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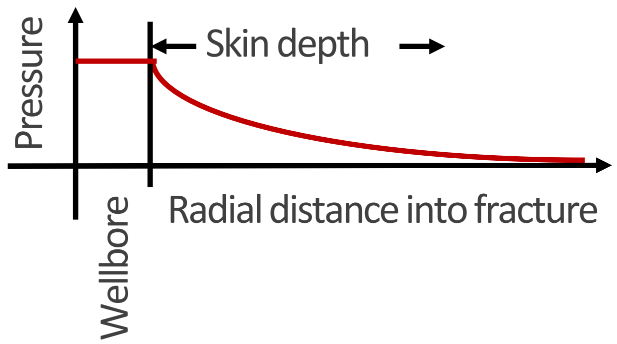
Near Field Conductivity Index (NFCI)

We "quantify" variations in fracture hydraulic impedance using the Near Field Conductivity Index (NFCI)

- Conductivity index because it combines the conductivities of all connected fractures within the current stage
- Near-field because of diffusion length constraints

$$Z(\omega) \approx -\frac{\mu}{2\pi k w} \ln\left(\sqrt{\frac{-i\omega}{D}}R\right) \qquad D = \frac{k}{\mu\beta}$$



ω = angular frequency, μ = fluid viscosity, w = width (aperture), k = permeability,
R = wellbore radius, β = (sum of fluid compressibility and pore compressibility) times porosity

Dunham et al., 2017

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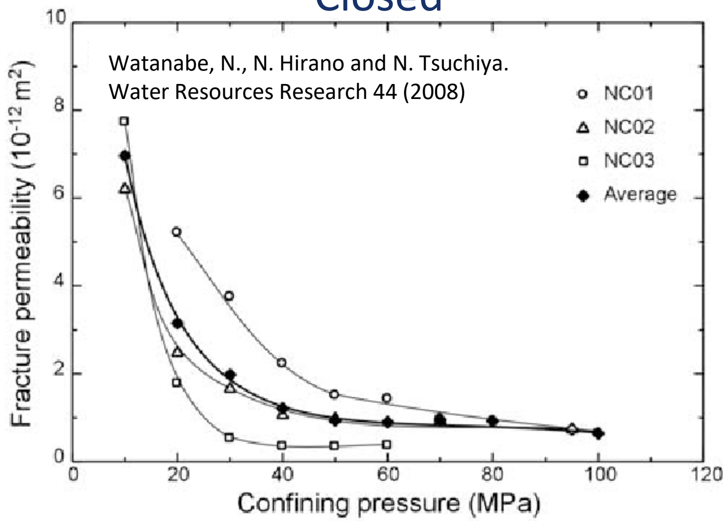
Hydraulic conductivity influenced by stress and pressure

Webinars

Closed



conductivity is a function of
$\sigma_n = S_n - P_{frac}$

Fracture hydraulic conductivity (NFCI)

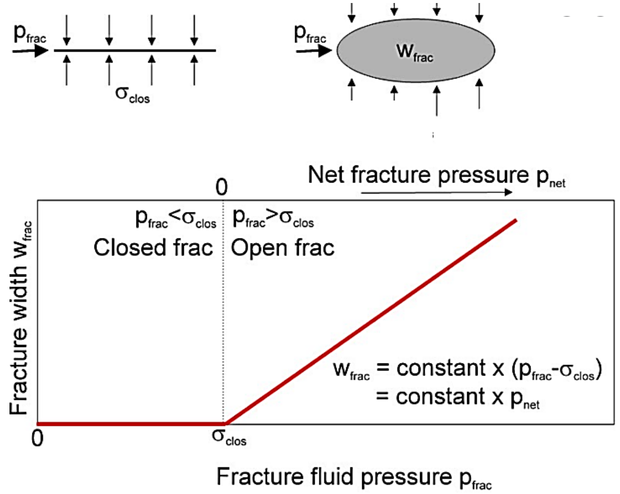
↓

Fracture Width

Decreases → Stress increase

Increases → Pressure increase

Closed Open



https://www.linkedin.com/pulse/brief-history-frac-model-calibration-cycle-i-fracture-leen-weijers

conductivity is a function of
$P_{net} = P_{frac} - S_n$

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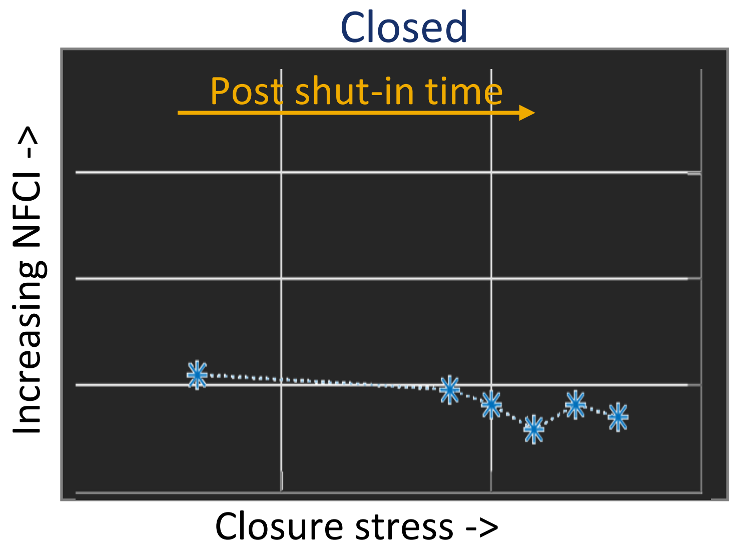
Examples of post shut-in fracture closure



conductivity is a function of
$s_n = S_n - P_{frac}$

Fracture hydraulic conductivity (NFCI)

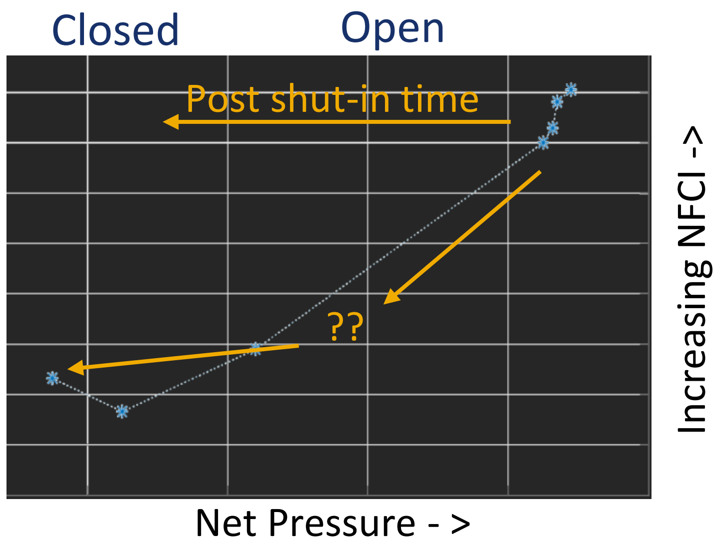
Fracture Width

Decreases

Increases

Stress increase

Pressure increase



conductivity is a function of
$P_{net} = P_{frac} - S_n$

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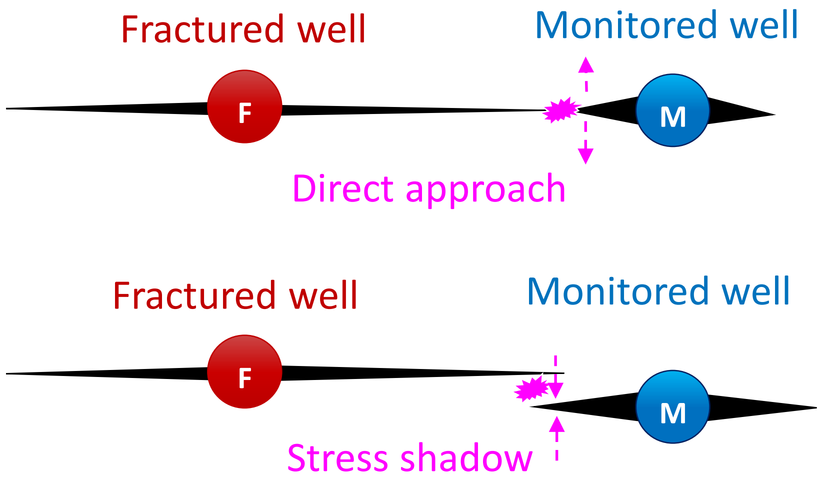
Offset acoustics: Combining NFCI and pressure

1. Hydraulic connection
   - ⬆ Offset NFCI
   - ⬆ Offset pressure

2. Fracture directly approaching an existing offset fracture (offset fracture dilates)
   - ⬆ Offset NFCI
   - ⬇ Offset pressure

3. Fracture bypassing an existing offset fracture (offset fracture closes due to stress shadow)
   - ⬇ Offset NFCI
   - ⬆ Offset pressure

NFCI differentiates between hydraulic connections, direct approaches, fracture bypasses



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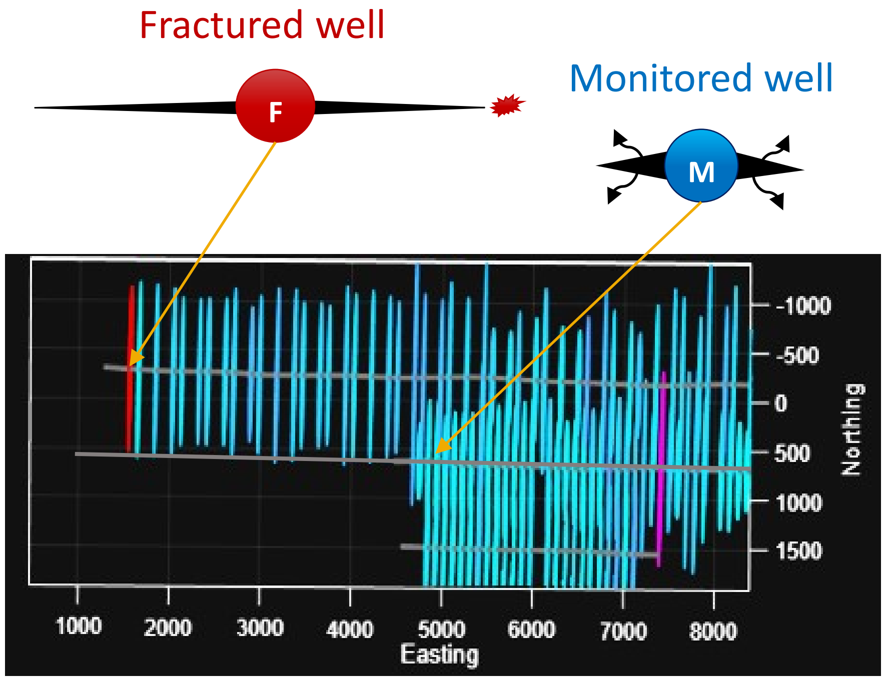
EXAMPLE 1: NO INTERACTION (HAYNESVILLE)

Normal fracture closure – Haynesville

- The fracture being pumped is significantly distant from the fracture being observed
- Minimal interference is expected – the pumped well is significantly ahead of the other wells

Expected closure signature



The red stage is being pumped.

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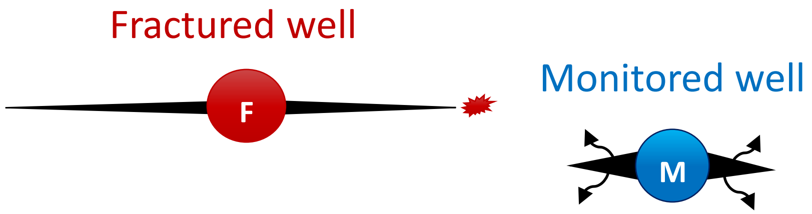
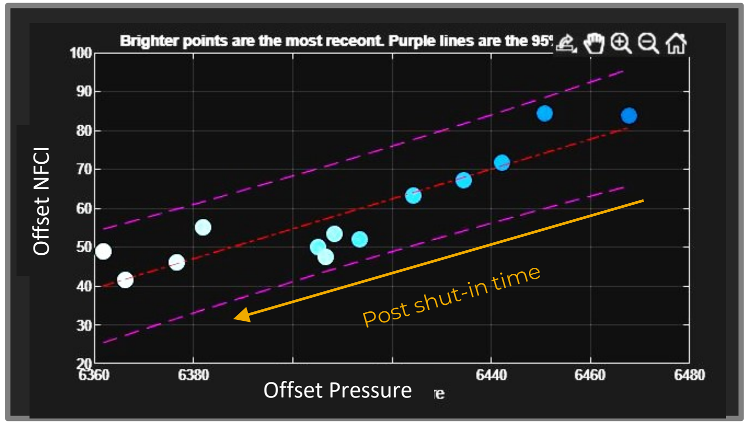
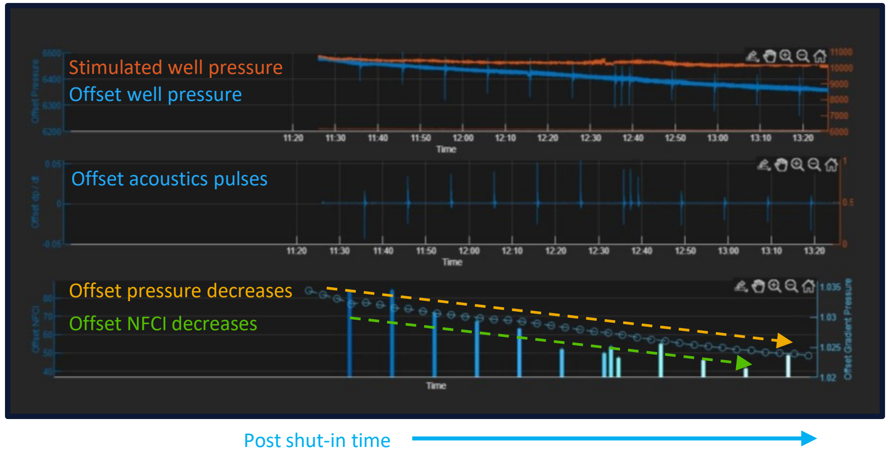
Normal fracture closure – Haynesville

- Normal pressure decline continues while the adjacent fracture is pumped
- NFCI decreases with pressure as the fracture closes

Expected closure signature







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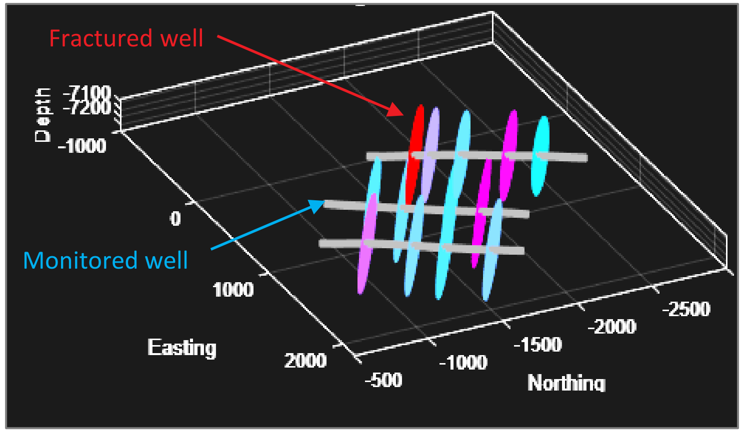
EXAMPLE 2 – DIRECT HYDRAULIC CONNECTION (EAGLE FORD)

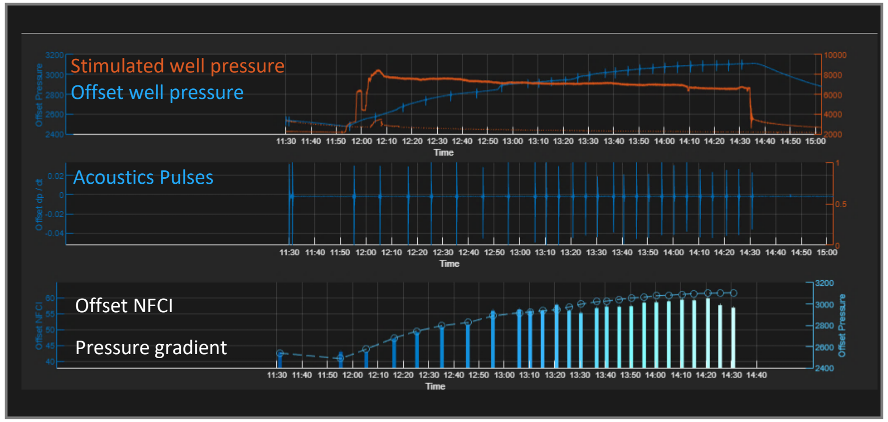
Direct hydraulic connection – Eagle Ford

- An induced fracture directly connecting to an offset well's existing fracture, causing a pressure increase and dilation.
- This connection was made when pumping a previous stage in the offset well

Hydraulic connection



The red stage is now being pumped.



Post shut-in time

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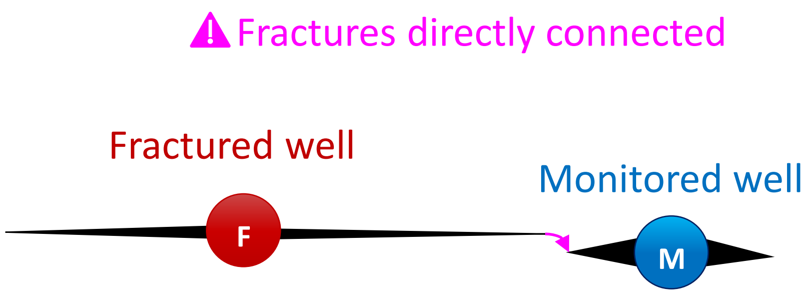
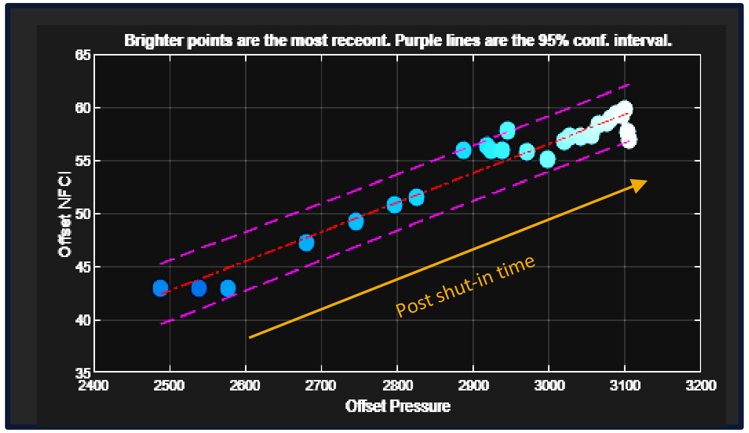
Direct hydraulic connection – Eagle Ford

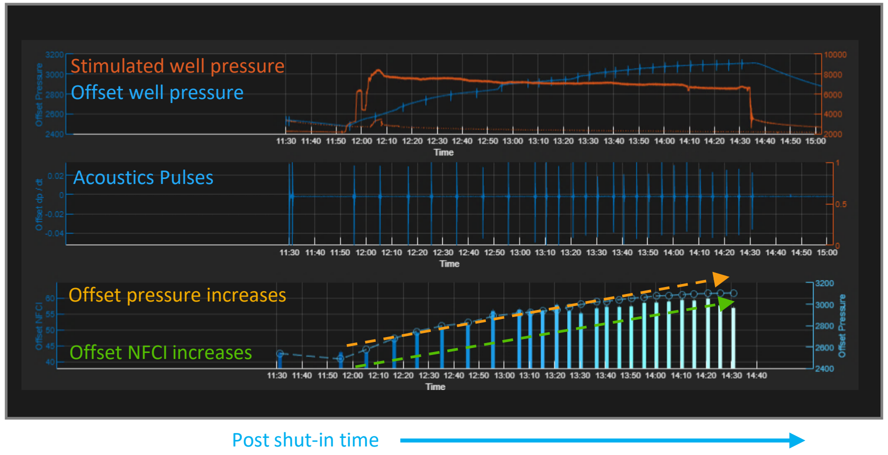
- Normal decay -> NFCI constant
- Offset stimulation starts -> pressure & NFCI rises
- Direct pressure connection dilates the offset well fracture



Offset NFCI

Offset pressure





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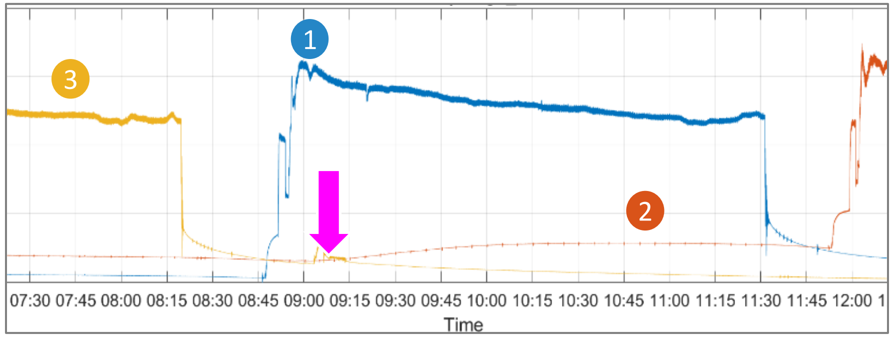
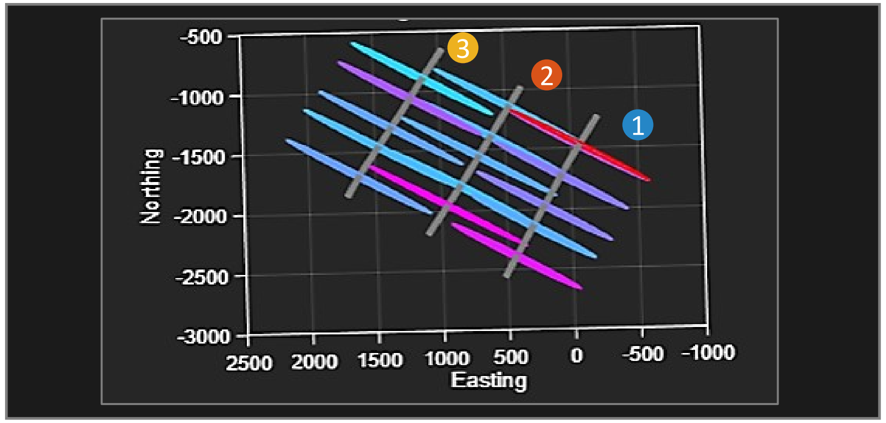
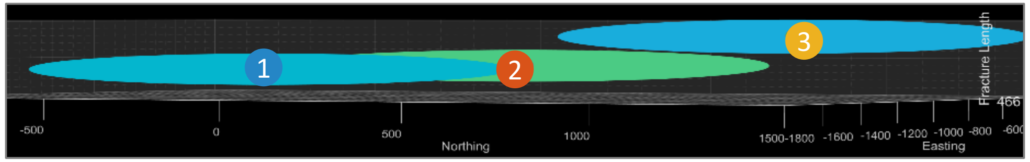
EXAMPLE 3 –FRACTURE BYPASS
(EAGLE FORD)

Fracture bypass – Eagle Ford

- Normal pressure decay is interrupted during pumping Stage 49 in Well 1
- Well 2 pressure rises
- Stages are adjacent to each other
- Estimated lengths of the fractures overlap







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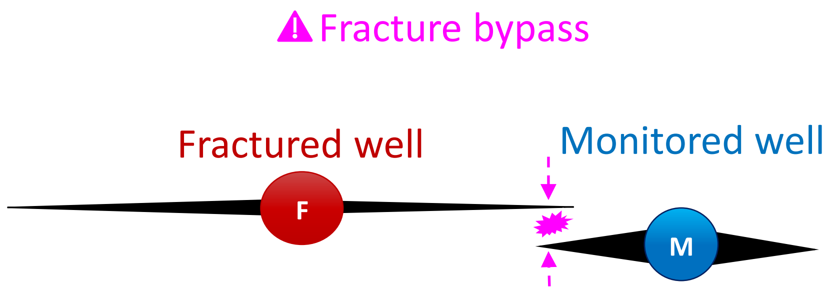
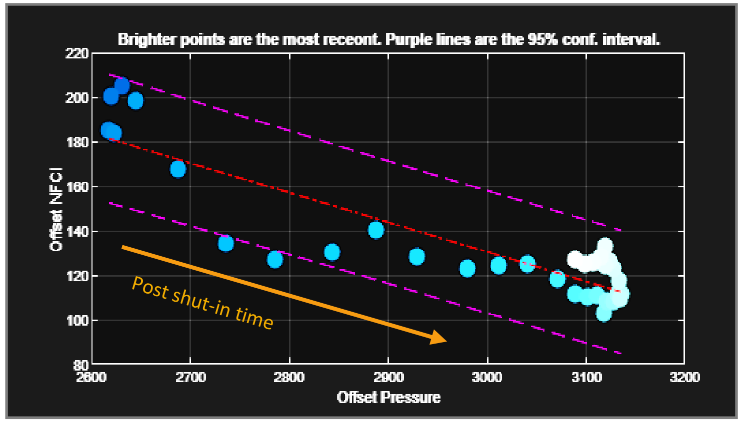
Fracture bypass – Eagle Ford

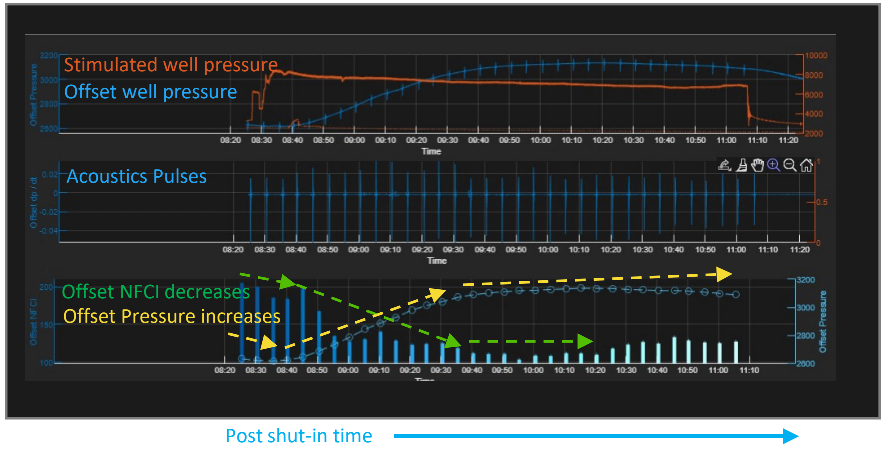
- The induced fracture passing the offset well's existing fracture causes it to close
- Closure causes pressure to increase because the well is shut in
- NFCI decreases even though pressure rises



Offset NFCI

Offset pressure





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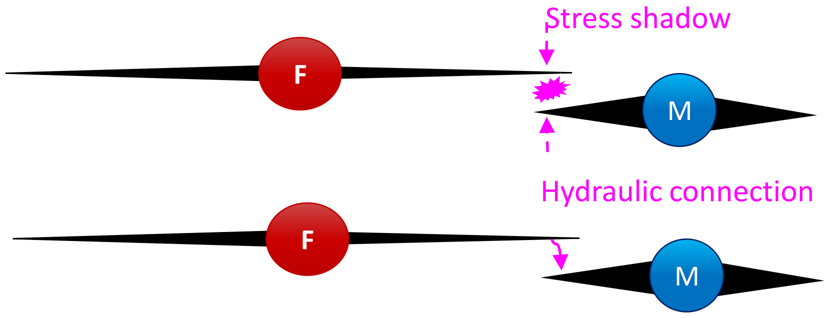
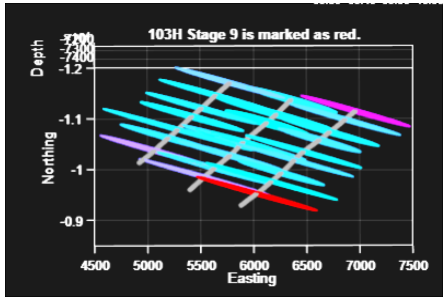
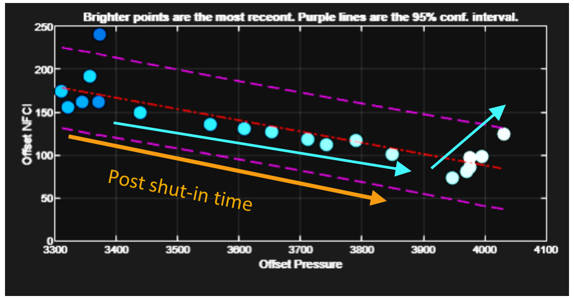
EXAMPLE 4 –FRACTURE BYPASS, THEN CONNECTION (EAGLE FORD)

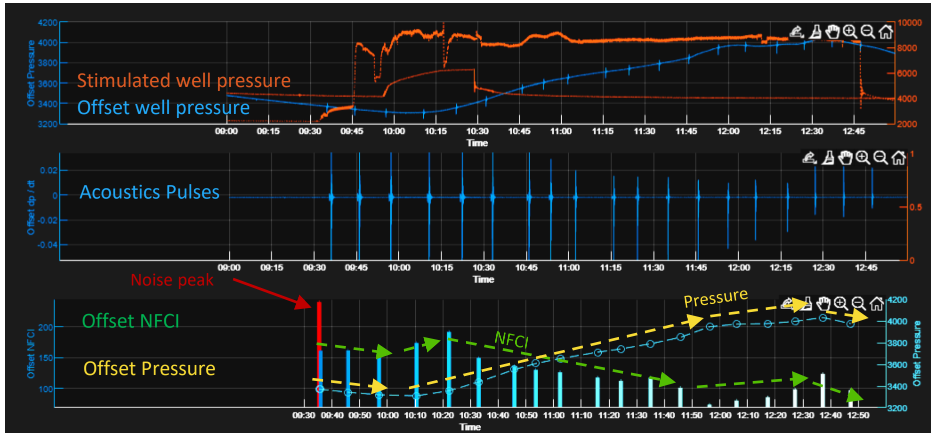
Fracture bypass; then connection – Eagle Ford

- An induced fracture passing the offset well's existing fracture causes it to close. Pressure goes up a bit because well is shut in, but stress shadow is larger so net pressure inside the fracture drops, decreasing NFCI
- Once a connection is made, NFCI rises, then falls on shut-in









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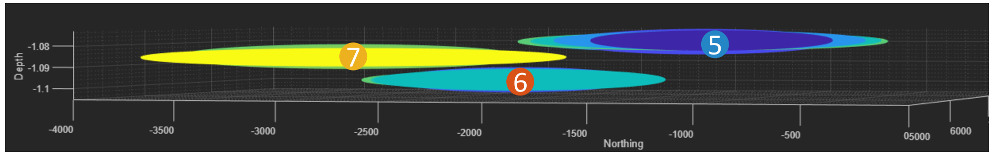
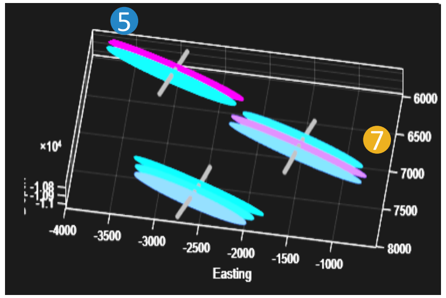
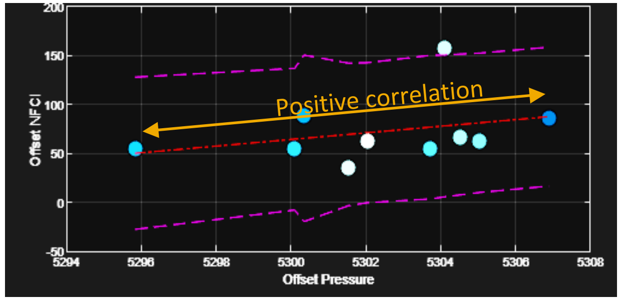
EXAMPLE 5 –DIFFUSIVE HYDRAULIC CONNECTION (HAYNESVILLE)

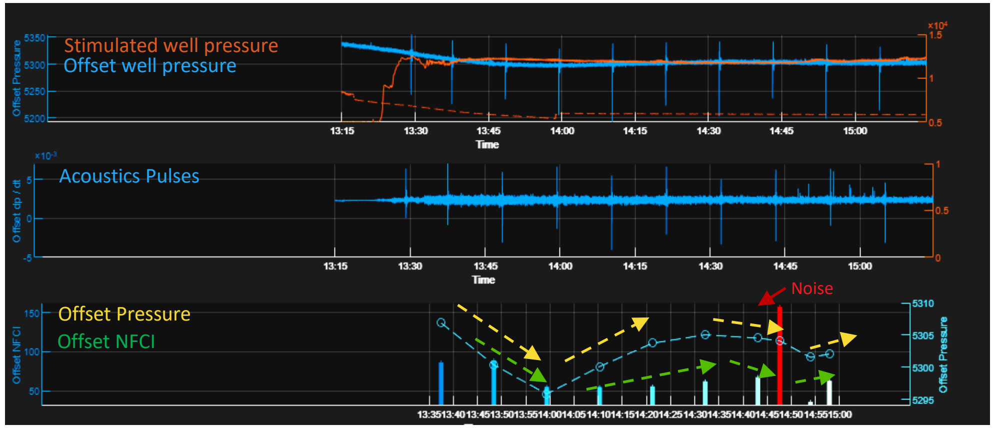
Diffusive hydraulic connection - Haynesville

- Pressure decline is interrupted
- Fracture stops closing
- NFCI correlates with pressure









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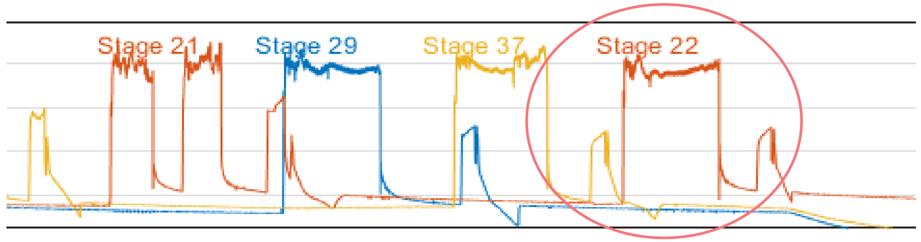
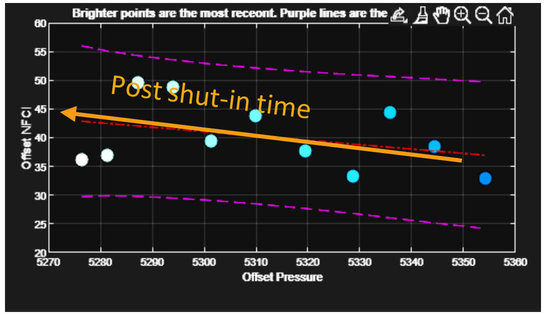
EXAMPLE 6 –POTENTIAL TIP TO TIP INTERACTION (HAYNESVILLE)

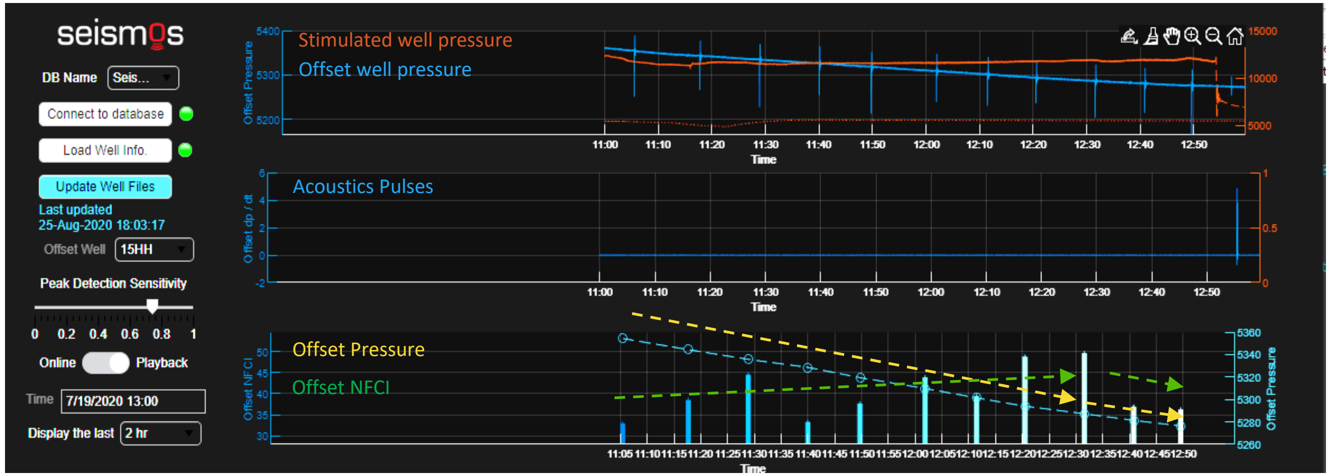
Potential tip to tip interaction - Haynesville

- Pressure decline continues
- Fracture begins to re-open
- NFCI and Pressure are inversely related



Offset NFCI
Offset pressure





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Summary

- Combining pressure and acoustics allows to differentiate between hydraulic and indirect stress interactions of adjacent fractures
  - Positive correlations between NFCI and pressure indicate a primarily hydraulic connection
  - Negative correlations between NFCI and pressure indicate a primarily stress effect
- Current stages can be affected by connections established during previous stages
- In all of the pads we looked at, pressure connections and stress shadow effects were observed in multiple stages
- Multiple behaviors can occur in a single stage
  - Stress shadow effects could be followed by direct connections
  - Once a pressure connection was established, it persisted
- By using this approach it is possible in near real time to detect interference and in many cases, to establish the cause

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Q&A

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