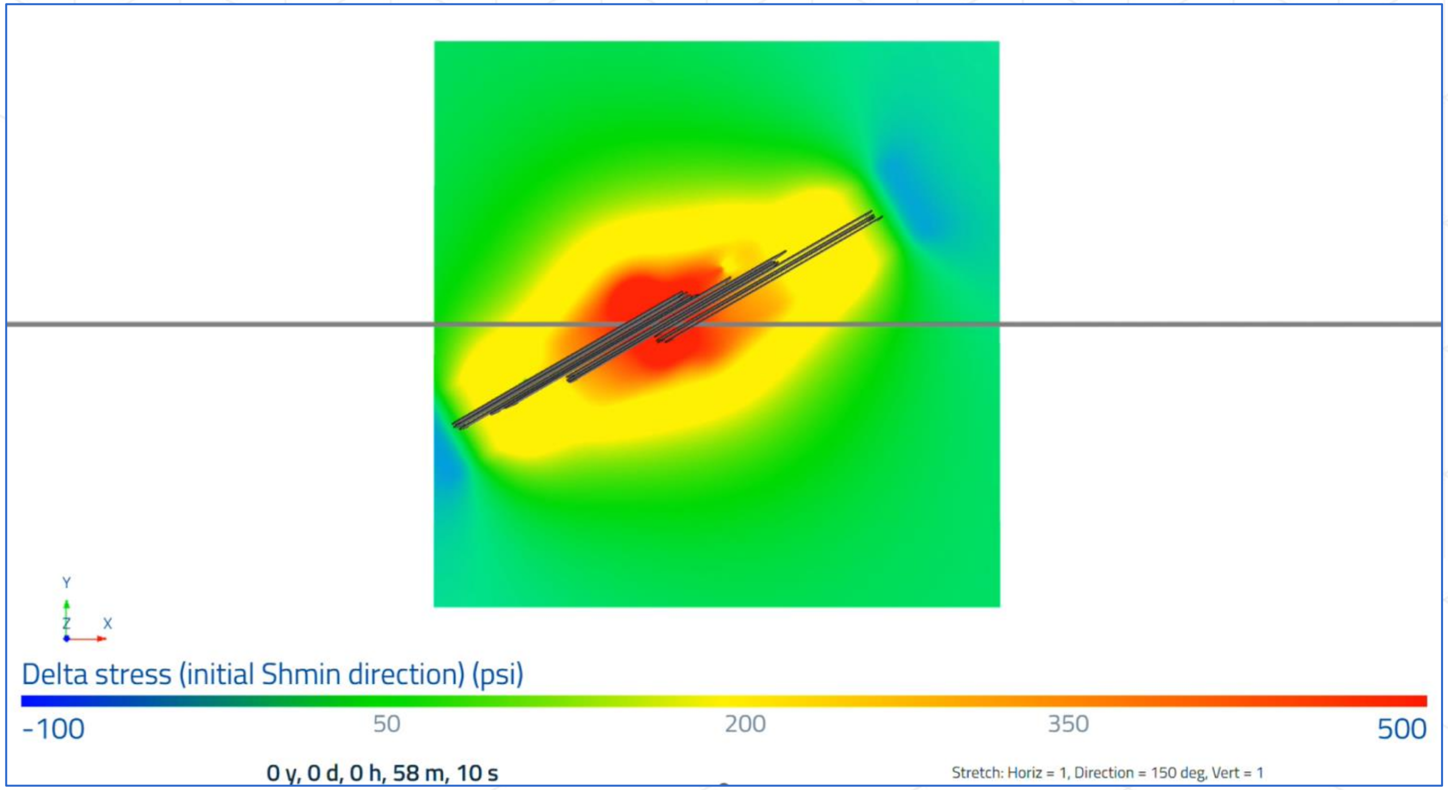
ResFrac



Discussion Topic:

Fracture Asymmetry and Well Orientation

Background

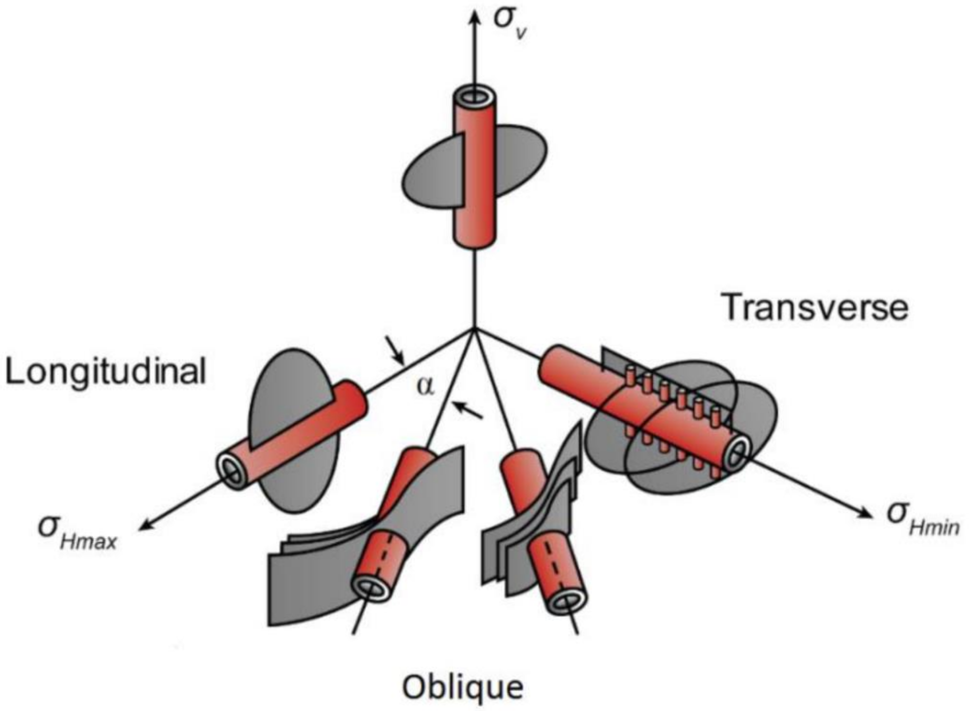
Mode I (opening mode tensile fractures) always form normal to the minimum principal stress; in most unconventional basins, this is a horizontal stress with a given azimuth (Shmin). As such, multi-fractured horizontal wells (MFHW) are most optimal when drilled parallel to Shmin (orthogonal to SHmax). This configuration provides the greatest opportunity for maximizing fracture surface area and stimulated rock volume.

However, this is not always possible. Acreage constraints or unit configurations may be such that wells are drilled to maximize the number of wells instead of the ideal orientation with respect to subsurface stresses. Or, the precise orientation of SHmax/Shmin may not be known.

Between the endmember states of fully transverse or fully longitudinal fractures, the sensitivity to well orientation vs Shmin azimuth depends on a wide variety of parameters including job size, cluster spacing, well spacing, and stage length.

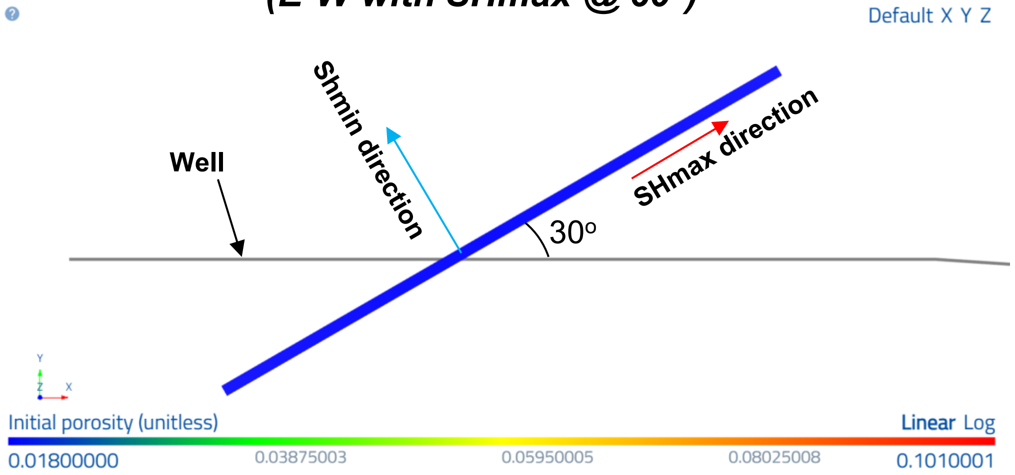
One of the more interesting consequences of not drilling MFHWs parallel to Shmin is the creation of asymmetric fractures from heel to toe of a stage. This effect, clearly observed in fracture models that include stress-shadowing capabilities, has large implications on drainage patterns and thus optimal well spacing and cluster spacing designs.

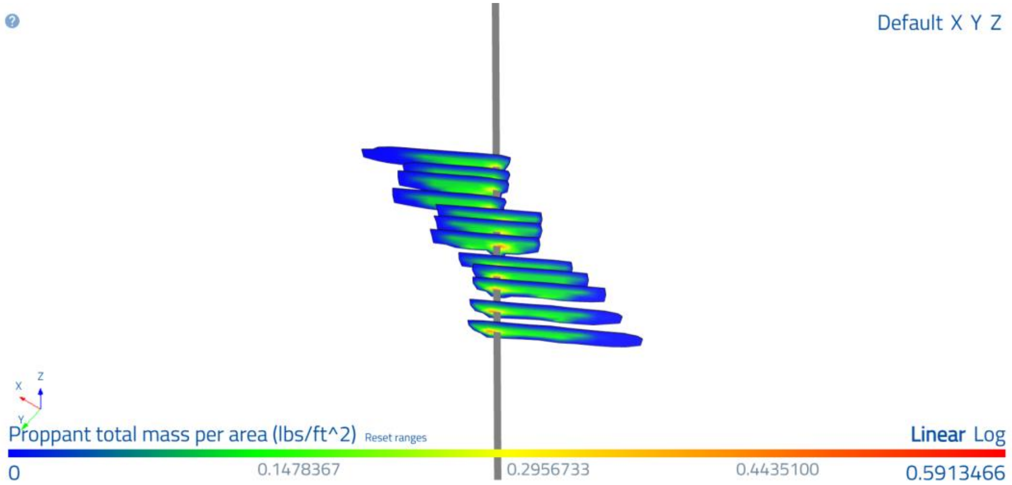
The examples in this presentation are based on the Bakken template in ResFrac.



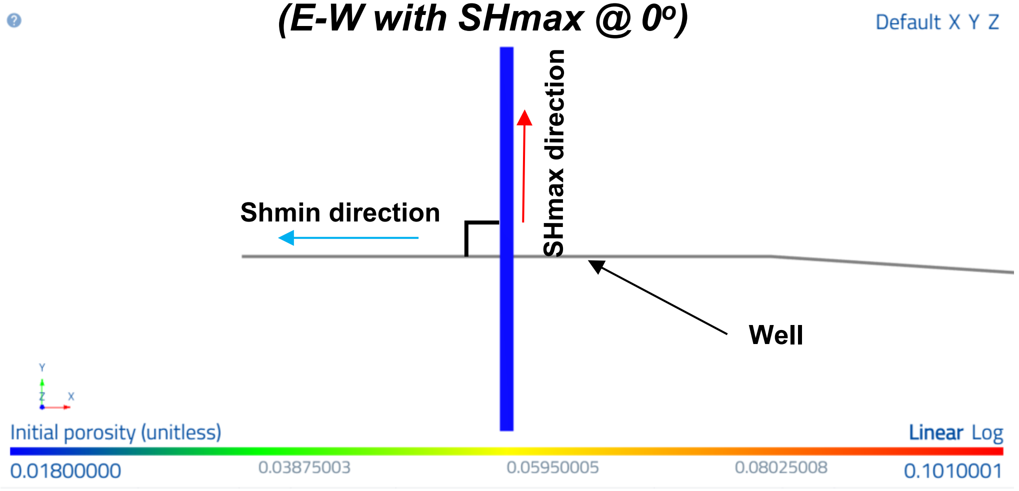
Geometry Overview

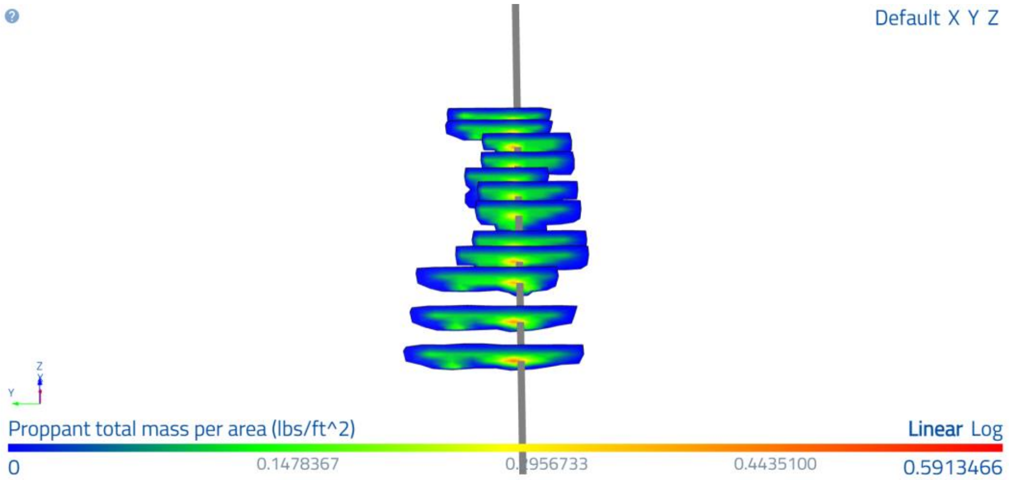
Well oriented off-azimuth (E-W with SHmax @ 60º)





Well oriented on-azimuth (E-W with SHmax @ 0º)





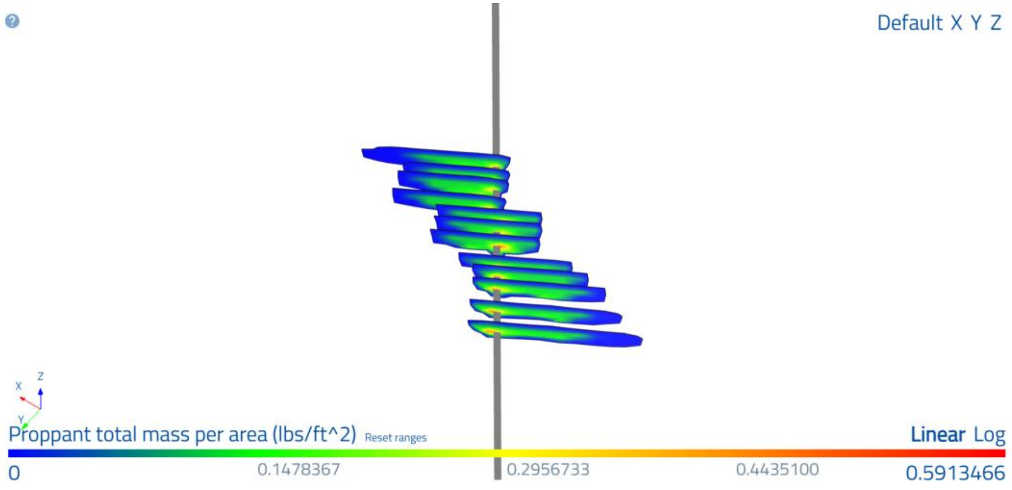
ResFrac

Note: In the bottom images, the view has been stretched 15x in the direction of Shmin and viewed looking from toe to heel.

Geometry Overview

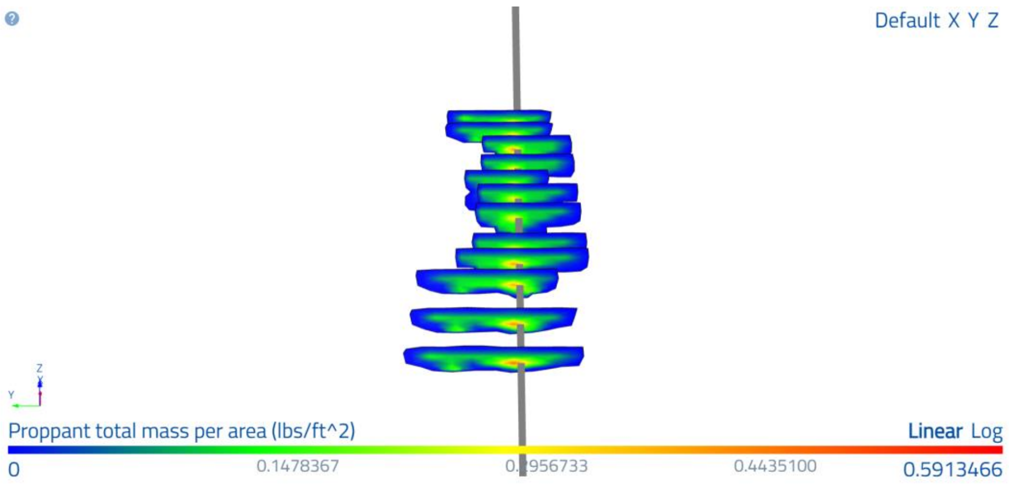
Well oriented off-azimuth
(E-W with SHmax @ 60º)

- Build-up of stress shadow between individual clusters results in asymmetry in fracture propagation and a trend from heel to toe of the stage.
- Fracture length is marginally increased as propagation is only in one direction or the other.



Well oriented on-azimuth
(E-W with SHmax @ 0º)

- Fracture are relatively symmetric across the wellbore with relatively equal length on either side.
- There is still some heterogeneity in fracture geometry as stress shadowing encourages fractures to avoid one-another.
- Fracture length is marginally decreased.

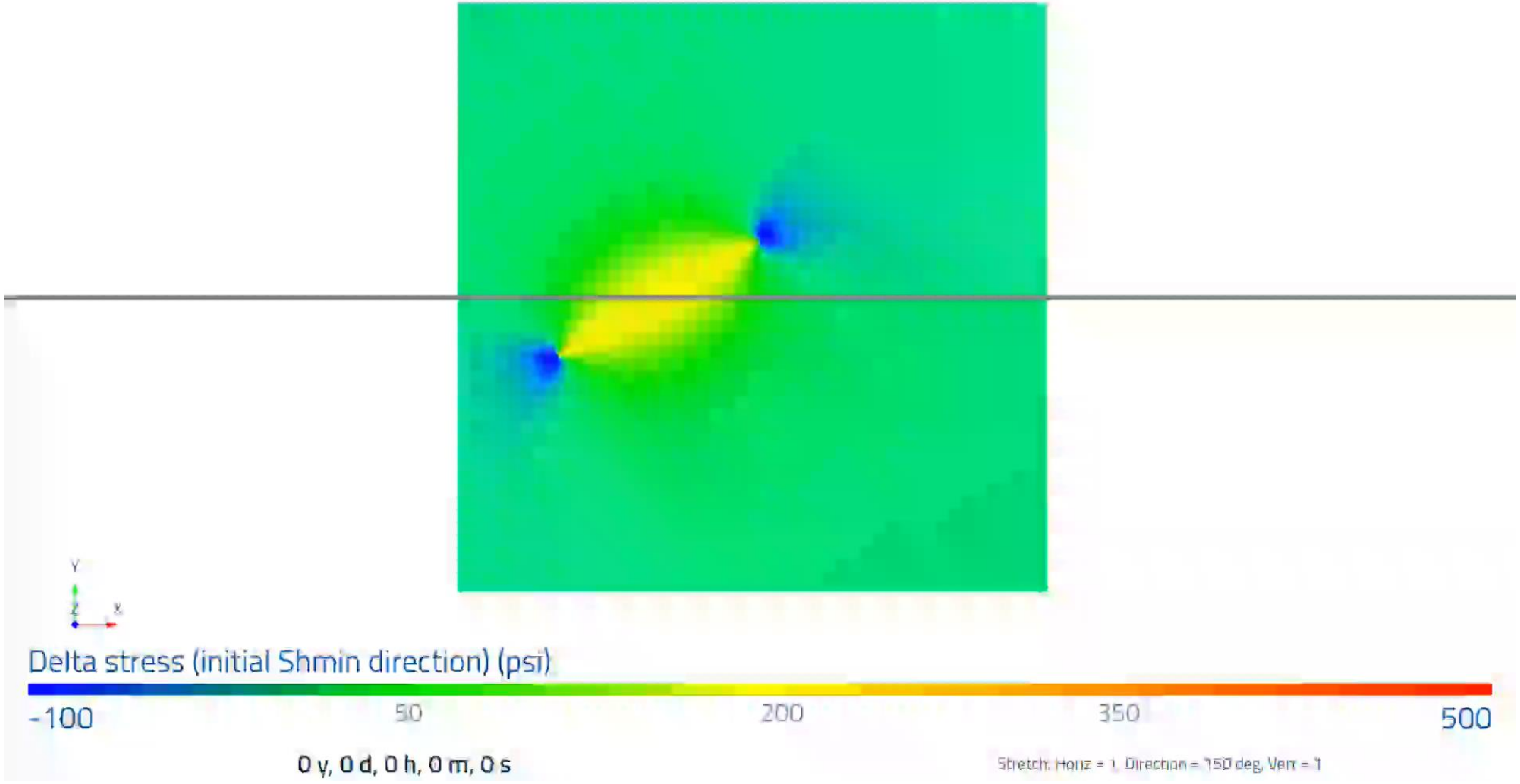


ResFrac

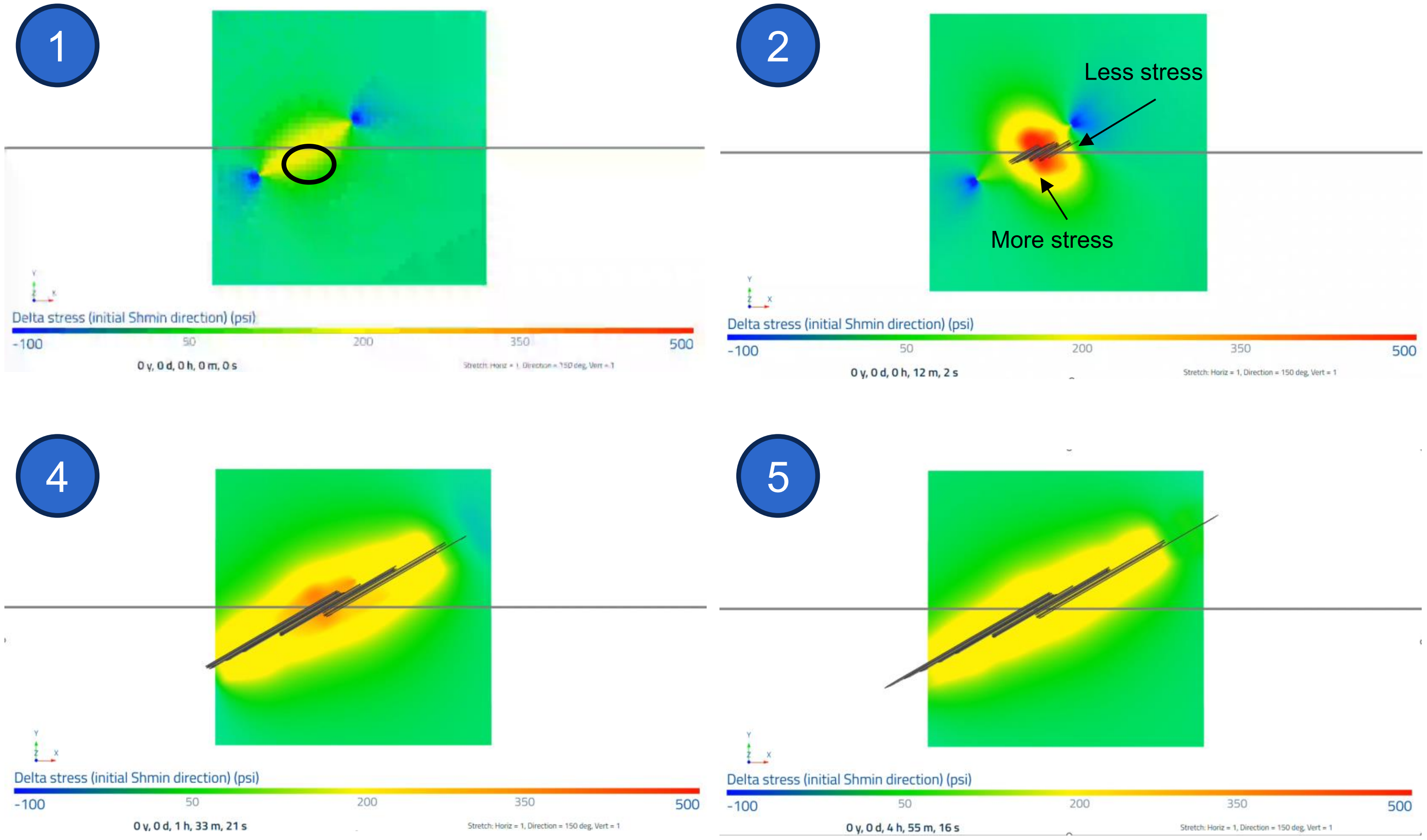
Note: In the bottom images, the view has been stretched 15x in the direction of Shmin and viewed looking from toe to heel.

Well oriented off-azimuth (E-W with SHmax @ 60°)

- This is a video of fracture propagation in map view. The stress observation plane shows the local change in Shmin due to stress shadowing – stress changes due to the mechanical opening of fractures.
- Blue is tension and red is compression.



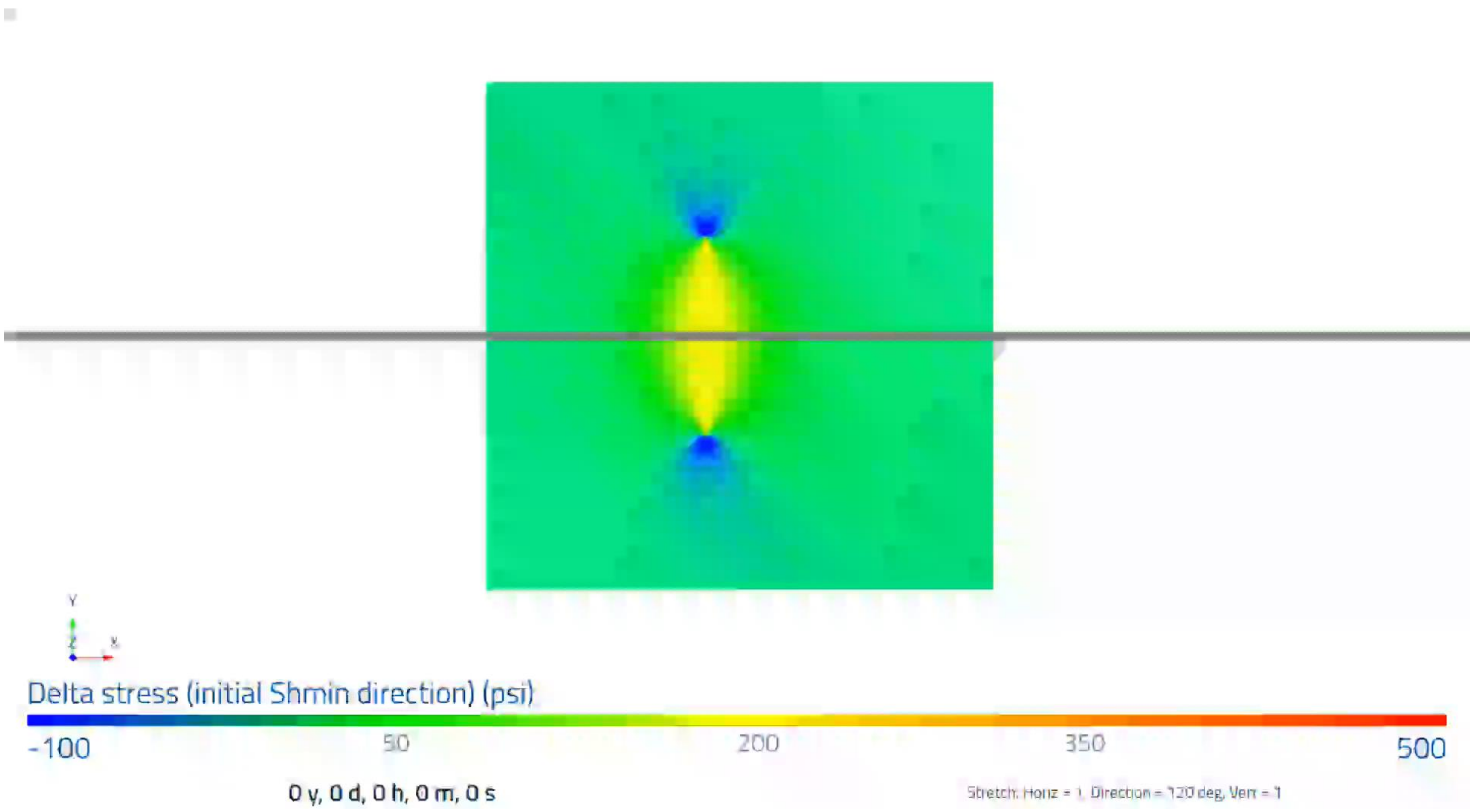
Well oriented off-azimuth (E-W with SHmax @ 60^{o})



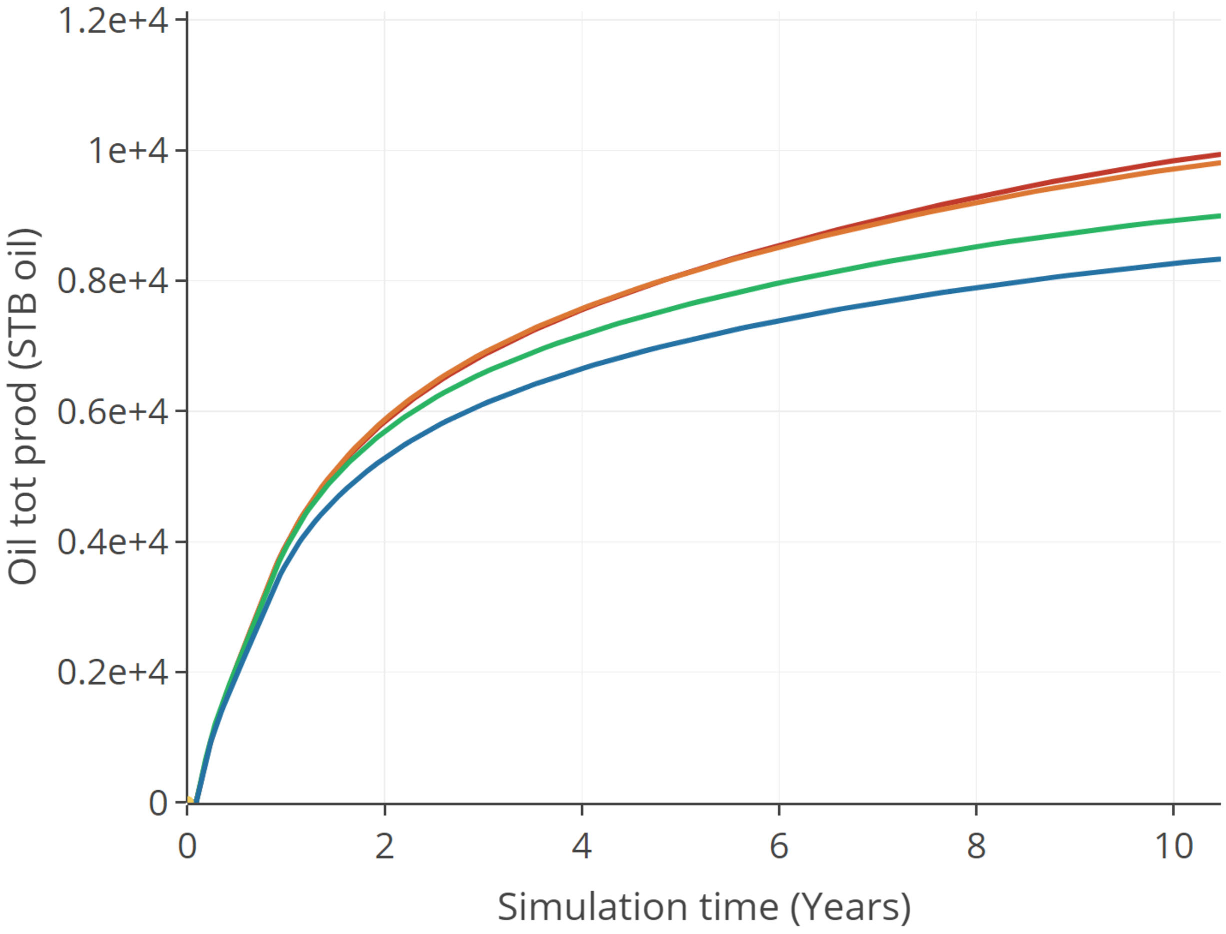
1. Stress shadow due to external fracture prior to the stimulation of the stage. Note how increased compression is focused on one side of the well.
2. Early into the stage. Note how the asymmetry in the stress shadow encourages the heel of the stage (left) to propagate south while the toe of the stage (right) propagates to the north.
3. Late in the stage. Stress shadow increases as the fractures grow.
4. Shortly after shut-in.
5. Several hours after shut-in. Leakoff reduces fracture aperture and fractures begin to close; stress shadow decreases.

Well oriented on-azimuth (E-W with SHmax @ 0°)

- In contrast to the off-azimuth case, the developing stress shadow is more symmetric around the wellbore.



Production Impact



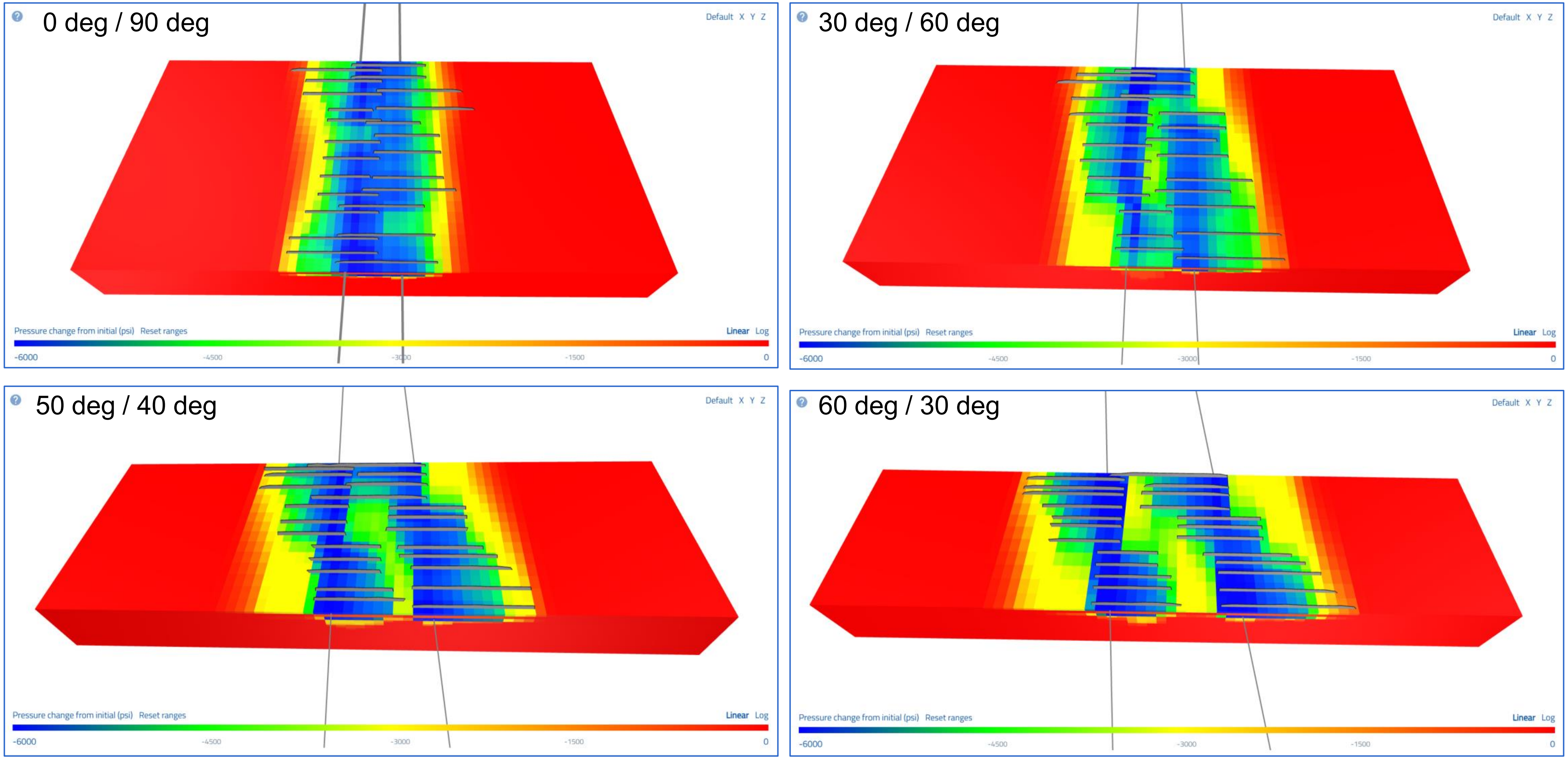
Direction of SHmax	Angle between well and SHmax	Relative oil production @ 10yr
0 deg	90 deg	1.00
30 deg	60 deg	0.97
50 deg	40 deg	0.91
60 deg	30 deg	0.84

- A comparison of several cases with different directions of SHmax shows the production degradation due to this orientation effect.
- Note that all cases have the same stage length, cluster spacing, fluid loading, and proppant loading.

- The next slide shows a comparison of the depletion patterns in a slice in the Middle Bakken after 10 years of production. The fracture asymmetry in the off-azimuth cases creates gaps in the depletion between the wells resulting in reduced recoveries.

Depletion Patterns at 10 years

Direction of SHmax / Angle between well and SHmax



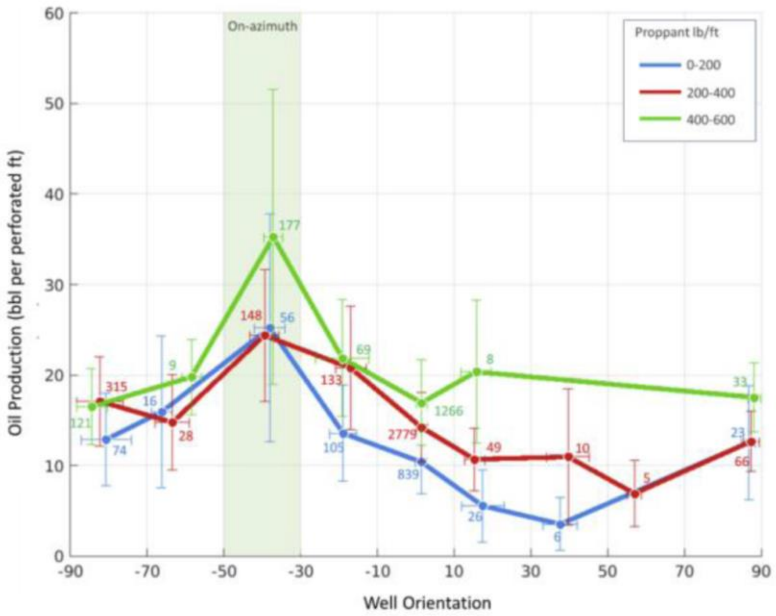
ResFrac

Note: In the images, the view has been stretched 15x in the direction of Shmin and viewed looking from toe to heel. Apparent differences in well spacing are a visual artifact due to the stretch; the well spacing is the same.

Results in literature

- Rostami et al. (2020) analyzes 7198 wells in the Bakken to examine the impact of well azimuth on the first 24 months oil production per lateral foot. The statistical analysis shows that wells drilled between 2007-2016, more than 20 degrees off Shmin underperformed by 60% or more. More modern completions and parent-child affects weakened the relationship. (URTEC-2020-281)
- Morsy et al. (2024) validated this field data with simulation studies and explored a variety of sensitivities including proppant loading, depletion, cluster spacing, and well spacing. Simulations showed that depletion, wider cluster spacing, and wider well spacing tended to lessen the effect of well orientation on well productivity. (SPE-217782-MS)

Rostami et al. (2020)



Morsy et al. (2024)

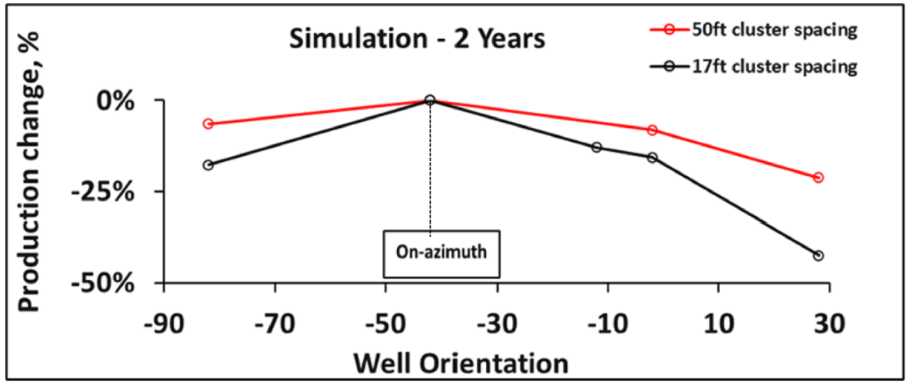


Figure 10—Average cumulative oil production per perforated foot percentage change after 24 months for different cluster spacing cases

Other Considerations

There are a variety of other considerations when modeling wells that are drilled off-azimuth from Shmin:

- The effective width of the frac corridor (in the direction of Shmin) is less than the actual stage length. Keep this in mind when setting up sector models so production from outside the frac corridor is not erroneously double counted.
- Similarly, the effective cluster spacing (distance between fractures in the Shmin direction) is tighter than the actual cluster spacing in MD. When analyzing designs with different cluster spacing and orientations, values could be normalized to an effective cluster spacing for a more apples-to-apples comparison.
- While groups of wells may be zippered in sequence, the actual time between stages of different wells within the same frac corridor may be far longer than the zipper schedule would suggest. Pay attention to the actual timing of the stages being modeled.
- If the angle between well azimuth and SHmax is fairly acute and frac lengths are sufficient, wells offset to one another parallel to the well azimuth can experience interference in the same way that offset wells orthogonal to well azimuth can interfere.

Thank You!

Chris Ponners
cponners@resfrac.com

Last updated Feb 2026