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Near Wellbore Complexity Considerations in Horizontal Well Completions

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Barree & Associates, LLC
September 9, 2015

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"Near Wellbore Complexity Considerations in Horizontal Well Completions"

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Jennifer L. Miskimins is a senior consulting engineer with Barree & Associates based in Lakewood, Colorado, where she specializes in well completions, stimulation, hydraulic fracturing, and production issues, as well as, teaches a variety of short courses.

Prior to joining the company, she was an associate professor in the Petroleum Engineering Department at the Colorado School of Mines, where she taught classes in completions, stimulation, petroleum economics, and multidisciplinary integration. Prior to joining Mines, she worked for Marathon Oil Company as a production engineer and production supervisor in a variety of locations.

Miskimins was an SPE Distinguished Lecturer in 2010-2011 and again in 2013-2014 on hydraulic fracturing in unconventional reservoirs. She served as the Executive Editor for the SPE Production & Operations Journal from 2008-2011 and has served on the Production & Operations Advisory Committee since 2010. She has also held positions on numerous other SPE committees.

Miskimins holds a BS from the Montana College of Mineral Science and Technology and MS and PhD degrees from the Colorado School of Mines, all in petroleum engineering.

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Slide 4

What is your level of education?

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Slide 5

What is your degree in?

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Slide 6

What part of the world do you work in?

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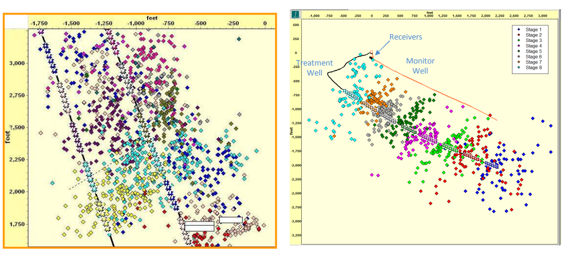
Presentation Outline

- Introduction
  - What is complexity?
- Kirsch (1898) equations
- Near wellbore complexity considerations
  - Longitudinal fracture growth/rock fabric
  - Perforation behavior and tortuosity
  - Impacts on diversion
  - Conductivity and fracture clean-up
- Conclusions

Introduction

- What is complexity?
- Stimulated reservoir volume (SRV)
- Far-field and near-wellbore?

Complexity?



From SPE 119896 (2008)

Slide 10

Kirsch (1898) Vertical Well Breakdown

$$\sigma_r = \frac{\sigma_h + \sigma_H}{2}\left(1 - \frac{r_w^2}{r^2}\right) + \frac{\sigma_h - \sigma_H}{2}\left(1 - 4\frac{r_w^2}{r^2} + 3\frac{r_w^4}{r^4}\right)\cos 2\theta + \frac{r_w^2}{r^2}(P_w - \alpha_v P_o)$$

$$\sigma_t = \frac{\sigma_h + \sigma_H}{2}\left(1 + \frac{r_w^2}{r^2}\right) - \frac{\sigma_h - \sigma_H}{2}\left(1 + 3\frac{r_w^4}{r^4}\right)\cos 2\theta - \frac{r_w^2}{r^2}(P_w - \alpha_v P_o)$$

$$\tau_{r\theta} = -\frac{\sigma_h + \sigma_H}{2}\left(1 + 2\frac{r_w^2}{r^2} - 3\frac{r_w^4}{r^4}\right)\sin 2\theta - \frac{r_w^2}{r^2}(P_w - \alpha_v P_o)$$

$$\sigma_v = P_{ob} - \alpha_v P_o$$

P_o = far field pore pressure
P_w = wellbore fluid pressure
P_{ob} = overburden pressure
r = distance from wellbore

σ_H = maximum horizontal stress
σ_h = minimum horizontal stress
θ = angle from direction of minimum stress

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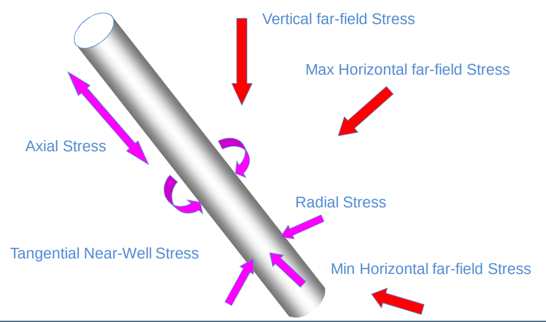
Near-Well Stresses In Rotated 3D Space



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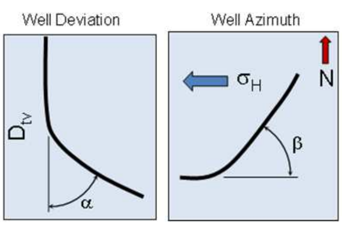
Deviated Wellbore Breakdown Calculations



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Slide 13

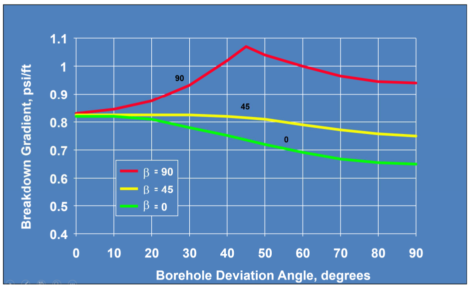
Deviated Wellbore Breakdown Calculations

Transformed x-direction stress (S_x): $S_x = \sigma_H \mathit{sin}(\beta)^2 + \sigma_h \mathit{cos}(\beta)^2$
Transformed y-direction stress (S_y): $S_y = \mathit{cos}(\alpha)^2 (\sigma_H \mathit{cos}(\beta)^2 + \sigma_h \mathit{sin}(\beta)^2) + \sigma_v \mathit{sin}(\alpha)^2$
Transformed z-direction stress (S_z): $S_z = \mathit{sin}(\alpha)^2 (\sigma_H \mathit{cos}(\beta)^2 + \sigma_h \mathit{sin}(\beta)^2) + \sigma_v \mathit{cos}(\alpha)^2$
Shear stress in x-y plane (S_{xy}): $S_{xy} = \mathit{cos}(\alpha)\, \mathit{sin}(\beta)\, \mathit{cos}(\beta)\, (\sigma_H - \sigma_h)$
Shear Stress in y-z plane (S_{yz}): $S_{yz} = \mathit{sin}(\alpha)\, \mathit{cos}(\alpha)\, (\sigma_v - \sigma_H \mathit{cos}(\beta)^2 - \sigma_h \mathit{sin}(\beta)^2)$
Shear Stress in z-x plane (S_{zx}): $S_{zx} = \mathit{sin}(\alpha)\, \mathit{sin}(\beta)\, \mathit{cos}(\beta)\, (\sigma_h - \sigma_H)$

Radial well stress (σ_r): $\sigma_r = P_w - P_o$
Tangential well stress (σ_t): $\sigma_t = S_x + S_y - 2(S_x - S_y)\, \mathit{cos}(2\lambda) - 4S_{xy} \mathit{sin}(2\lambda) - \sigma_r$
Axial well stress (σ_z): $\sigma_z = S_z - 2\nu\, ((S_x - S_y)\, \mathit{cos}(2\lambda) + 2S_{xy} \mathit{sin}(2\lambda))$

Slide 10

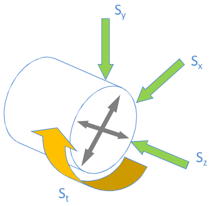
High Breakdown Pressures Can Be Caused by Well Deviation



Slide 11

Possible Breakdown Conditions

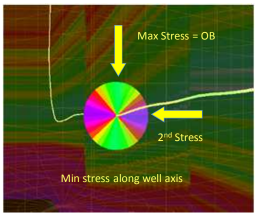
- Internal pressure exceeds minimum tangential stress plus rock strength
  - Longitudinal fracture
- Fluid pressure invades pore space or existing crack and exceeds axial stress
  - Transverse fracture
- Internal pressure stretches borehole and may induce failure along bedding planes
  - Possible horizontal fracture



Slide 12

Stress Varies Around the Hole

- Tangential or hoop stress changes significantly around the circumference of the borehole
- Breakdown occurs when well pressure exceeds minimum tangential stress by the rock tensile strength
- The following slides show required breakdown pressure and position of the minimum stress



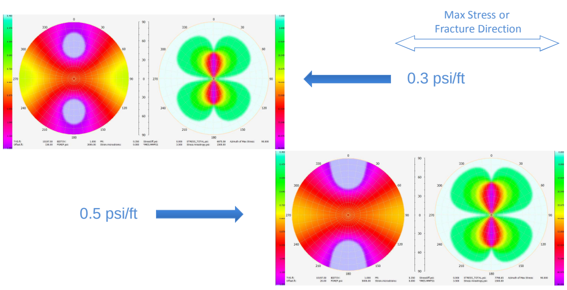
Slide 17

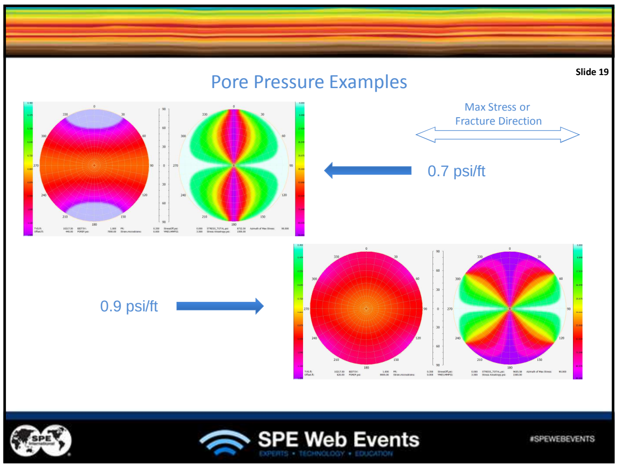
Deviation/Azimuth Impacts on Breakdown

- Well depth = 10,000 ft; well azimuth 90° - 270°
- Pore pressures
  - PR = 0.35, differential = 1500 psi
  - 0.3 psi/ft, 0.5 psi/ft, 0.7 psi/ft, and 0.9 psi/ft
- Poisson's ratio
  - Pore pressure = 5000 psi, differential = 1500 psi
  - 0.15, 0.25, 0.35, and 0.48
- Horizontal stress differentials
  - PR = 0.30, pore pressure = 6000 psi
  - 500 psi, 1000 psi, 1500 psi, and 2000 psi

Slide 18

Pore Pressure Examples




Slide 19
Pore Pressure Examples
Max Stress or
Fracture Direction
0.7 psi/ft
0.9 psi/ft
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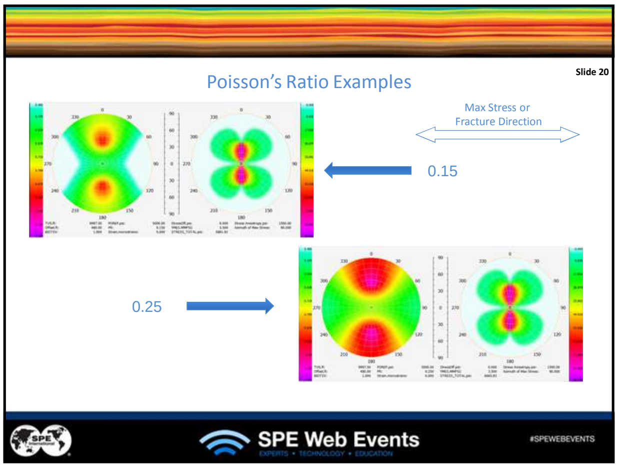
Slide 20
Poisson's Ratio Examples
Max Stress or
Fracture Direction
0.15
0.25
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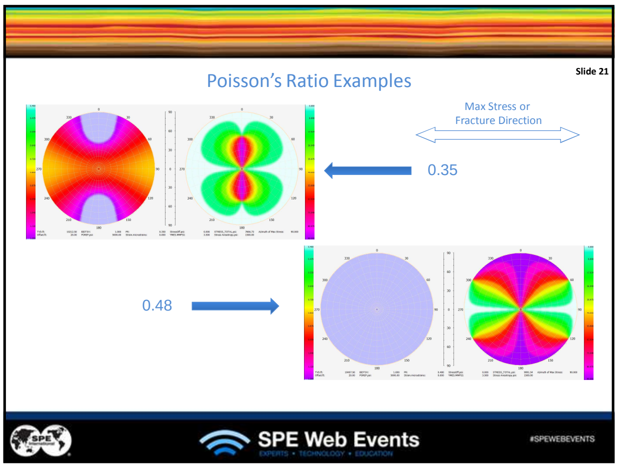
Slide 21
Poisson's Ratio Examples
Max Stress or
Fracture Direction
0.35
0.48
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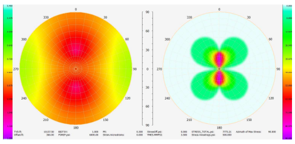
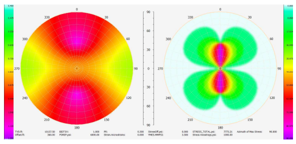
Differential Stress Examples



Max Stress or Fracture Direction

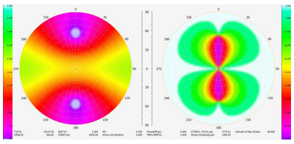
500 psi

1000 psi



Slide 23

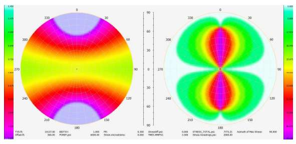
Differential Stress Examples



Max Stress or Fracture Direction

1500 psi

2000 psi



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Slide 24

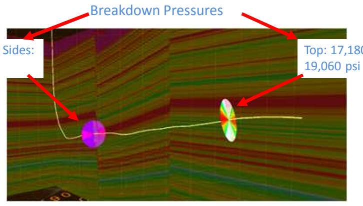
Implications of Tangential Stress Variation

- Extreme case; 0.92 psi/ft and 2,000 psi differential
- TVD = 13,475 feet

Breakdown Pressures

Top: 20,560 psi Sides: 19,390 psi

Top: 17,180 psi Sides: 19,060 psi



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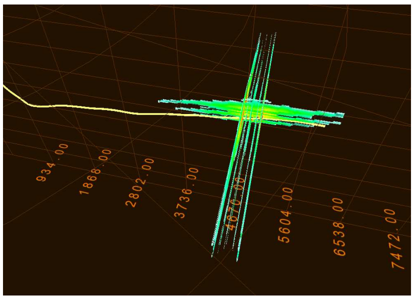
Near Wellbore Complexity Considerations

- Longitudinal fracture growth/rock fabric
- Perforation behavior and tortuosity
- Impacts on diversion
- Conductivity and fracture clean-up

Slide 26

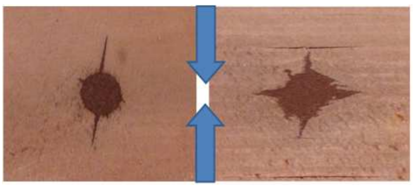
Transverse and Longitudinal Failure

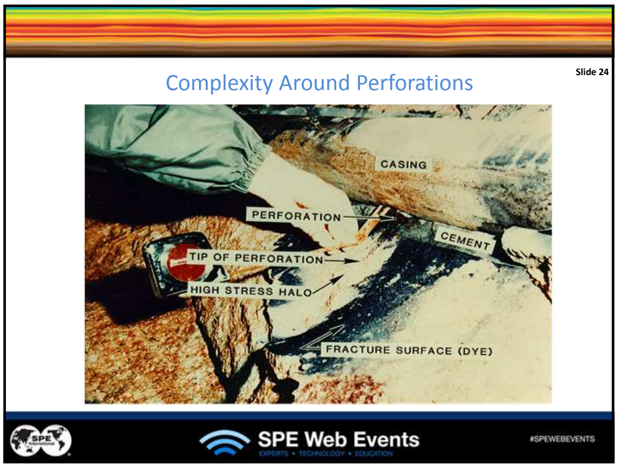


Slide 27

Effects of Rock Fabric

- Isotropic and homogeneous vs. laminated systems




Slide 24
Complexity Around Perforations
CASING
PERFORATION
CEMENT
TIP OF PERFORATION
HIGH STRESS HALO
FRACTURE SURFACE (DYE)
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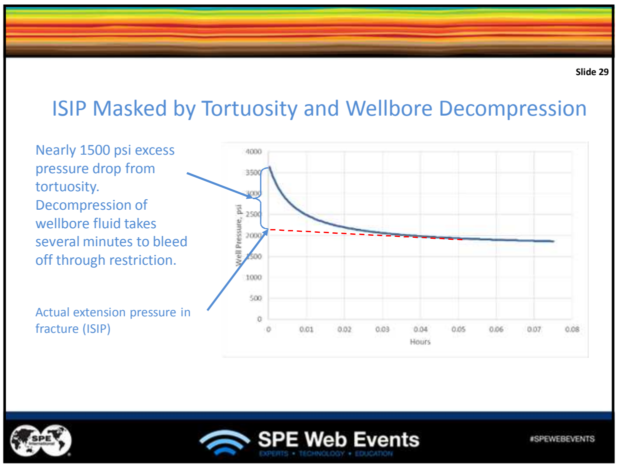
Slide 29
ISIP Masked by Tortuosity and Wellbore Decompression
Nearly 1500 psi excess pressure drop from tortuosity.
Decompression of wellbore fluid takes several minutes to bleed off through restriction.
Actual extension pressure in fracture (ISIP)
Well Pressure, psi
Hours
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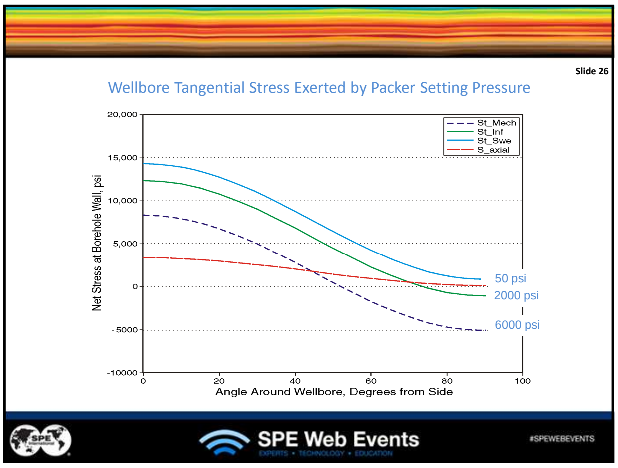
Slide 26
Wellbore Tangential Stress Exerted by Packer Setting Pressure
St_Mech
St_Inf
St_Swe
S_axial
50 psi
2000 psi
6000 psi
Net Stress at Borehole Wall, psi
Angle Around Wellbore, Degrees from Side
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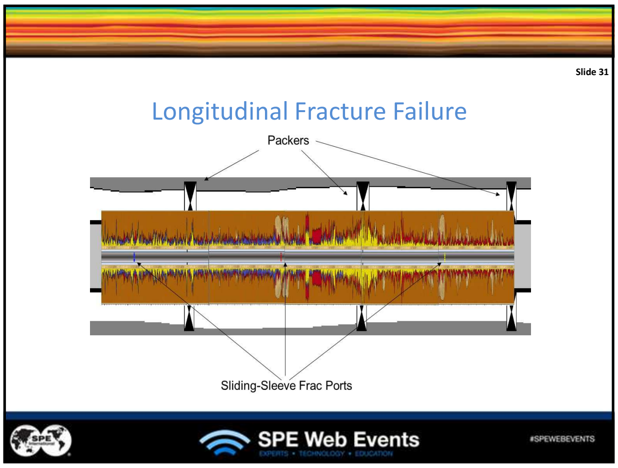
Slide 31
Longitudinal Fracture Failure
Packers
Sliding-Sleeve Frac Ports
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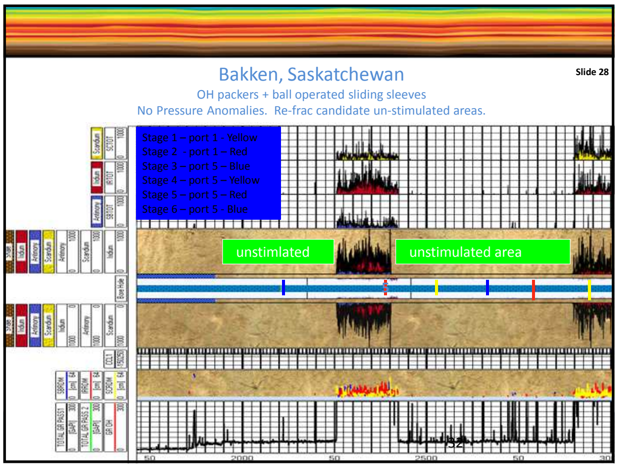
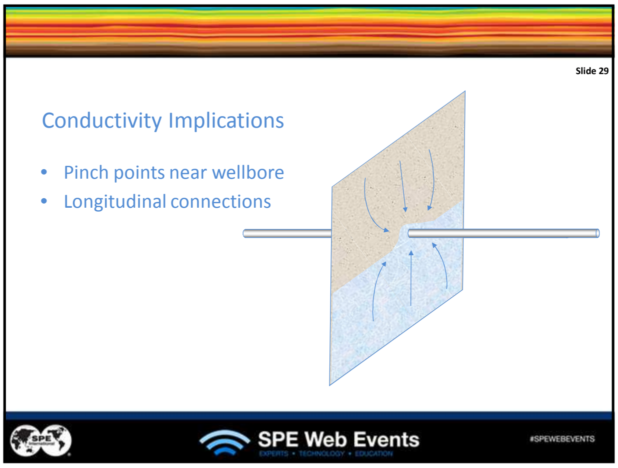

Bakken, Saskatchewan
Slide 28
OH packers + ball operated sliding sleeves
No Pressure Anomalies. Re-frac candidate un-stimulated areas.
Stage 1 – port 1 - Yellow
Stage 2 - port 1 – Red
Stage 3 – port 5 – Blue
Stage 4 – port 5 – Yellow
Stage 5 – port 5 – Red
Stage 6 – port 5 - Blue
unstimlated
unstimulated area


Slide 29
Conductivity Implications
• Pinch points near wellbore
• Longitudinal connections
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Slide 30

Conclusions

- Combinations of reservoir pressure, stress differential, rock properties, and well orientation can make breakdown at safe operating pressures difficult or impossible
  - Under many fracture initiation conditions in deviated wells, a longitudinal component of a fracture will occur that runs parallel with the wellbore. These longitudinal fractures may be short or run along a significant portion of the wellbore, however, they are almost impossible to eliminate completely.
- Both tangential stress and rock fabric control borehole breakdown
  - The effects of highly laminated systems, such as those that occur in most unconventional reservoirs, are frequently ignored in breakdown. Such systems can and will have an impact on fracture initiation, leading to shear failure conditions and the potential for extremely complex near-wellbore fracture conditions.

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Conclusions

- Tangential stress variation should be considered in perforation phasing and orientation
  - Perforation breakdown may be hampered in certain orientations.
  - The generated near-wellbore tortuosity can cause screenouts and impact conductivity, which will lead to the loss of treated reservoir and reserves.
- Longitudinal fractures impact completion designs and execution
  - Packer isolation effectiveness may be compromised.
  - Longitudinal fracture components may provide communication between stages no matter what type of wellbore diversion is used.
  - Tortuosity and screenout potential could be increased.
- Conductivity and post-treatment production can be hampered by the complexity generated

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