Seismically driven geomechanical simulation to constrain engineering models

Ahmed Ouenes

FracGeo
The Future of Shale Management, Today

Acknowledgements

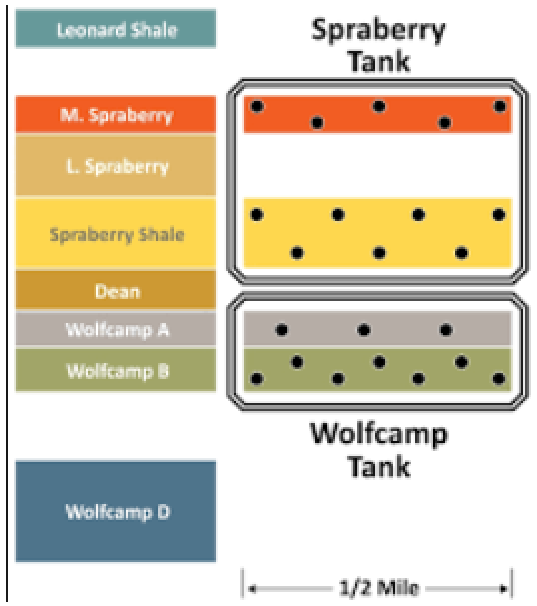
- URTEC committee for the invitation
- TGS, Anadarko, Shell for URTEC 932
- Painted Pony for URTEC 975
- Equinor for URTEC 951
- Current and upcoming members of FracGeo's Weak Interface Consortium (WIC)

Plus others currently finalizing their contracts

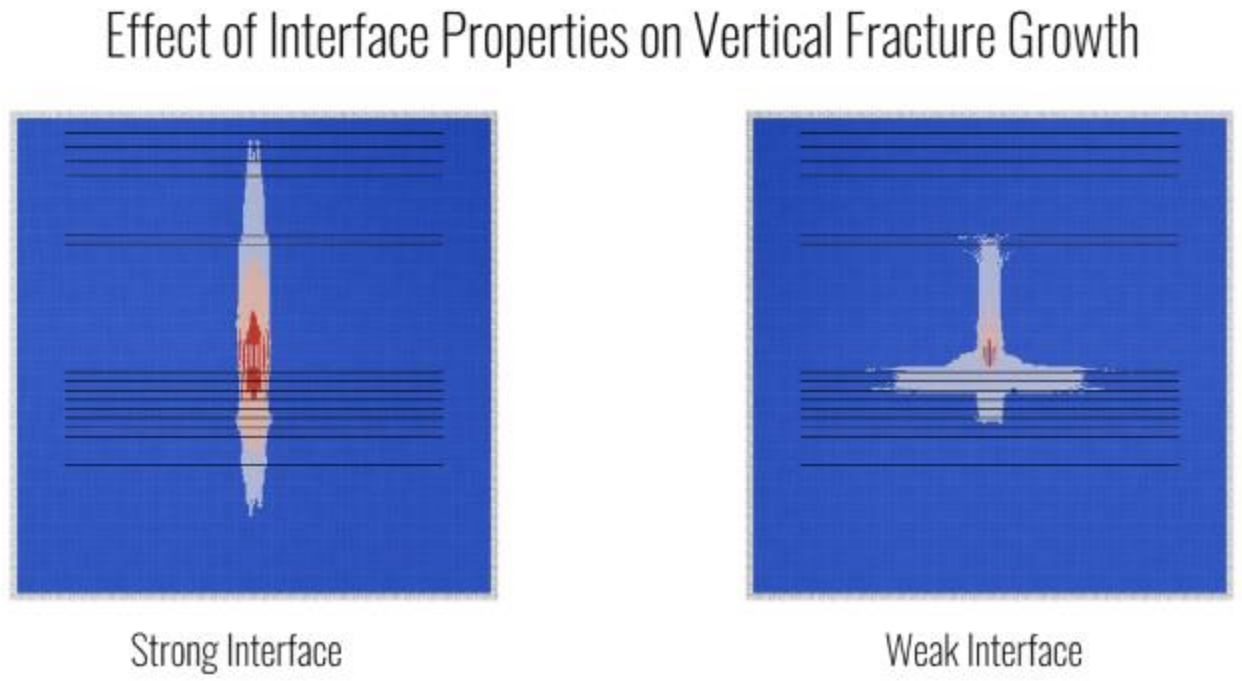
The reservoir matters

its properties control both initiation and propagation of hydraulic fractures

- Today Wall Street is smarter than 2010



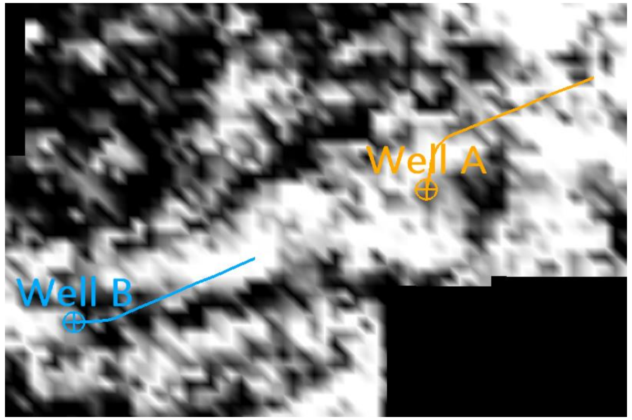
E&P company asking 100 million for a cube by showing to Wall St constant reservoir properties !!!



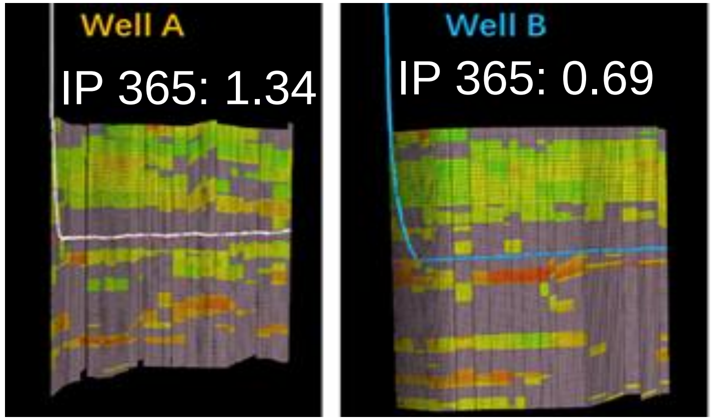
https://youtu.be/QN0PjWcR9hw

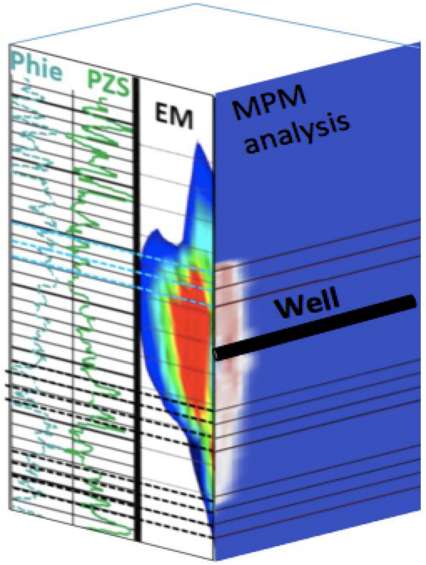
The reservoir matters: vertical direction

- Vertical reservoir properties such as weak interfaces affect vertical fracture growth ➔ well performance



Average interface property in the reservoir interval

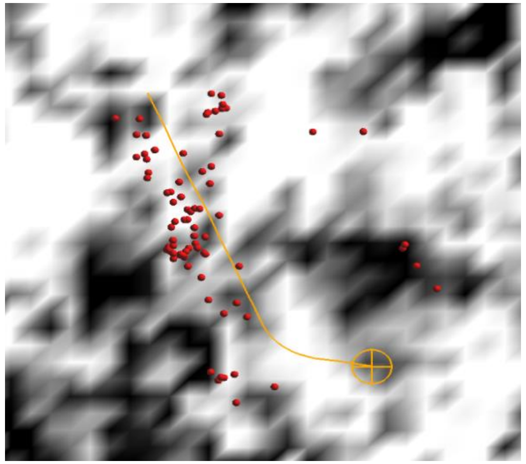




Geomechanical simulation with weak interfaces validated with EM proppant

and

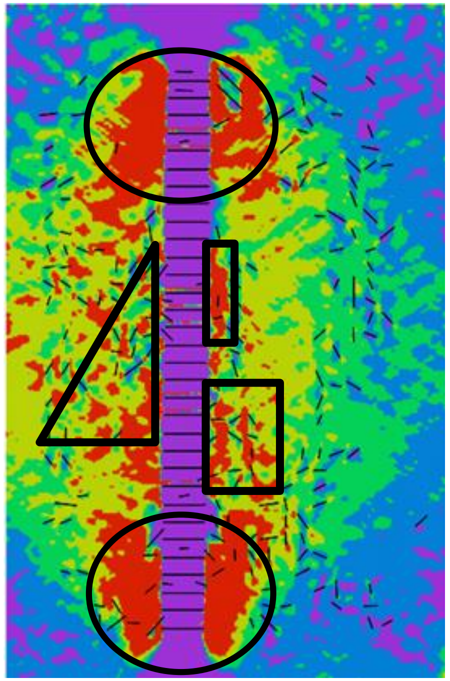
Microseismic Moment Tensor Inversion

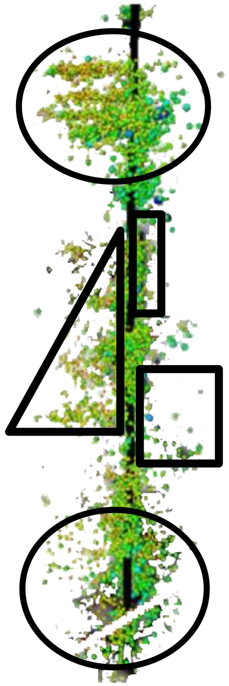


Horizontal shear failures planes where Interfaces are present

URTEC 975, 2019

The reservoir matters: lateral direction





Asymmetric, stimulation

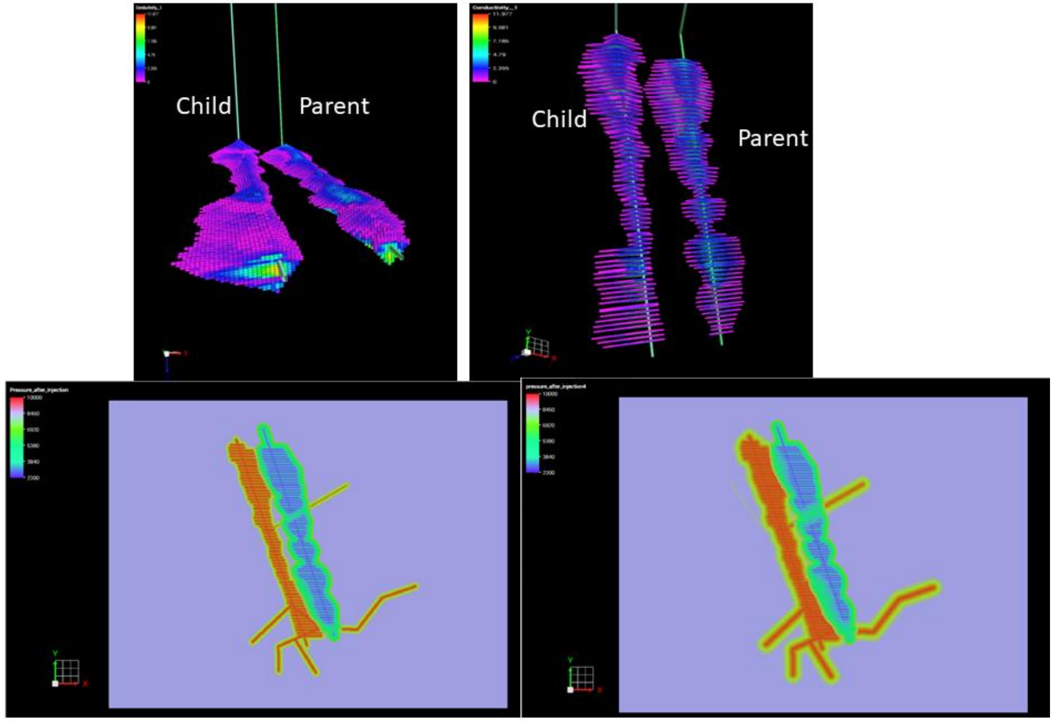
Discontinued

“Poor”

Large SRV successful stimulation

geomechanical simulation of the interaction between hydraulic and natural fractures validated (not calibrated) with microseismic
URTEC 2173459 (2015)

The reservoir matters: lateral direction

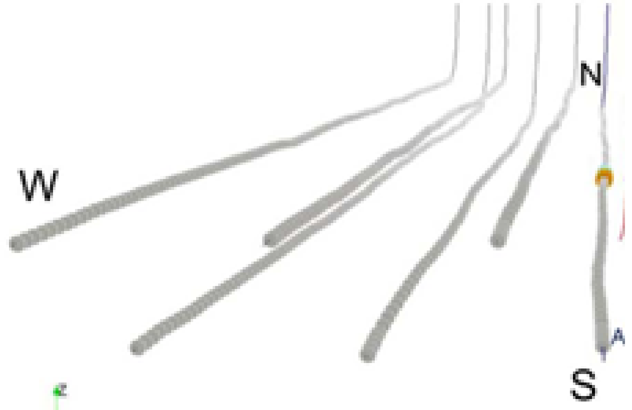


Poroelastic geomechanical simulation of frac hits
With Embedded Discrete Fracture Models in
Fast Marching Simulation

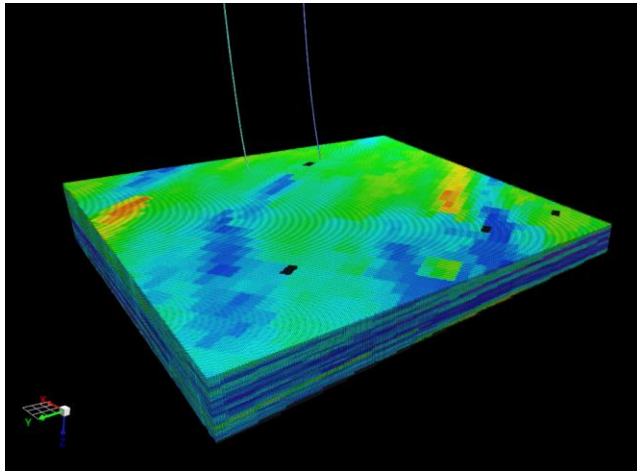
First Break, April 2019

How to capture the reservoir properties ?

- Step 1: capture the key reservoir properties at each well drilled in the past, present and future

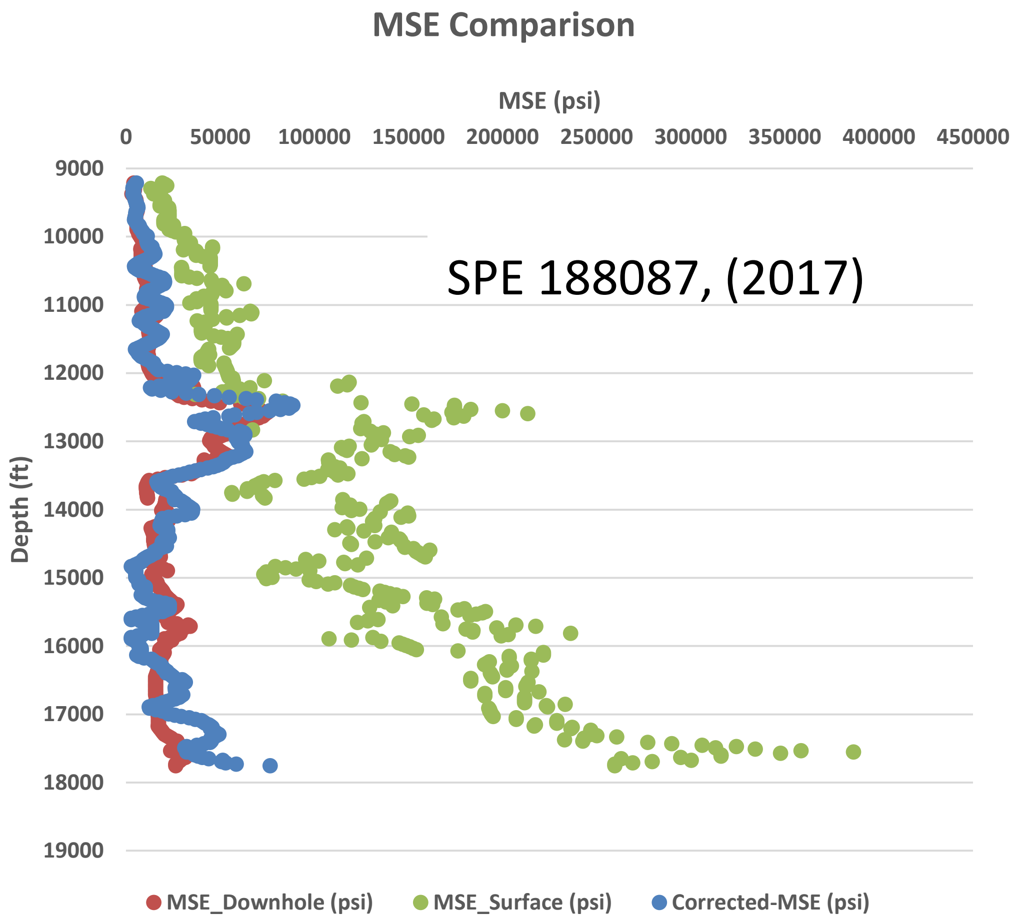


- Step 2: propagate these properties in 3D in real time or as soon as we TD the well

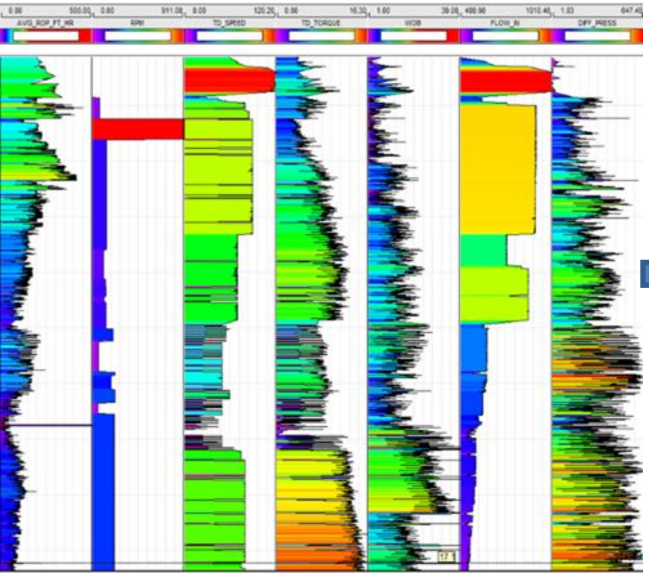


Step 1: FracGeo's Corrected Mechanical Specific Energy (CMSE) for capturing key rock properties using surface drilling data

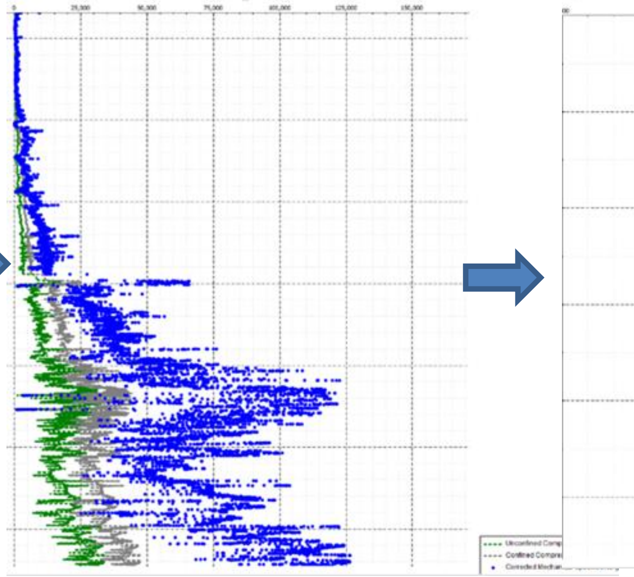
- Pseudo logs estimated simultaneously in real time from surface drilling data
  - Pore pressure
  - Differential stress
  - Natural fracture index
  - Porosity
  - Static geomechanical properties



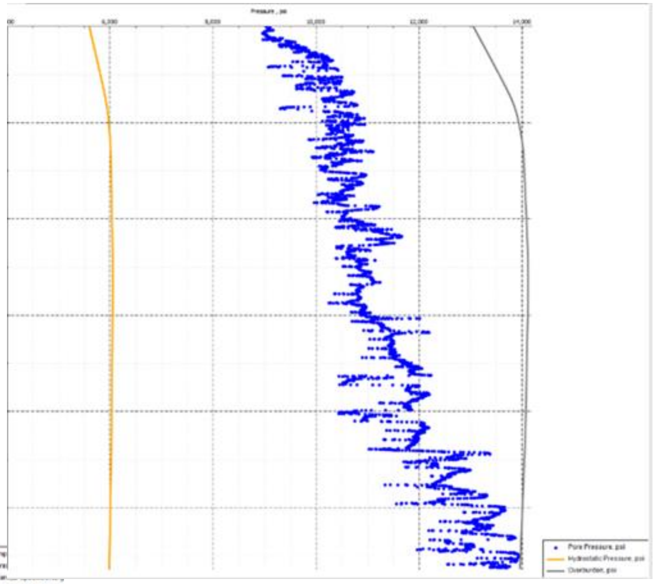
Step 1: FracGeo's Corrected Mechanical Specific Energy (CMSE) for capturing key rock properties using surface drilling data



Surface Drilling Data

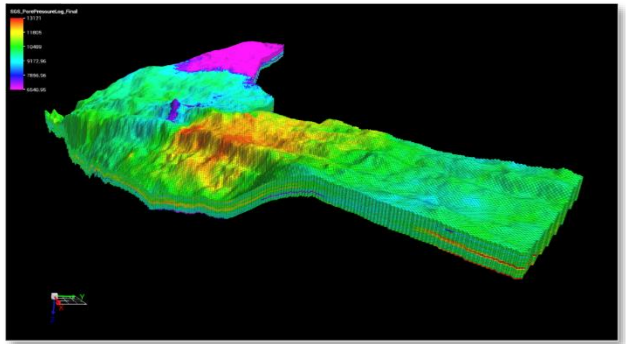


CMSE, CCS, UCS



Pore Pressure log

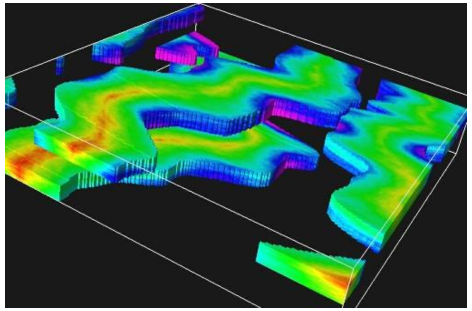
Step 2



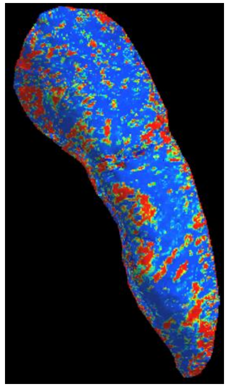
3D Distribution of Pore Pressure

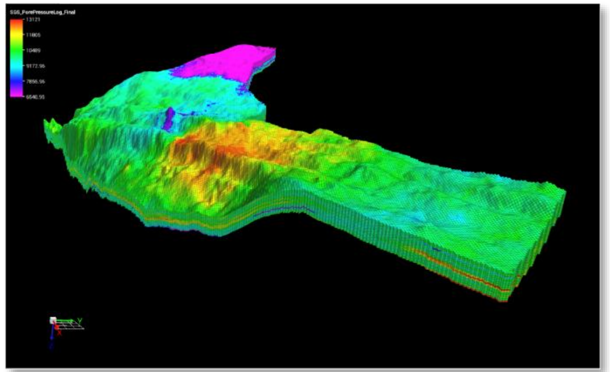
URTEC 511, (2019)

Step 2: How to propagate the surface drilling derived log properties in 3D for geomechanical simulation, frac design and reservoir simulation ?



- Geostatistics ➔ properties controlled by deposition like porosity
- Artificial Intelligence ➔ natural fractures, pore pressure, etc.

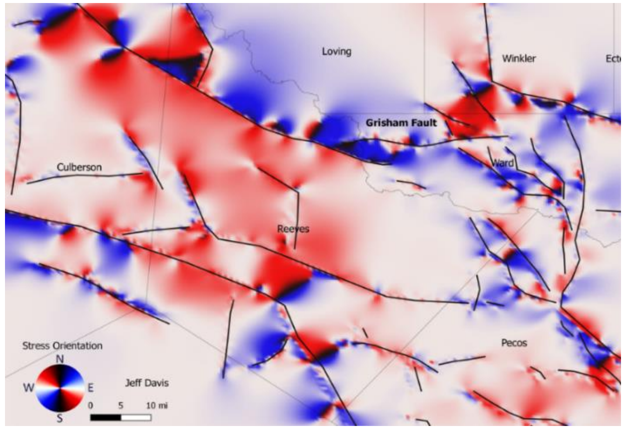




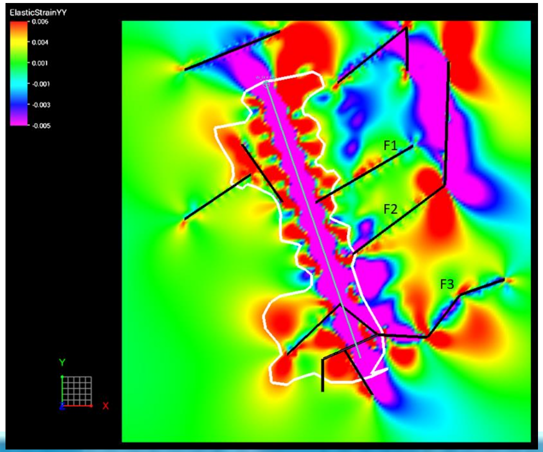
- How to get stress magnitude and orientation ?
- How to make these models predictive ?

3D Seismic ➔ Critical input for accurate geomechanical simulations

- 3D seismic to capture stress rotation

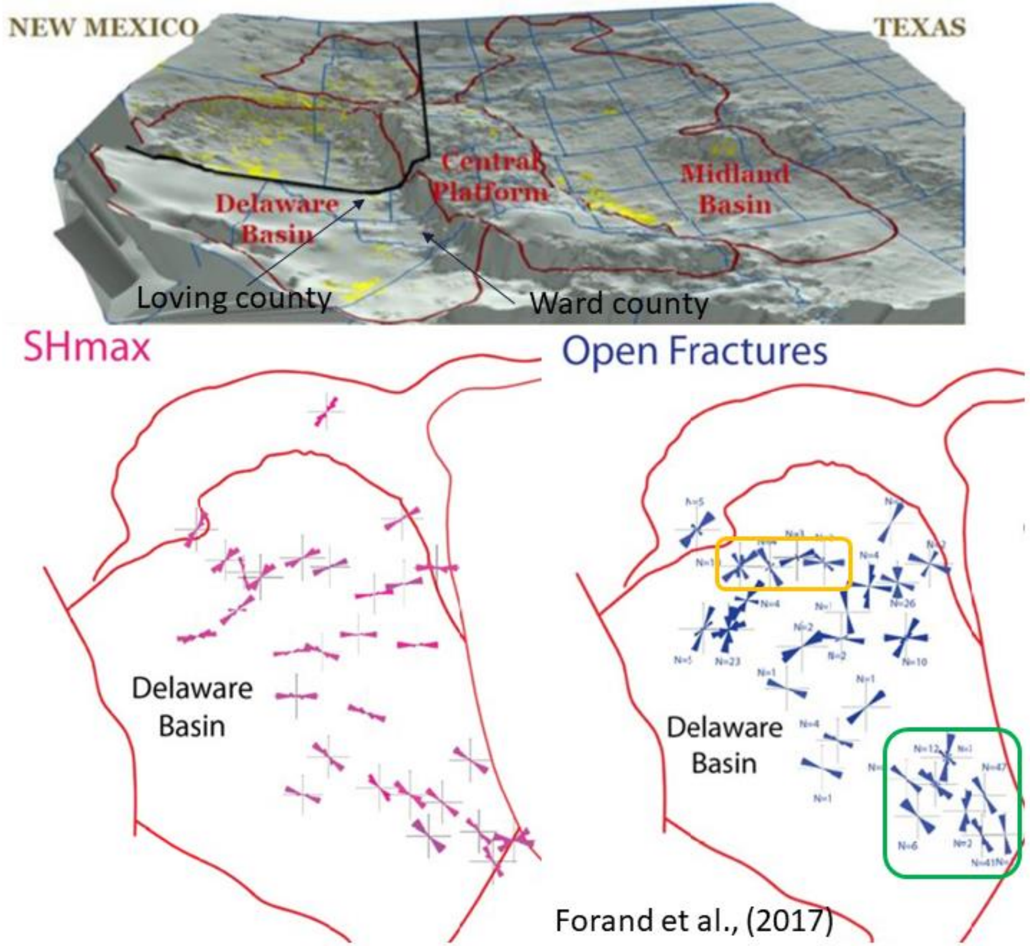


- 3D seismic to capture differential stress and natural fractures affecting hydraulic fracture propagation

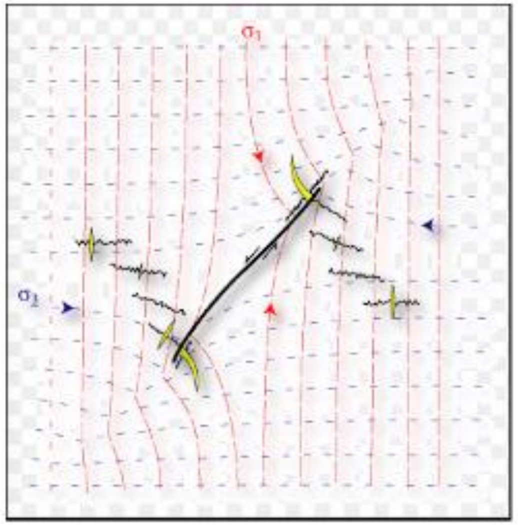


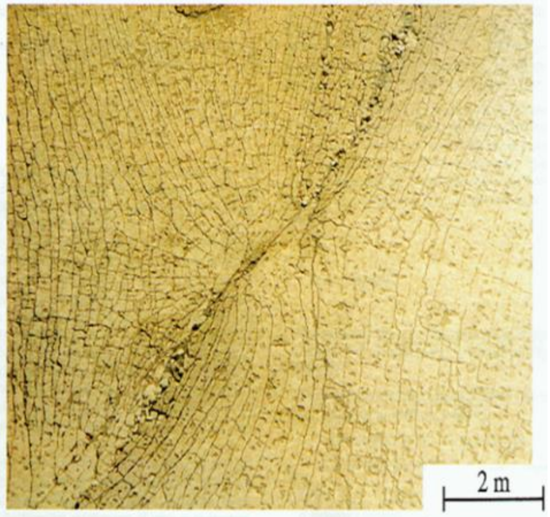
URTeC workshop

Natural Fractures & Faults Perturb Stress Fields

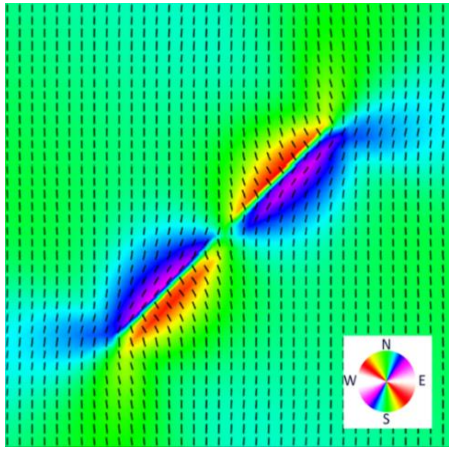


Forand et al., (2017)



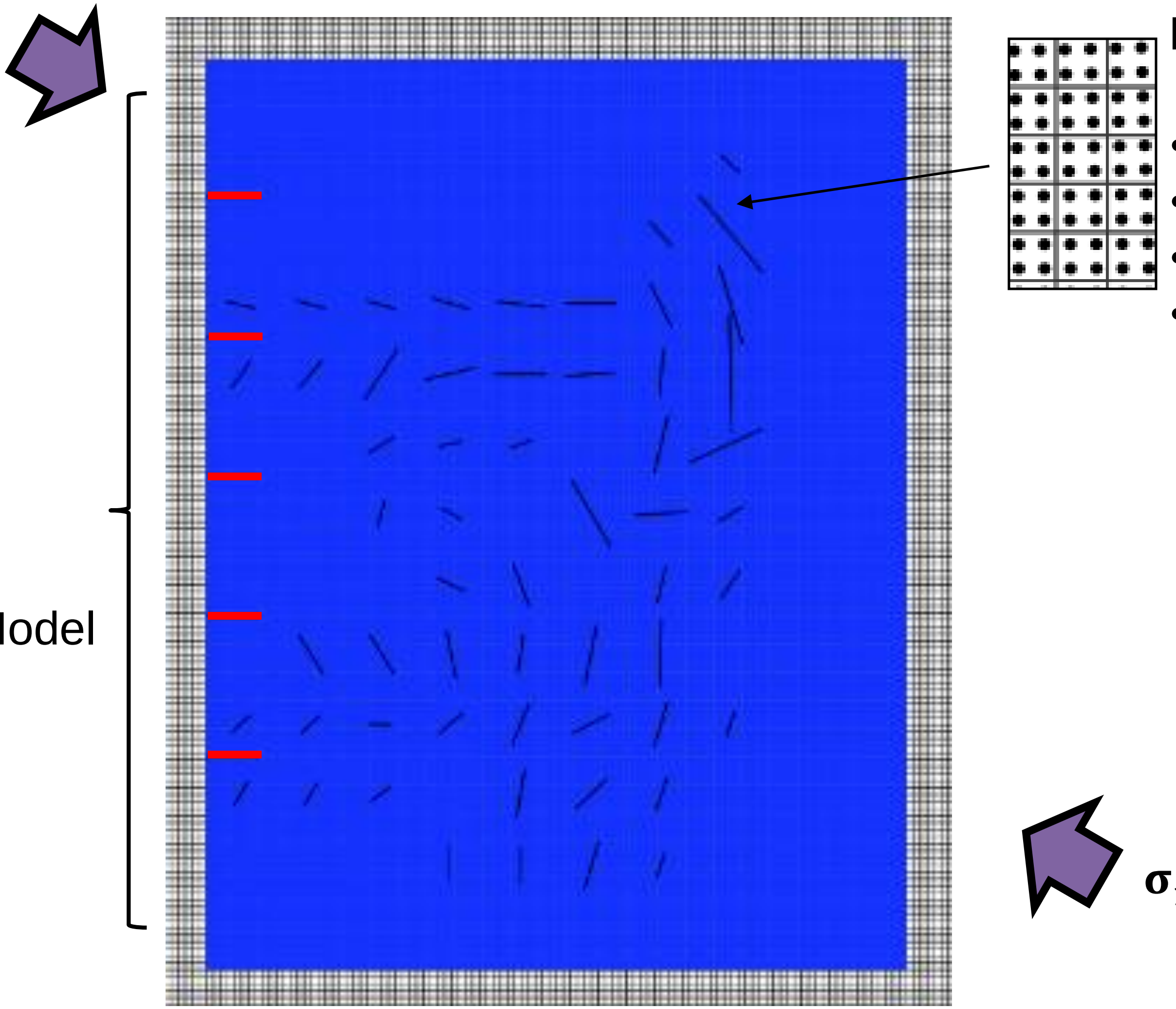


Geomechanical simulation
is used to estimate the resulting
aariable stress magnitude and
orientation



URTEC 932
(2019)

Dynamic geomechanical simulation using the Material Point Method (MPM)



Rock Mechanical Properties

- Young's Modulus
- Poisson's Ratio
- Density
- Pore pressure

Fractures

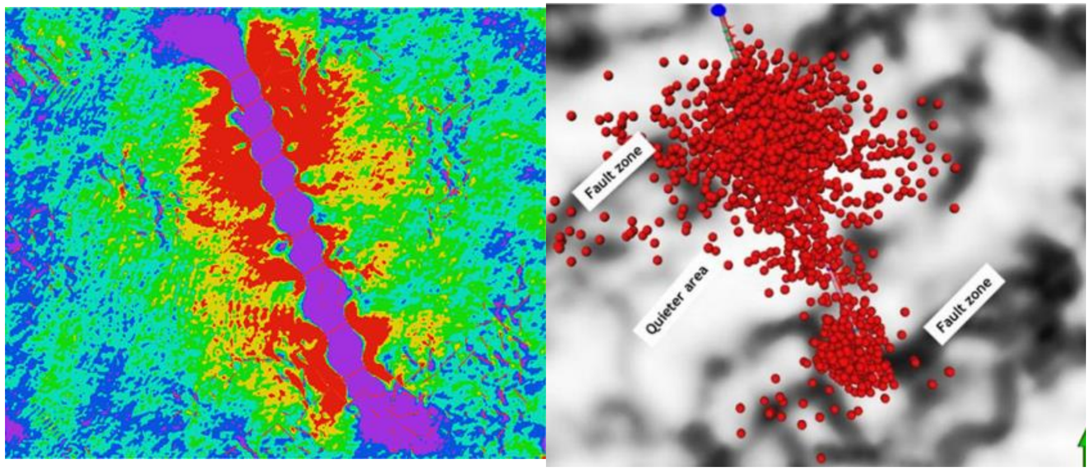
- Equivalent Fracture Model (EFM)
- Hydraulic Fractures

Regional Stress

- Orientation
- Magnitude
- Anisotropy

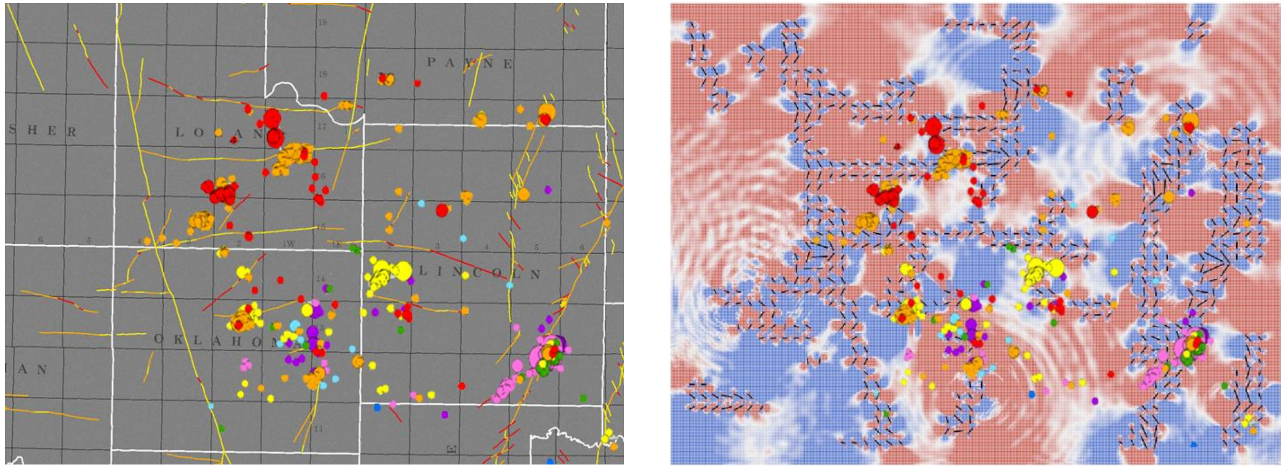
URTEC 1923762 (2014)

MPM geomechanical simulations from well scale to state of Oklahoma



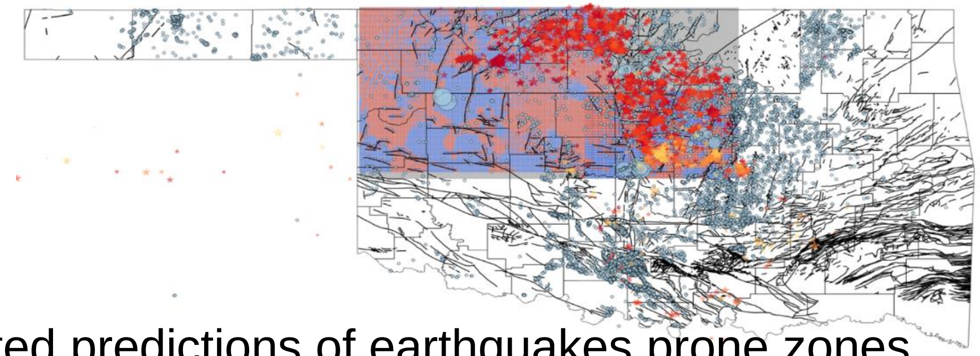
URTEC 1923762, (2014)

Validated predictions of stimulated zones that saw shearing of natural fractures during stimulation



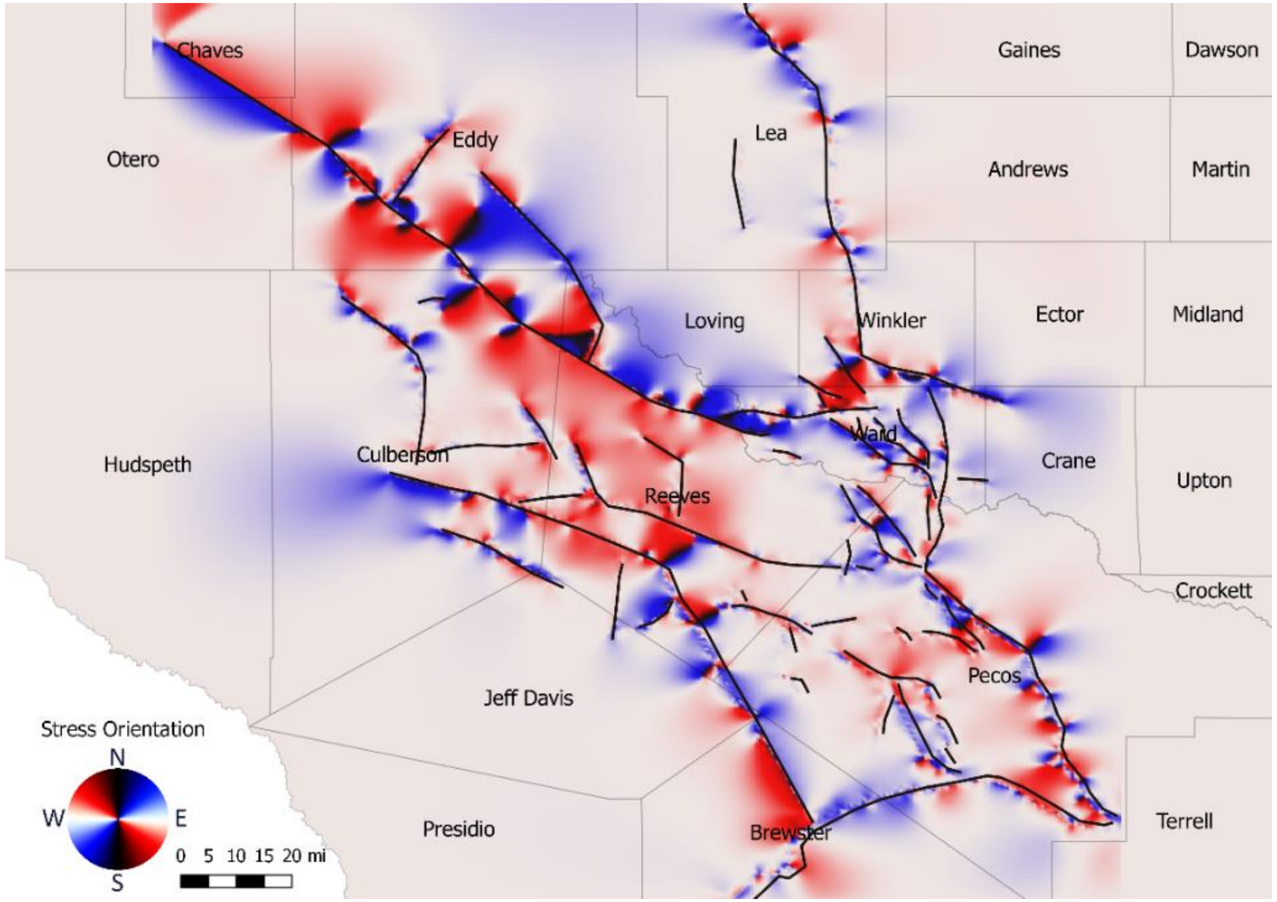
SPE 176932 (2015)

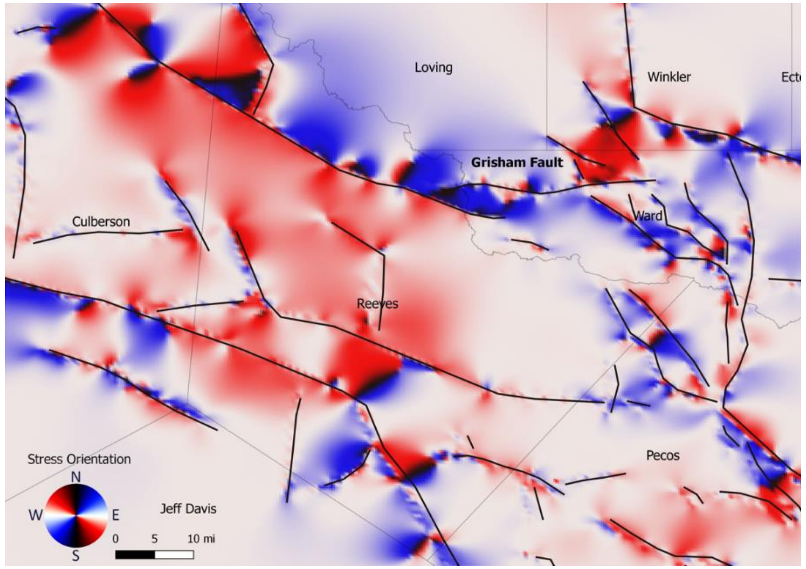
J. Sustainable Energy Eng. Vol 4, Nos 3-4 Decembre 2016



Validated predictions of earthquakes prone zones

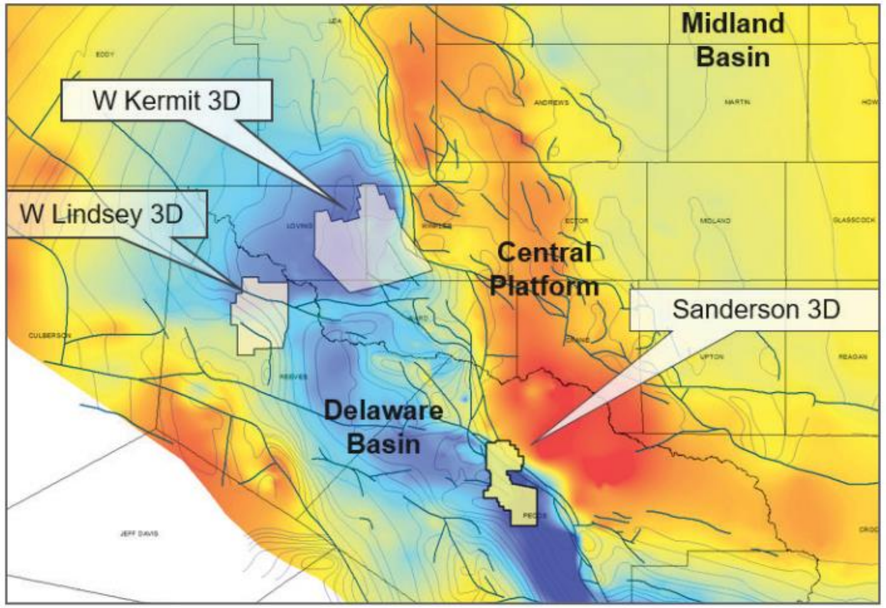
Regional scale MPM geomechanical simulation using public data
➔ stress orientation using public data





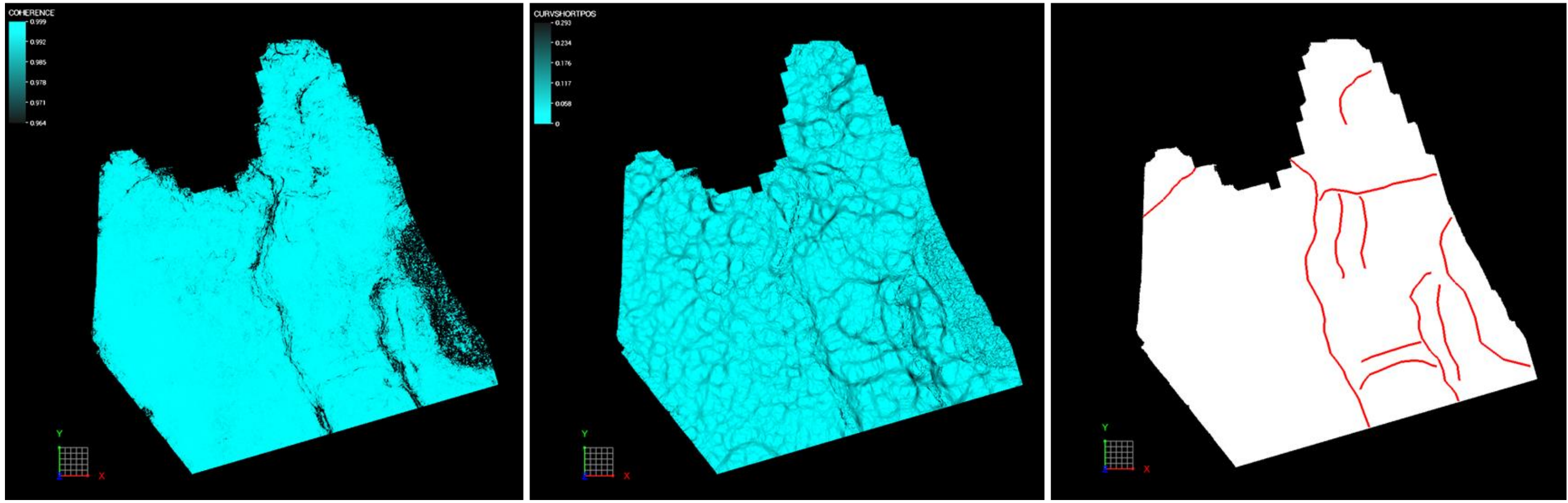
URTEC 932 (2019)

How good are these public data compared to 3D seismic derived discontinuities ?

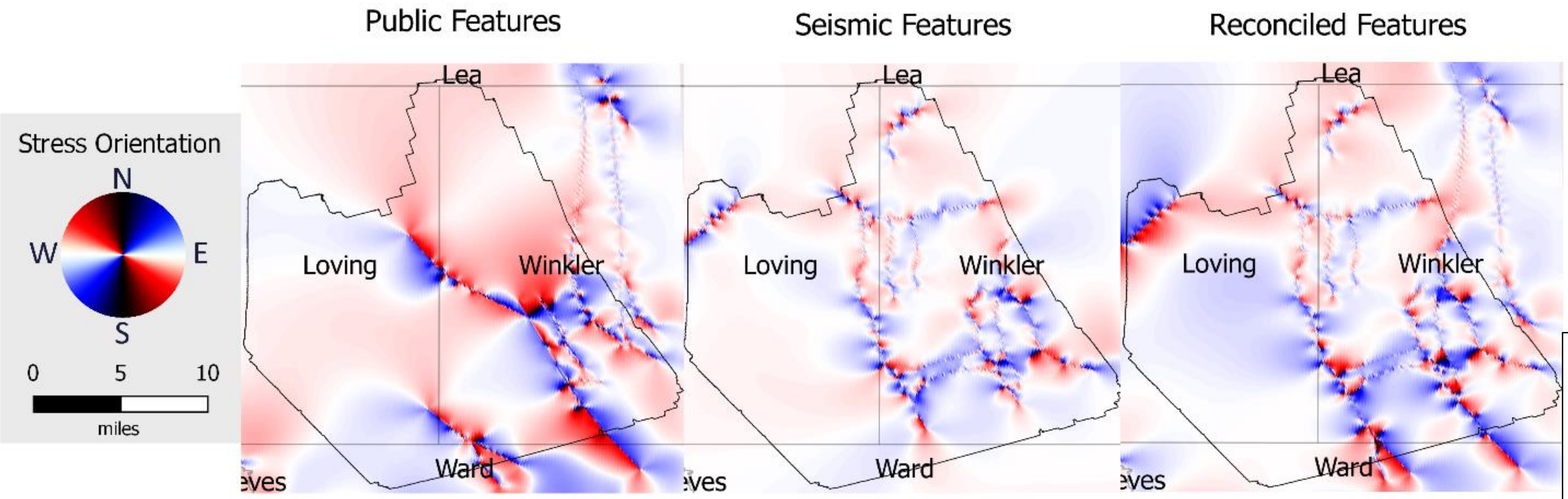


URTEC 932 (2019)

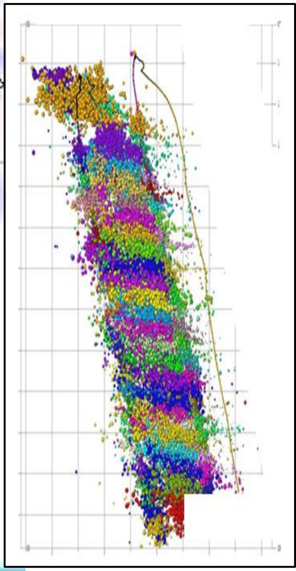
Coherency | Most Positive Curvature | Interpreted Faults



Improved Stress Orientation Estimation with the 3D seismic

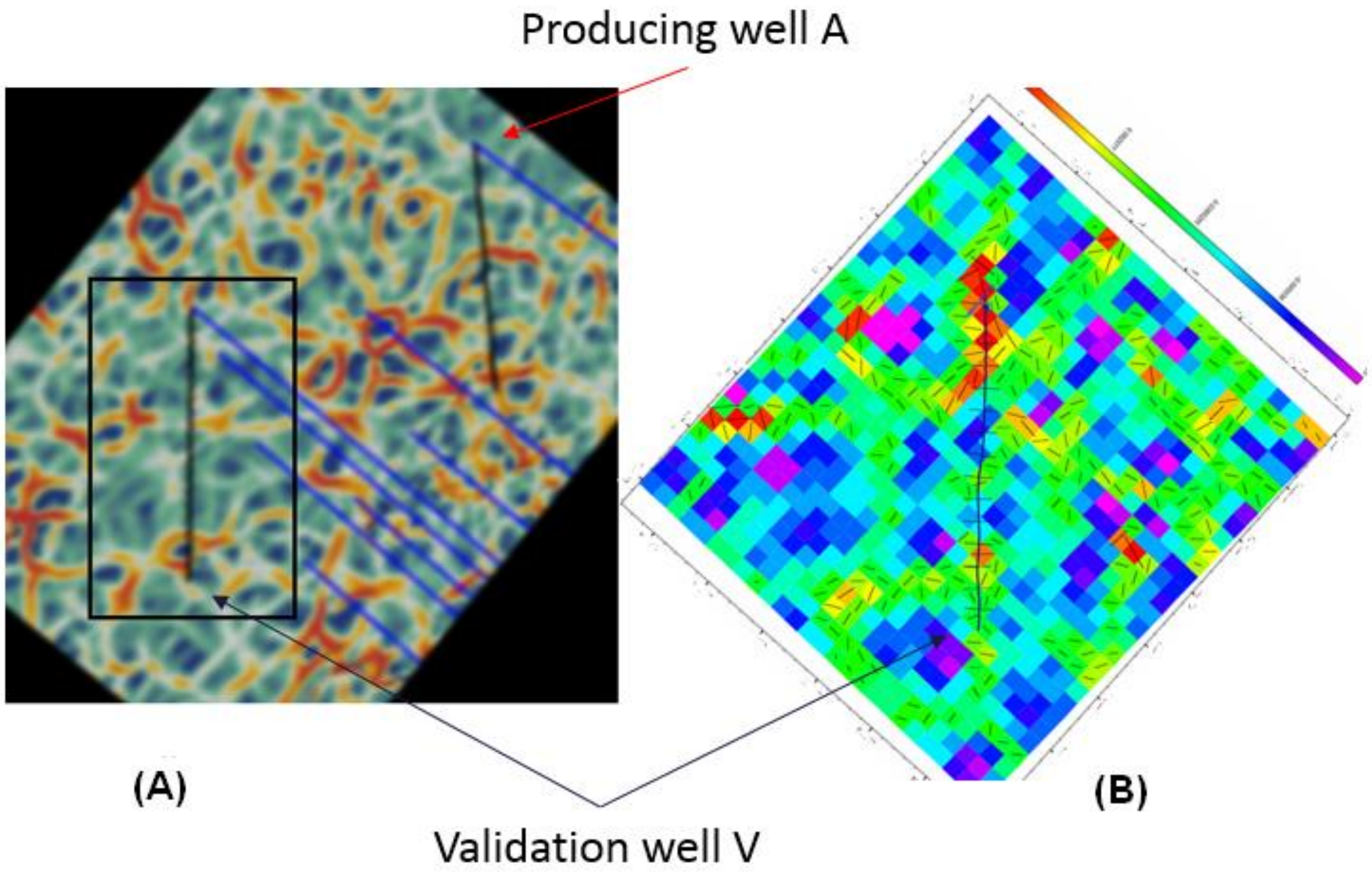


URTEC 932 (2019)



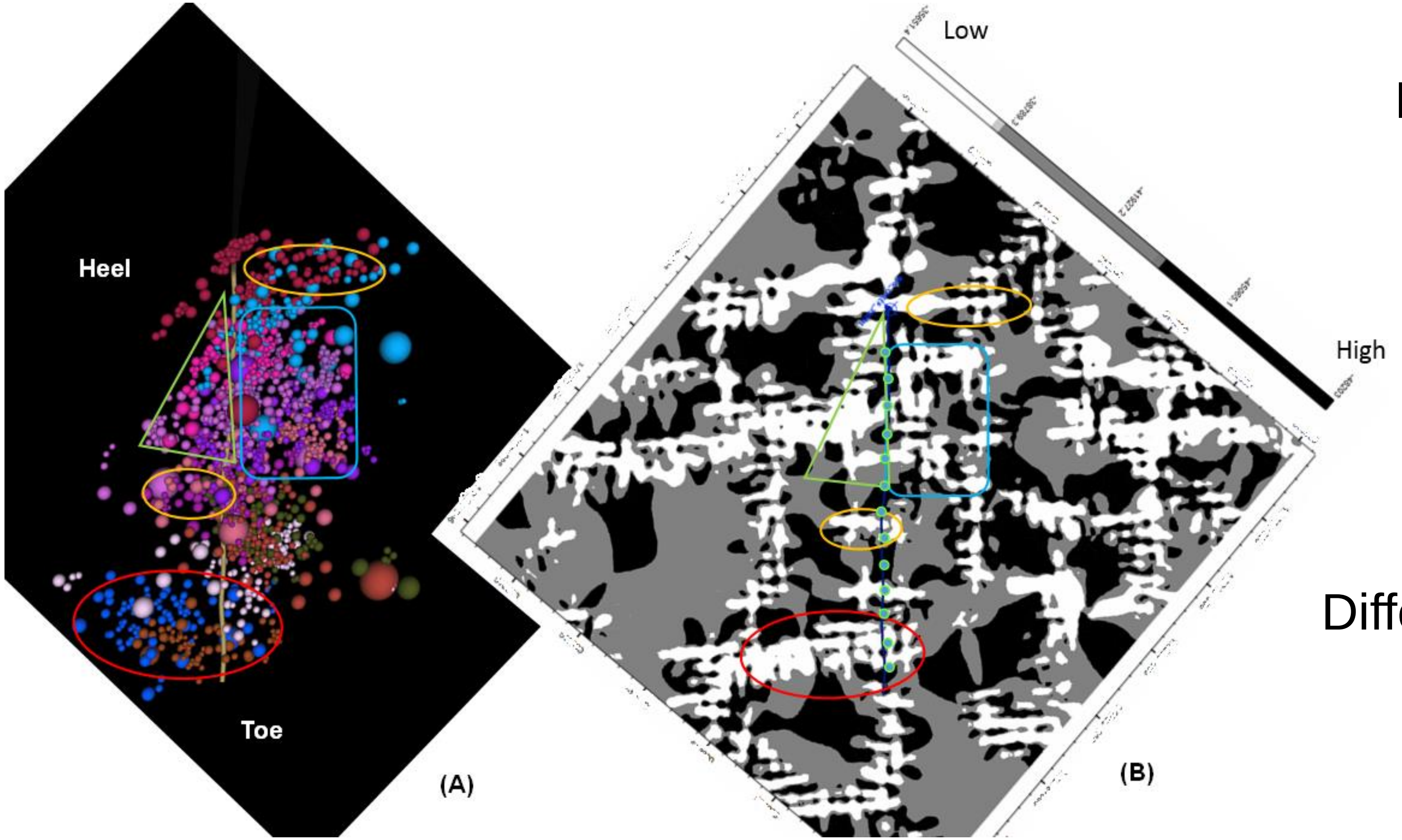
The maximum stress orientation seen in the microseismic is matched when adding the 3D features to the public data and running a new geomechanical simulation with the enriched map of discontinuities

Estimation of Equivalent Fracture Model with 3D seismic



SPE 185044 (2017)

Estimation of Differential Stress along and around the wellbore

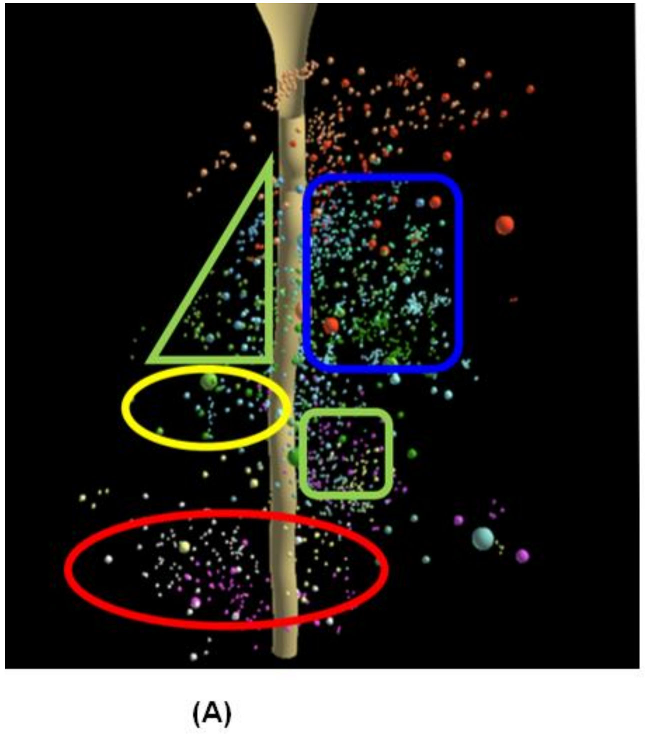


Initial Condition Prior to Hydraulic Fracturing

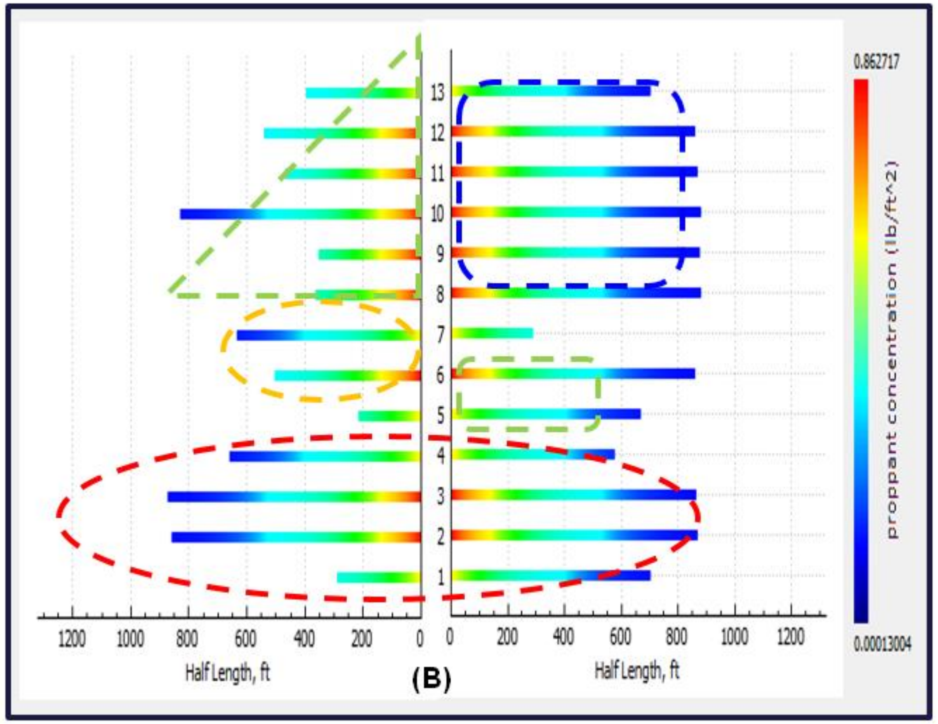
Differential Stress = $\sigma_{hmax} - \sigma_{hmin}$

SPE 185044 (2017)

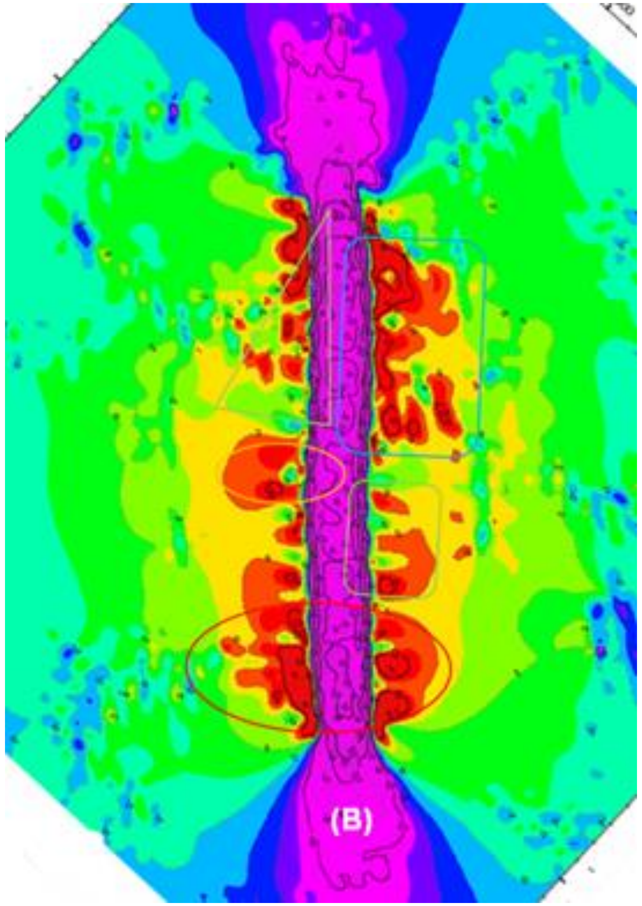
Geomechanically constrained frac design and analysis validated (NOT CALIBRATED) with microseismic



SPE 185044 (2017)

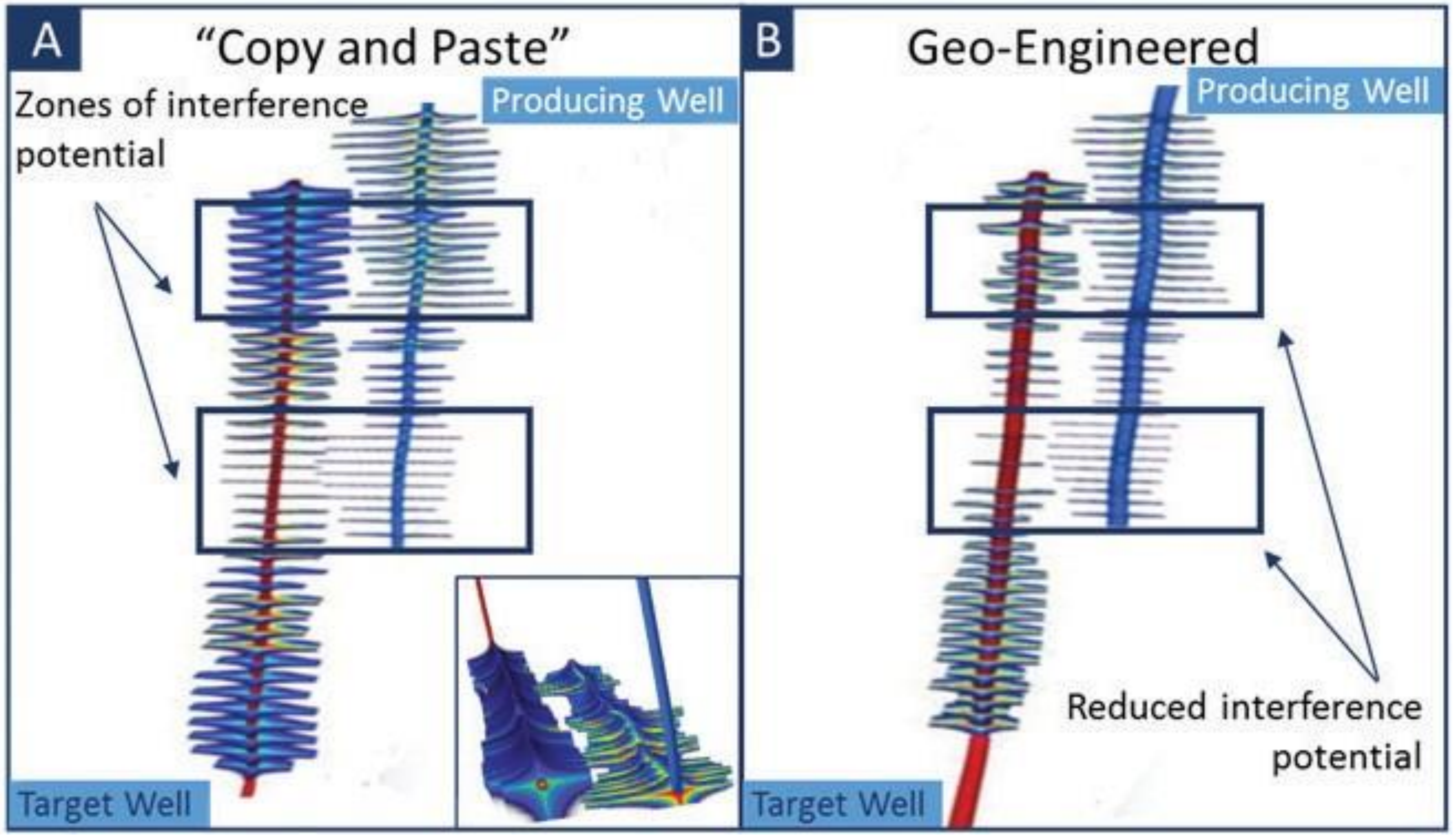


Proppant concentration



Strain from geomechanical simulation

Minimizing the damage caused by child well too close to parent well

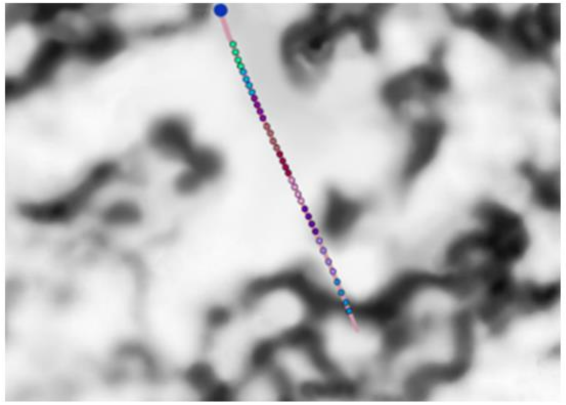


Date	Oil	Gas	Water	Wells
08/2015	18268	18317	27267	1
09/2015	24870	23603	37121	1
10/2015	19729	18849	29447	1
11/2015	16028	15332	23923	1
12/2015	22043	22206	32901	1
01/2016	15090	21584	23208	1
02/2016	12241	17827	18826	1
03/2016	10949	15683	16839	1
04/2016	7607	9102	11699	1
05/2016	4248	5386	6533	1
06/2016	9823	10698	15107	1
07/2016	9292	11385	14291	1
08/2016	7283	10726	11201	1
09/2016	7270	11257	11181	1
10/2016	5599	8670	8611	1
11/2016	5804	12876	8926	1
12/2016	2879	9550	4428	1
01/2017	6258	12049	9624	1
02/2017	5896	6237	9068	1
03/2017	8255	9211	12696	1
04/2017	4037	4703	6209	1

on May 2016, as a result of not following the recommended geoengineered frac design, the operator lost 33% of its production in the unit and a 7 million child well

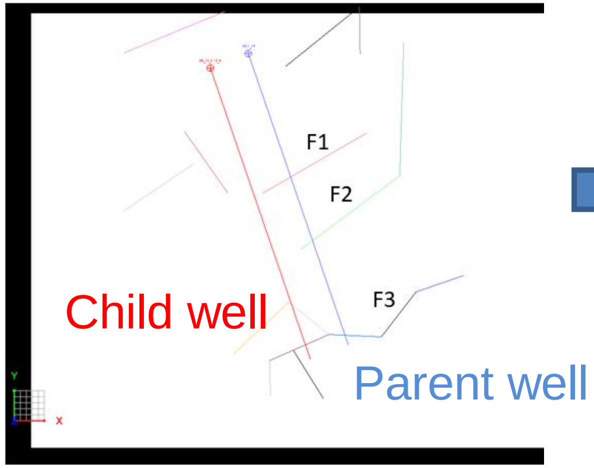
3D Seismic to capture faults in the lateral direction

Seismic coherency



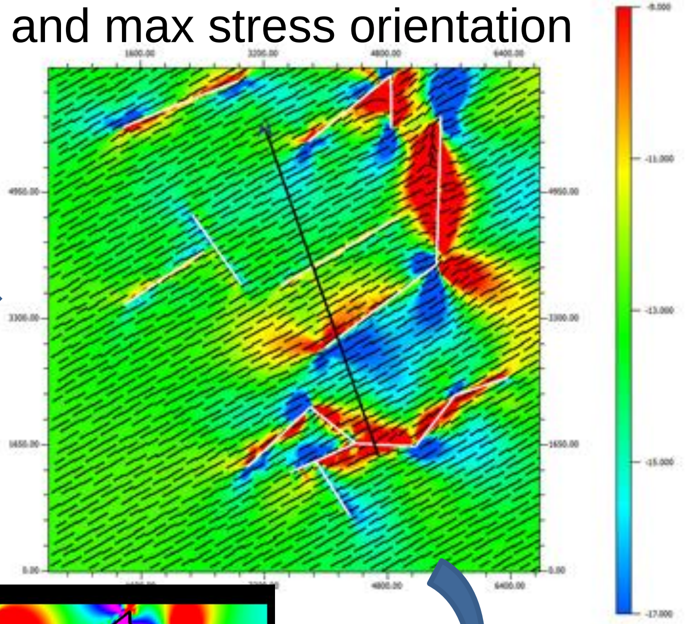
(A)

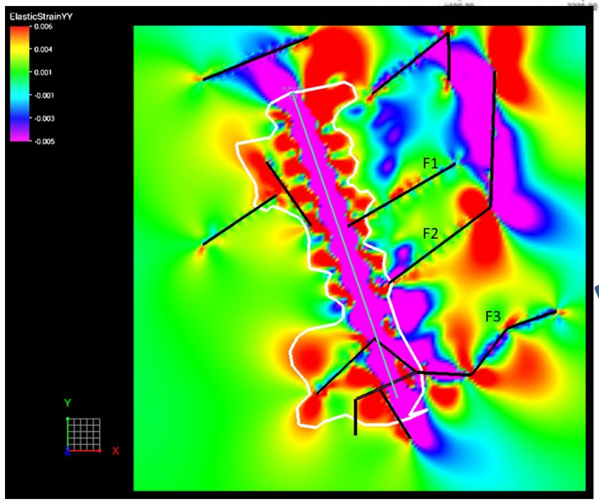
Major faults



(B)

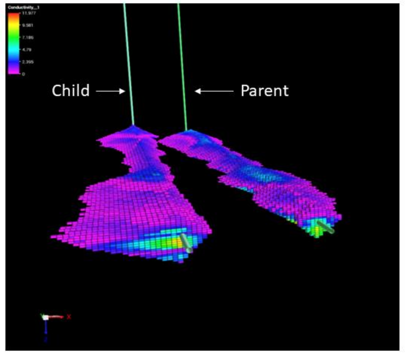
Diff stress and max stress orientation





Strain in the presence of depleted parent well

First Break, Vol 37
April 2019

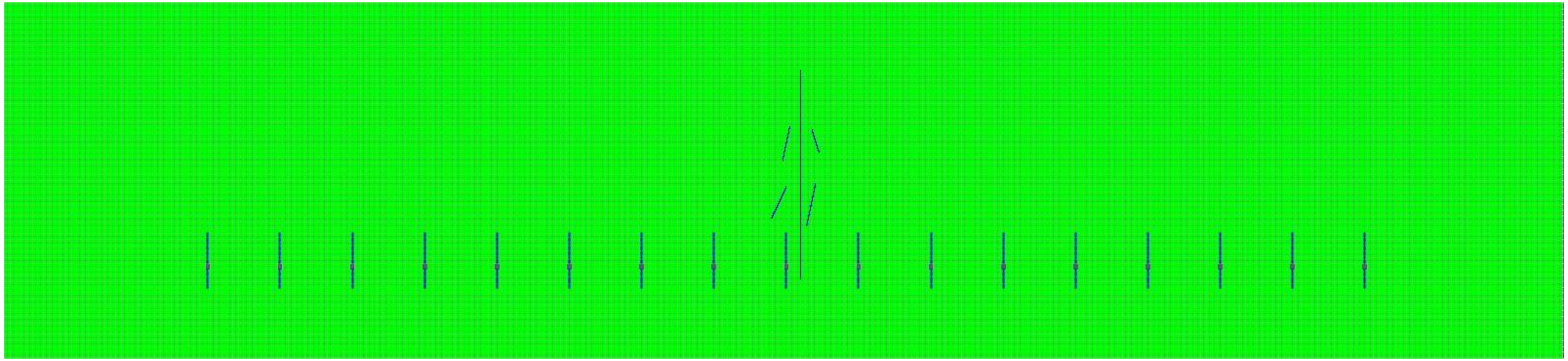


(A)

(B)

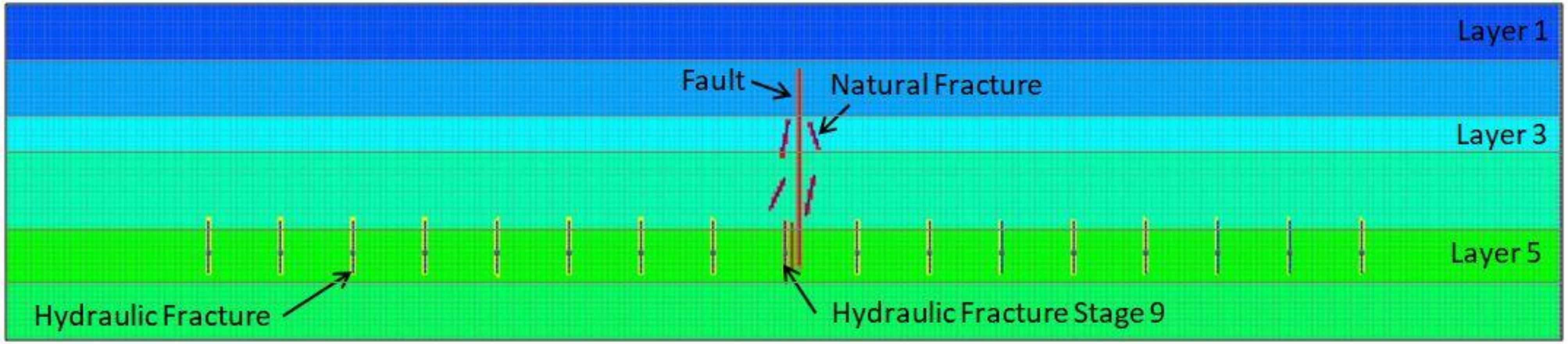
Fracture geometry and proppant concentration

3D Seismic to capture faults in the vertical direction



Cross Section View

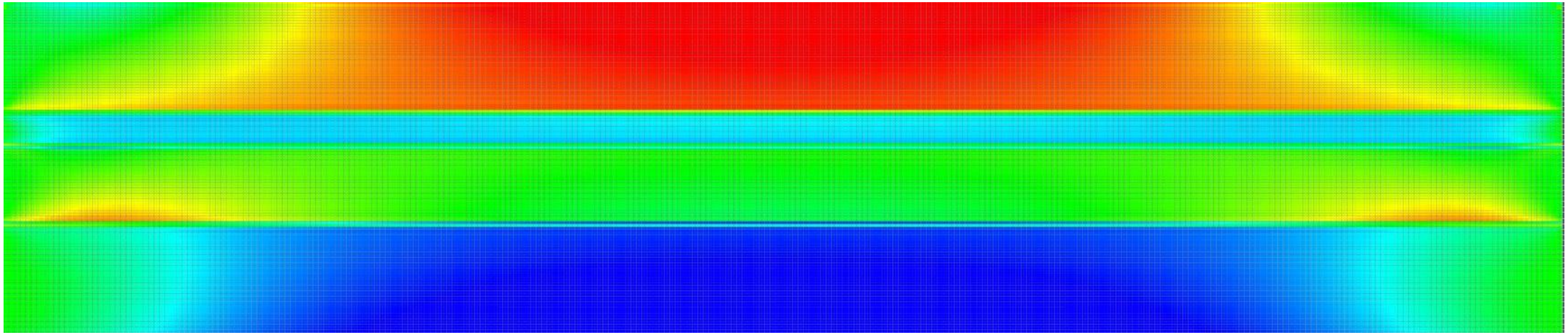
Initial Fracture/Fault Model



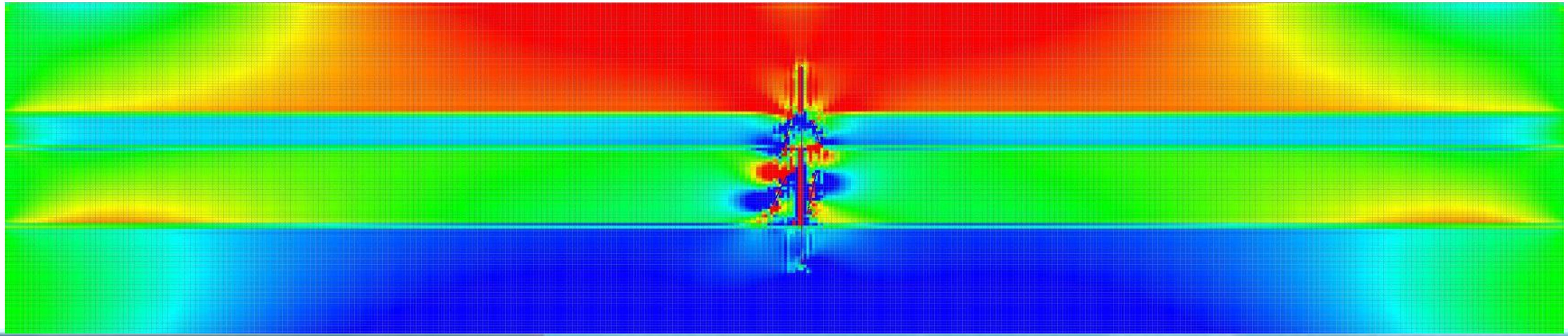
SPE 187535 (2017)

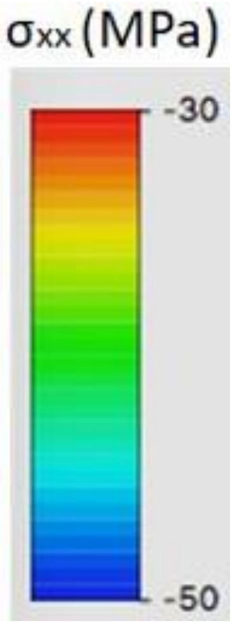
faults disturb the stress field in the vertical direction

Stress Distribution Without Fault



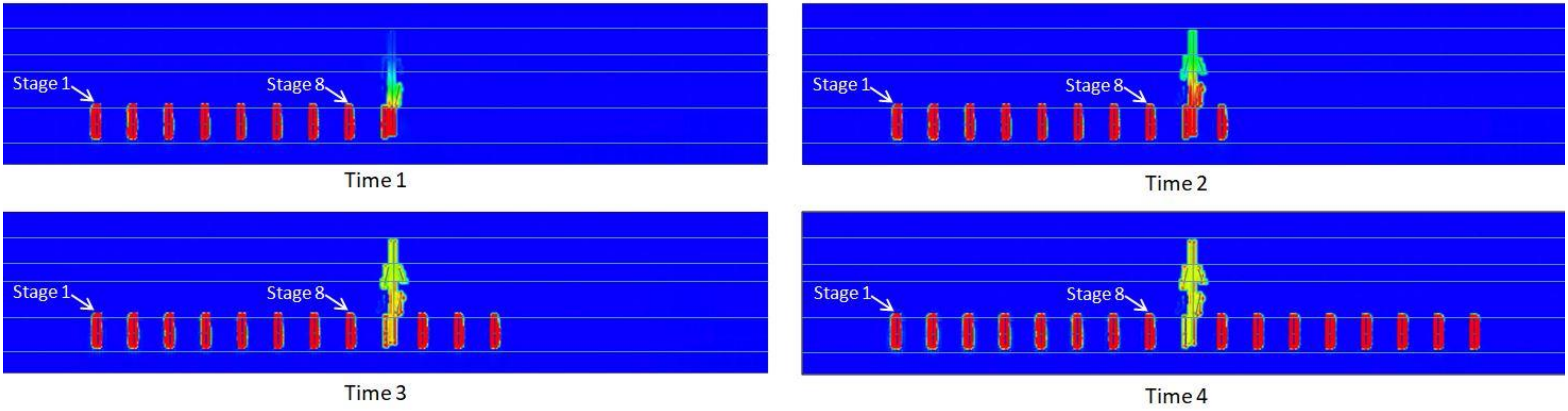
Stress Distribution With Fault





SPE 187535 (2017)

Poroelastic effects through faults in the vertical direction → lot of water in the Permian wells coming from this effect



https://youtu.be/AtN97CncSZE

SPE 187535 (2017)

Food for thought

- The field evidence and their validated geomechanical modeling supports the extensive use of seismic as a critical input to derive the necessary information required by frac design, analysis and reservoir simulation

- New workflows and software have been developed to make the use of seismic in geologic and geomechanical modeling for engineering applications easy and fast.

Food for thought

- The cost of the seismic and the software to use it efficiently is a fraction of the cost of a well.
- The economical loss resulting from poor landing zone selection, poor geosteering, frac hits, high water production (and all other disasters created due to a lack of seismic and appropriate tools to use it efficiently) is many orders of magnitude the cost of that seismic
- Do not go cheap on seismic (Believe me I am an engineer who has been developing and using seismic algorithms for 3 decades)

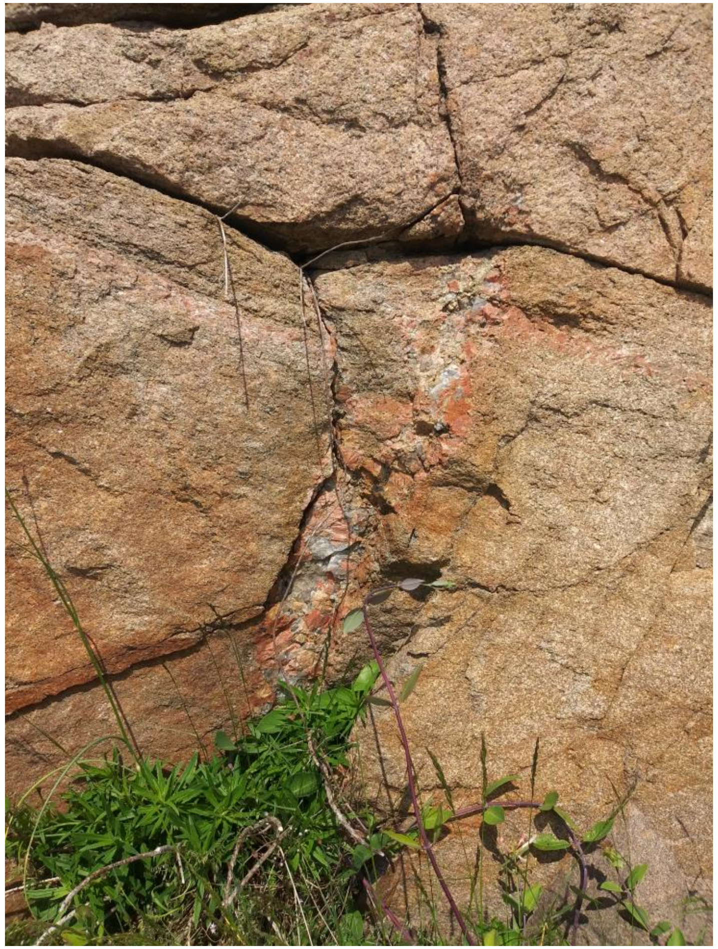
Further reading

URTEC 2019

- "Seismically Driven Estimation Of Stress Rotation And Anisotropy And Its Impact On Well Performance Application To The Delaware Basin" , Anadarko, TGS, FracGeo, URTEC 932 (2019)
- "Quantifying Hydraulic Fracture Height Reduction In The Presence Of Laminations And Weak Interfaces - Validation With Microseismic Moment Tensor Inversion In The Montney Shale" Painted Pony, FracGeo, URTEC 875 (2019)
- "Estimation Of 3D Distribution Of Pore Pressure From Surface Drilling Data - Application To Optimal Drilling And Frac Hit Prevention In The Eagle Ford" Equinor, FracGeo, URTEC 511 (2019)
- "Bayesian Probabilistic Analysis To Quantify Uncertainties In Hydraulic Fracture Geometry Application To Laminations And Their Impact On Fracture Height" FracGeo, URTEC 517 (2019)

- Preventing frac hits and well interferences with fast marching simulation using embedded discrete fracture models constrained by poroelastic geomechanical modelling of enhanced permeability, FracGeo, First Break, Vol 37, (April 2019)
- Adaptive fracturing to avoid frac hits and interference: a Wolcamp shale case study, FracGeo, SPE 185044 (2017)
- Geomechanical modeling of fault systems using the Material Point Method – Application to the estimation of induced seismicity potential to bolster hydraulic fracturing social license, FracGeo, DOI:10.7569/JSEE.2016.629515
- Surface drilling data for constrained hydraulic fracturing and fast reservoir simulation of unconventional wells, FracGeo (2019) https://www.intechopen.com/online-first/surface-drilling-data-for-constrained-hydraulic-fracturing-and-fast-reservoir-simulation-of-unconven

Thank you !



Humbling mother nature lessons in interaction between fractures and the impact of interfaces