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A Novel Application of Geocellular Modeling in Lab-scale Studies of Injection-induced Seismicity

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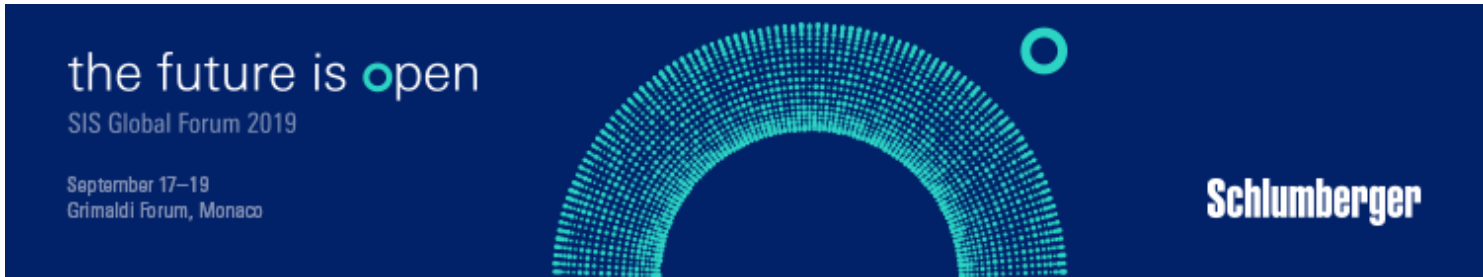


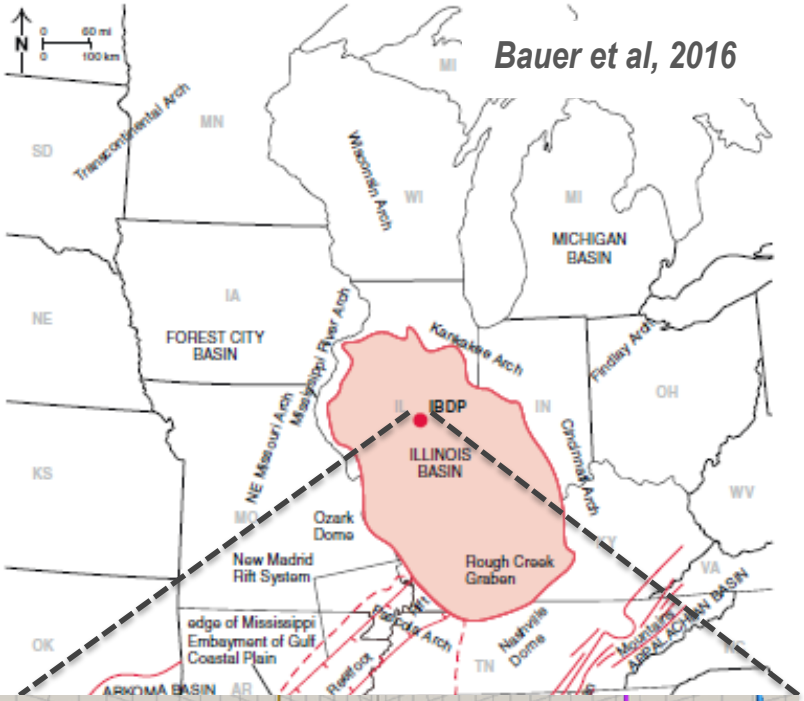
Background and motivation

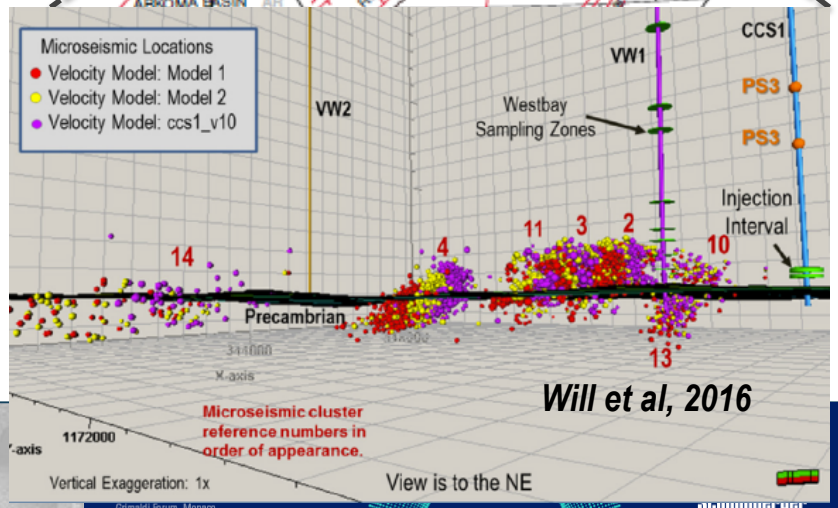
Background:

- Recorded low-magnitude microseismic events at CO_2 and fluid injection projects (e.g. Illinois Basin Decatur project)
- To investigate the impact of flow processes on event occurrence, a large block test was conducted through collaborative effort of multi-institutes

Motivation for study:

- Apply geocellular modeling to study dynamic processes observed in lab experiment and provide deeper insight to these processes





Presentation outline

- Background
  - Large sandstone block test design and scenarios
  - Test result
- Geocellular Modeling;
  - Block sampling and petrophysics
  - Structural and property modeling
- Modeling
  - Dynamic modeling effort
  - Coupled reservoir-geomechanics model
- Preliminary results
- Summary and conclusions

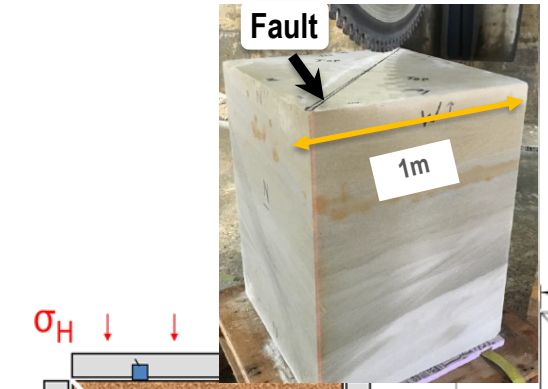
Background: Test design and scenarios

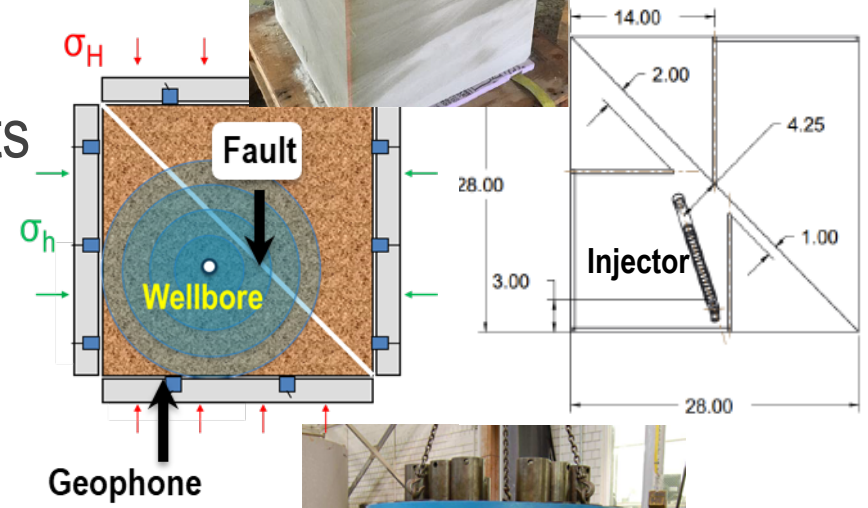
Test Design:

- Block was sawed into two halves to mimic a fracture/fault
- Boreholes include 1 main injector and 3 pore pressure monitoring ports
- Geophones were buried on block sides to detect acoustic emissions

Scenarios:

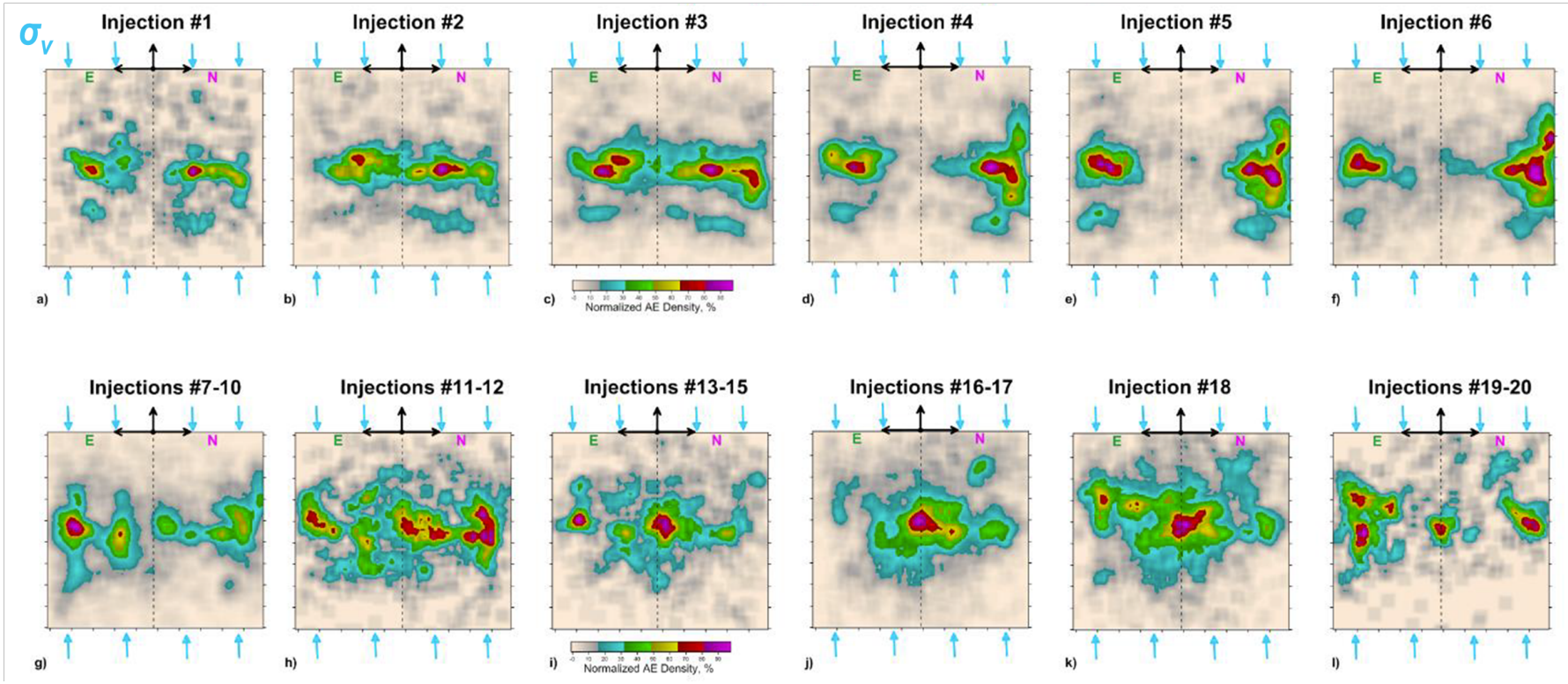
- 22 stages of fluid injection was performed on the block under varying differential stress in a triaxial stress frame over 2 days





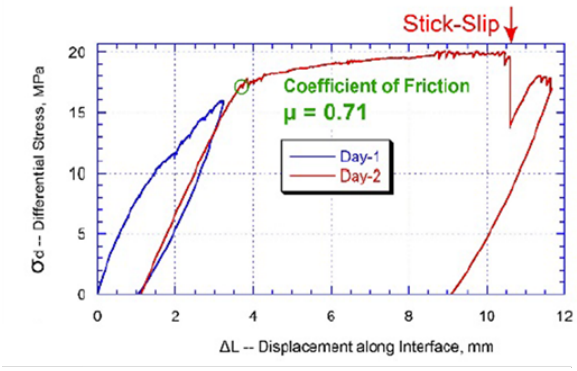
Background: Test results

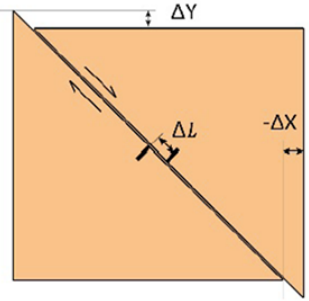
- Over 36,000 acoustic emissions were recorded
- Pore pressure around 1MPa did not initiate slip along the fault

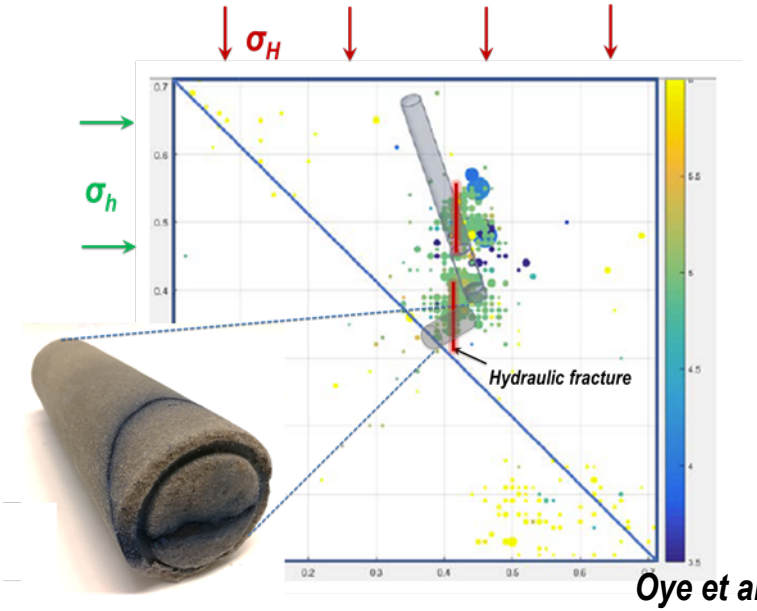


Background: Test results

- Displacement along fault increased linearly with increased differential stress
- Pore pressure above 3.5MPa created hydraulic fracture around main injector
- Hydraulic fracture enhanced pressure communication between the injector and interface, causing a stick slip motion along the interface





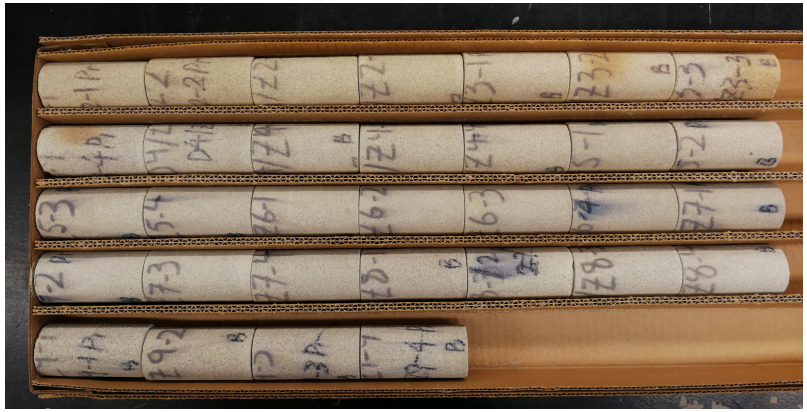


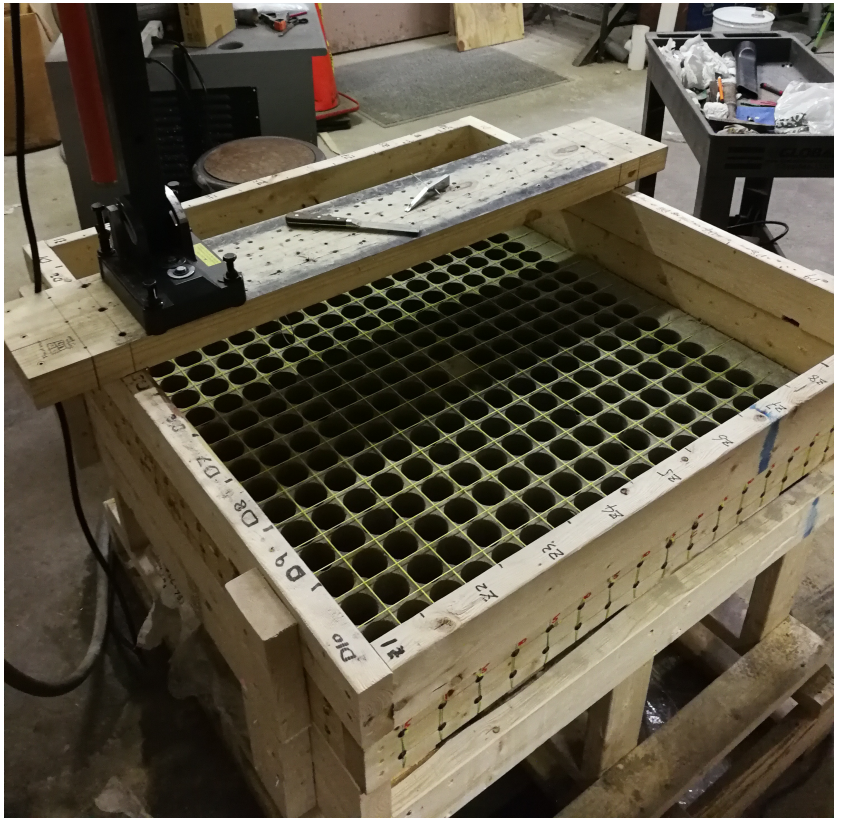
Oye et al, 2018

Geocellular Modeling

Geocellular modeling: Block sampling

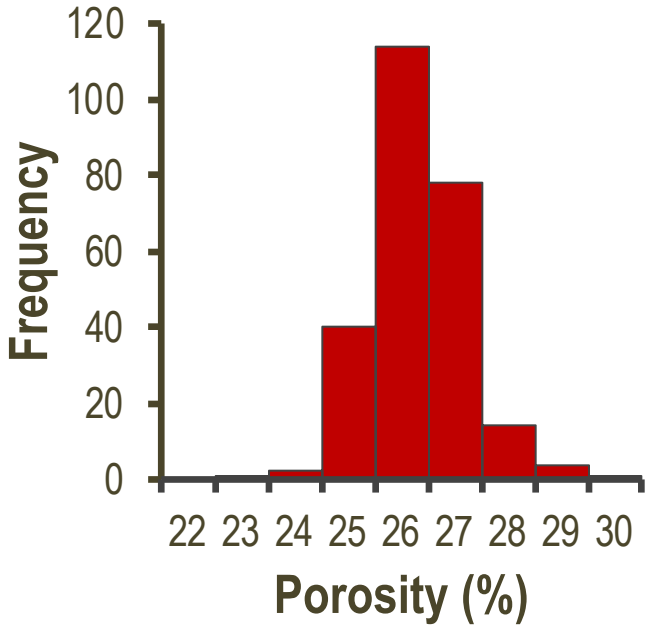
- Around 320 plugs was collected along the fault surface
- RCAL was conducted on collected core plugs

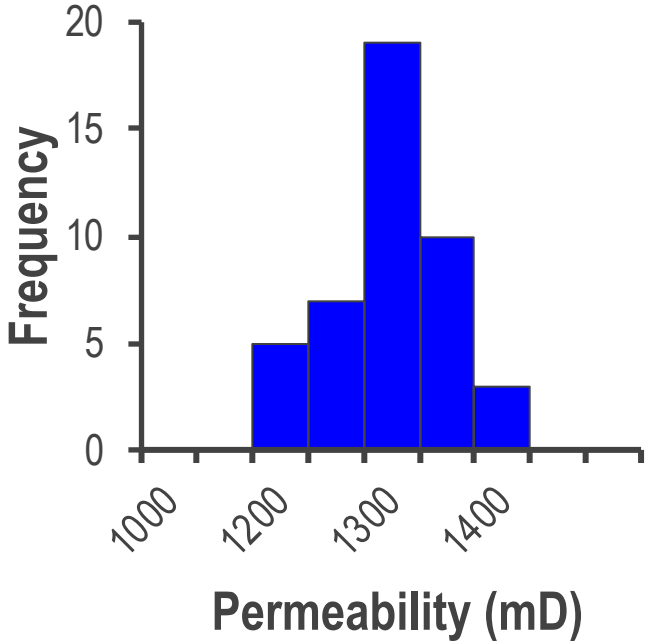




Geocellular modeling: Petrophysics

- Summary statistics of core test result



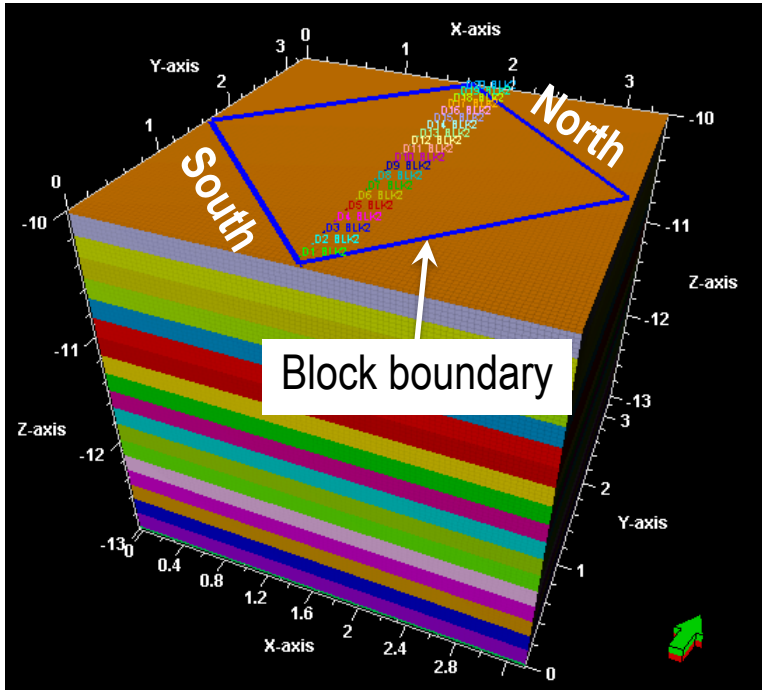


Mean	*27.8 %*
Standard deviation	*1.7 %*
Minimum	*23 %*
Maximum	*32.1 %*

Mean	*1277 mD*
Standard deviation	*48.7 mD*
Minimum	*1176 mD*
Maximum	*1377 mD*

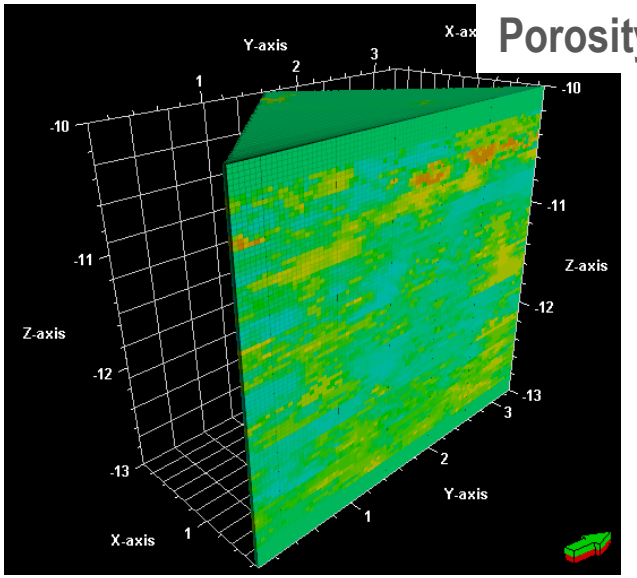
Geocellular modeling: Importing core test data

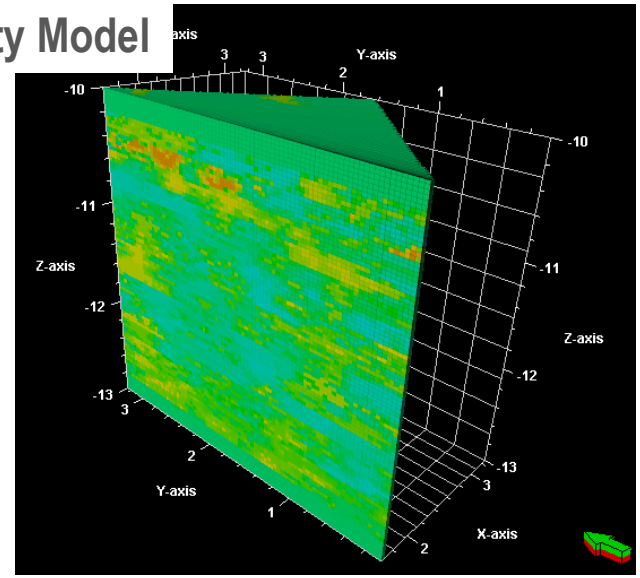
- Core measurements were used to create synthetic well data/logs imported into Petrel
- Flat surfaces were created in Petrel to capture grid design, create layers, and zones

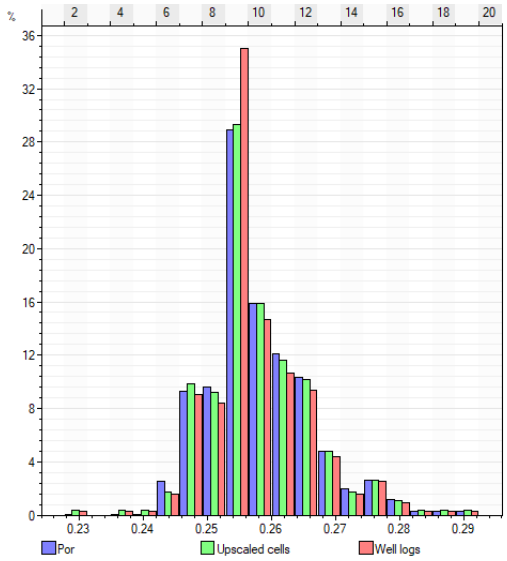


Geocellular modeling: porosity & permeability

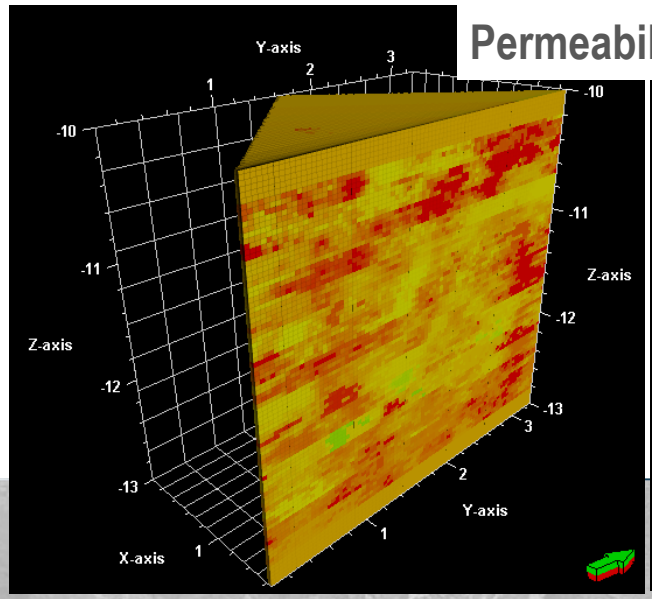
Porosity Model

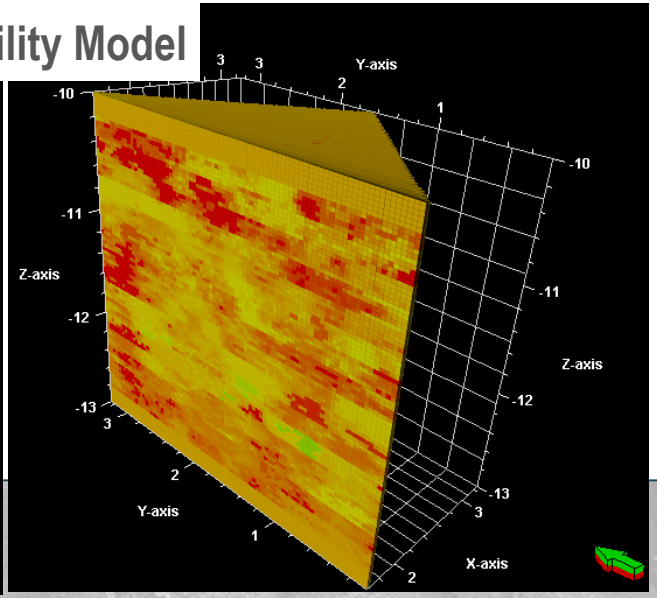


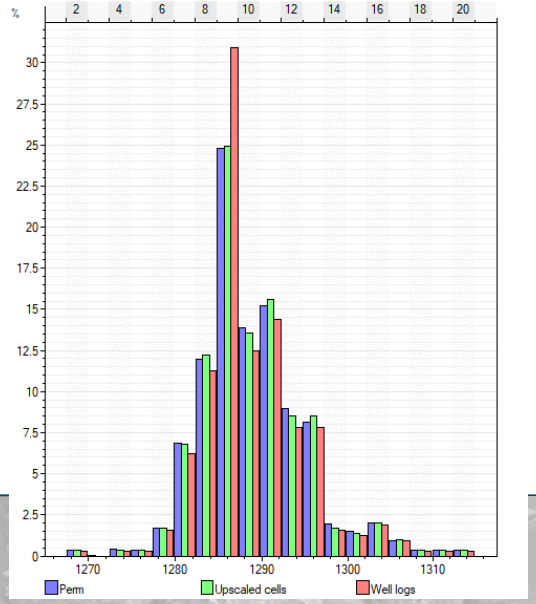




Permeability Model

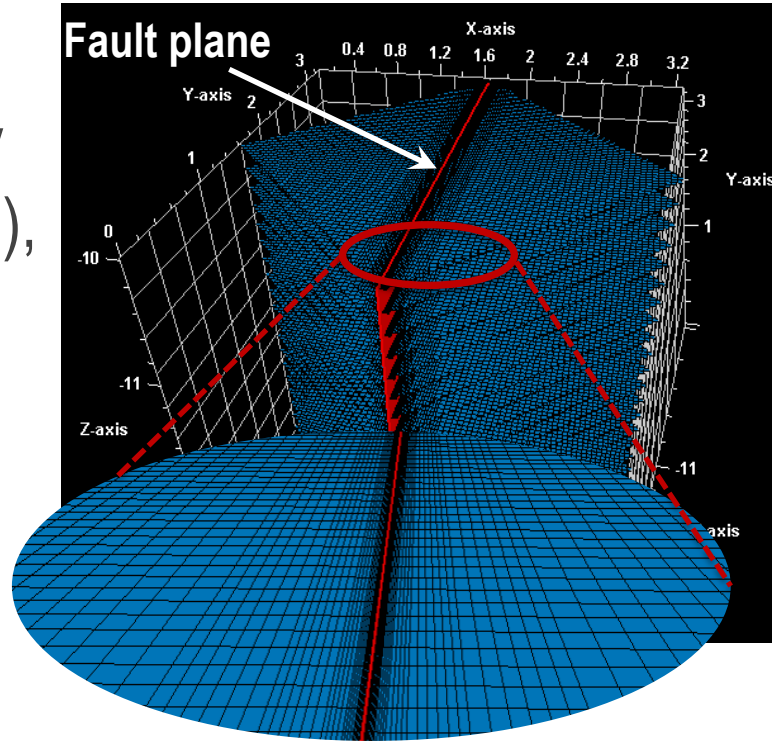






Geocellular modeling: Fault and Grid design

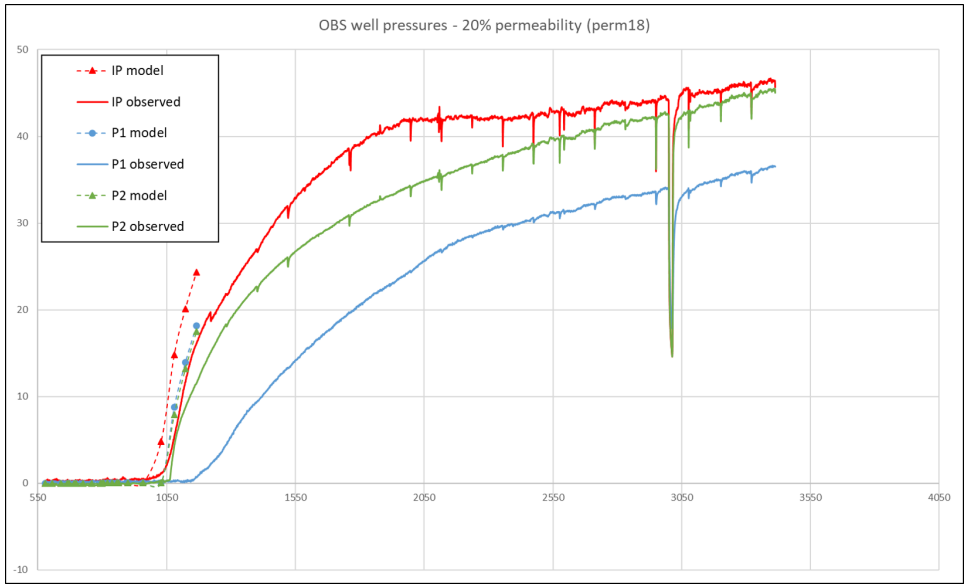
- For dynamic modeling;
  - ➢Model grid was designed to be finely gridded around the fault (0.2 mm width), and
  - ➢Cell size increases in multiples (0.2, 0.4,…,12.8 mm) away from the fault until cell width reaches 12.8 mm
- For coupled reservoir-geomechanics modeling;
  - ➢Model grid was made uniform in order to include simulated fault in the model



Grid cell (Uniform)=12.8 x 12.8 mm (.04 x .04 ft)
Total number of grid cell ≈ 10^6

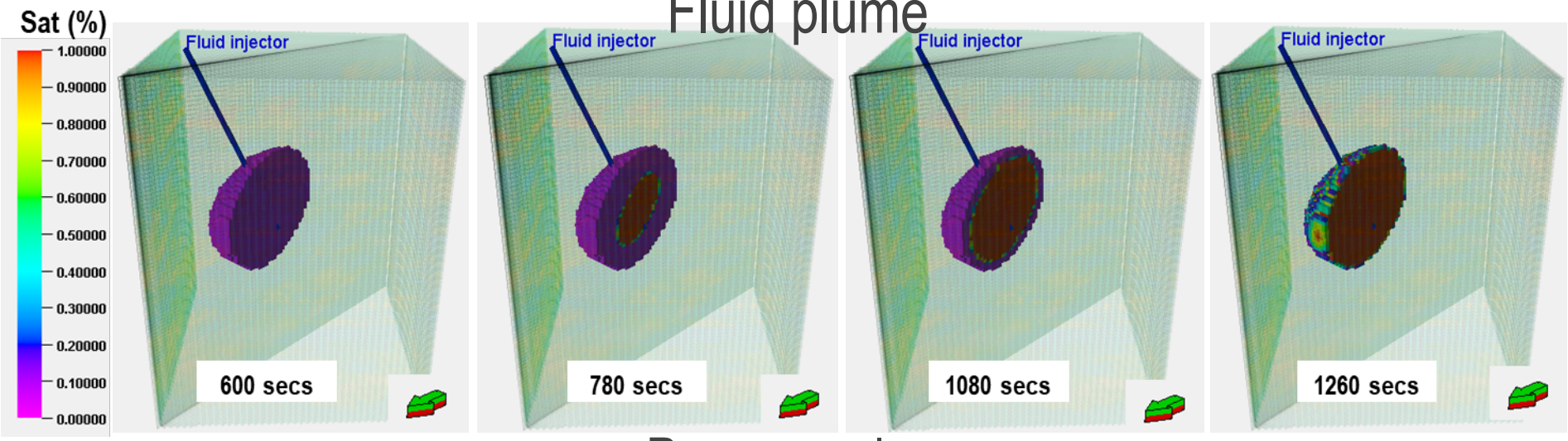
Dynamic modeling

- Preliminary pressure response from dynamic modeling was used as data input for geomechanical modeling
- To geomechanically simulate second to last injection stage of the experiment, magnitude of the pressure plume was upscaled to match pressure response recorded during that stage

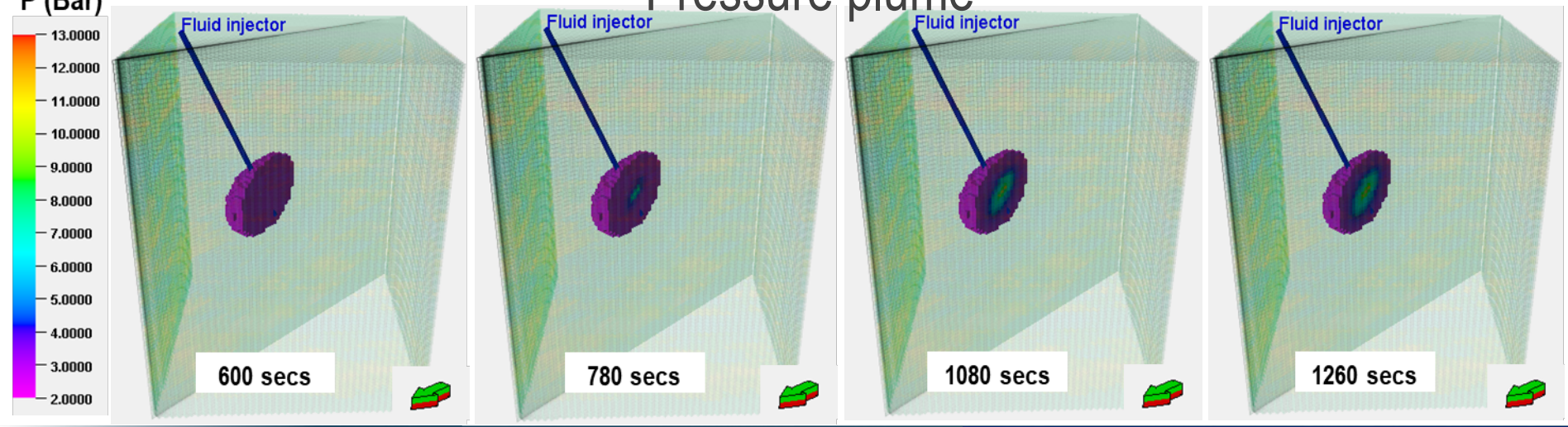


Dynamic modeling

Fluid plume



Pressure plume



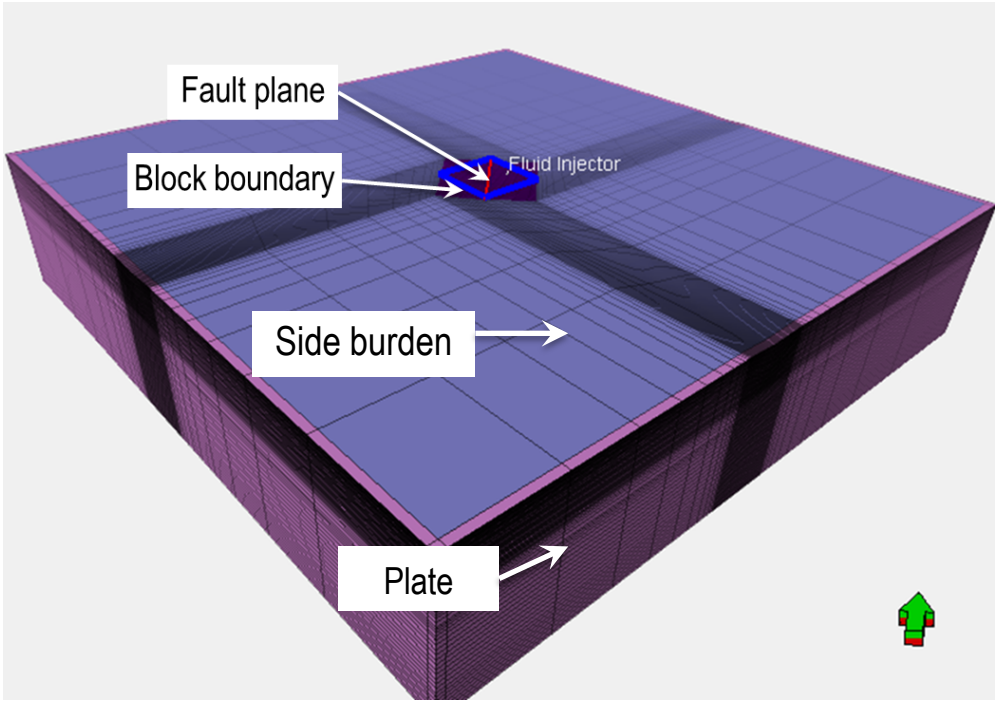
Material and geomechanical models

- A homogenous 3-D geomechanical model of Castlegate Sandstone was used as MEM
- Default properties of discontinuities in Petrel were used

Material	Geomechanical Property	Value
Castlegate Sandstone	Bulk Density (g/cc)	2.2
	Unconfined Compressive Strength (bar)	120
	Triaxial Compressive Strength (bar)	965
	Young's Modulus (GPa)	5
	Poisson's Ratio	0.25
	Friction Angle (deg)	37
	Dilation Angle (deg)	18
Fault	Normal Stiffness (bar/m)	40000
	Shear Stiffness (bar/m)	15000
	Cohesion (bar)	0.01
	Friction Angle (deg)	20
	Dilation Angle (deg)	10

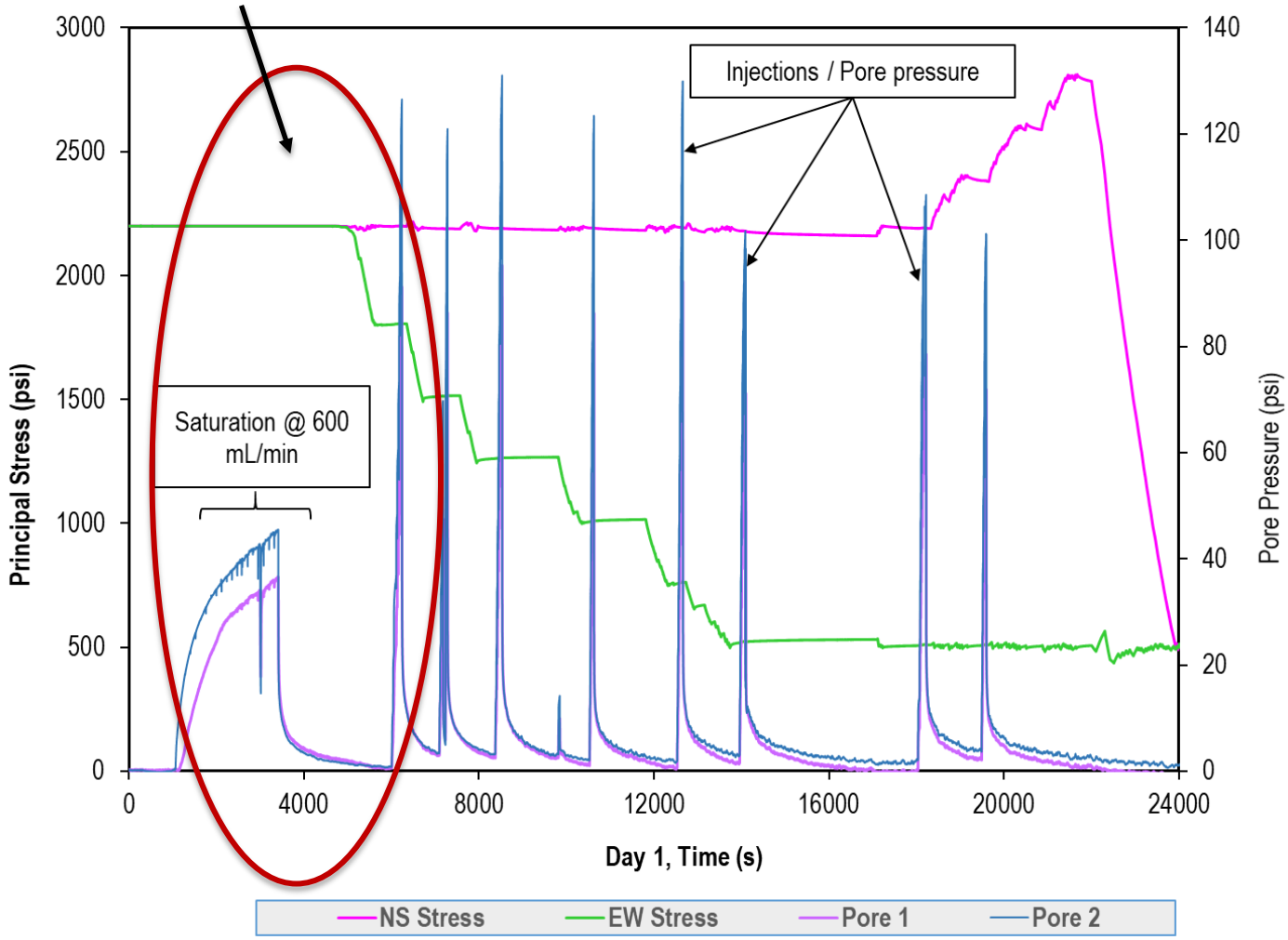
Geomechanical grid (model for Visage)

Material	Geomechanical Property	Value
Side-, under-, and over-burdens	Bulk Density (g/cc)	2.8
	Young's Modulus (GPa)	7.5
	Poisson's Ratio	0.15
	Biot Elastic Constant	1
	Porosity	0.01
Side Plate	Bulk Density (g/cc)	2.8
	Young's Modulus (GPa)	15
	Poisson's Ratio	0.15
	Biot Elastic Constant	1
	Porosity	0.01



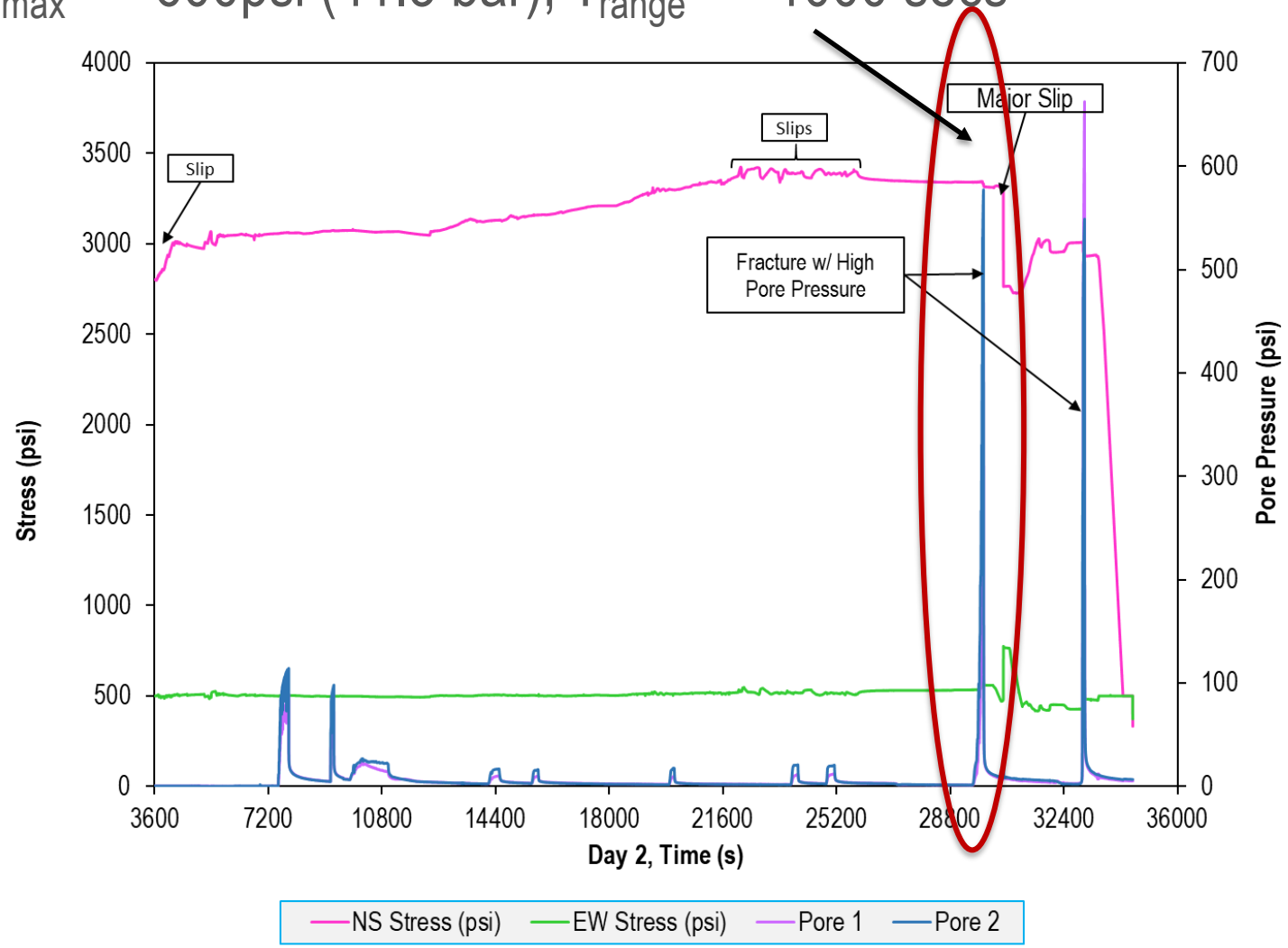
Geomechanical modeling (Visage case 1)

Saturation stage, , $\sigma_H / \sigma_v = 1.18$, $\sigma_h = \sigma_v = 1750$ psi (124 bar), P_{max} = ~50psi, T_{range} = ~ 3500 secs

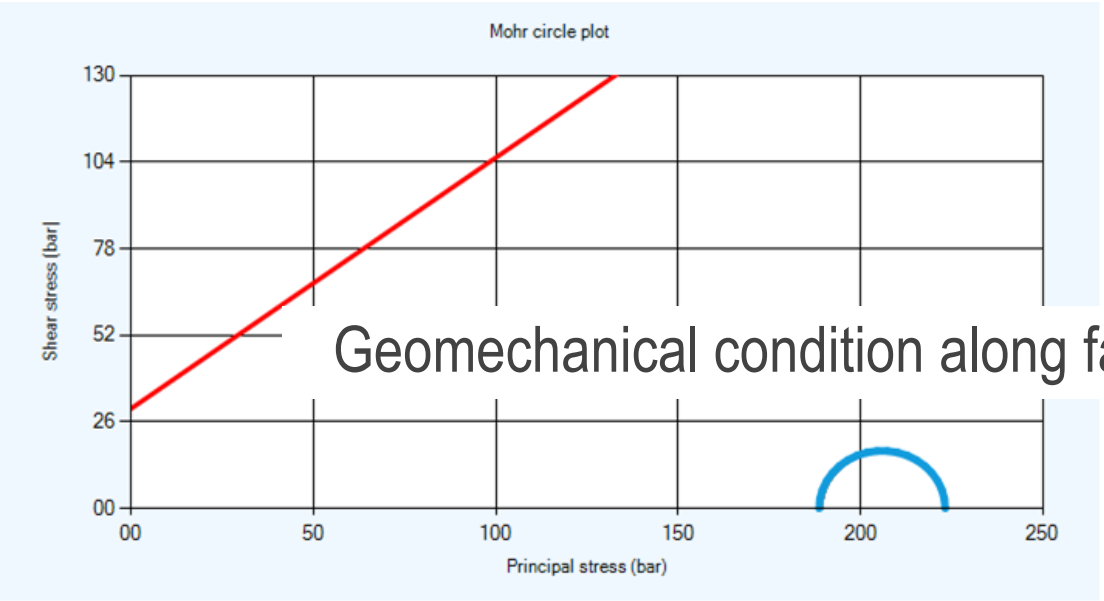


Geomechanical modeling (Visage case 2)

Inj # 21, $\sigma_H / \sigma_v = 6.8$, $\sigma_h = \sigma_v = 500$ psi (34.5 bar),
P_{max} = ~600psi (41.3 bar), T_{range} = ~ 1000 secs

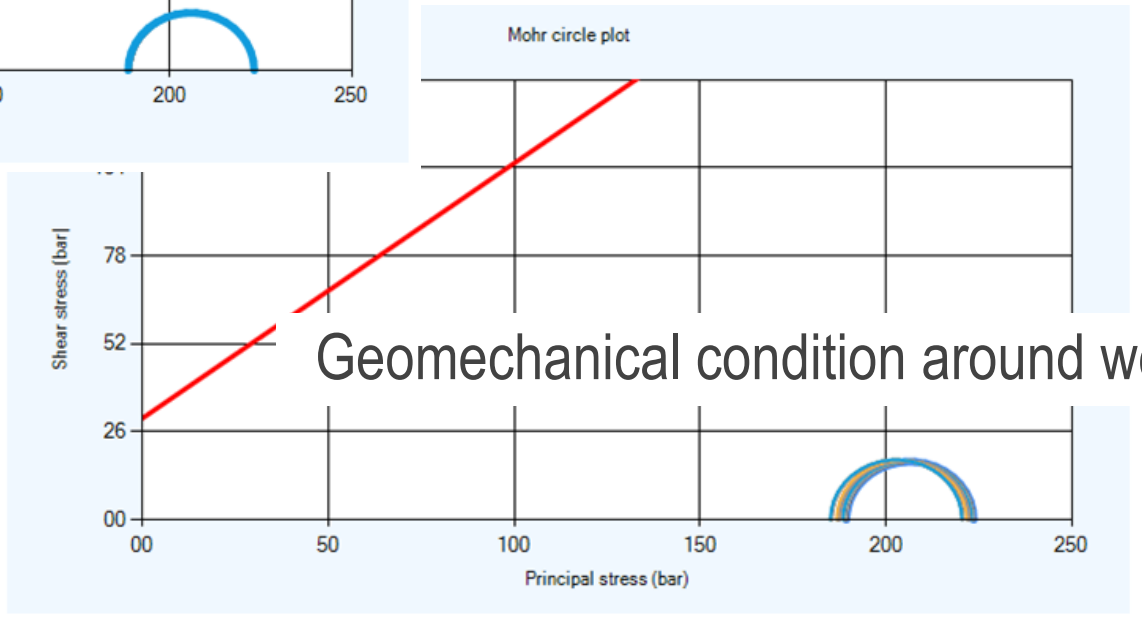


Geomechanical response (Preliminary result)



Visage case 1: Saturation stage

Geomechanical condition along fault

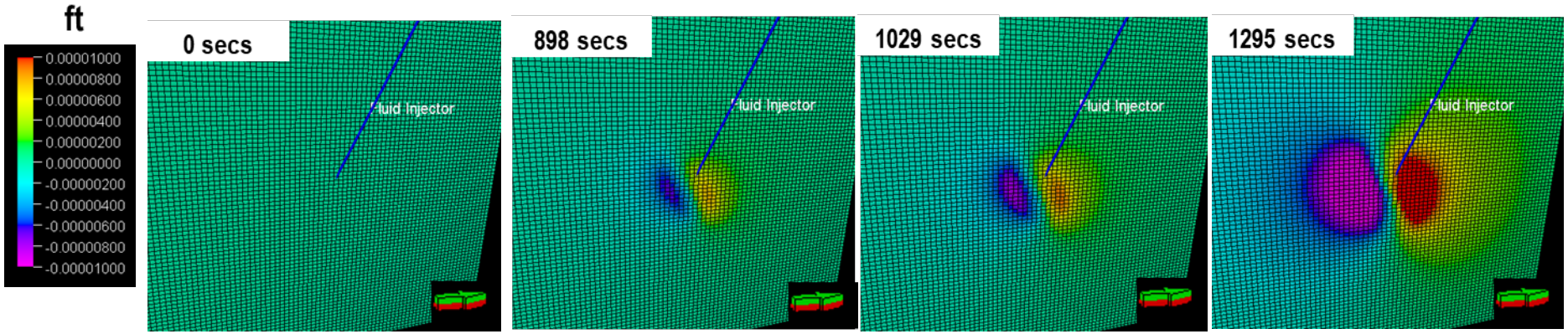


Geomechanical condition around well

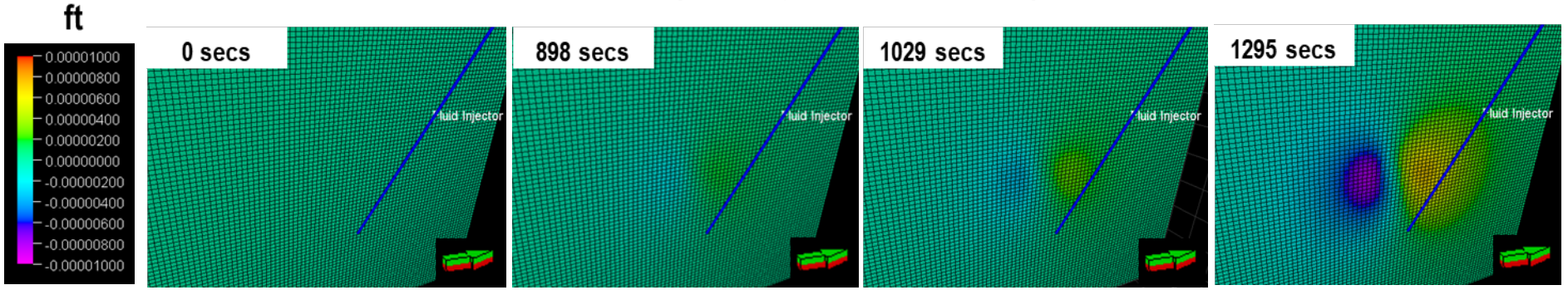
Geomechanical response (Preliminary result)

Visage case 2: Injection stage #21

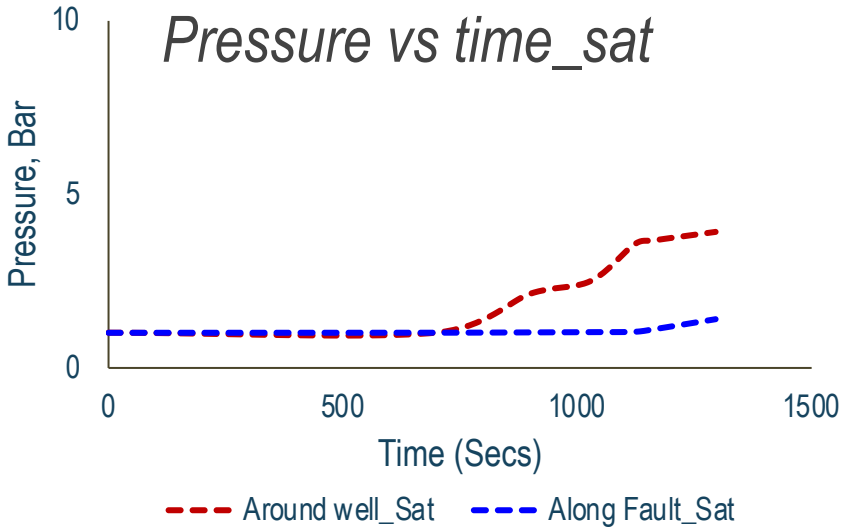
Displacement (along fault plane) around injection well

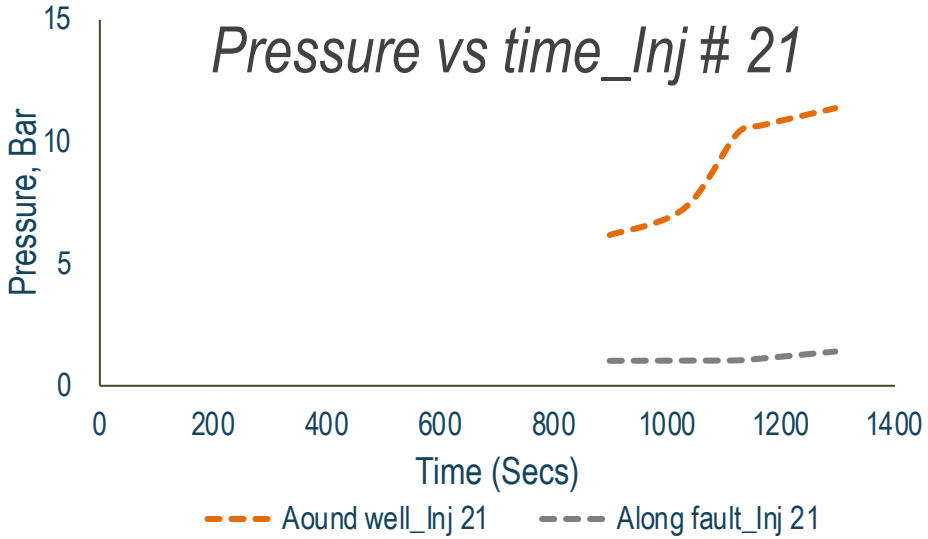


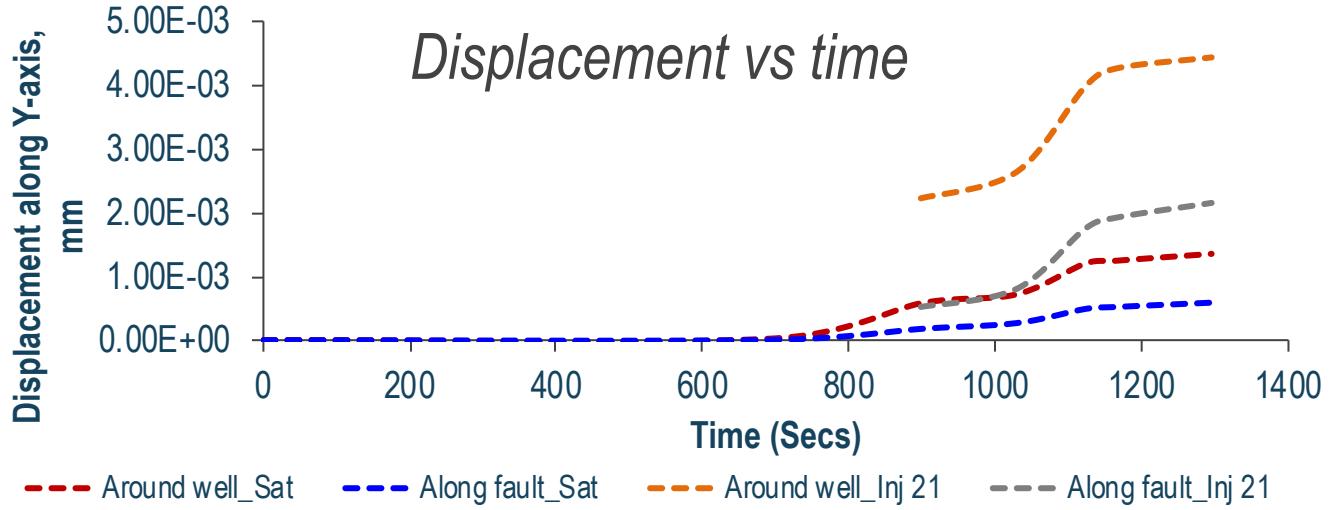
Displacement (along fault plane) around fault



Geomechanical response (Preliminary result)



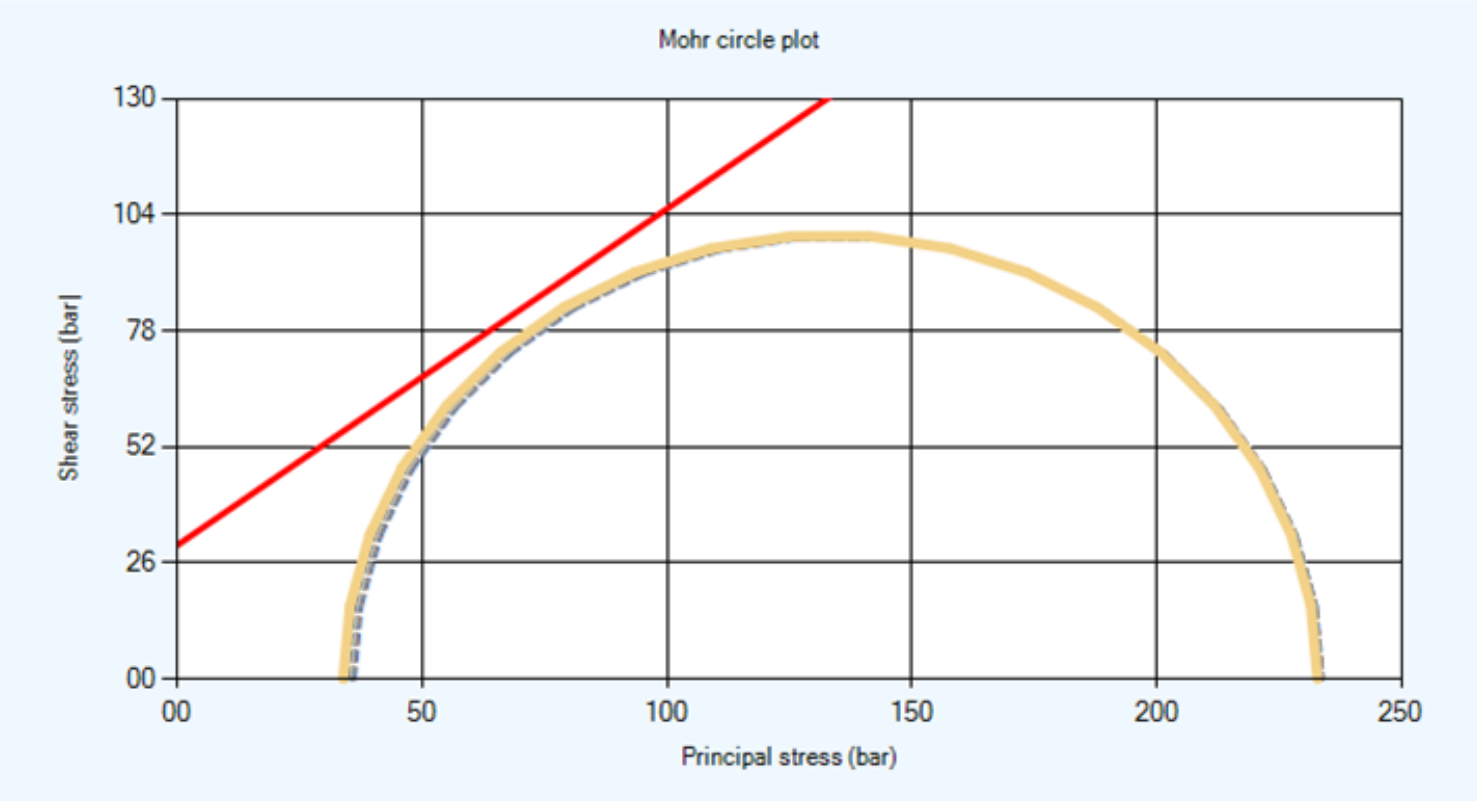




Geomechanical response (Preliminary result)

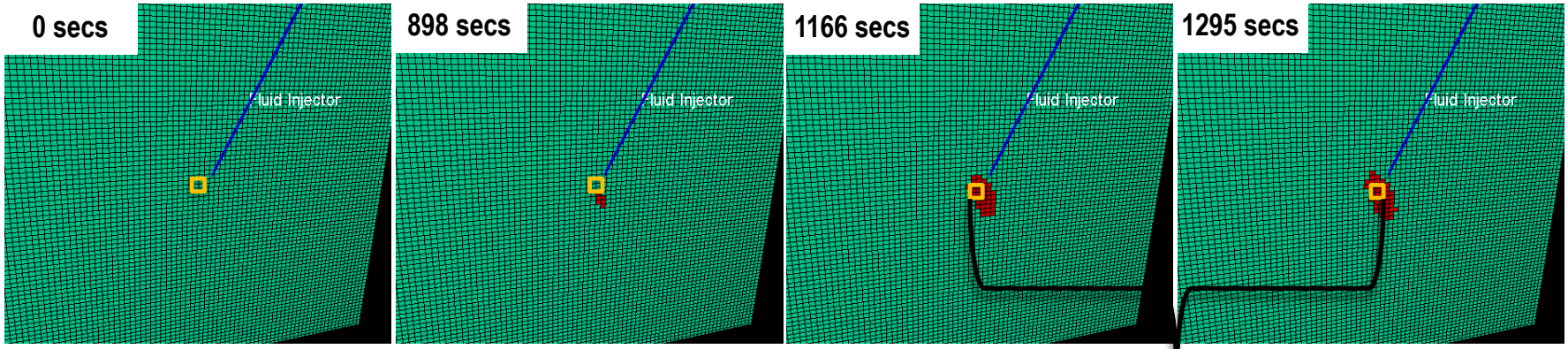
Visage case 2: Injection stage #21

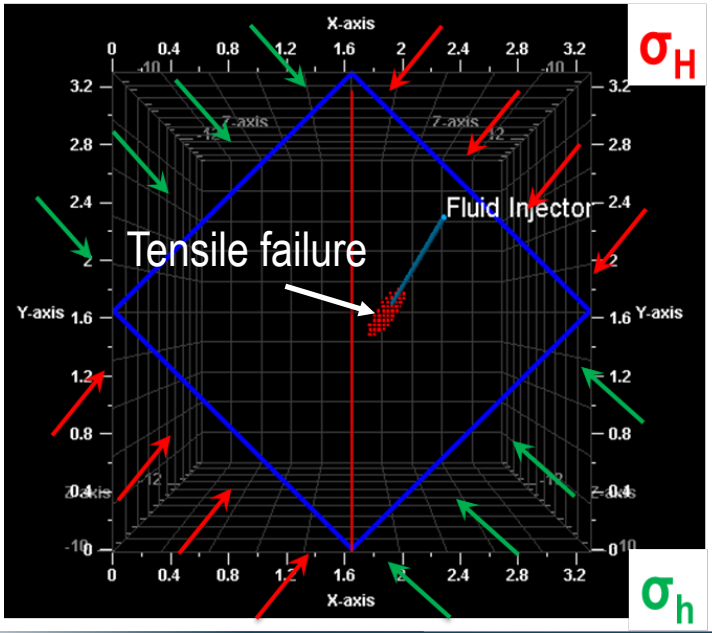
Geomechanical condition along fault

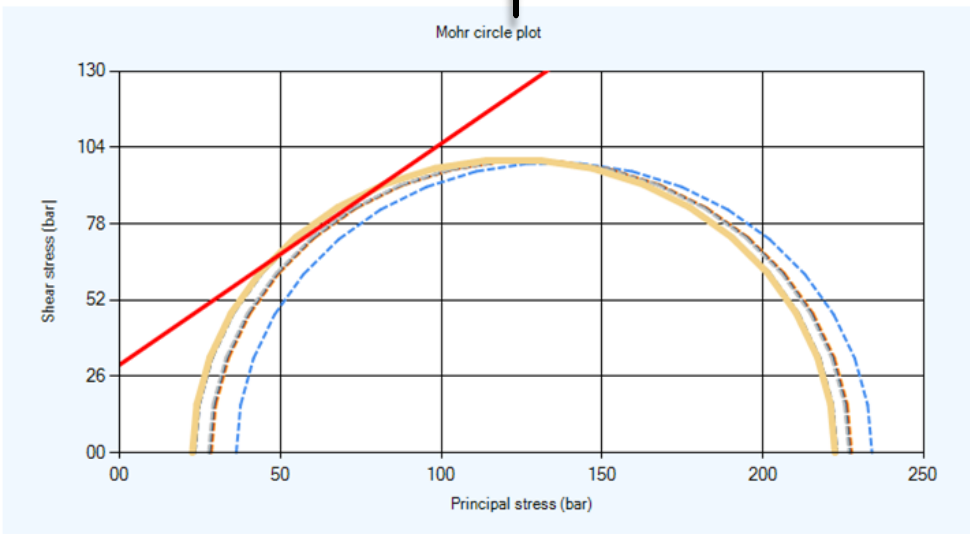


Geomechanical response (Preliminary result)

Geomechanical condition around well







Visage case 2: Injection stage #21

Summary and conclusions

- 3-D geocellular models of laboratory specimen are buildable in Petrel
- Results from lab experiments can be evaluated along with geocellular models to better understand dynamic processes
- Modeling result confirmed pressure changes up to 1 MPa did not cause tensile failure around the well
- Modeling result indicated pressure changes up to 3.5 MPa initiated tensile fracture around the well
- Modeling result indicates and confirms the initiation and propagation of hydraulic fracture parallel to the σ_{Hmax} direction

Future work

- Complete dynamic simulation that spans all injection stages and test period
- Re-run coupled reservoir-geomechanics model
- Conduct sensitivity study on parameters that were not measured, such as normal and shear stiffness of fault
- Calibrate geomechanical response to measurements observed post experiment

Acknowledgement

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an Energy Frontier Research Center funded by
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Project team and individual roles

Scott Frailey (ISGS)- GSCO2 Center director/principal investigator/modeling advisor

Sergey Stanchits (Skoltech Institute)- Experiment design and event analysis

Volker Oye (NORSAR)- Microseismic theme lead, experiment design and event analysis

Nick Seprodi (Schlumberger)- Laboratory manager

Robert Bauer (ISGS)- Experiment design and event analysis

Pierre Cerasi (SINTEF)- Experiment design and event analysis

Steve Whittaker (ISGS)- Geologic advisor

Dustin Sweet (TexasTech)- Geology theme lead

Ed Mehnert (ISGS)- Reservoir modeling

Ankit Verma (ISGS)- Reservoir modeling

Shuo Yan (ISGS) – Reservoir modeling

Zihe Zhao (ISGS)- Block sampling and core testing

Thanks for your attention

Questions?