Multi-Scale Simulation of Hydraulic Fracturing and Production:

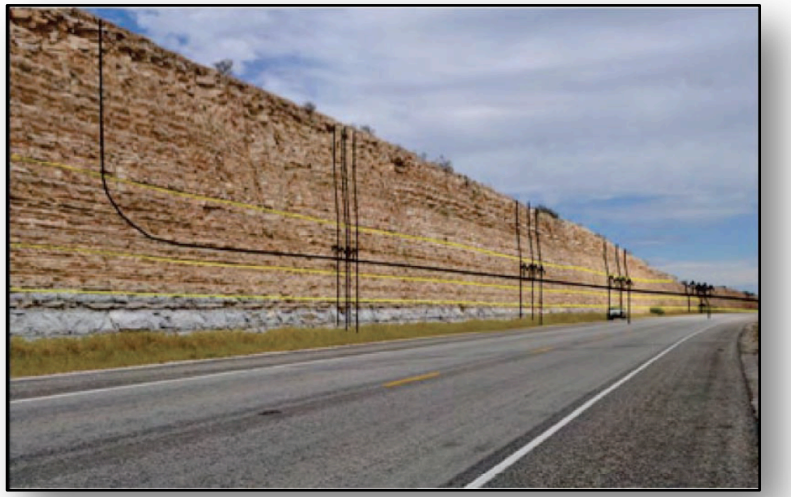
Testing with Comprehensive Data from the Hydraulic Fracturing Field Test in the Permian Basin

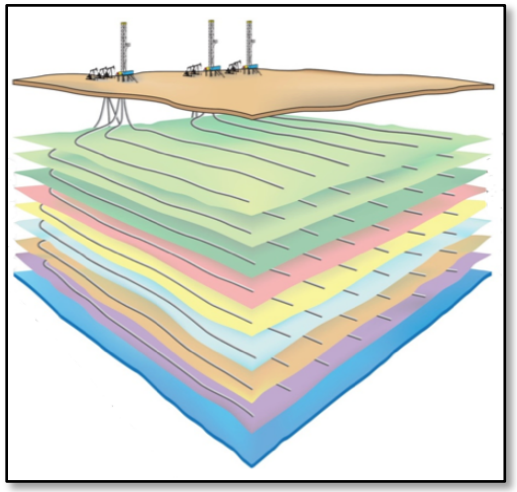
The HFTS Modeling Team (LBNL, LLNL, NETL, SLAC)

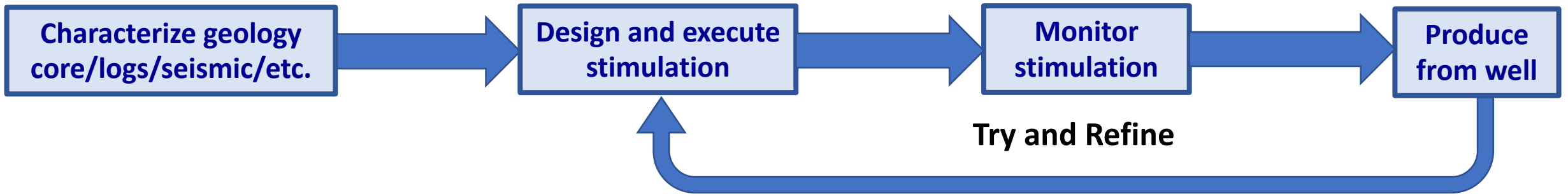
Jens Birkholzer, Joseph Morris, John Bargar, Abdullah Cihan, Dustin Crandall, Hang Deng, Pengcheng Fu, Angela Goodman, Alexandra Hakala, Yue Hao, Adam Jew, Timothy Kneafsey, Christina Lopano, Sergi Molins Rafa, Seiji Nakagawa, George Moridis, Matthew Reagan, Randolph Settgast, Carl Steefel, Marco Voltolini

LBNL - FWP FP00008049, LLNL - FWP FEW0250, NETL - FWP 1022415, SLAC - FWP 10048

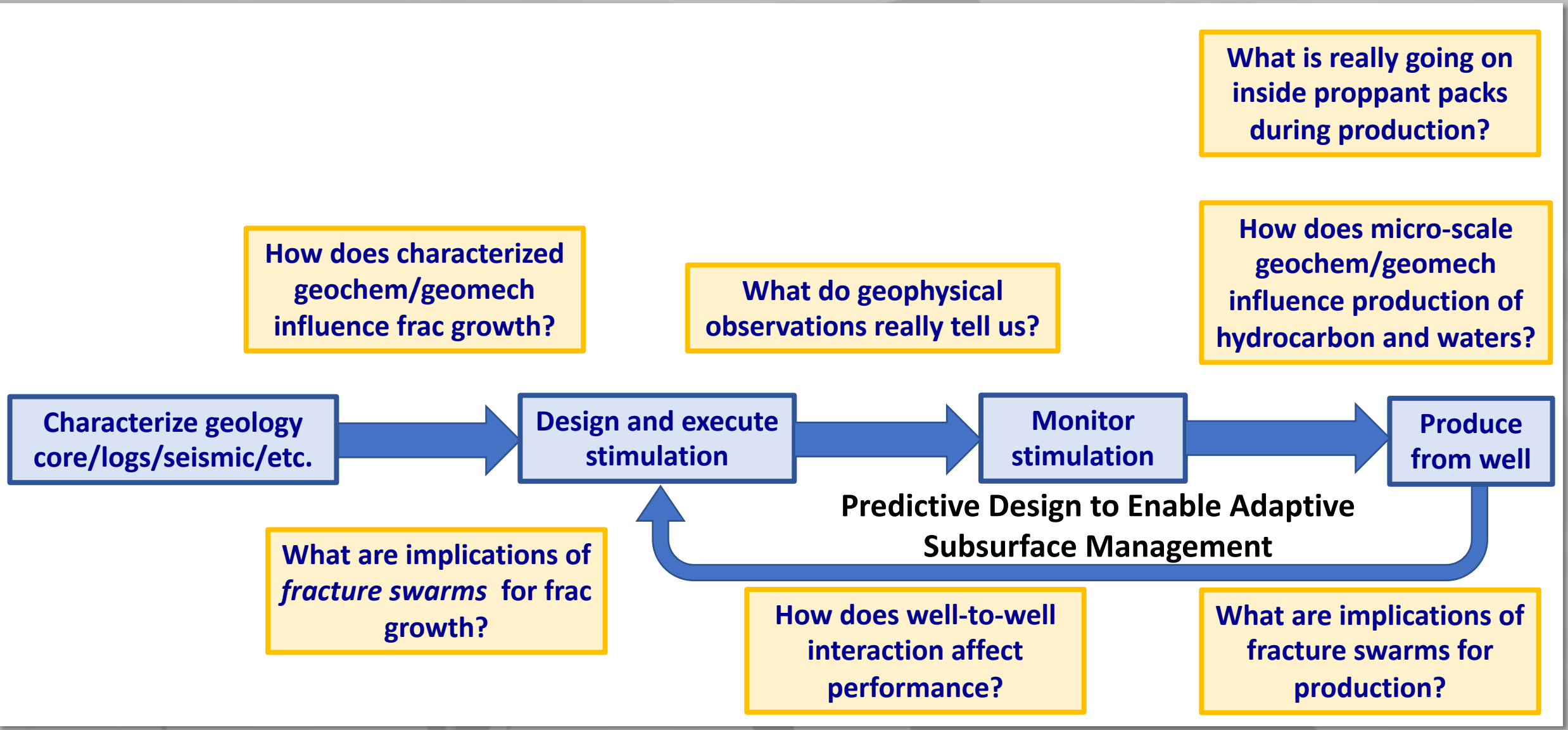
Typical Process in Unconventionals Today



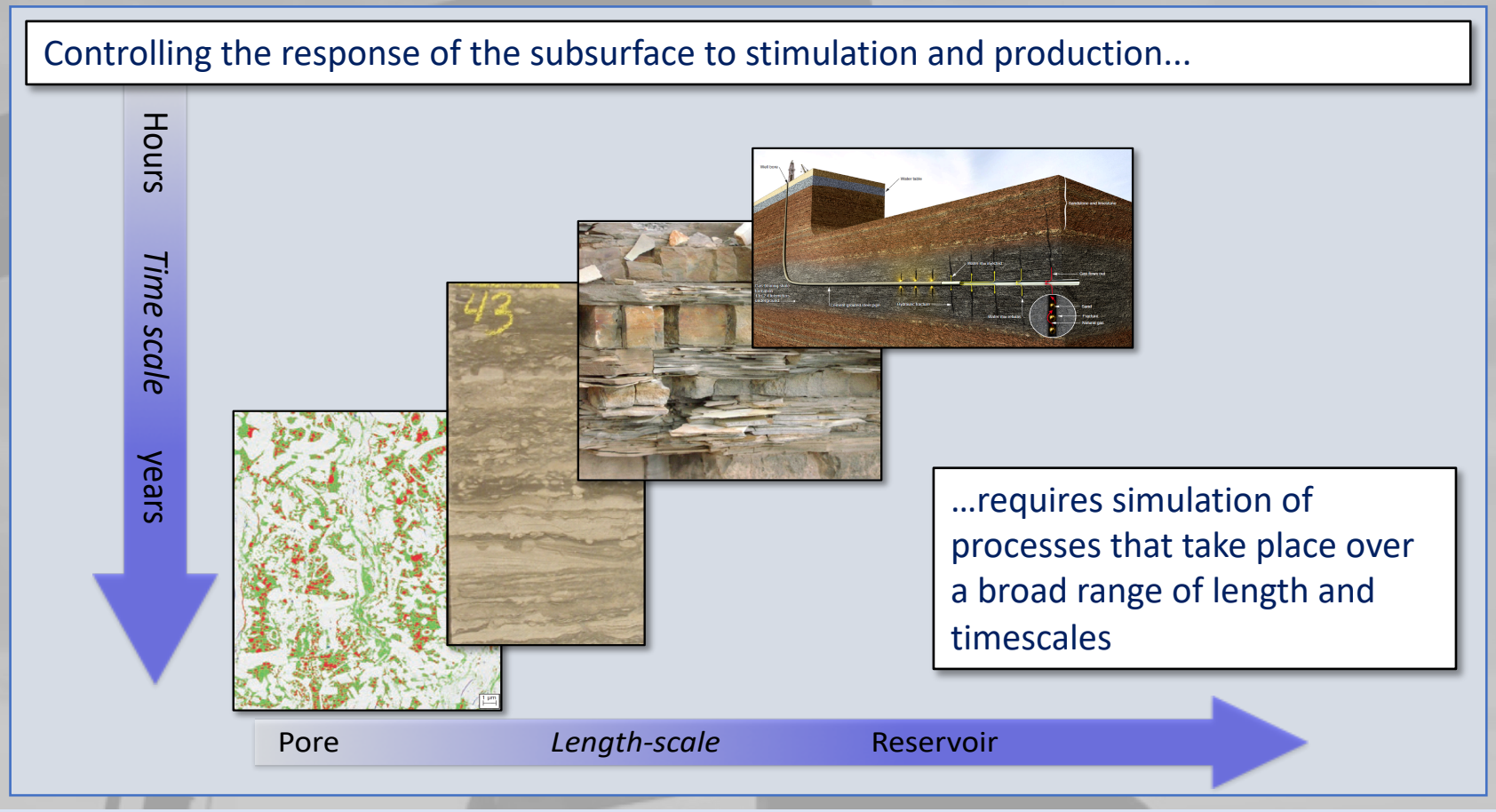




Multiple Gaps in Understanding Prevent Predictive Design



Adaptive Subsurface Management Based on Multi-Scale Modeling of Stimulation and Production



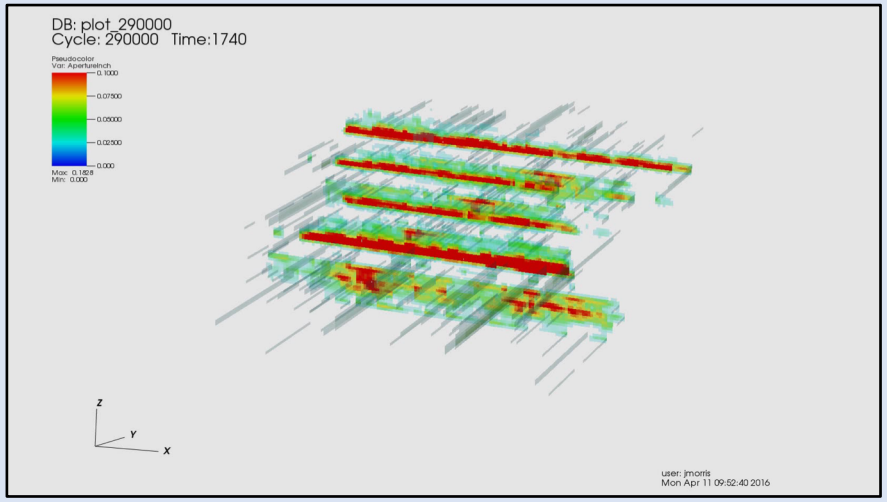
A New Framework for Microscopic to Reservoir-Scale Simulation of Hydraulic Fracturing and Production:

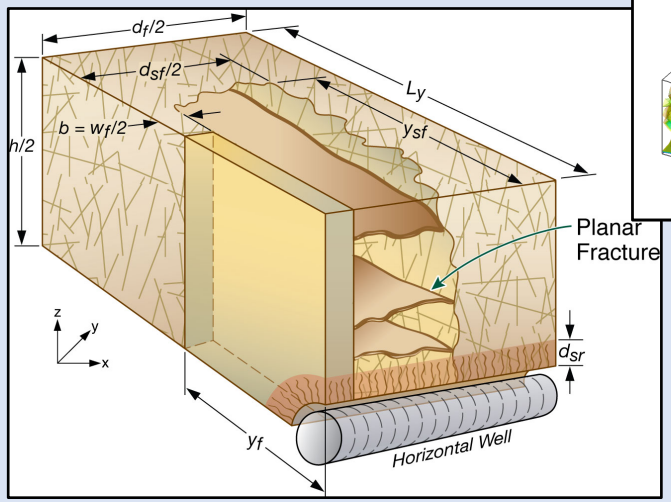
Fusing Existing HPC and Experimental Capabilities at DOE's National Labs

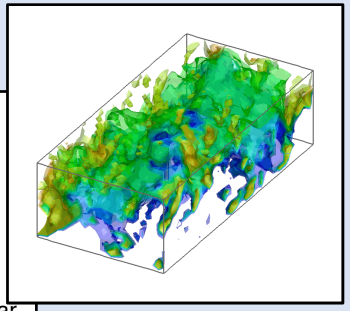
A Multi-Scale Multi-Physics Multi-Lab Project

Linking Two Powerful Simulators to Answer Complex Questions at the Reservoir Scale: GEOS for Stimulation Behavior, TOUGH for Production

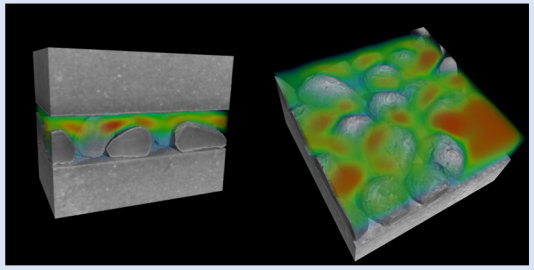
GEOS ⟷ TOUGH

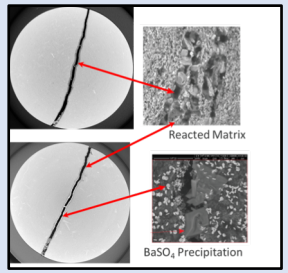


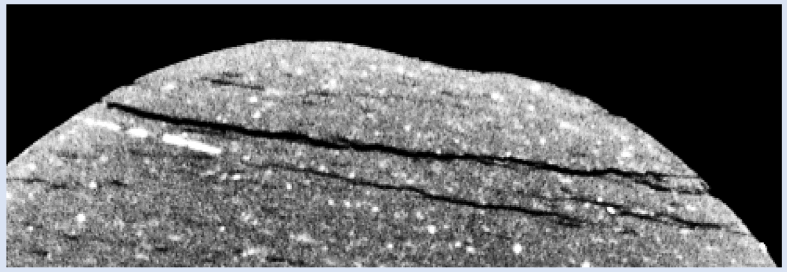


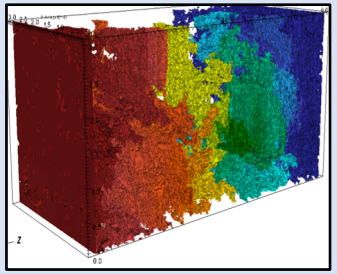


New Constitutive Models for Shale Property Evolution from Geomechanics and Reactions Based on Micro-scale and Core-Scale Experiments and Simulations

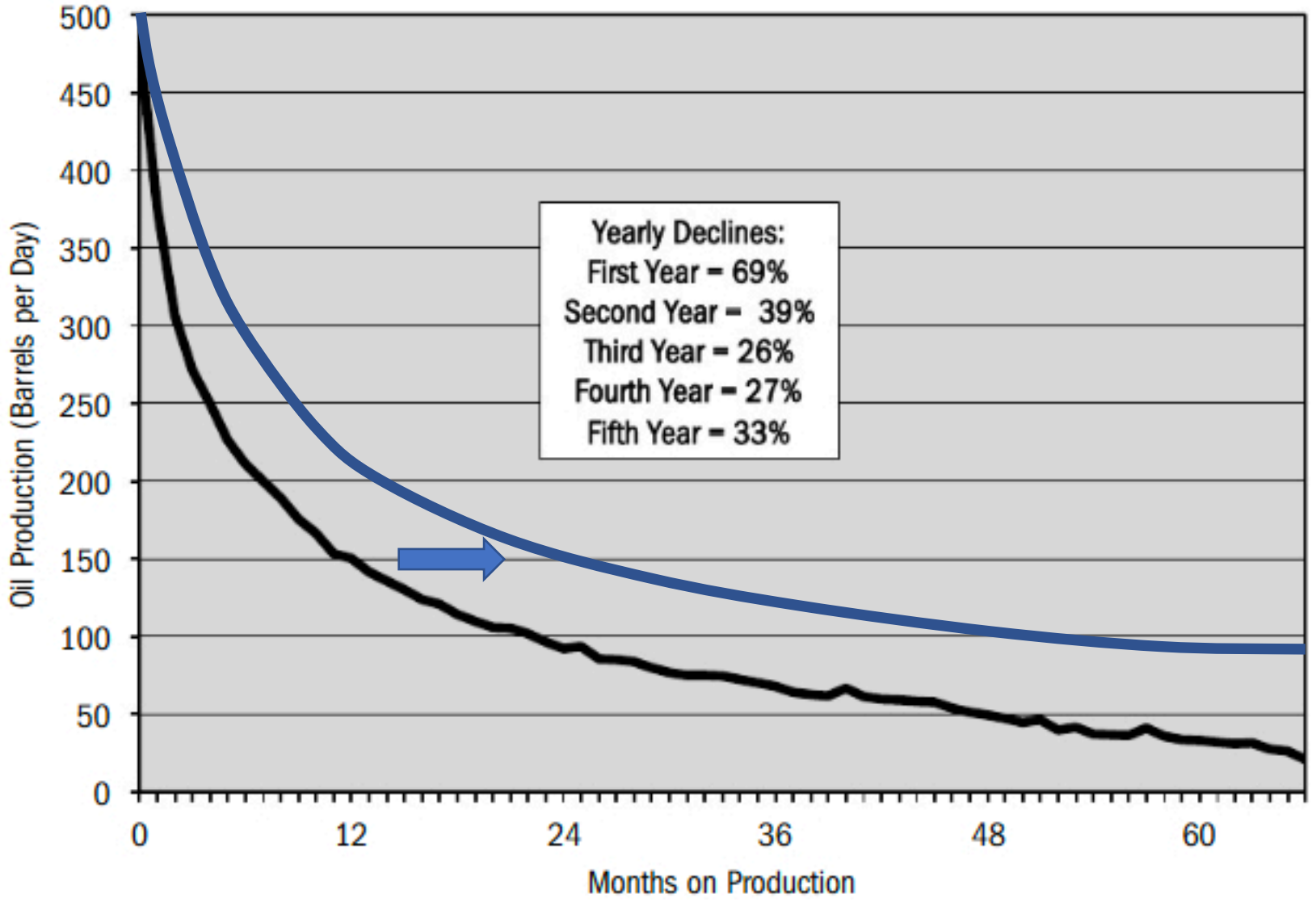








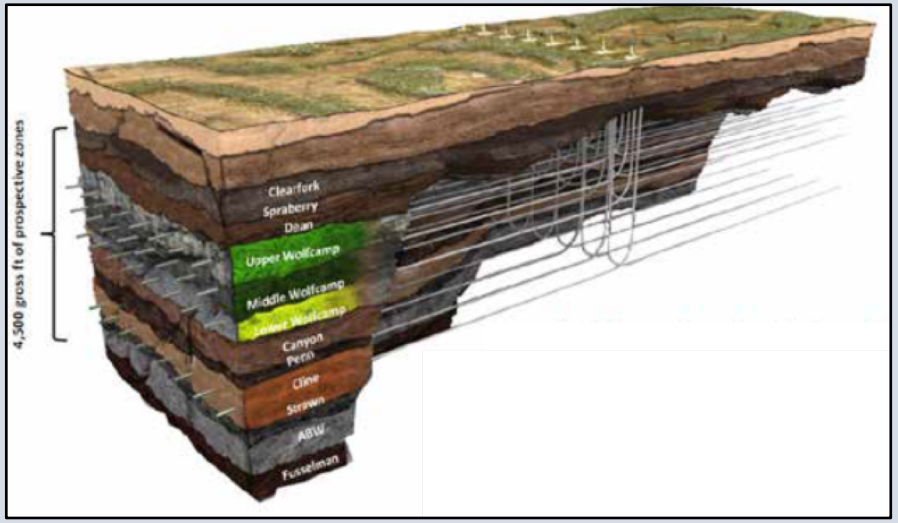
Ultimate Objective – Changing the Production Decline Curve

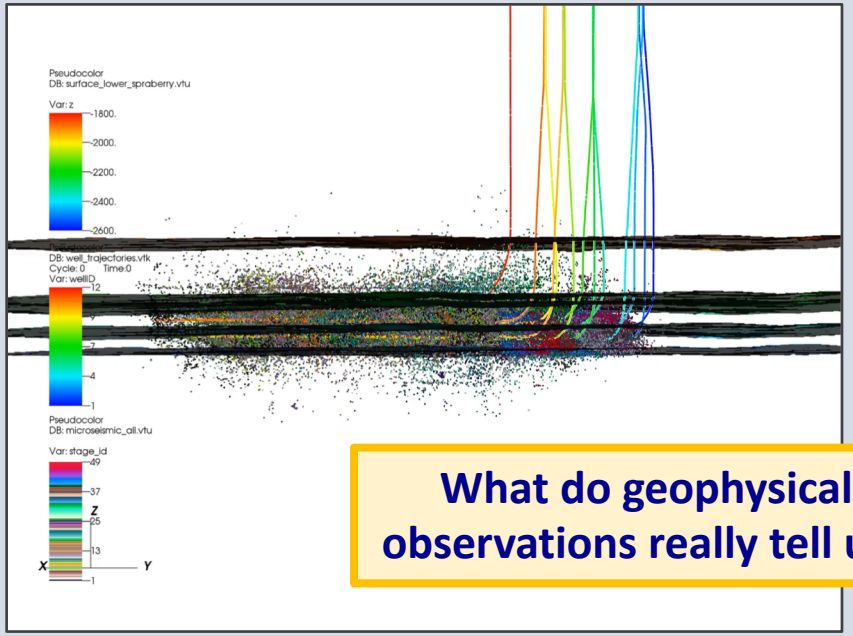


Reservoir Simulations

- HFTS data analysis and model preparations
- Initial stimulation modeling with GEOS
- Development of new upscaling techniques
- Coupling between GEOS and TOUGH
- Preliminary production simulations with TOUGH

Hydraulic Fracturing Test Site (HFTS)

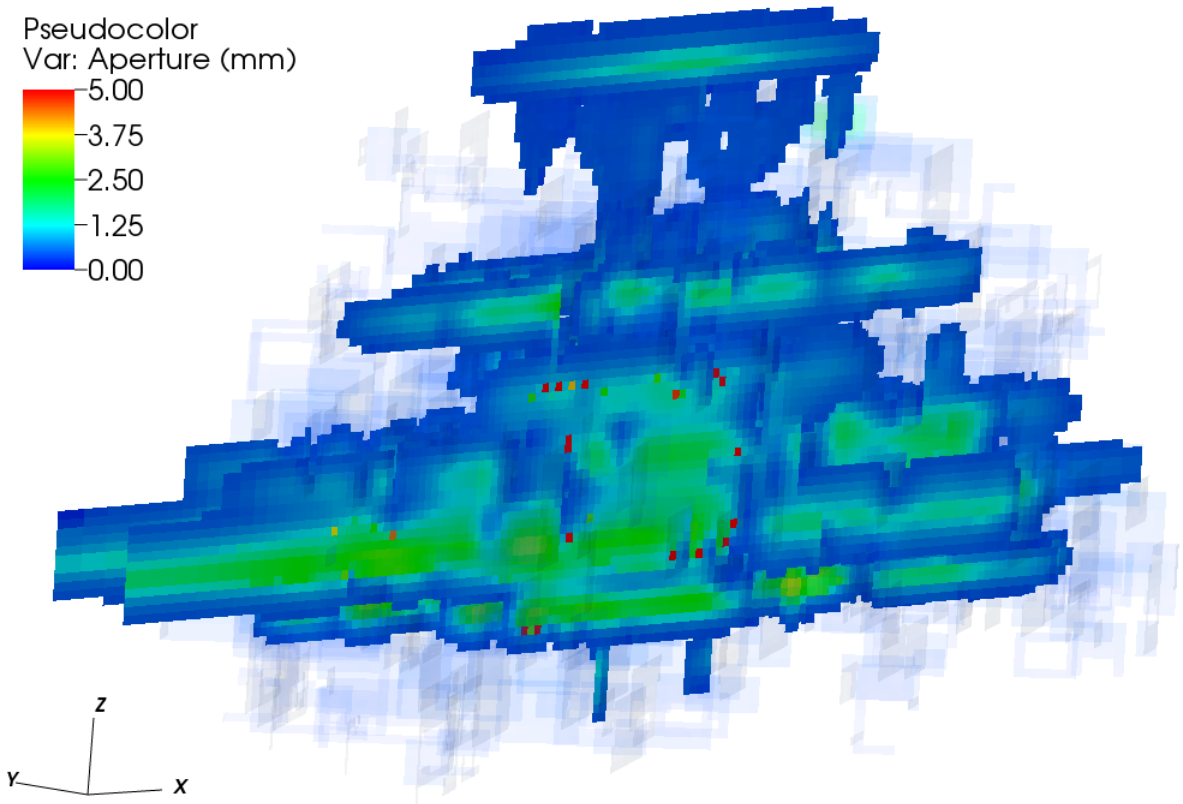


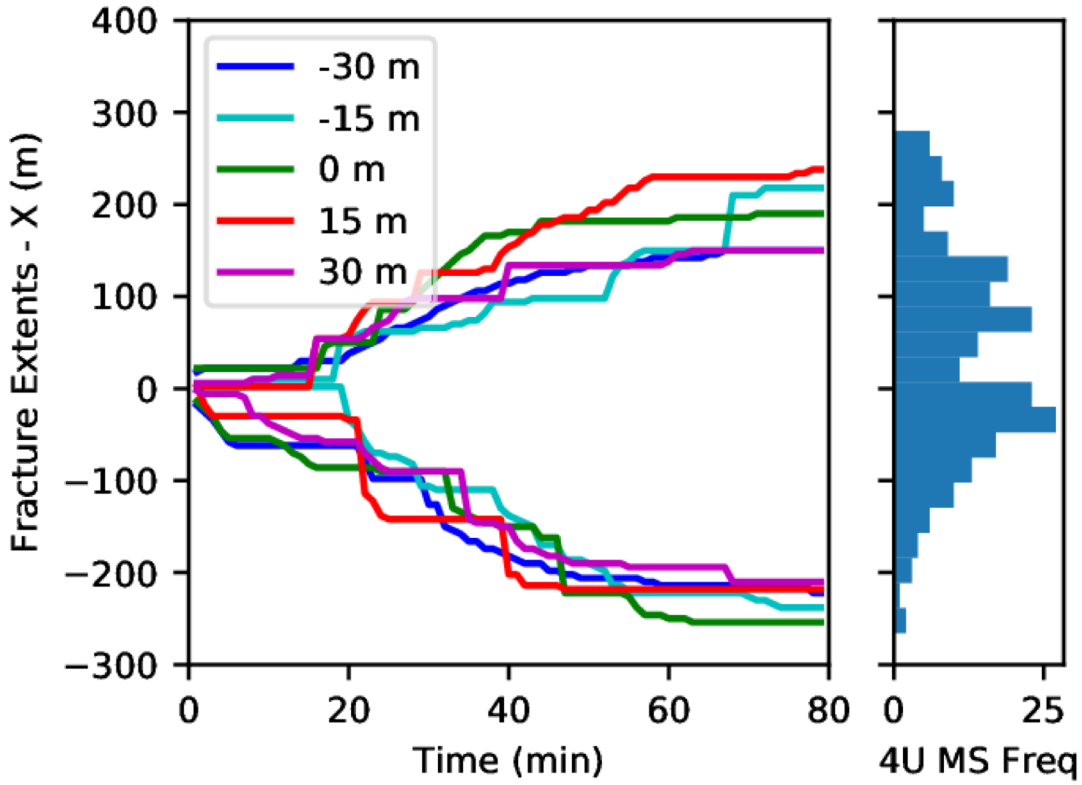


What do geophysical observations really tell us?

- Over 240 GB, hosted in an EDX Workspace
- Raw geophysical logs
- Fiber-based temperature data
- Extensive microseismic catalog
- Production and tracer data
- Multitude of reports and presentations
- *Special thanks to GTI for facilitating access and navigating the dataset!*

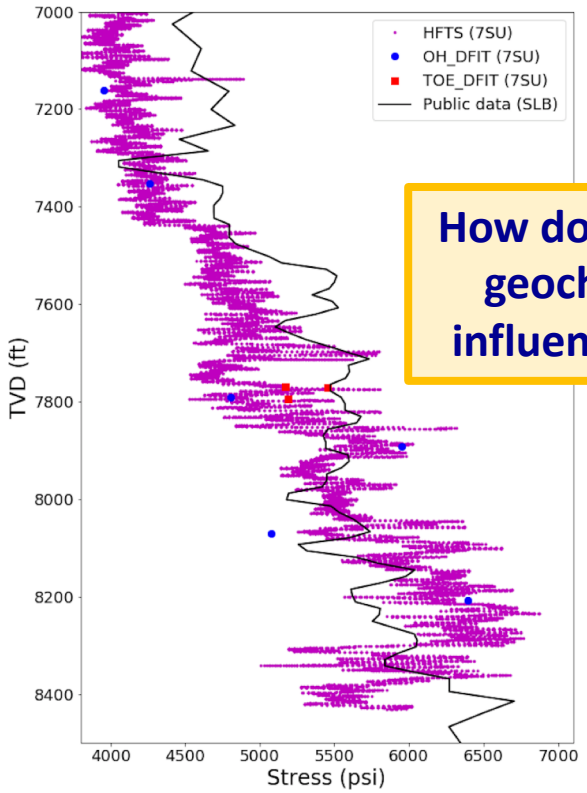
Preliminary GEOS Models Have Been Built That Match Microseismic



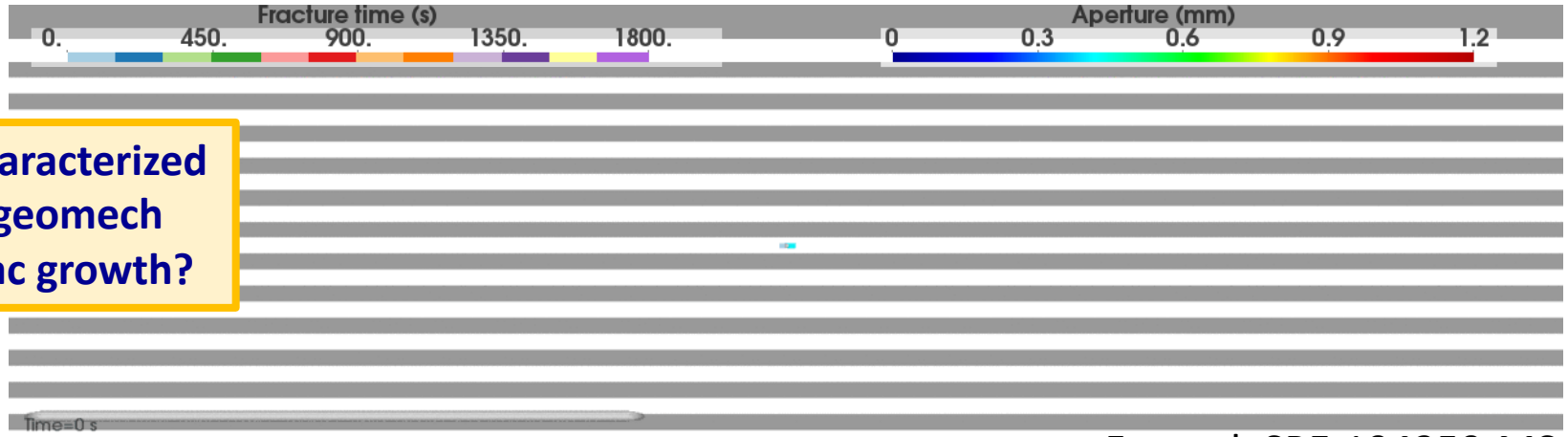


These models use a “top-down” approach to match observed behavior (e.g.: tuning leak-off)

Upscaling of Stress Heterogeneity and Fracture Swarms

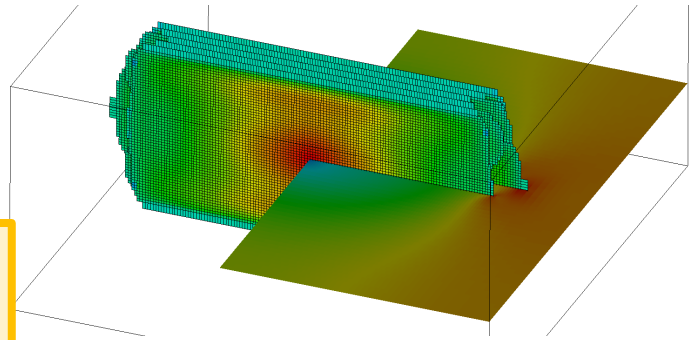


How does characterized geochem/geomech influence frac growth?

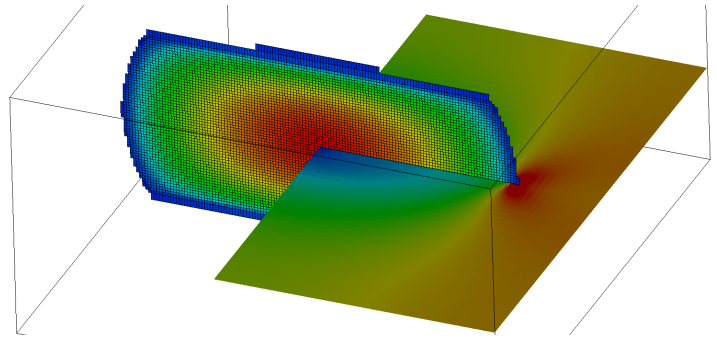


Fu et al. SPE-194359-MS

What are implications of *fracture swarms* for frac growth?



Five fractures in a swarm

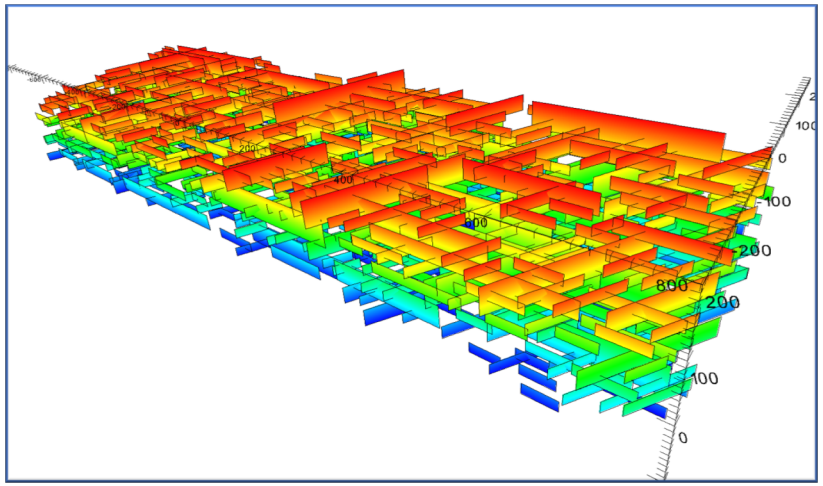


Upscaled, monolithic approximation

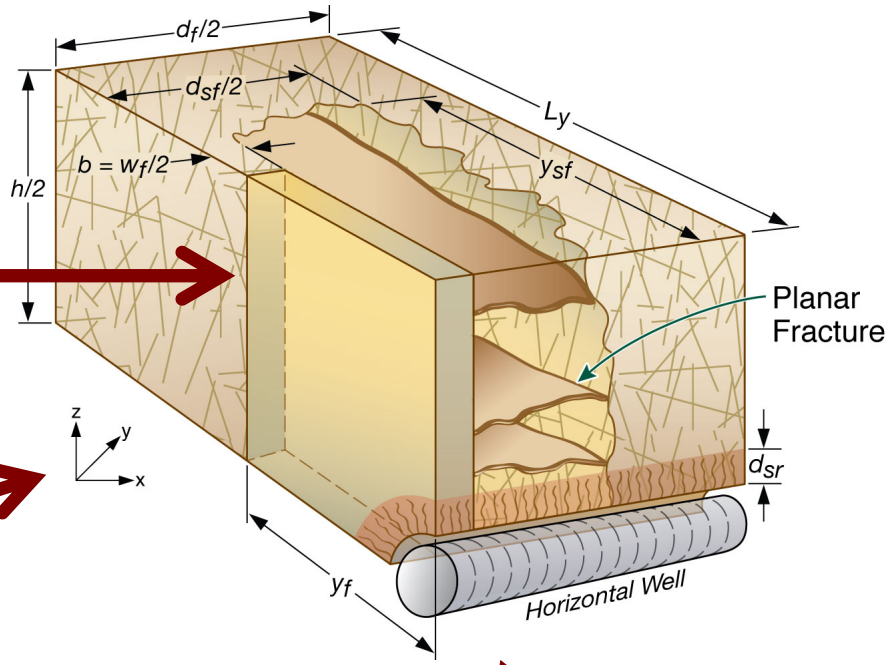
New upscaling concepts show promise for predictive modeling

Workflow for Production Simulations with TOUGH+

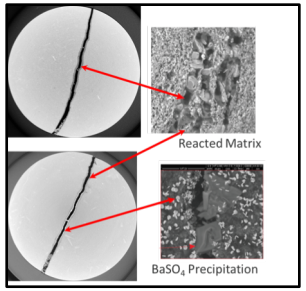
GEOS (LLNL)



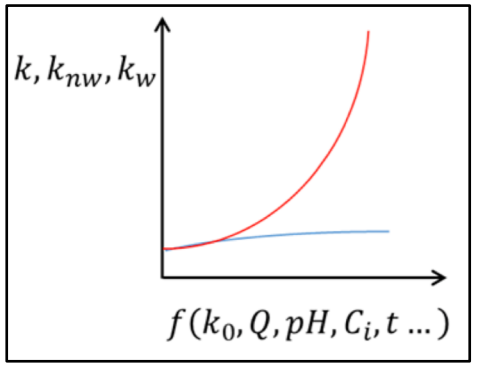
Large fractures as predicted from GEOS that dominate behavior

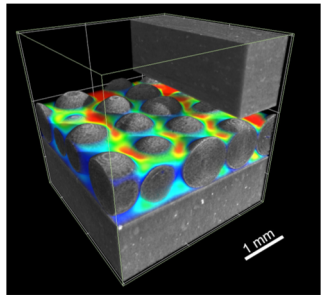


Input from Micro-Mechanics and Micro-Reaction Tasks



Geochemistry, Impact on Permeability and Porosity





Geomechanics, Proppant Behavior, Impact on Permeability and Porosity

Hybrid MINC Modeling for Efficient Reservoir Simulations:

- Large-scale fractures simulated as discrete features in model domain
- Small fractures and shale matrix simulated as multi-continuum

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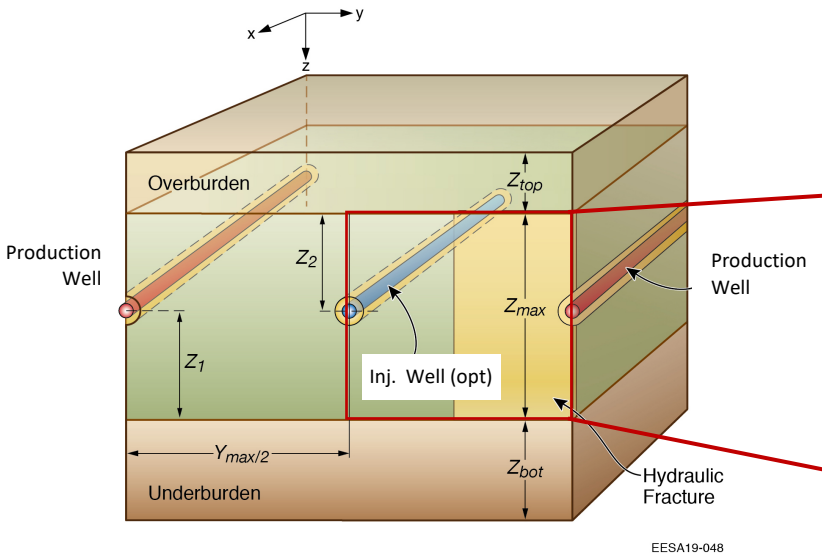
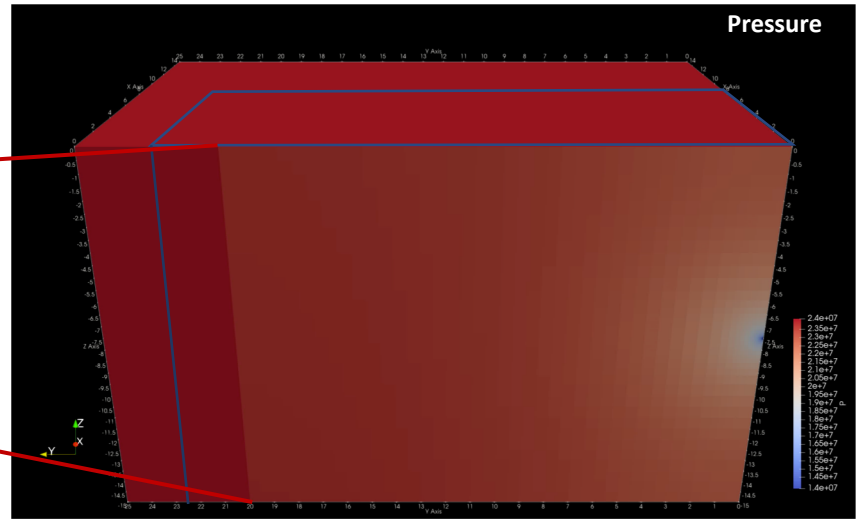
Preliminary Simulations and Testing: Base Case Plus SRV

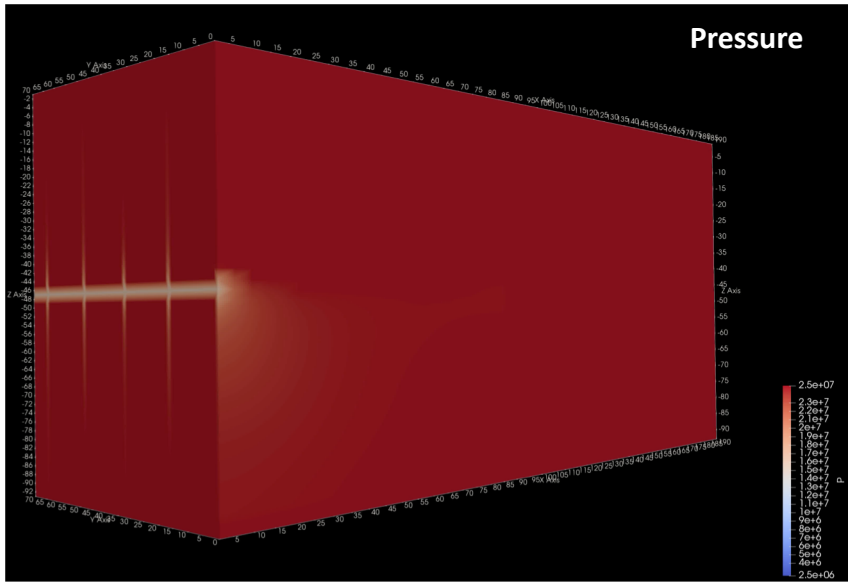


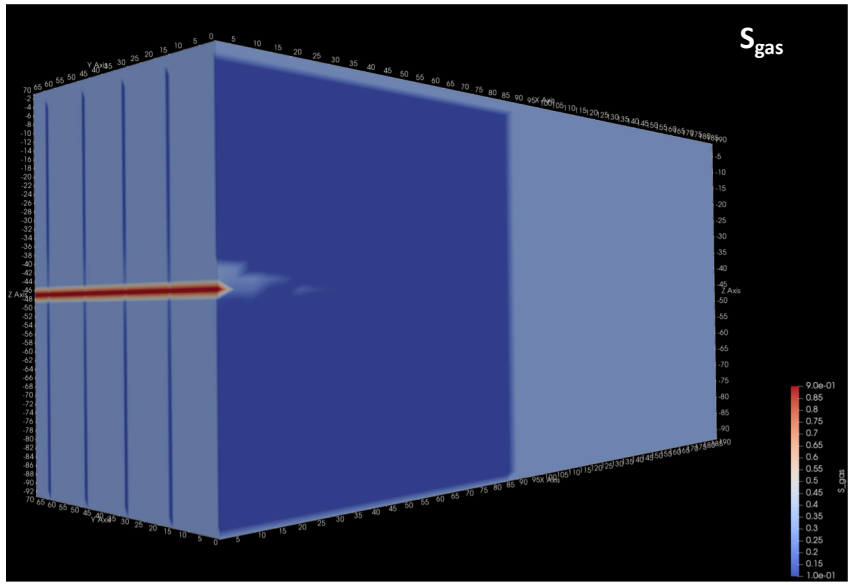


- **Test simulations use industry data**
- **Shale oil system, multiple wells**
- **Shale permeability: 1.1 μD**
- **Stimulated reservoir volume (SRV): k = 5.5 μD**
- **Fracture options: Hydraulic fractures, Type I**
- ***t* = 60 months**

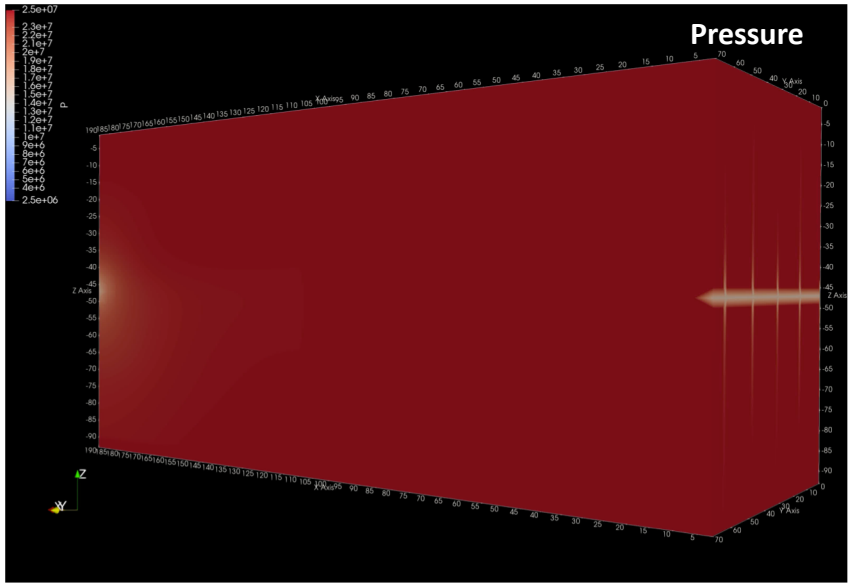
- **Progress of pressure front enhanced by SRV**
- **Gas exsolved from oil in fracture and in matrix**

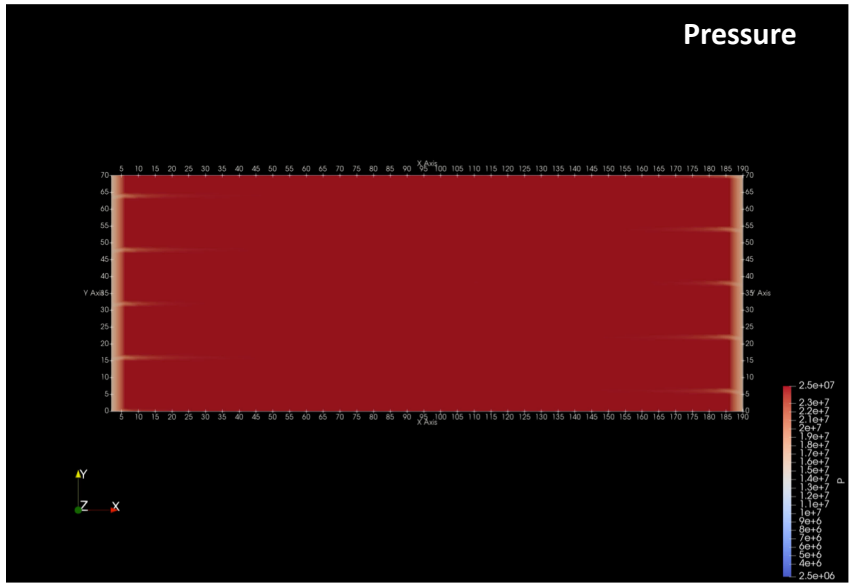
Preliminary GEOS – TOUGH Simulations for HFTS: 5-Cluster Case





- 5-fractures from GEOS test problem
- One well or **two wells** (3SU/4SU)
- Matrix and fracture properties from dataset
- Variable well BHPs from dataset

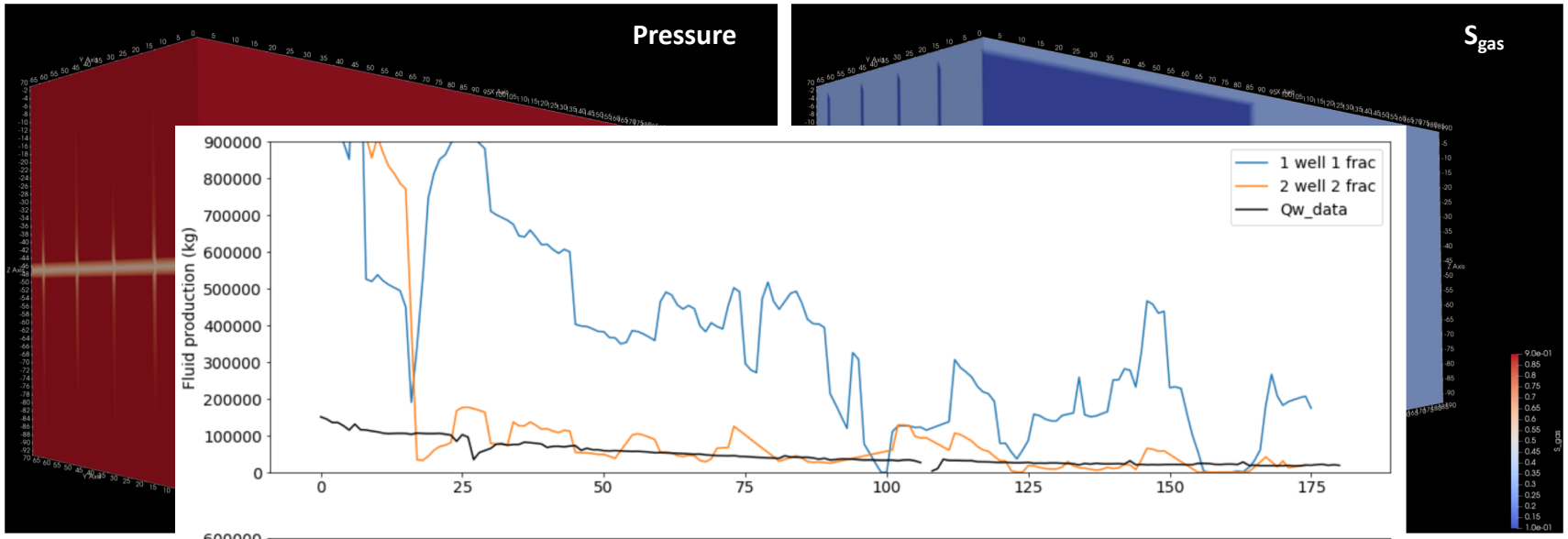


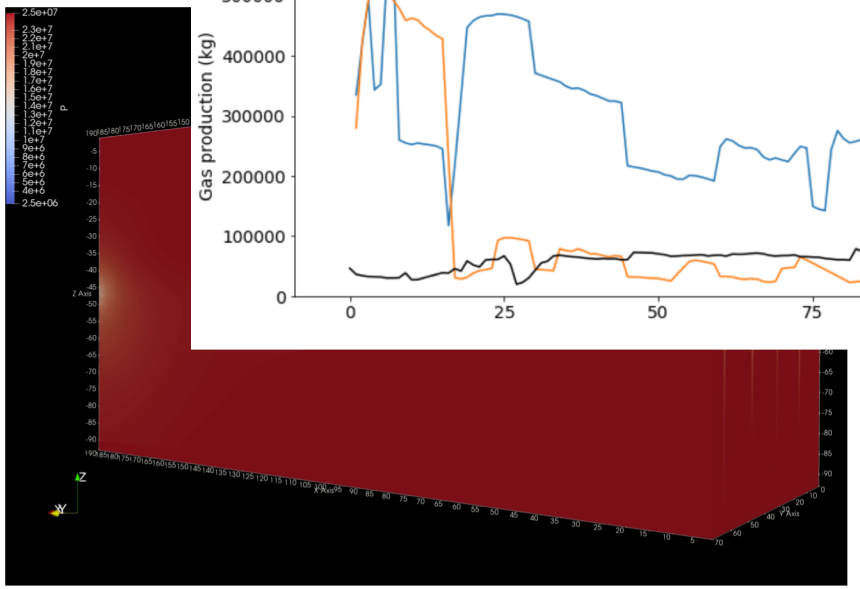


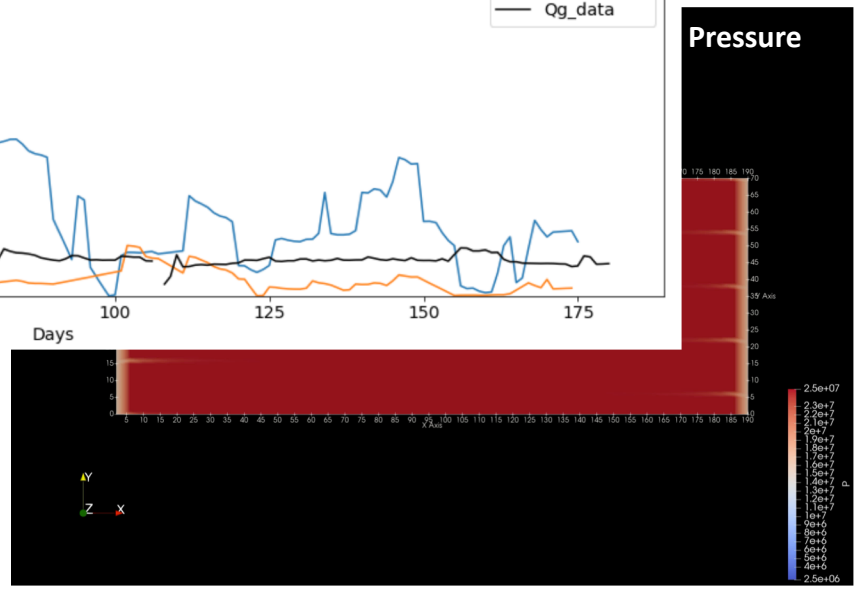
- Depressurization, fluid production, exsolution of gas
- Interference between fractures
- **Interference between wells**

Two wells, five fractures each (offset)

Preliminary GEOS – TOUGH Simulations for HFTS: 5-Cluster Case







Two wells, five fractures x 2 (offset)

- 5-fractures from GEOS test problem
- One well or **two wells** (3SU/4SU)
- Matrix and fracture properties from dataset
- Variable well BHPs from dataset

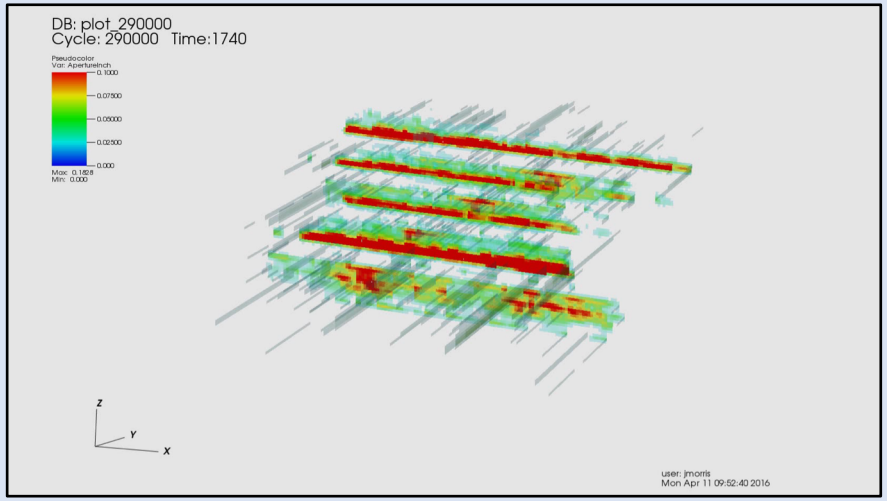
- Depressurization, fluid production, exsolution of gas
- Interference between fractures
- **Interference between wells**

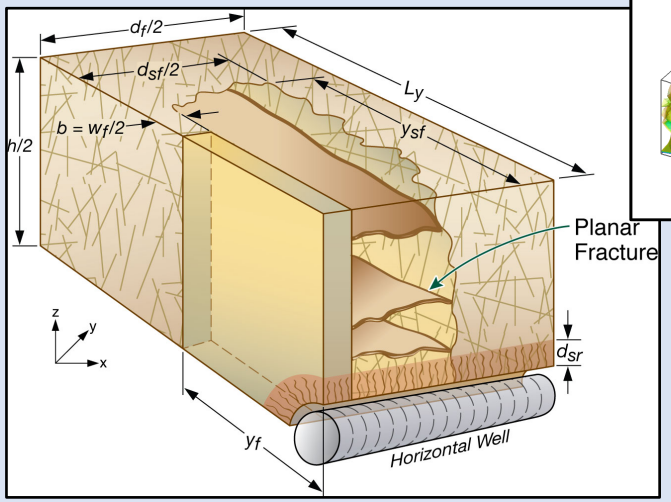
Micro-scale Experiments and Modeling

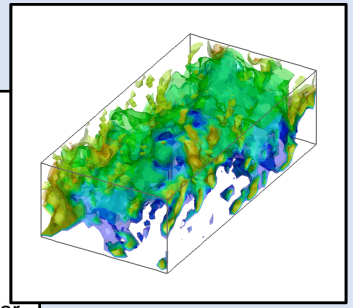
- Micro-mechanical investigations of proppant/shale interactions
- Micro-scale reactions, chemical alterations, and impact on fracture/matrix properties

Micro-scale Experiments/Modeling to Inform Reservoir-Scale Models

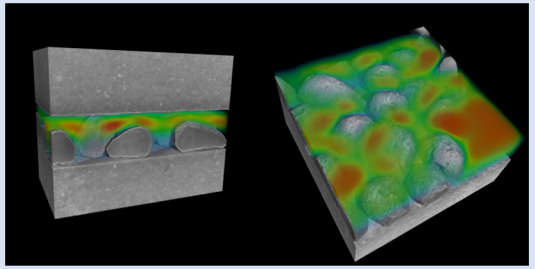
GEOS ⟷ **TOUGH**

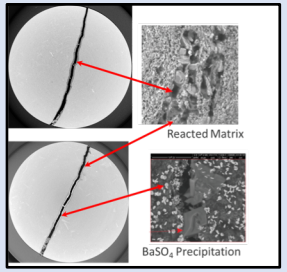


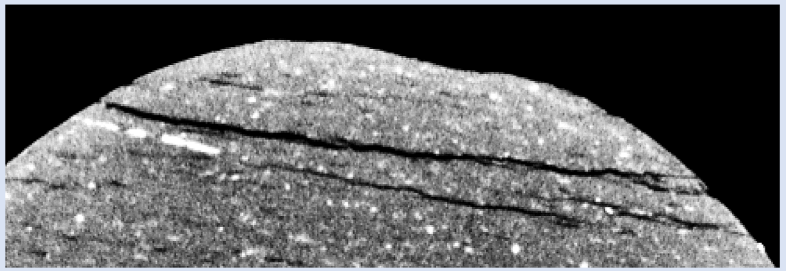


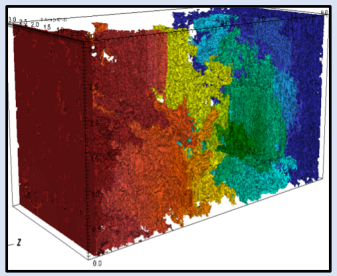


New Constitutive Models for Shale Property Evolution from Geomechanics and Reactions Based on Micro-scale and Core-Scale Experiments and Simulations





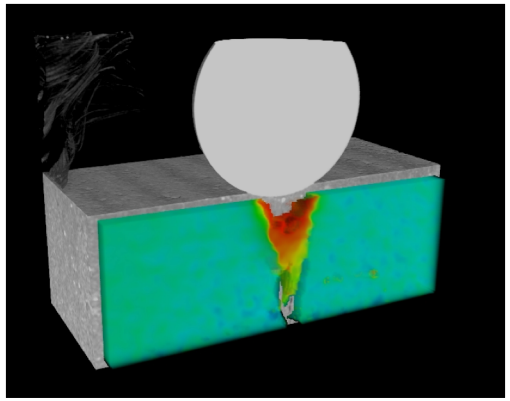


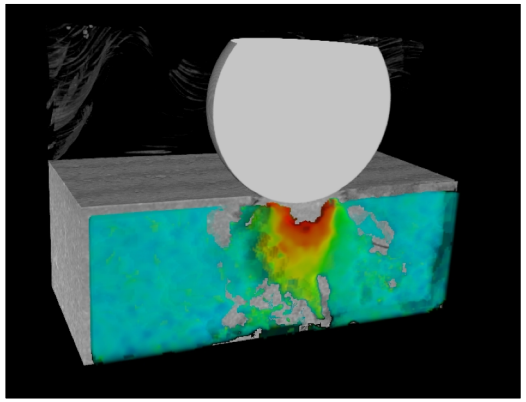


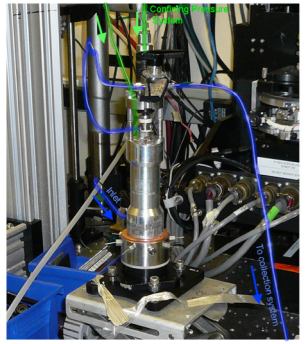
Understanding Proppant/Shale Interaction: Experiments at Grain and Monolayer Scale

- Microscale provides single proppant grain/shale interaction information

Micro (proppant grain)- scale
Indentation experiments



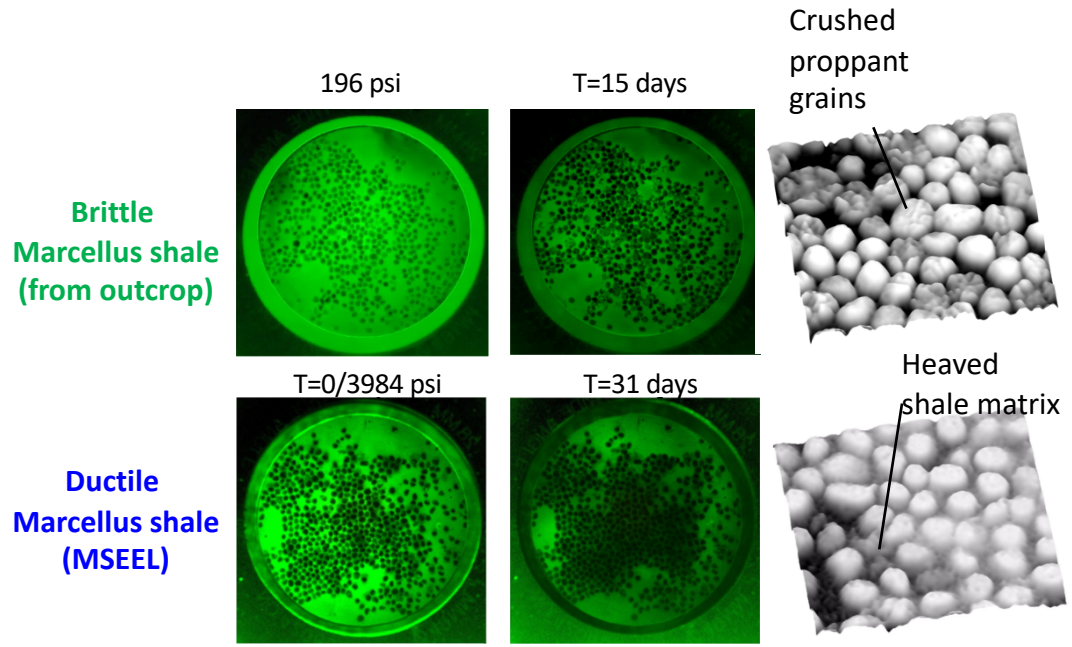




Mini-triaxial cell for synchroton X-ray micro Computed Tomography (SXR-microCT) at ALS

- Mesoscale allows handling of partial and whole monolayers

Sub-monolayer (small continuum)-scale
Indentation experiments

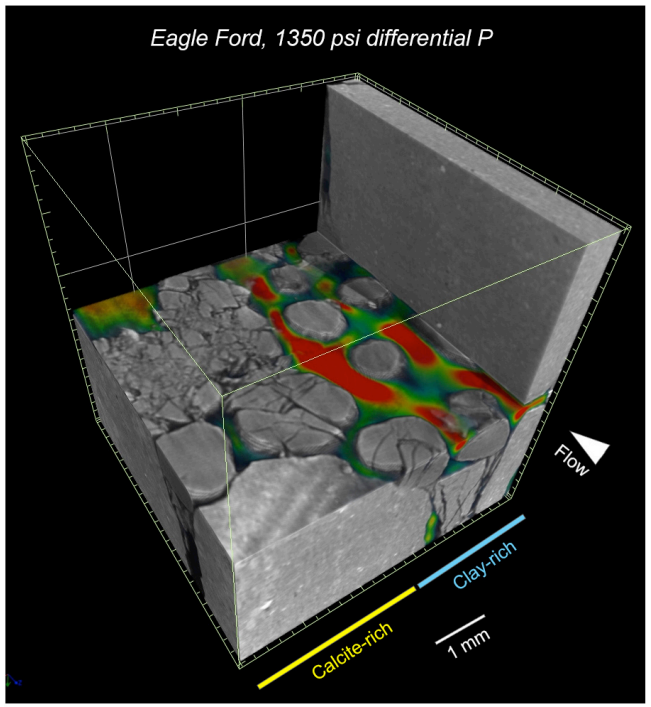


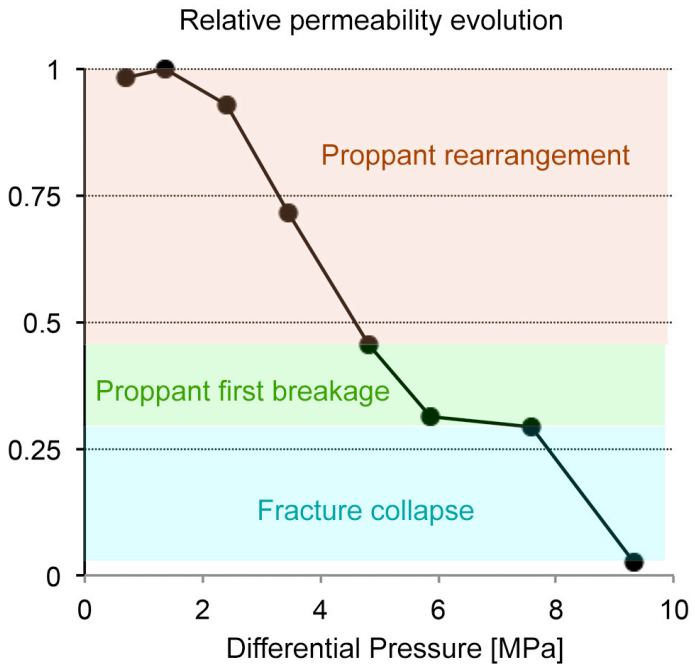
What is really going on inside proppant packs during production?

Micro-scale to Meso-scale Fracturing and Proppant Mechanics

Micro-scale Observations/Measurements

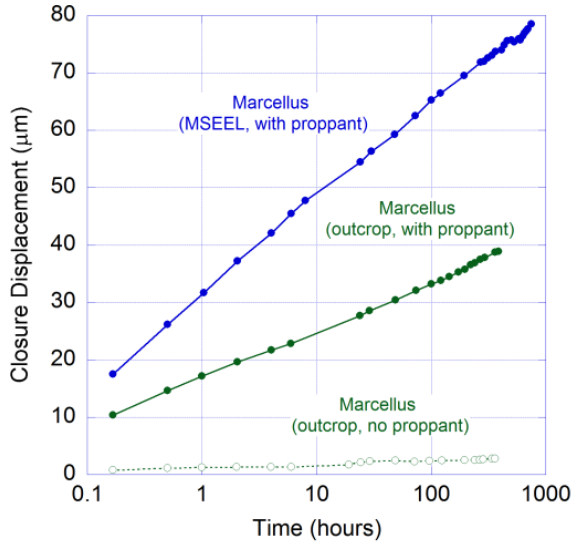
Data from in-situ SXR-microCT can be used to model the evolution of physical properties of the sample, e.g. permeability.



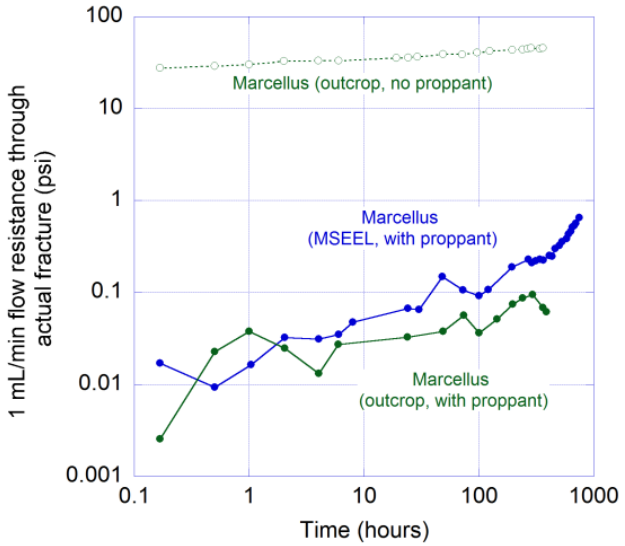


Meso-scale Observations/Measurements

Closure

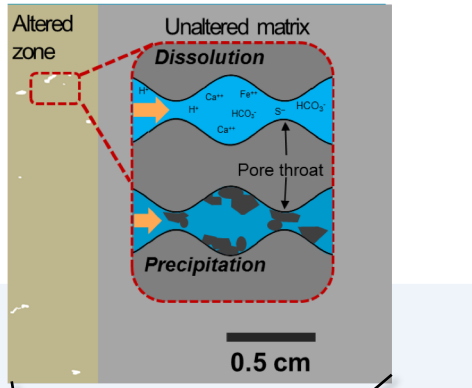


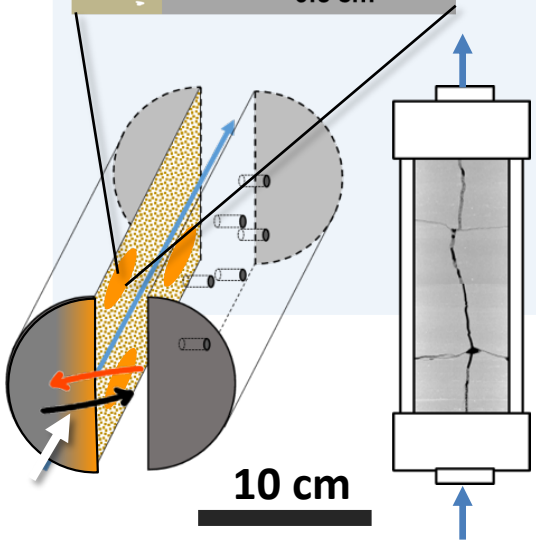
Flow resistance



Impact of Micro-scale Reactions on Fracture and Matrix Permeability

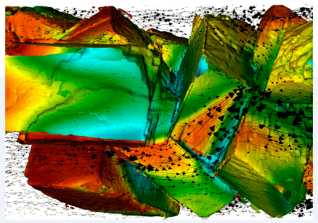
1. SLAC: Characterization of shale matrix pre- and post- injection

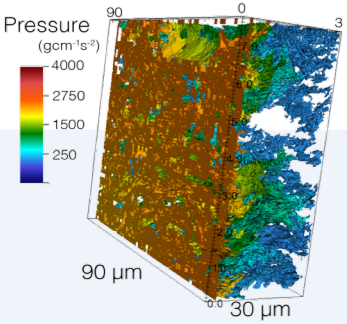


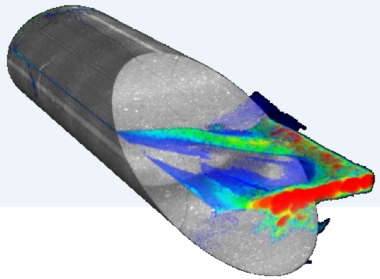


2. NETL: Fracture flow experiments

3. LBNL: pore- and continuum- scale modeling



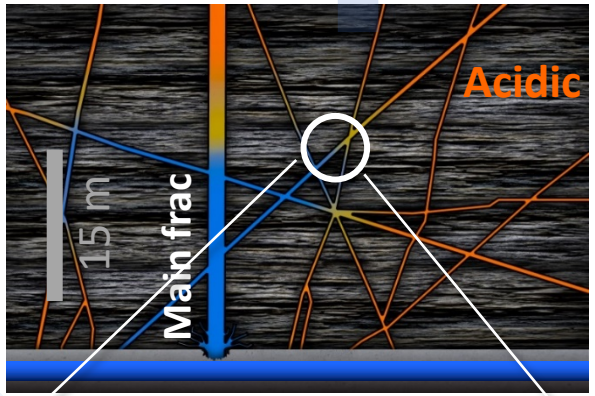


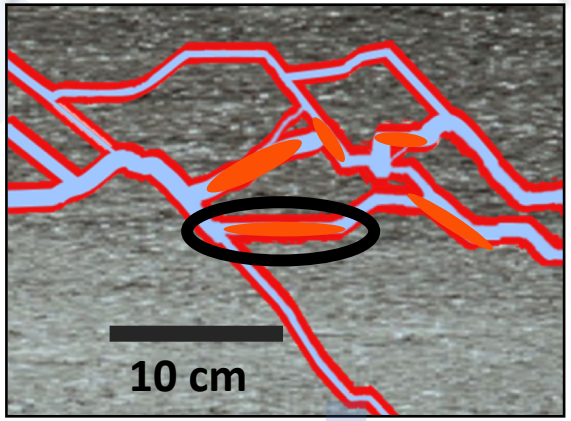


Deliverables:
constitutive laws that describe permeability and diffusivity evolution due to coupled physical-chemical alteration, especially at the matrix-fracture interface

$$k = f(k_0, Q, pH, C_i, t \ldots)$$

To be applied in the reservoir scale modeling to inform fracking operations





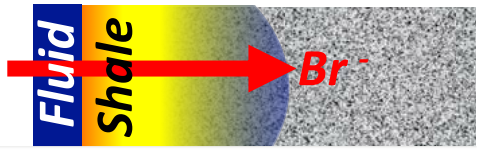
Experimental conditions relevant to the field practice (e.g. pH and salinity across the stimulated rock volume), and samples from the test site.

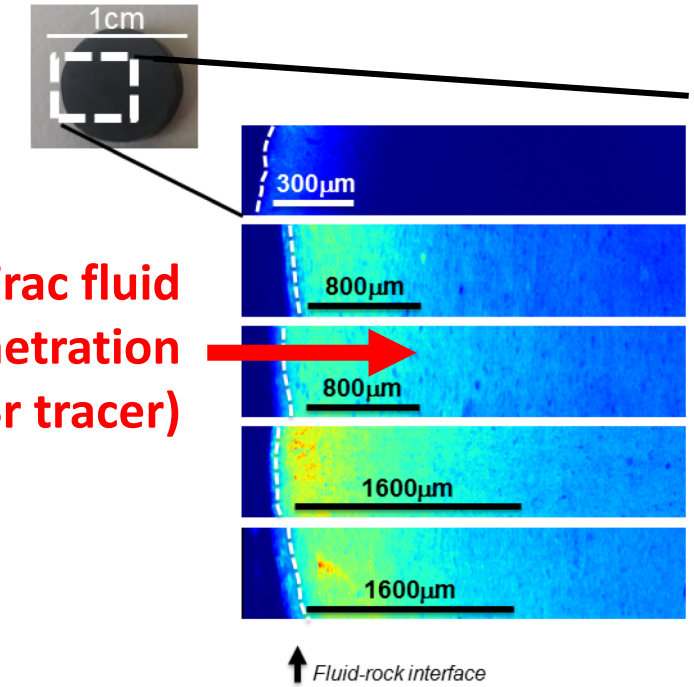
New Method for Imaging Fluid Penetration into Shale Matrix

SLAC

X-ray microprobe imaging

Br⁻ tracer





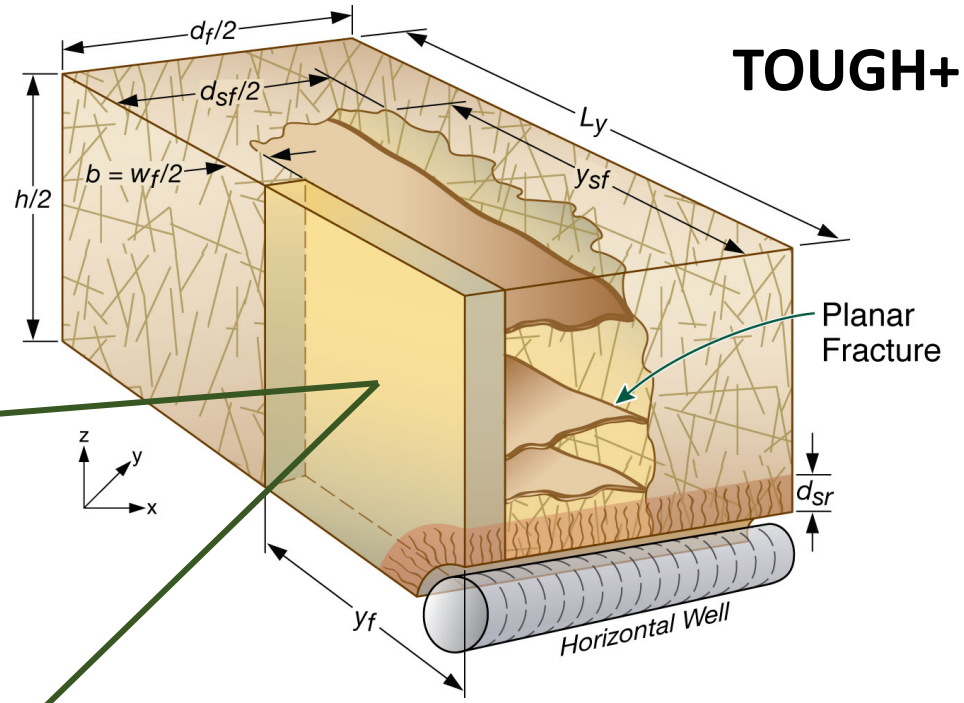
Frac fluid penetration (Br tracer)

5 min

Time

21 days

TOUGH+



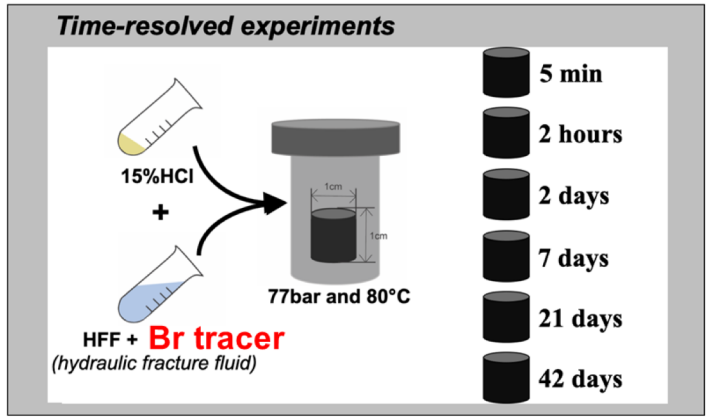
Wolfcamp testing in progress FY 2020, #1:

X-ray microprobe: Fluid penetration SLAC, NETL	→	Fracture skin model LBNL

Chemical-Mechanical Weakening of Fracture Faces by Fracture Fluid

React Wolfcamp shale with fracture fluid

SLAC



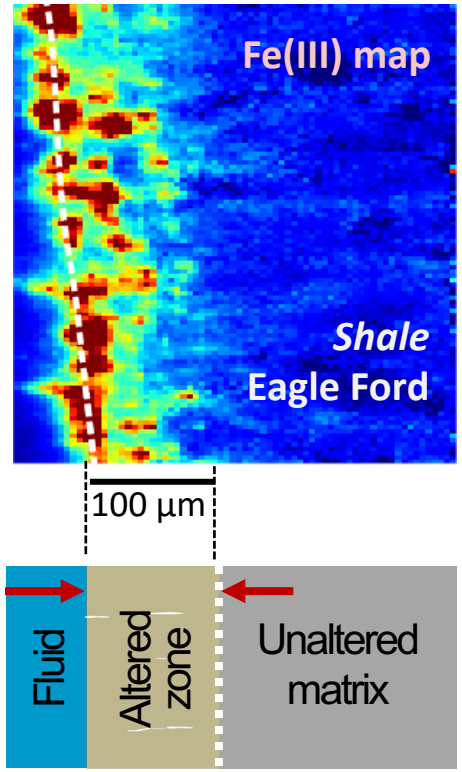
Microscale alteration of fracture face
SLAC

→

Assess geomechanical alteration
LBNL

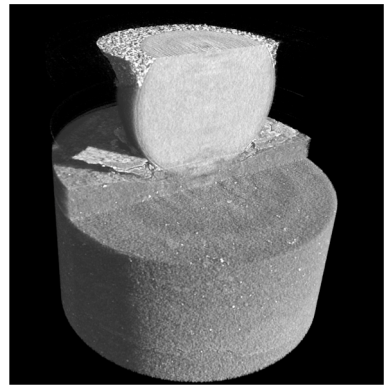
Characterize microscale chemical alteration

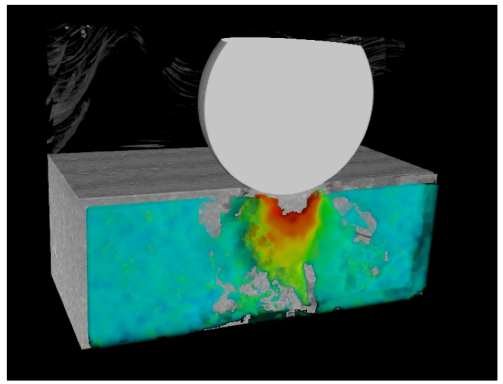
SLAC



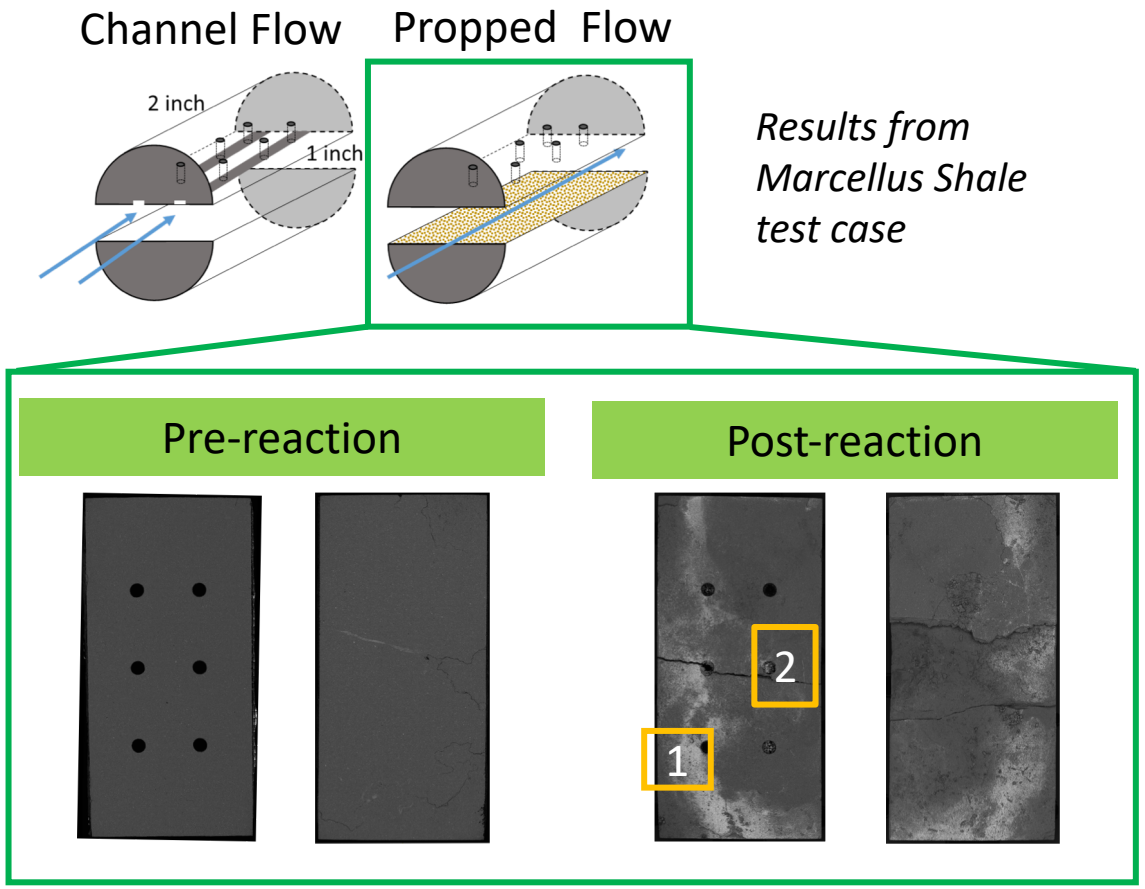
Indentation measurements

LBNL



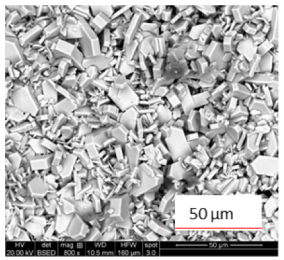


Fracture Flow Experiments: Chemical Reactions in Realistic Fractures

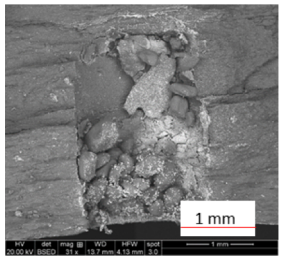


Results from Marcellus Shale test case

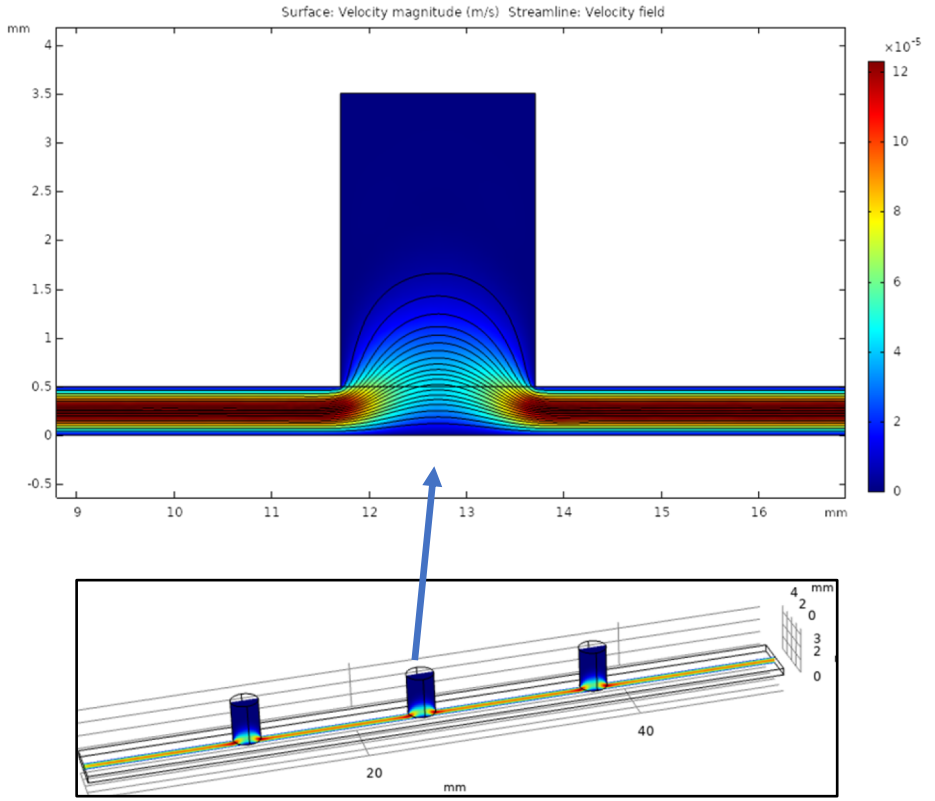
1. Euhedral barite along surface



2. Proppant cemented by barite in “dead end”



CFD simulations with experimental inputs show slower flow around “dead end” zone - possibly also enhanced precipitation (LBNL)



Summary - Using the HFTS Opportunity to…

- Validate DOE's high-performance computational capabilities for fracturing and production against a unique high-quality field and lab data set
- Develop a framework for reservoir simulations informed by micro-scale processes for adaptive subsurface management
- Develop a better predictive understanding of fracturing processes in ultra-tight shale
- Develop a better predictive understanding of production processes as impacted by detailed fracture-characteristics and micro-scale transport

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