A New Framework for Microscopic to Reservoir-Scale Simulation of Hydraulic Fracturing and Production: Testing with Comprehensive Data from HFTS

Jens Birkholzer (LBNL), Joe Morris (LLNL) and the HFTS Team (LBNL, LLNL, SLAC, NETL)

Project Update Presentation, August 27, 2019

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

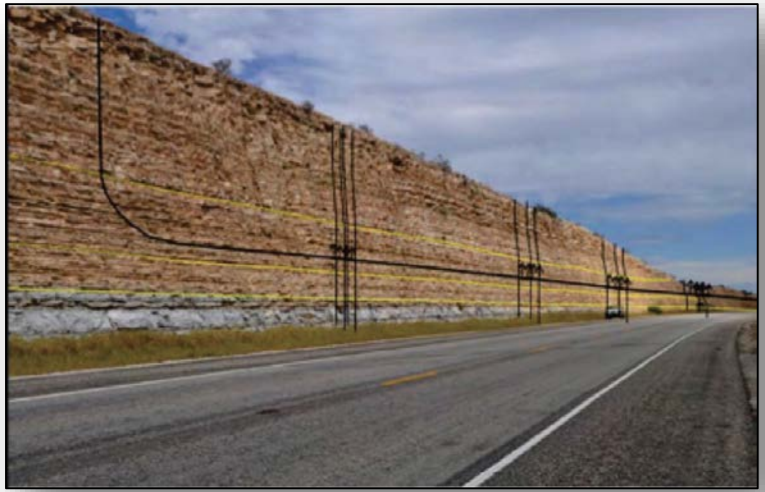
U.S. Department of Energy

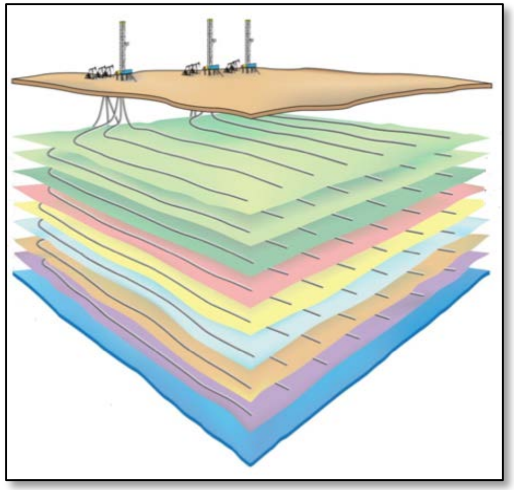
National Energy Technology Laboratory

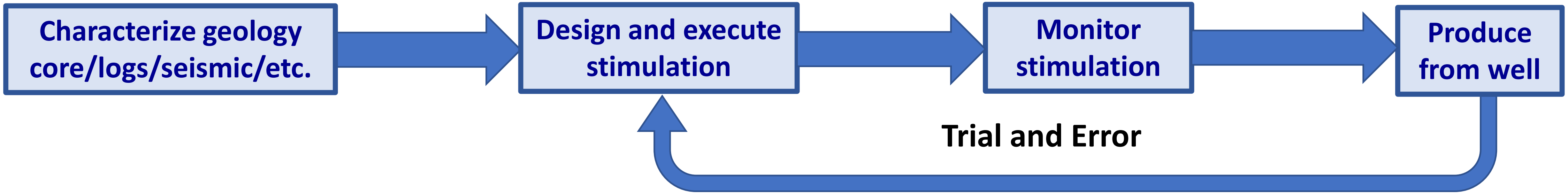
Addressing the Nation's Energy Needs Through Technology Innovation – 2019 Carbon Capture, Utilization, Storage, and Oil and Gas Technologies Integrated Review Meeting

August 26-30, 2019

Typical Process in Unconventionals Today







Multiple Gaps in Understanding Prevent Predictive Design

What is really going on inside proppant packs during production?

How does characterized geochem/geomech influence frac growth?

What do geophysical observations really tell us?

How does micro-scale geochem/geomech influence production of hydrocarbon and waters?

Characterize geology core/logs/seismic/etc. → Design and execute stimulation → Monitor stimulation → Produce from well → Design and execute stimulation

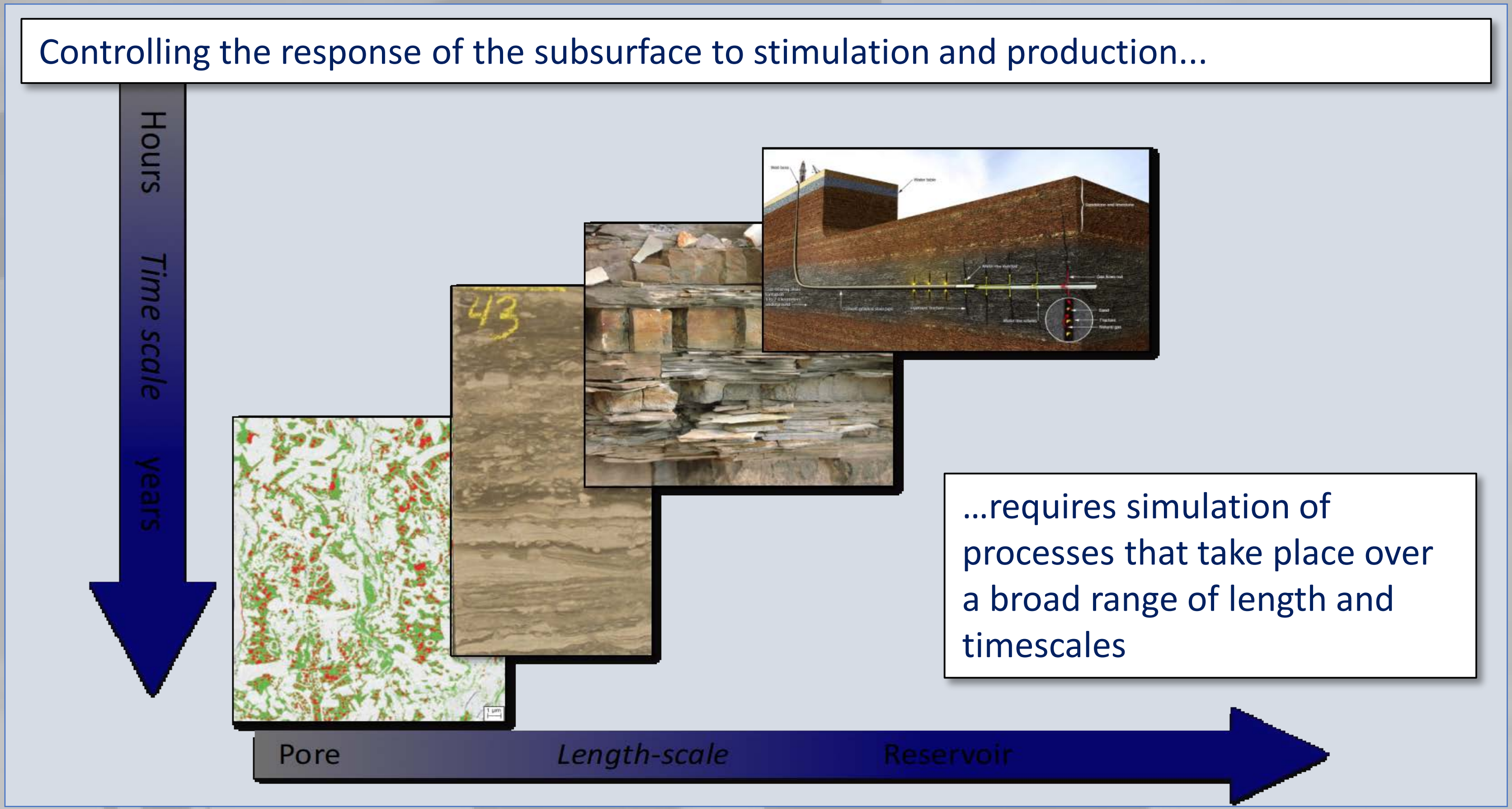
Predictive Design to Enable Adaptive Subsurface Management

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

How does well-to-well interaction affect performance?

What are implications of fracture swarms for production?

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



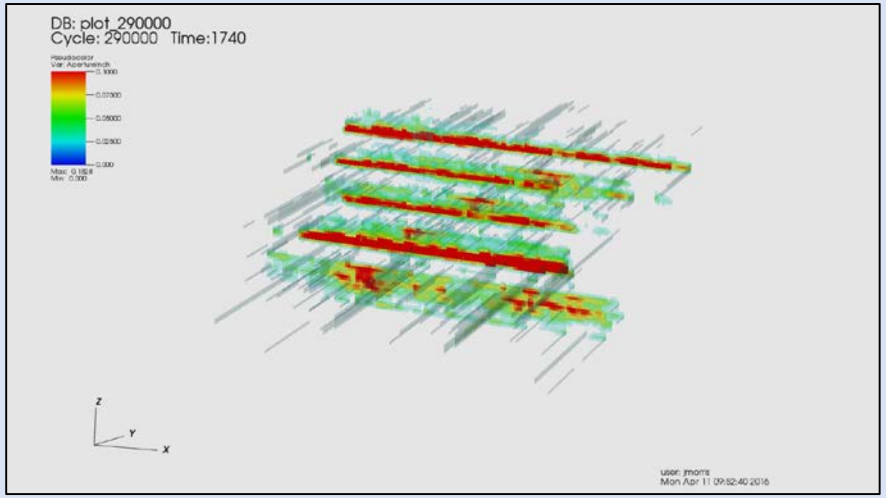
A New Framework for Microscopic to Reservoir-Scale Simulation of Hydraulic Fracturing and Production:

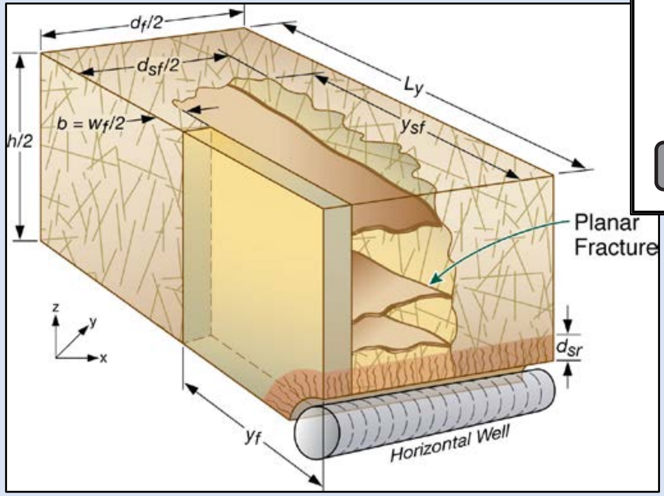
Fusing Existing HPC and Experimental Capabilities at DOE's National Labs

A Multi-Scale Multi-Physics Multi-Lab Project

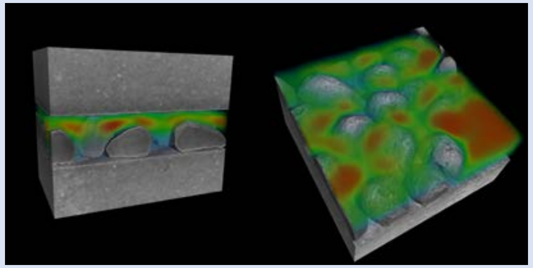
**Linking Two Powerful Simulators to Answer Complex Questions at the Reservoir Scale:
GEOS for Stimulation Behavior, TOUGH for Production**

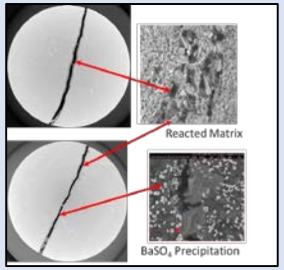
GEOS ⟷ **TOUGH**

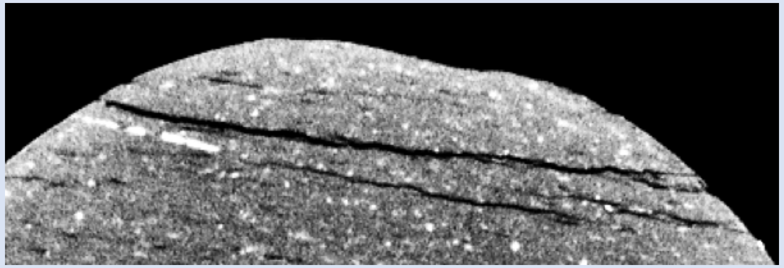


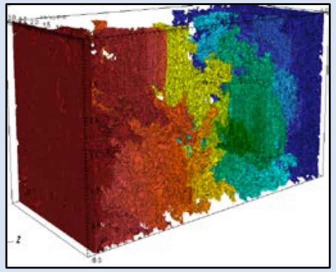


New Constitutive Models for Shale Property Evolution from Geomechanics and Reactions Based on Micro-scale and Core-Scale Experiments and Simulations





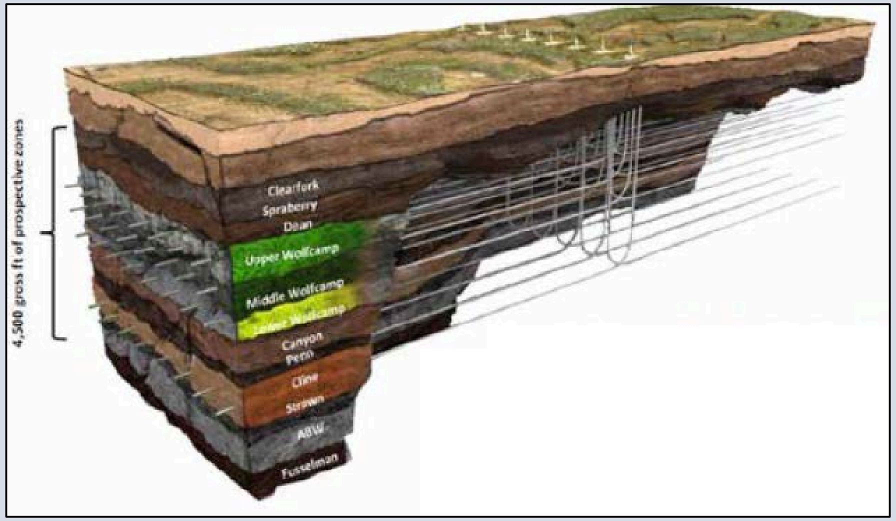




Reservoir Simulations

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

Hydraulic Fracturing Test Site (HFTS)



- 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!*

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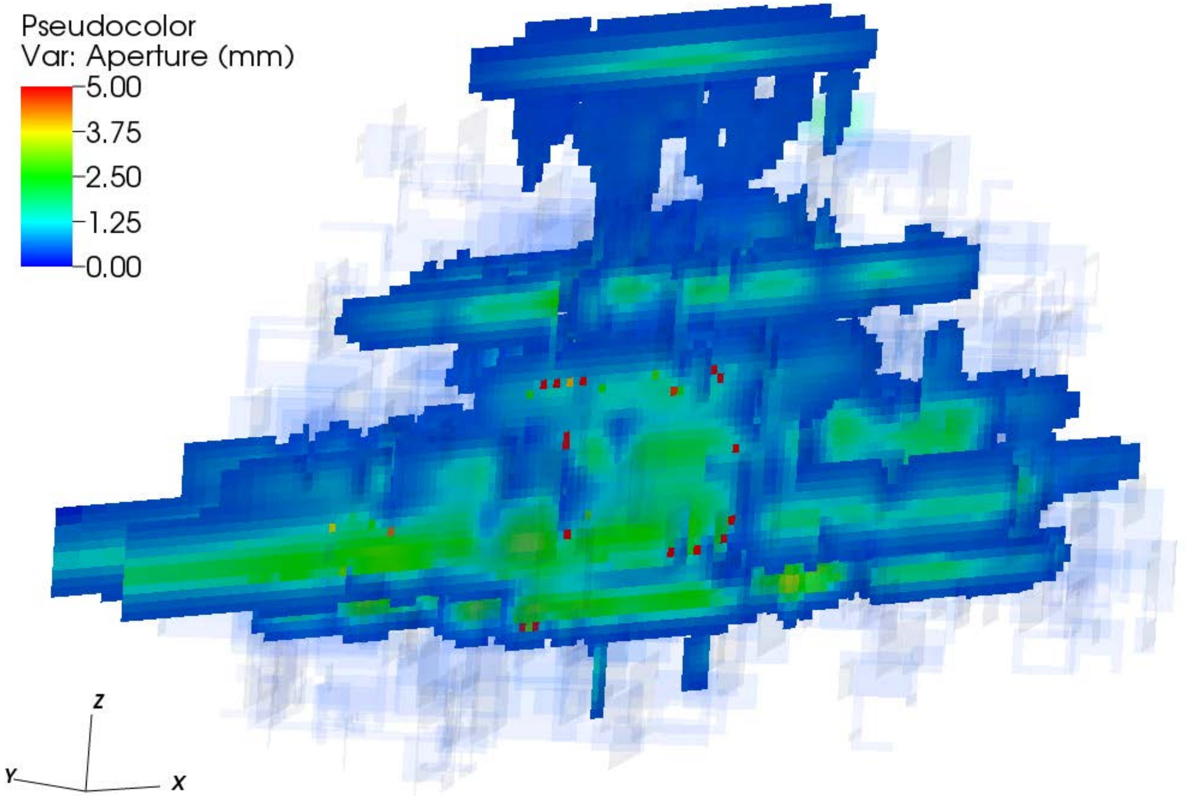
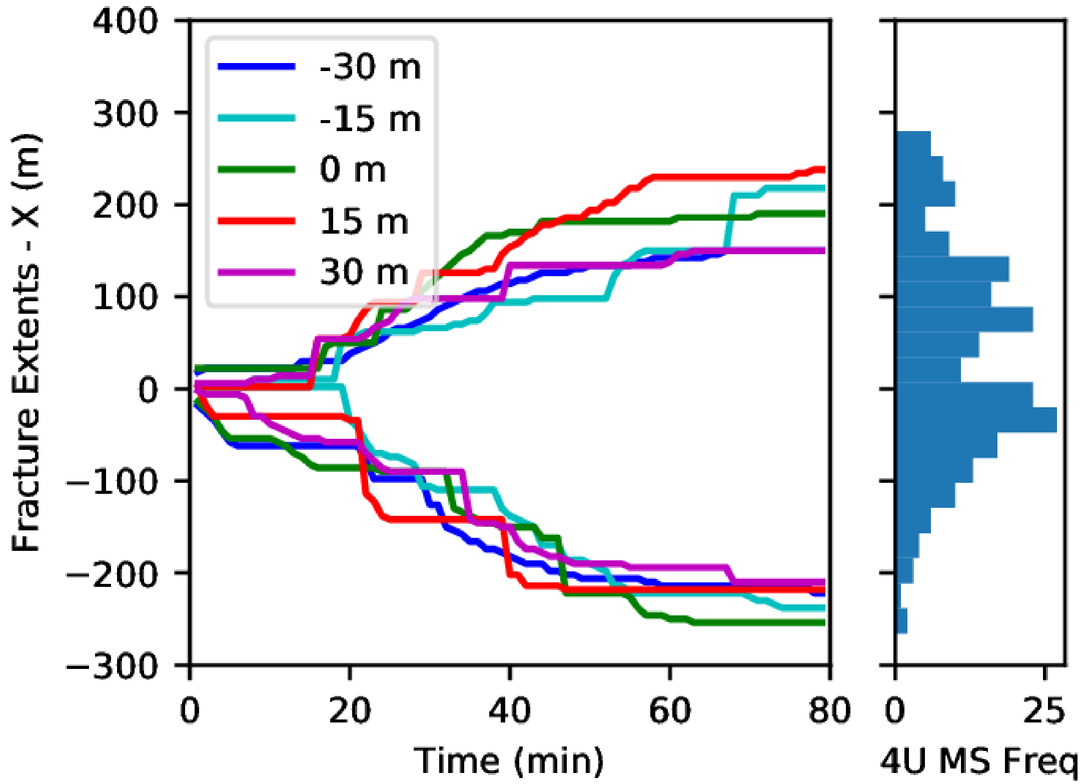
us?

See Presentation by Jordan Ciezobka tomorrow 8 am, Ballroom B

Preliminary GEOS Models Have Been Built That Match Microseismic

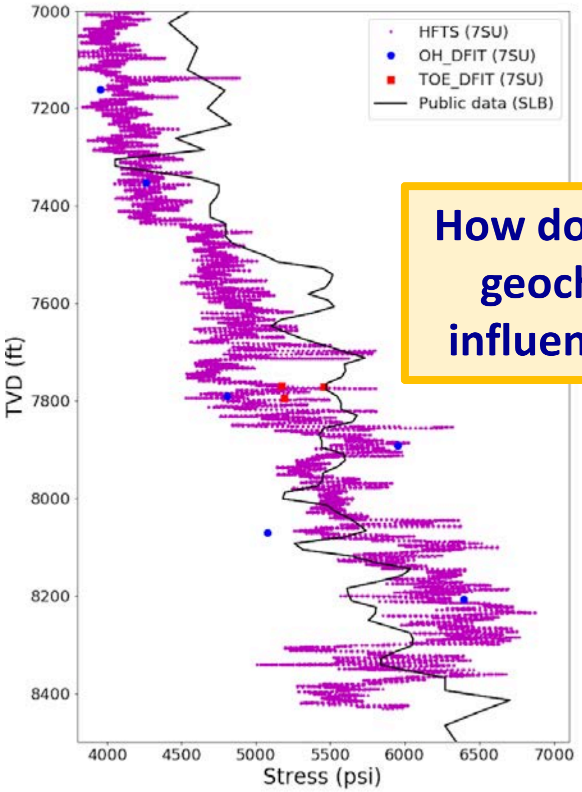




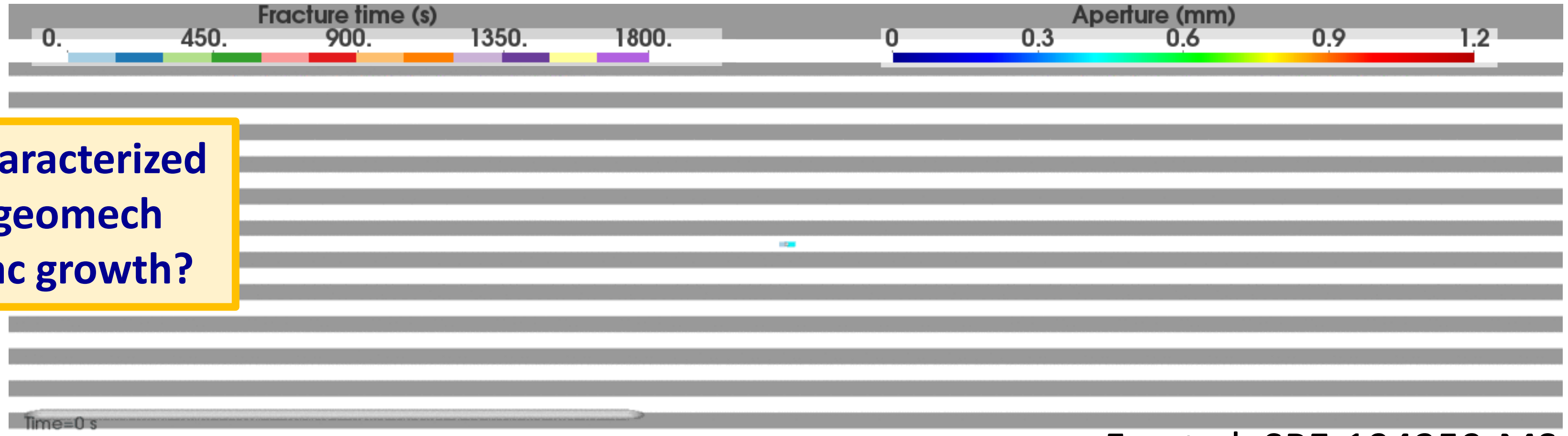
These models use a "top-down" approach to match observed behavior (e.g.: tuning leak-off)

Upscaling of Stress Heterogeneity and Fracture Swarms

Depth

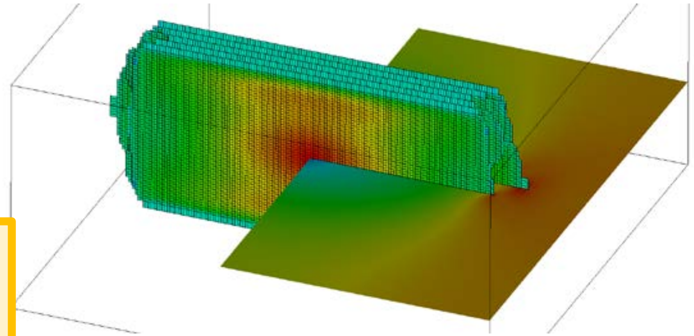


How does characterized geochem/geomech influence frac growth?

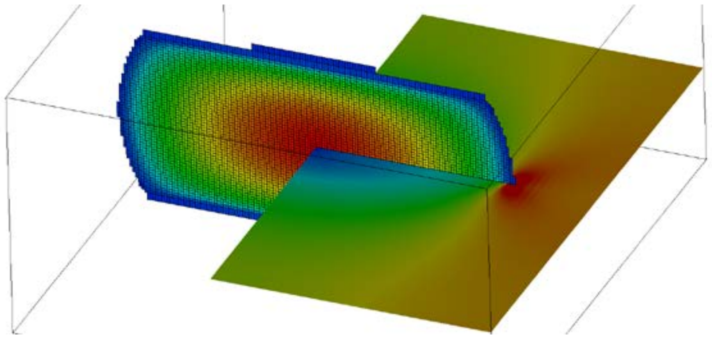


Fu et al. SPE-194359-MS

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



Five fractures in a swarm

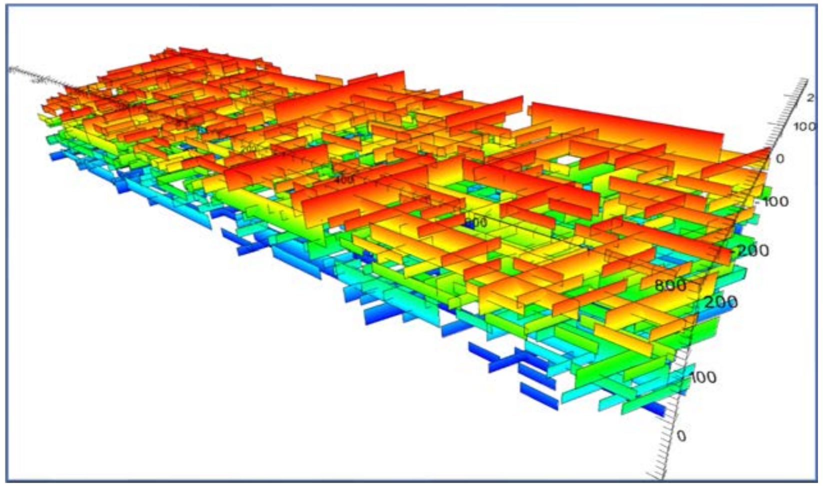


Upscaled, monolithic approximation

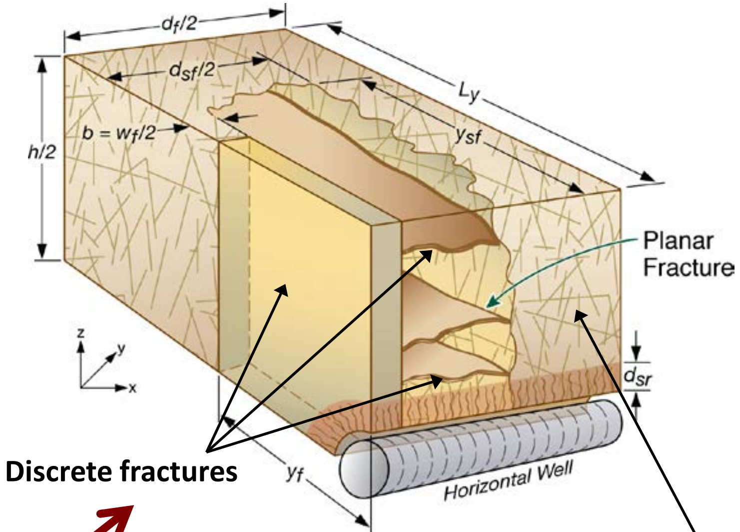
New upscaling concepts show promise for predictive modeling

Workflow for Production Simulations with TOUGH+

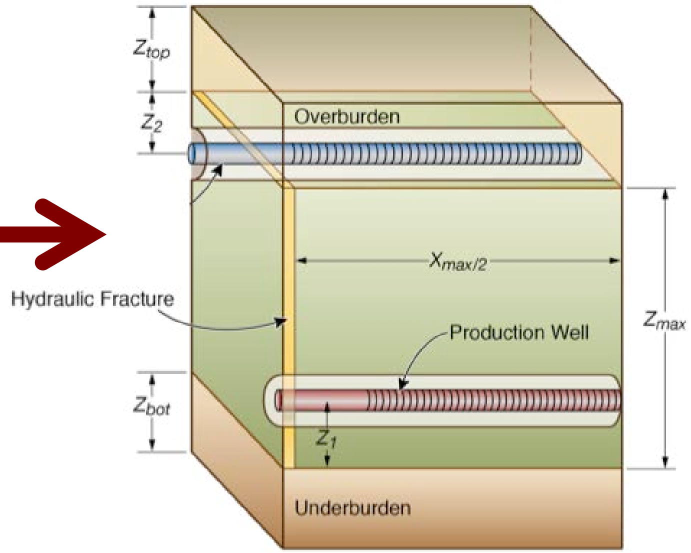
GEOS (LLNL)



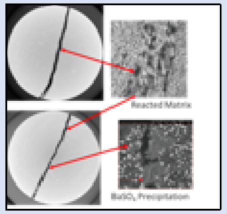
Model and Mesh Development (LBNL)



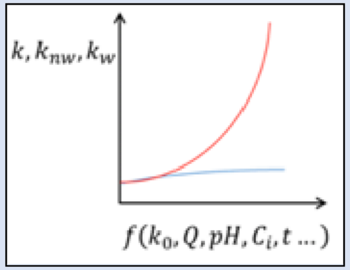
TOUGH+OilGasBrine Simulation (LBNL)

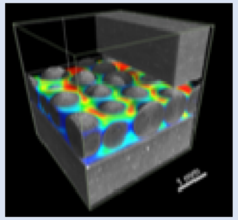


Input from Micro-Mechanics and Micro-Reaction Tasks



Geochemistry, Impact on Permeability and Porosity



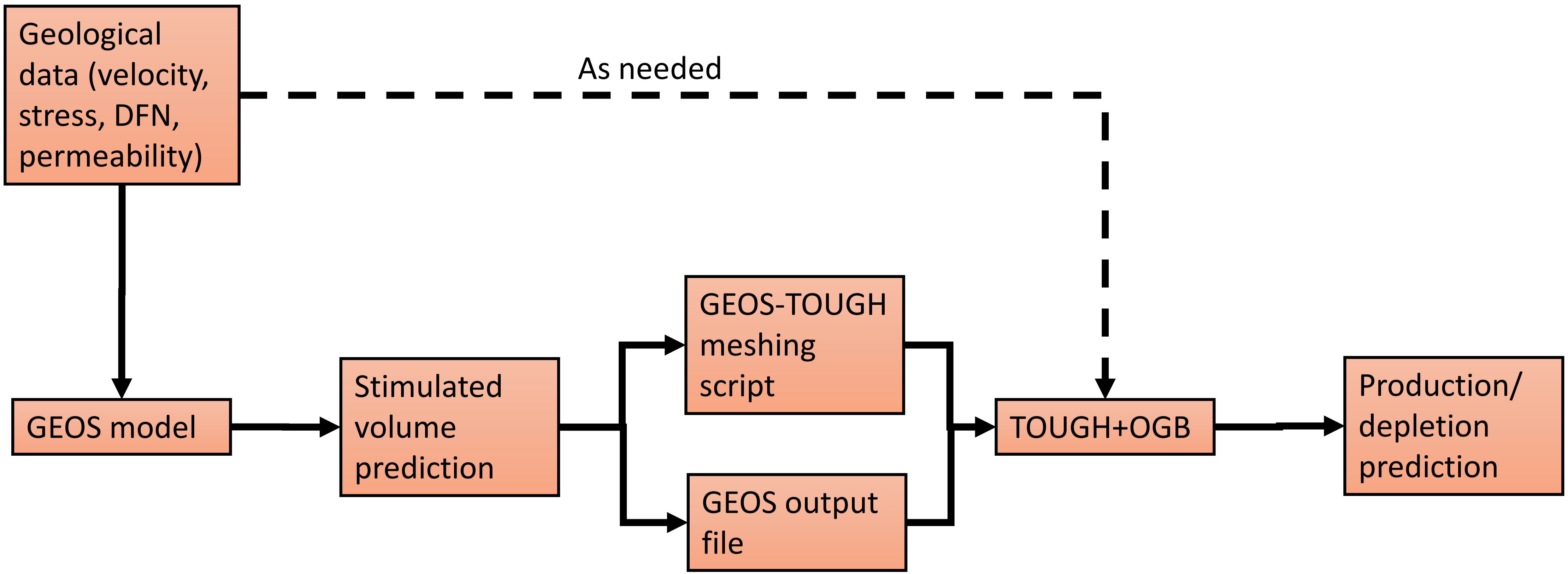


Geomechanics, Proppant Behavior, Impact on Permeability and Porosity

Hybrid MINC Modeling for Efficient Reservoir Simulations:

- Large-scale fractures simulated as discrete features in model domain
- Smaller fractures simulated as secondary fracture continuum
- Shale matrix simulated as multi-continuum

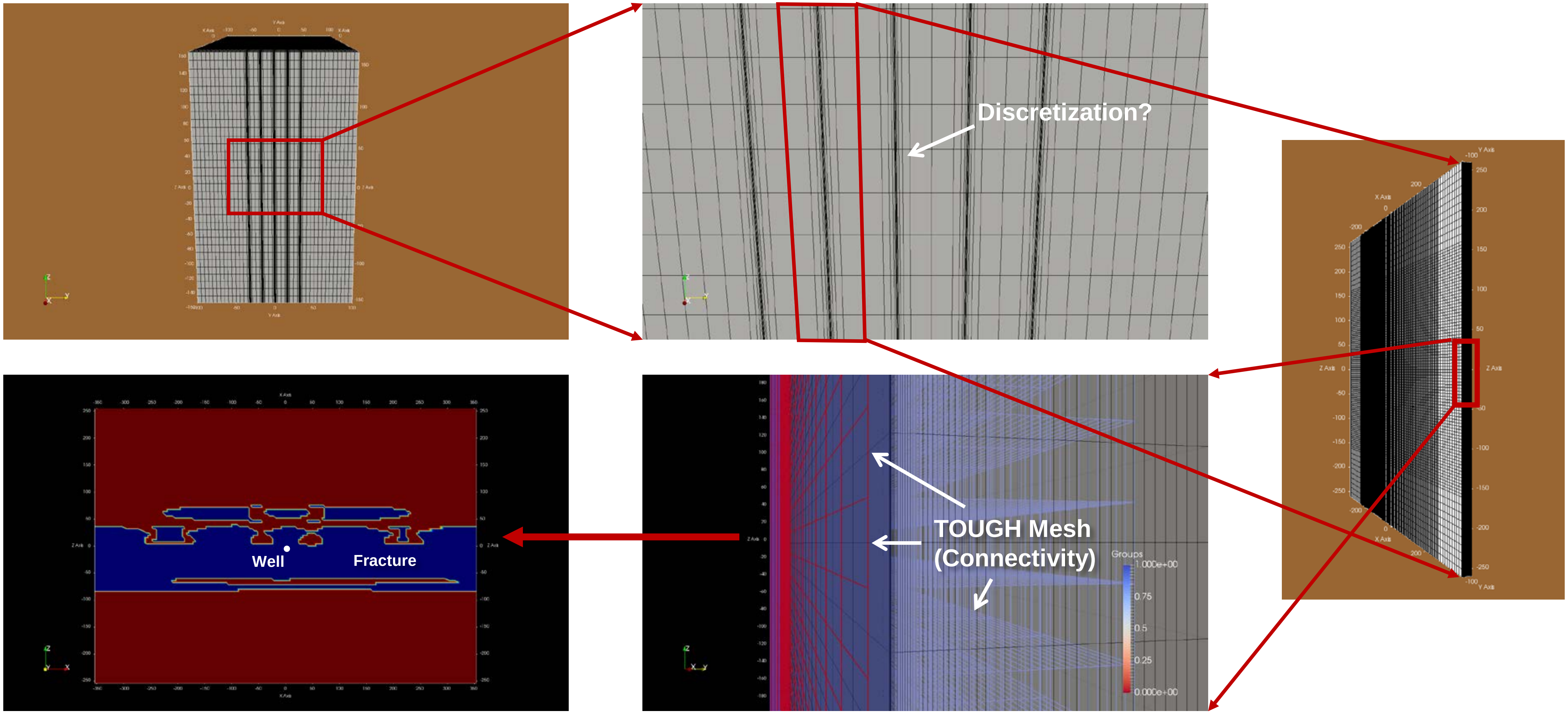
Coupling Between GEOS and TOUGH: We Have Developed and Demonstrated an Initial Coupling Method



Next steps:

- Perform further validation of the mapping between GEOS and TOUGH+
- Increase complexity of the GEOS models that are mapped to TOUGH+

Designing and Testing Coupling Method Between GEOS and TOUGH

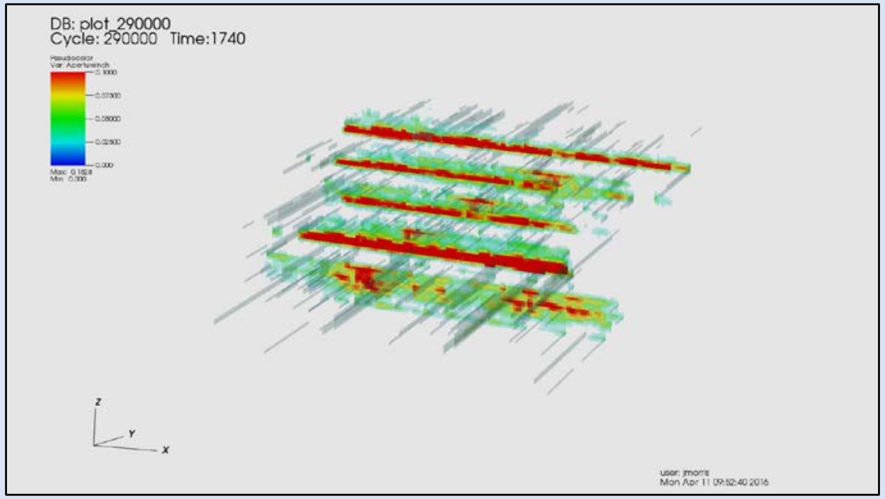


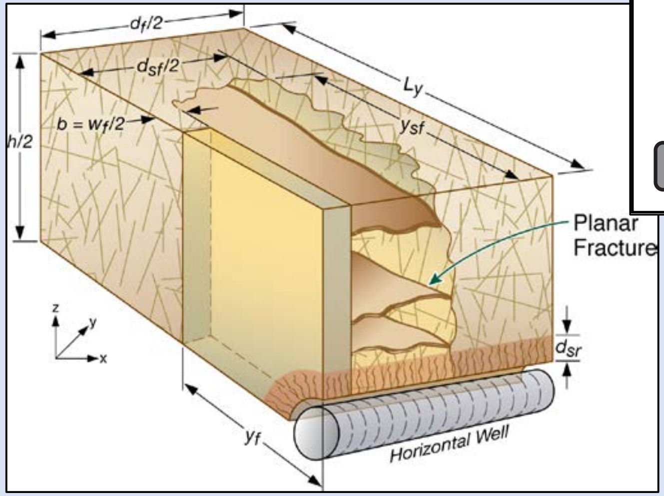
Micro-scale Experiments and Modeling

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

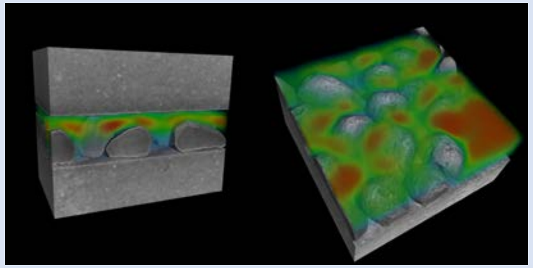
Micro-scale Experiments/Modeling to Inform Reservoir-Scale Models

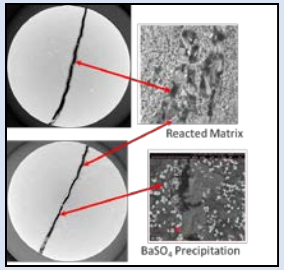
GEOS ⟷ **TOUGH**

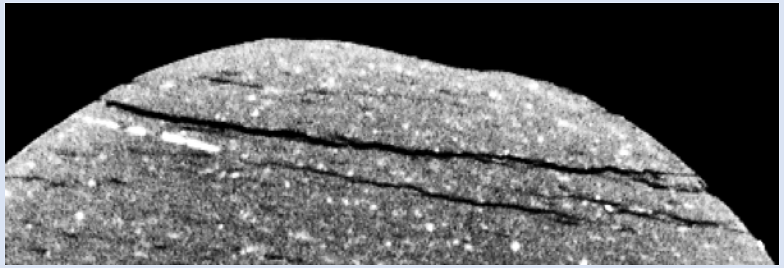


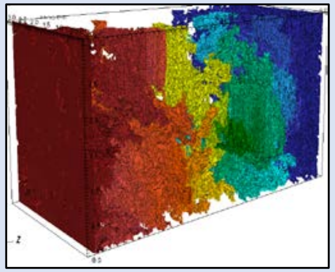


New Constitutive Models for Shale Property Evolution from Geomechanics and Reactions Based on Micro-scale and Core-Scale Experiments and Simulations

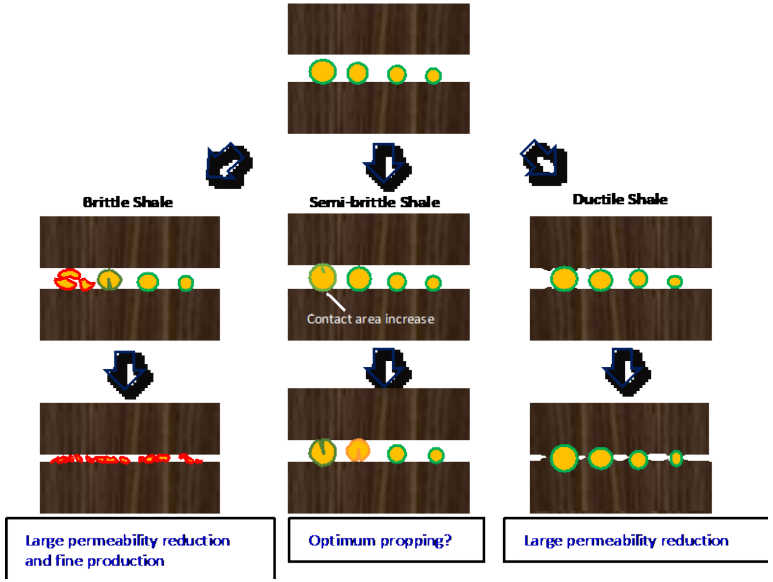




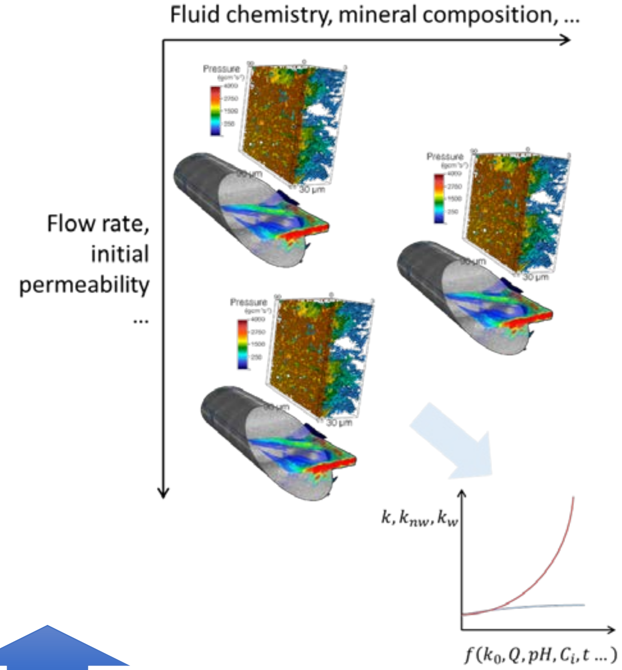




Micro-scale Experiments/Modeling to Inform Reservoir-Scale Models



Need a workflow and relationships that work over a broad range of conditions (Phase I: Marcellus, Phase II: Wolfcamp)



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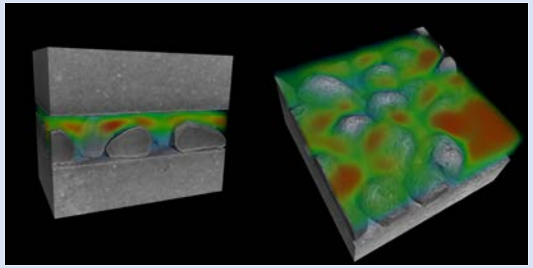
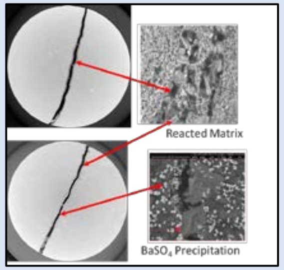
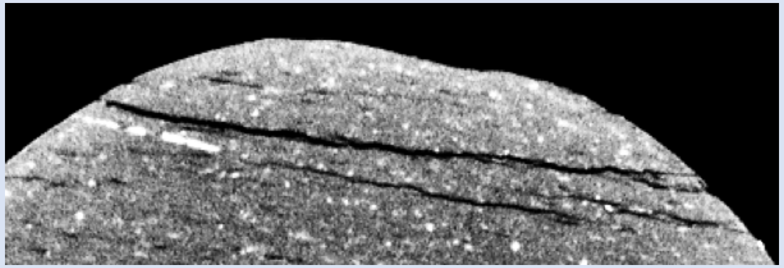
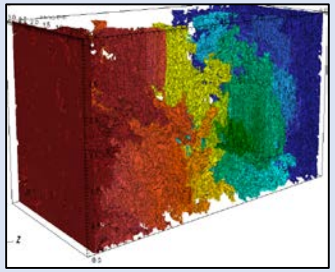








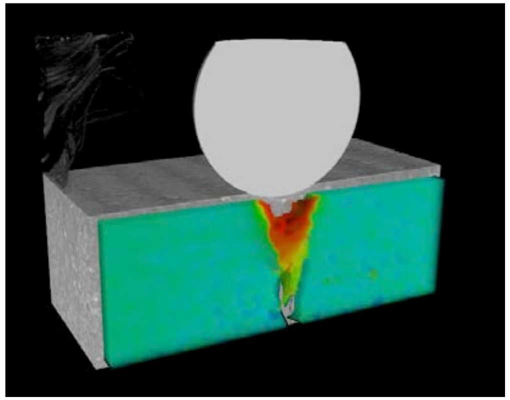
Understanding Proppant/Shale Interaction: Experiments at Grain and Monolayer Scale

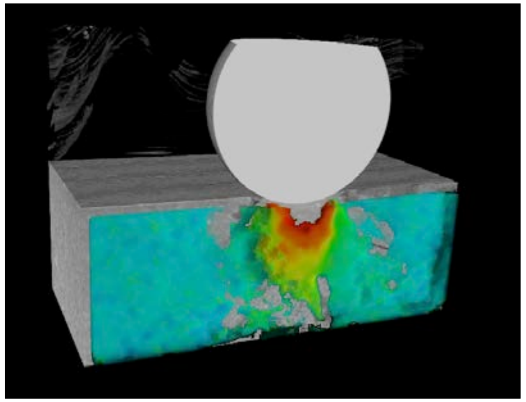
- Microscale provides single proppant grain/shale interaction information

- Mesoscale allows handling of partial and whole monolayers

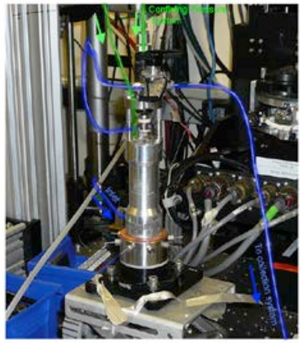
Micro (proppant grain)- scale

Indentation experiments





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



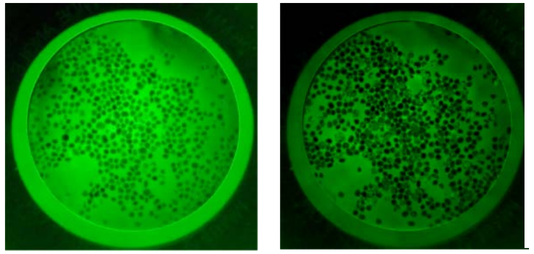
Sub-monolayer (small continuum)-scale

Indentation experiments

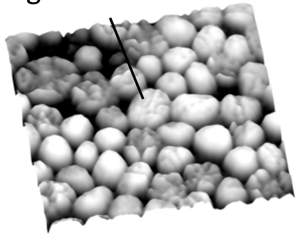
T=0/196 psi

T=15 days

Brittle Marcellus shale (from outcrop)



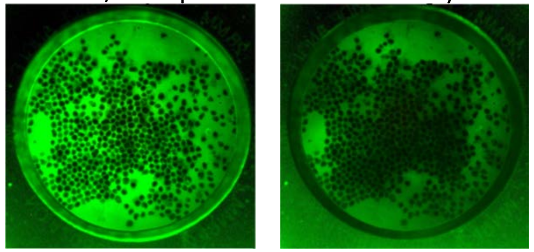
Crushed proppant grains



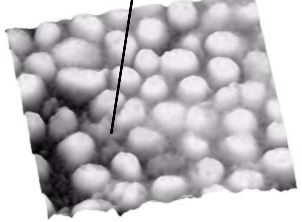
T=0/3984 psi

T=31 days

Ductile Marcellus shale (MSEEL)



Heaved shale matrix



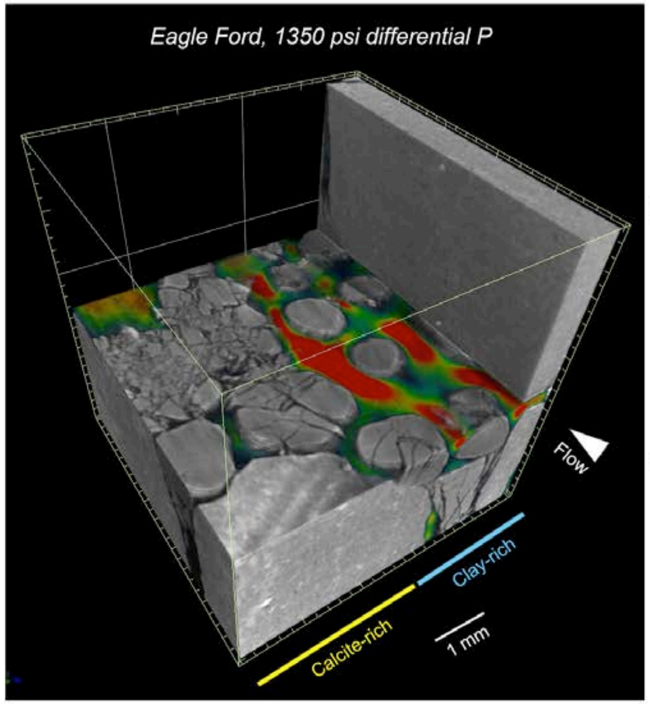
Closure experiment with fluorescent visualization

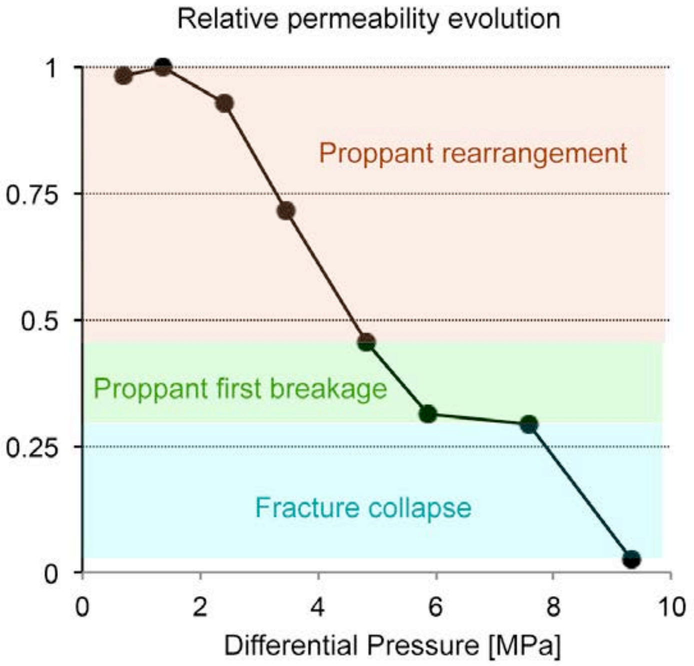
What is really going on inside proppant packs during production?

Micro-scale to Meso-scale Fracturing and Proppant Mechanics

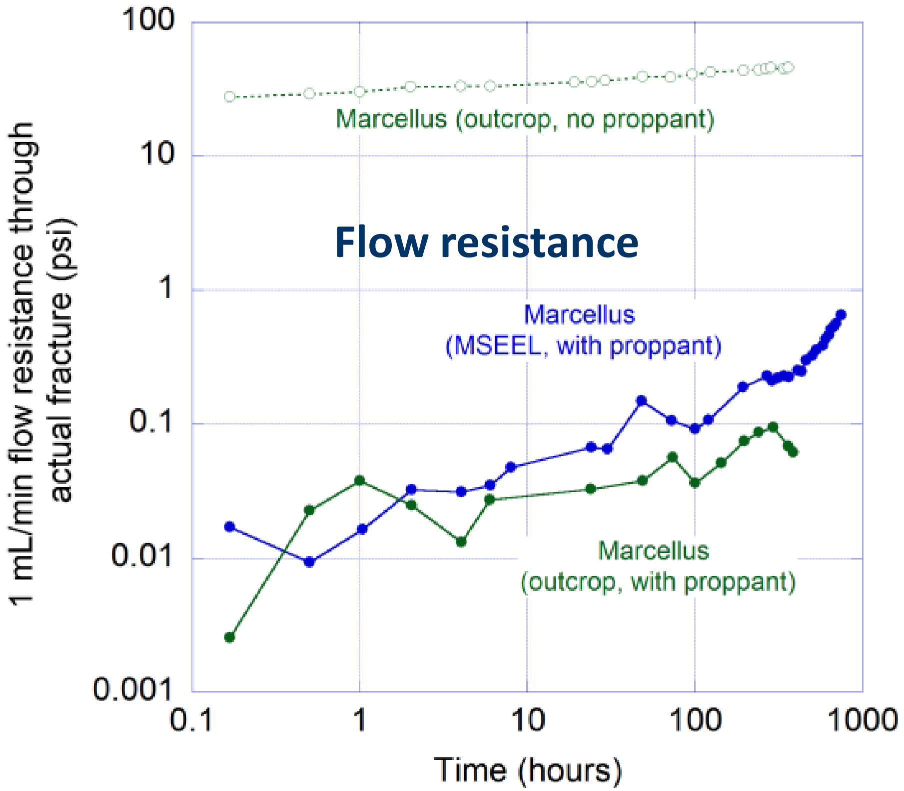
Data from indentation experiments can be used to model the evolution of physical properties of the sample, e.g. permeability, or flow resistance.

Micro-scale Observations/Measurements





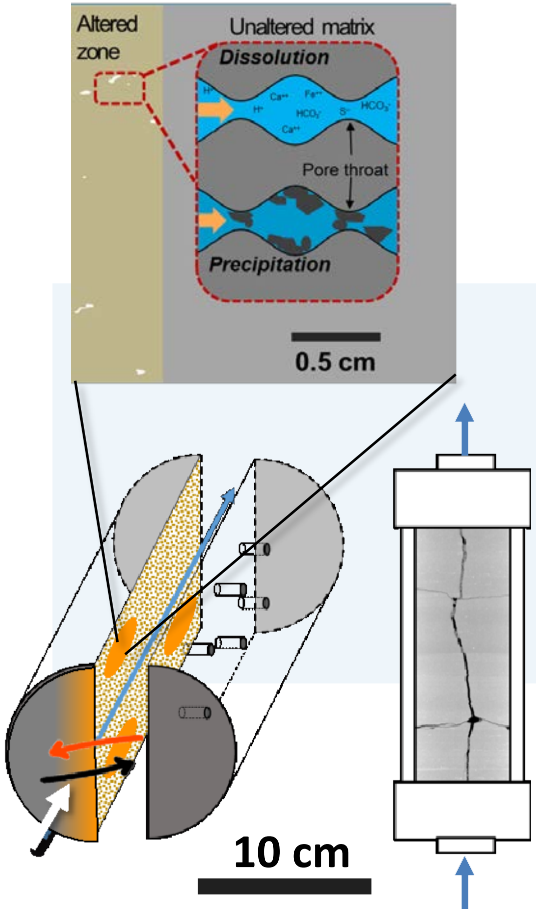
Meso-scale Observations/Measurements



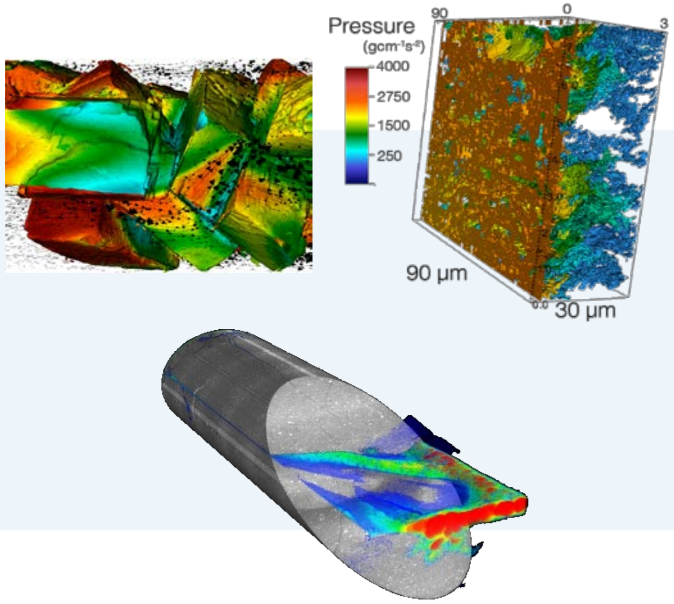
Next step is to do the same experiments on HFTS core

Impact of Micro-scale Reactions on Fracture and Matrix Permeability

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



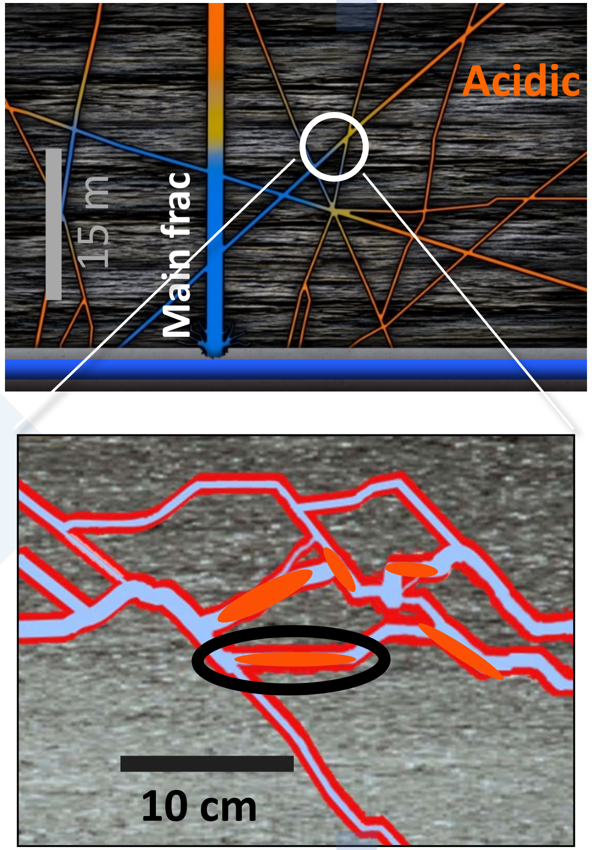
LBNL: pore- and continuum- scale modeling



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 at reservoir scale to inform fracturing and production simulations



NETL: Fracture flow experiments

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

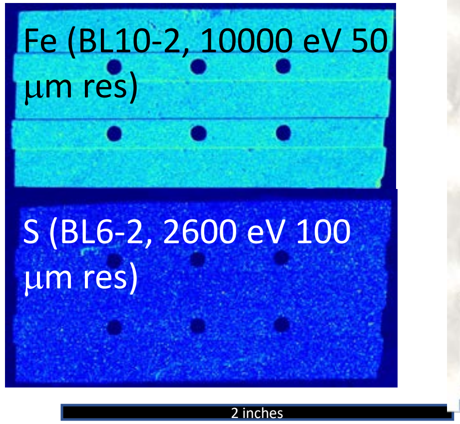
Fracture Flow Experiments

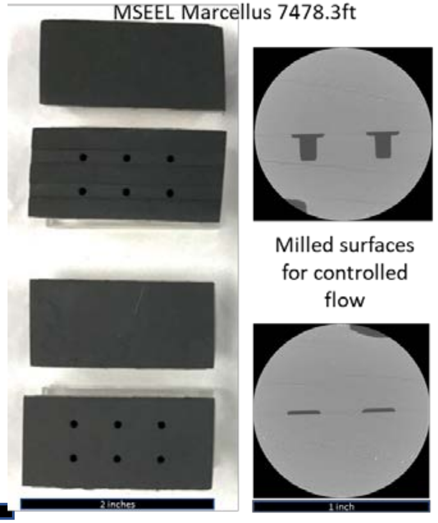
Research question: How does reactive flow influence fracture alteration?

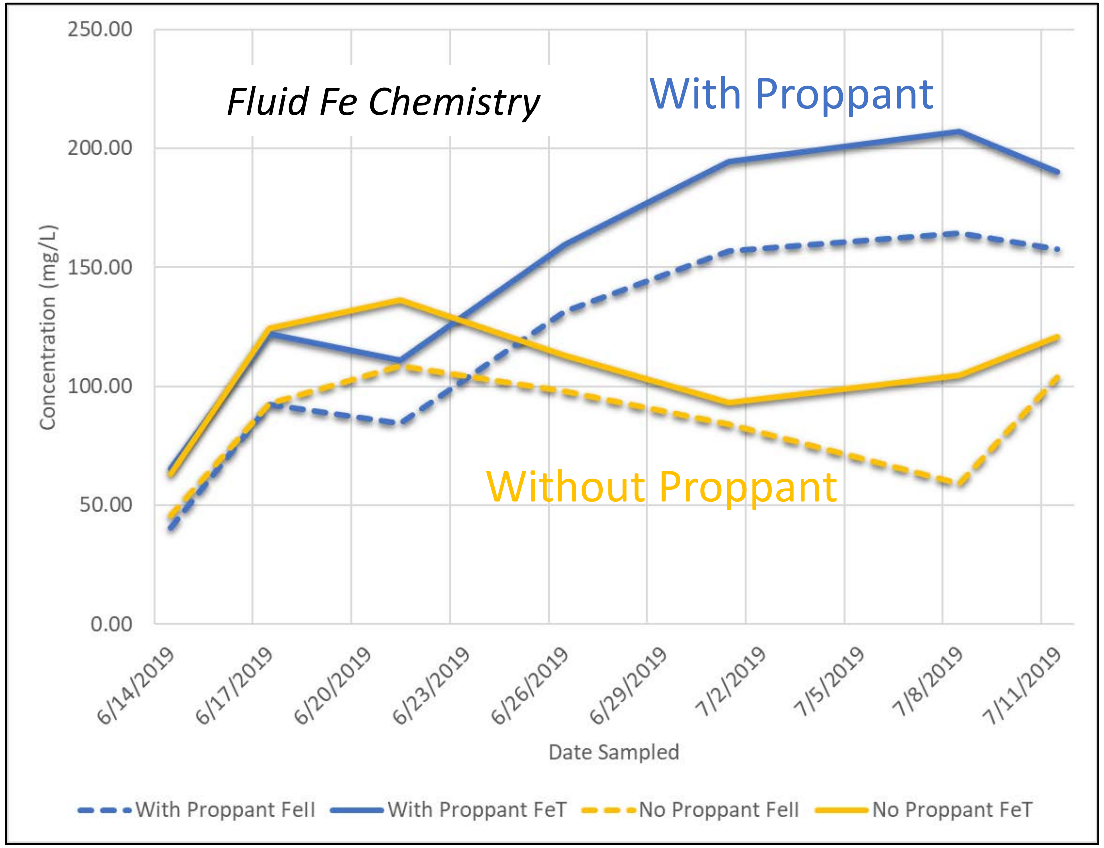
Major activities:

- Focus on fracture alteration driven by reactive flow pathway
- Controlled core flood experiments relate reactive flow in fractures to fracture permeability and matrix changes
- Fe chemistry is clearly controlled by reactive flow conditions
- Next step is to do experiments on HFTS core

Control fluid flow and residence time





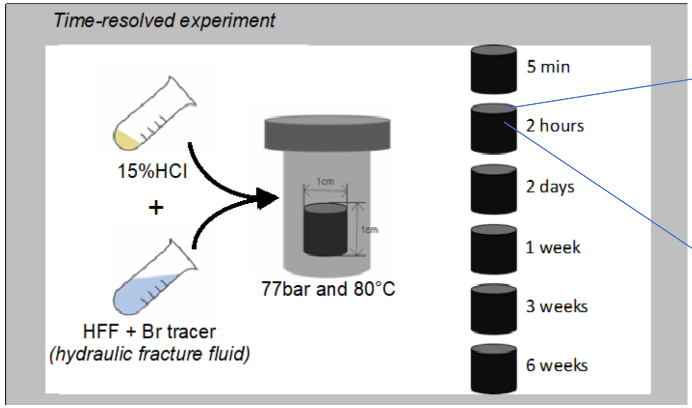


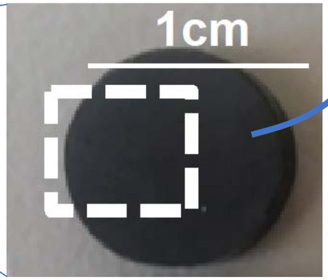
Matrix Alteration

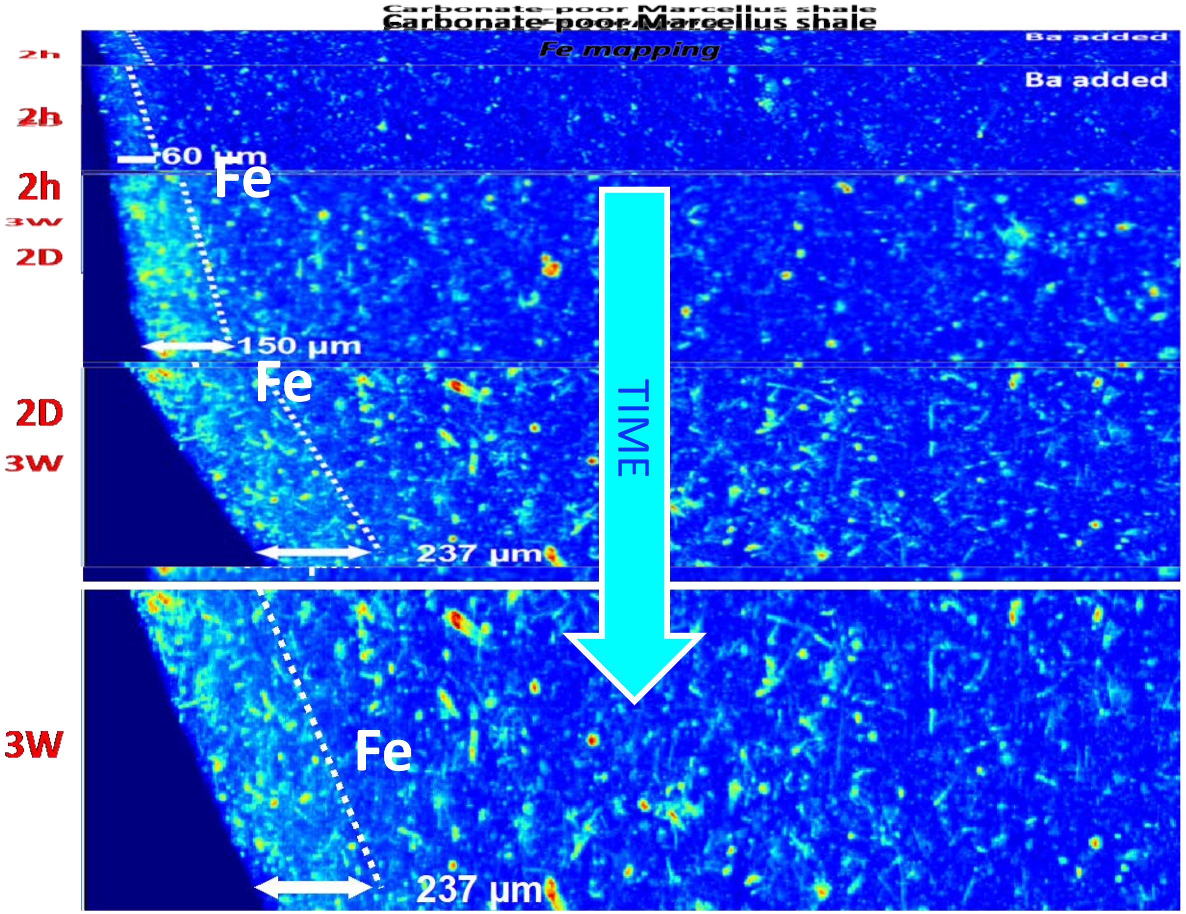
Research question: How does the altered zone forming at the fracture-matrix interface evolve over time?

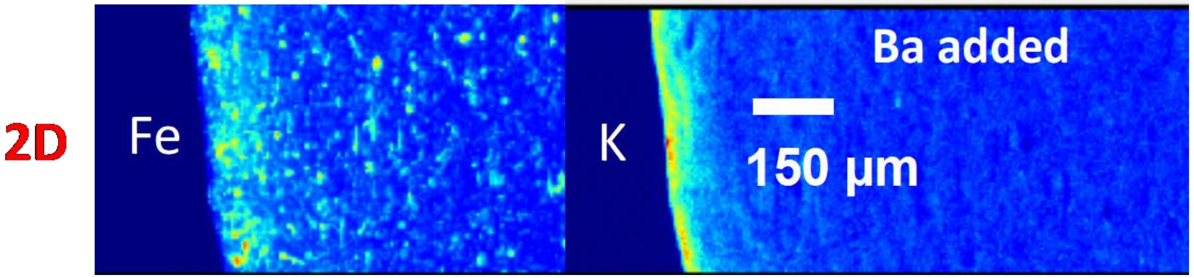
Major activities:

- Focus on matrix alteration driven by fluid chemistry
- Time-lapse reactors cover *wide* range of time steps & chemical conditions
- Characterization of reacted cores and fluids shows that:
  - Fe(III)-oxide scale rim thickens over time in spite of persistent acidic conditions (first time observed!)
  - K/Fe co-accumulation not observed before; Fe-rich *clay mineral scale* precipitated (first time observed!)
- Next step is to relate results matrix alterations to changes in porosity and permeability (using HFTS core)









Accomplishments to Date

- Built an integrated multi-lab, multi-scale project team
- Developed initial stimulation and production models and demonstrated efficient GEOS-TOUGH coupling
- Developed upscaling approaches for stress structure and fracture swarms
- Conducted workflows for testing shale/proppant behavior and how this can be accounted for in reservoir models
- Established frameworks for integrated investigation of shale alteration due to interactions with fracturing fluids

Next Steps

- Conduct experiments on HFTS core and develop upscaling relationships
- Perform final stimulation and production simulations

Lessons Learned

- Access to data and core is a process of unpredictable length

Synergy Opportunities

- HPC simulators GEOS and TOUGH have been developed with DOE resources across multiple DOE programs, from SC-BES to geothermal to nuclear waste, and NNSA
- Micro-scale experimental and simulation work is closely aligned with several fundamental shale research projects across national labs
  - See special session on "National Lab Fundamental Shale Research", Rooms 301-302, Monday 4 pm
- New modeling framework can be applied to other DOE-funded field test sites for unconventional oil and gas, e.g.
  - Tuscaloosa Marine Shale Laboratory (Ballroom B, Tuesday 10:30 am)
  - Marcellus Shale Energy and Environment Laboratory (Ballroom B, Tuesday 11:00 am)
  - Eagle Ford Shale Laboratory (Ballroom B, Wednesday 8:30 am)
  - Hydraulic Fracturing Field Test Site II (Ballroom B, Wednesday 9:00 am)
  - …
- New modeling framework can be used to provide a better predictive understanding of stimulation and production processes in various industry projects

Project Partners

Funding and Project Management

Research

HFTS Collaboration

and various other HFTS I consortium partners

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 tight shale
- Develop a better predictive understanding of production processes as impacted by detailed fracture-characteristics and micro-scale transport

Appendix

Benefits to the Program

- Allows the program to benefit from combined investments across multiple labs and multiple programs
- Helps draw additional value from the HFTS investment
- Developing new concepts that can be readily transferred to industry
  - Rigorous upscaled approaches for integration into fast-running tools
  - New insights into fracturing fluid-formation compatibility

Organization Chart

Project Leadership:

Co-Leads: Jens Birkholzer, LBNL; Joe Morris, LLNL

Project Management: Multi-Lab Leadership Team

Task 1: Reservoir Scale

Joe Morris, LLNL; George Moridis, LBNL

Subtask 1.1: HFTS Data Assessment

Lead: Joe Morris, LLNL

Participating Lab POCs: George Moridis, LBNL

Subtask 1.2: Hydraulic Fracturing Simulations

Lead: Pengcheng Fu, LLNL

Participating Lab POCs: George Moridis, LBNL

Subtask 1.3: Production Simulations

Lead: Matt Reagan, LBNL

Participating Lab POCs: Yue Hao, LLNL

Subtask 1.4: Coupling Methodologies

Lead: George Moridis, LBNL

Participating Lab POCs: Randy Settgast, LLNL

Task 2: Micro Scale

Carl Steefel (LBNL); Joe Morris (LLNL)

Subtask 2.1: Micro-scale Mechanics

Leads: Randy Settgast and Joe Morris, LLNL

Participating Lab POCs: Tim Kneafsey, LBNL

Subtask 2.2: Micro-scale Reactions

Lead: Hang Deng, LBNL

Participating Lab POCs: C. Lopano, NETL; J. Bargar, SLAC; Y. Hao, LLNL

Subtask 2.3: Core-Scale Validation

Lead: Matt Reagan, LBNL

Participating Lab POCs: Dustin Crandall, NETL; Yue Hao, LLNL

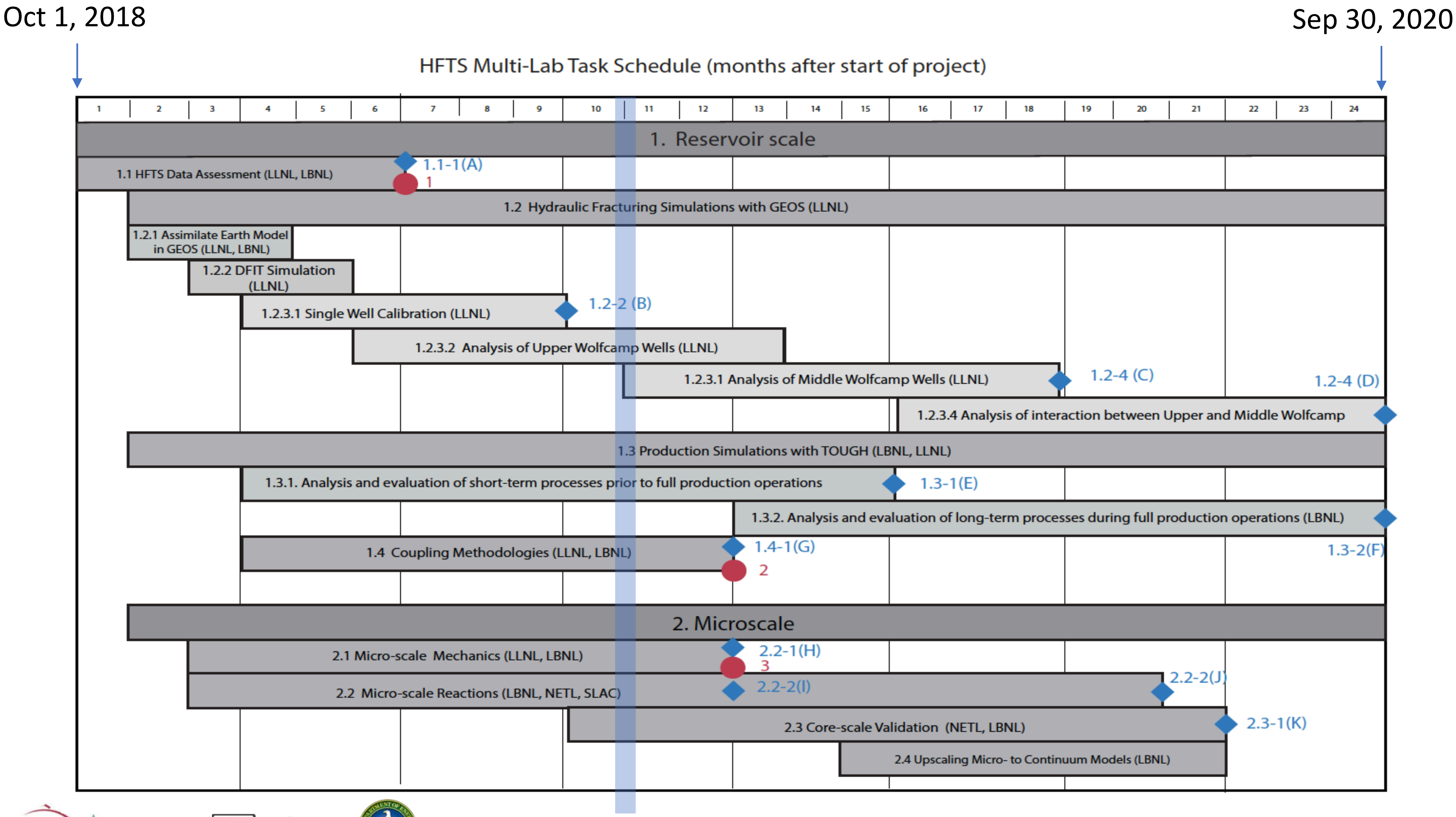
Subtask 2.4: Upscaling Micro- to Continuum

Leads: Matt Reagan, LBNL

Participating Lab POCs: Randy Settgast, Joe Morris, LLNL

*Multi-Lab Leadership Team: Comprises PI's, Task and Sub-Task Leads, and Lab POCs

Gantt Chart



Oct 1, 2018
Sep 30, 2020
HFTS Multi-Lab Task Schedule (months after start of project)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
1. Reservoir scale
1.1 HFTS Data Assessment (LLNL, LBNL)
1.1-1(A)
1
1.2 Hydraulic Fracturing Simulations with GEOS (LLNL)
1.2.1 Assimilate Earth Model in GEOS (LLNL, LBNL)
1.2.2 DFIT Simulation (LLNL)
1.2.3.1 Single Well Calibration (LLNL)
1.2-2 (B)
1.2.3.2 Analysis of Upper Wolfcamp Wells (LLNL)
1.2.3.1 Analysis of Middle Wolfcamp Wells (LLNL)
1.2-4 (C)
1.2-4 (D)
1.2.3.4 Analysis of interaction between Upper and Middle Wolfcamp
1.3 Production Simulations with TOUGH (LBNL, LLNL)
1.3.1. Analysis and evaluation of short-term processes prior to full production operations
1.3-1(E)
1.3.2. Analysis and evaluation of long-term processes during full production operations (LBNL)
1.4 Coupling Methodologies (LLNL, LBNL)
1.4-1(G)
2
1.3-2(F)
2. Microscale
2.1 Micro-scale Mechanics (LLNL, LBNL)
2.2-1(H)
3
2.2 Micro-scale Reactions (LBNL, NETL, SLAC)
2.2-2(I)
2.2-2(J)
2.3 Core-scale Validation (NETL, LBNL)
2.3-1(K)
2.4 Upscaling Micro- to Continuum Models (LBNL)

Bibliography

- Moridis, G.J., Reagan, M.T., Queiruga, A.F., “High-Definition Analysis and Evaluation of Gas Displacement EOR Processes in Fractured Shale Oil Formations,” IPTC-19276, Proc. Int. Petroleum Technology Conference, Beijing, China, 26-28 March 2019.
- Queiruga, A.F., Reagan, M.T., Moridis G.J., “Interdependence of Flow and Geomechanical Processes During Short- and Long- Term Gas Displacement EOR Processes in Fractured Shale Oil Formations,” IPTC-19421, Proc. Int. Petroleum Technology Conference, Beijing, China, 26-28 March 2019.
- Huang, J., Fu, P., Morris, J.P., Settgast, R.R., Sherman, C. S., Hao, Y., Ryerson F.J., “Numerical Modeling of Well Interference Across Formations at the Hydraulic Fracturing Test Site,” ARMA 19–1995.
- Morris, J. P., Sherman, C. S., Fu, P., Settgast, R. R., Huang, J. Fu, W., Wu, H., Hao, Y., Ryerson, F. J., “Multiscale Geomechanical Analysis of the Hydraulic Fracturing Test Site,” ARMA 19–2069.