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Title: Mechanistic Approach to Analyzing and Improving Unconventional Hydrocarbon Production

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Mechanistic Approach to Analyzing and Improving Unconventional Hydrocarbon Production

Bill Carey, Luke Frash, George Guthrie, Jeffrey Hyman, Qinjun Kang,
Rajesh Pawar, Nataliia Makedonska, Hari Viswanathan, and Hongwu Xu

Hypothesis: **The production of unconventional reservoirs can be predicted through physics-based processes in large fractures, small fractures, & matrix.**

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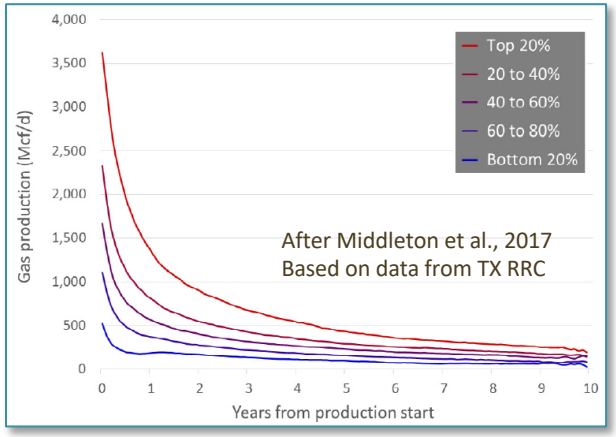
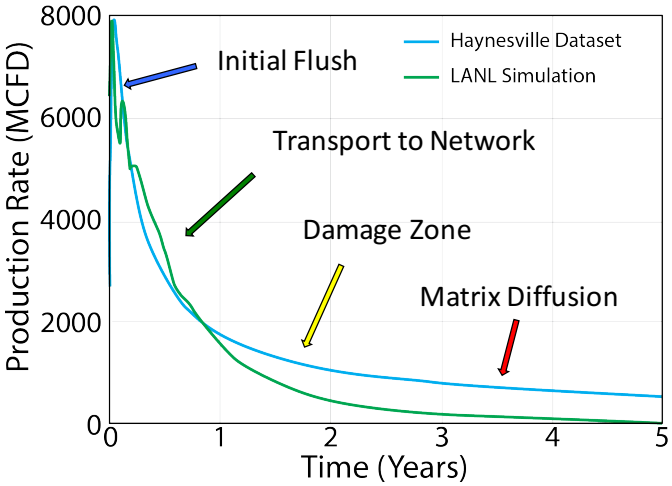
Motivation

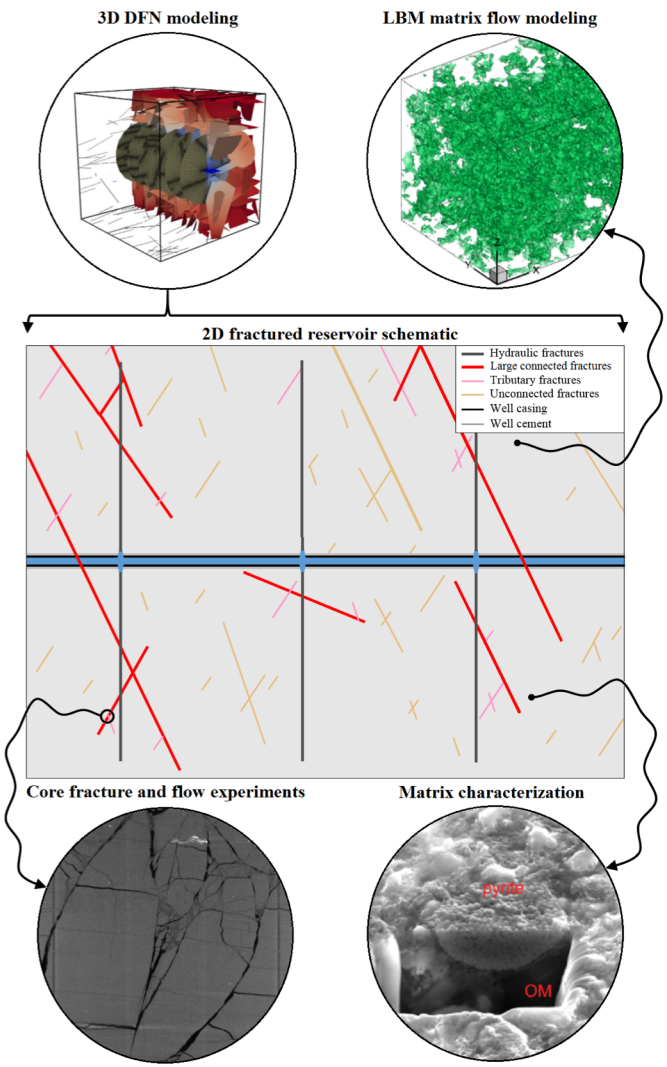
- **Fractured systems behave differently from conventional reservoirs, necessitating different tools and physics to elucidate the behavior of reservoirs during production**



- **Why? Elucidating the controls on production at a site can lead to new strategies to optimize stimulation and reservoir management in order to increase recovery efficiency**



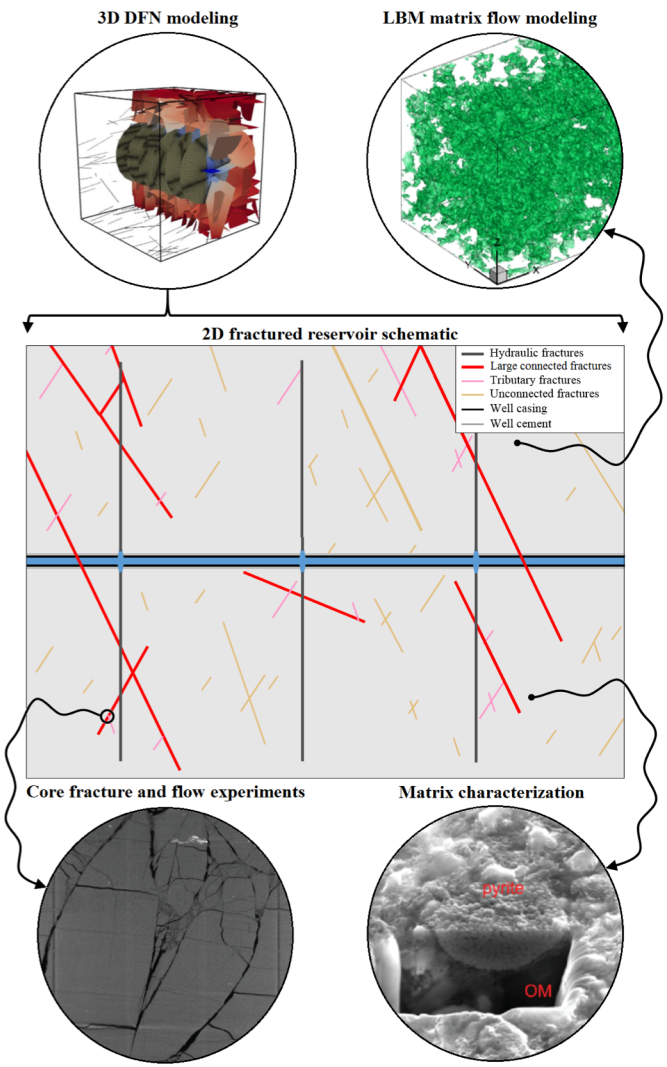
Our Conceptualization of a Shale-Gas Reservoir



Fractured shale system consisting of:

- A horizontal well (blue) with…
- …intersecting hydraulic fractures (grey/blue) that…
- …intersect a natural fracture network (red)…
- …with an adjacent set of smaller fractures that we term “tributary fracture zone” (yellow)…
- …that interacts with embedded matrix fragments

Existing physics-based tools address parts of the system but have limitations



Conventional reservoir simulators

- Define a representative elementary volume (REV) that captures the average behavior of a volume of rock
- Extensively demonstrated in porous-flow systems
- Adapted to fracture systems by defining multiple sets of REVs, attempting to account for average fracture behavior and average matrix behavior

Discrete-fracture network simulators

- Define flow on a discrete set of fractures, capturing the behavior of individual fractures
- Extensively demonstrated in fracture-flow systems
- Typically cannot address porous flow phenomena from matrix, are not suitable for HPC platforms, and cannot address coupled reactive flow

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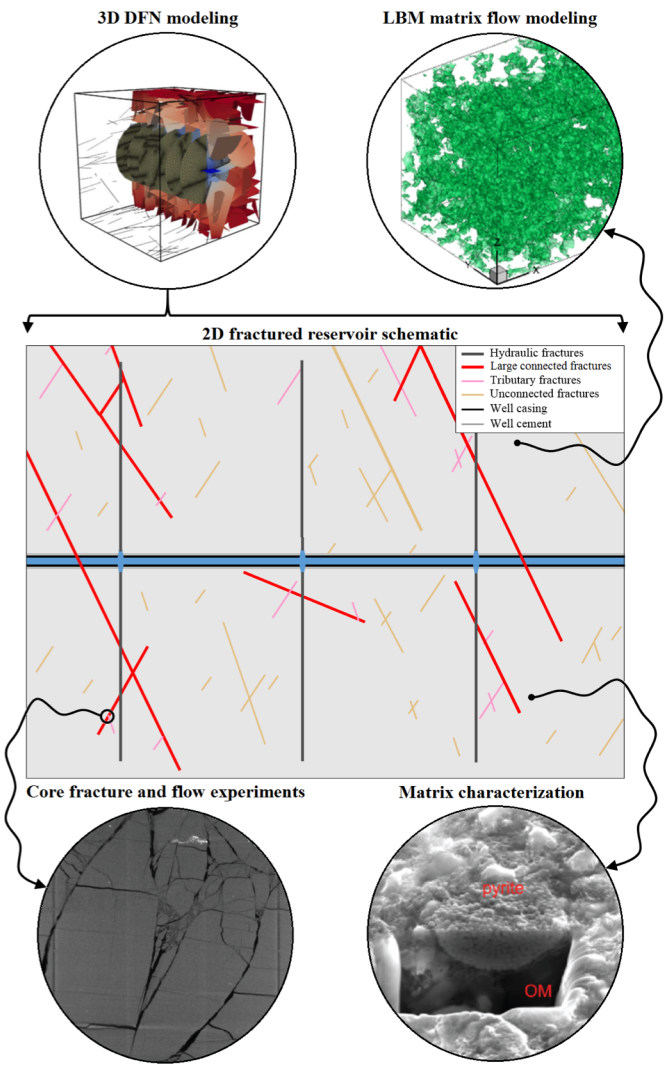
Overview of Los Alamos Shale Effort

Hypothesis: The production of unconventional reservoirs can be predicted through physics-based processes in large fractures, small fractures, and matrix.



Develop experimental and simulation tools to address physics of shale system

- Simulation toolset at reservoir scale that captures both fracture flow and porous flow
- Experimental and simulation toolset at the core scale to elucidate the fracturing and transport behavior of shale systems
- Experimental and simulation toolset at the pore scale to elucidate matrix-scale physics

Integrate experimental & simulation results to enable physics-based predictions shales

(Use machine-learning & ROMs to accumulate knowledge from the physics-based prediction of shales via simulation of realistic "virtual reality" scenarios)

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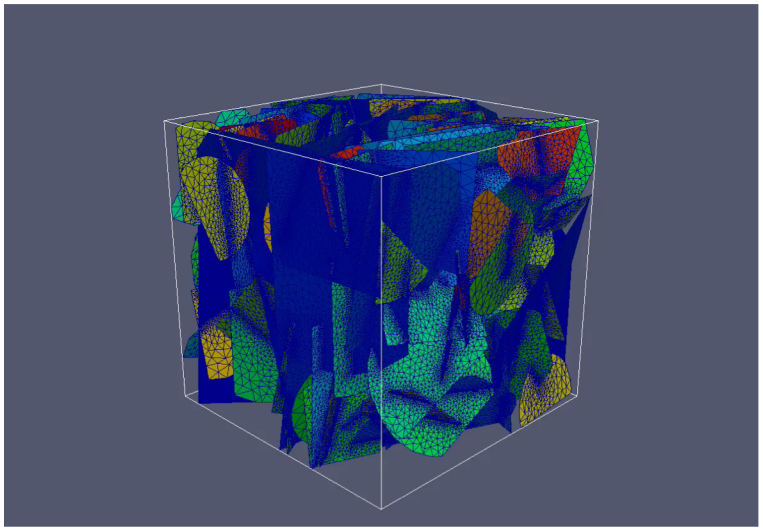
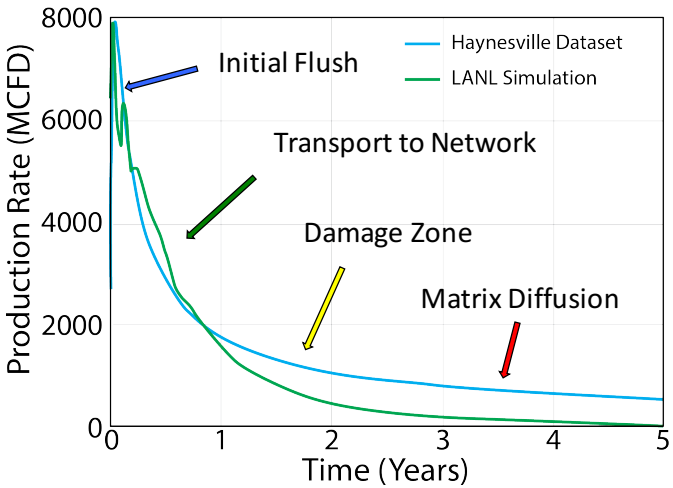
DOE-FE shale work builds on recent internal investments to build an HPC compatible simulation platform for DFNs

Multi-platform Compatible (HPC & laptop) Modeling Suite for Discrete Fracture Networks



Hyman et al. (2015)



dfnGen: Stochastic fracture generation, mesh generation, model setup

dfnFlow: Flow solution using PFLOTRAN or FEHM

dfnTrans: Particle tracking through 3D DFNs

Easy to incorporate site data – fracture statistics

But computationally very intensive

Parallel algorithms – 10,000s to million fractures

LDRD innovation for our nation

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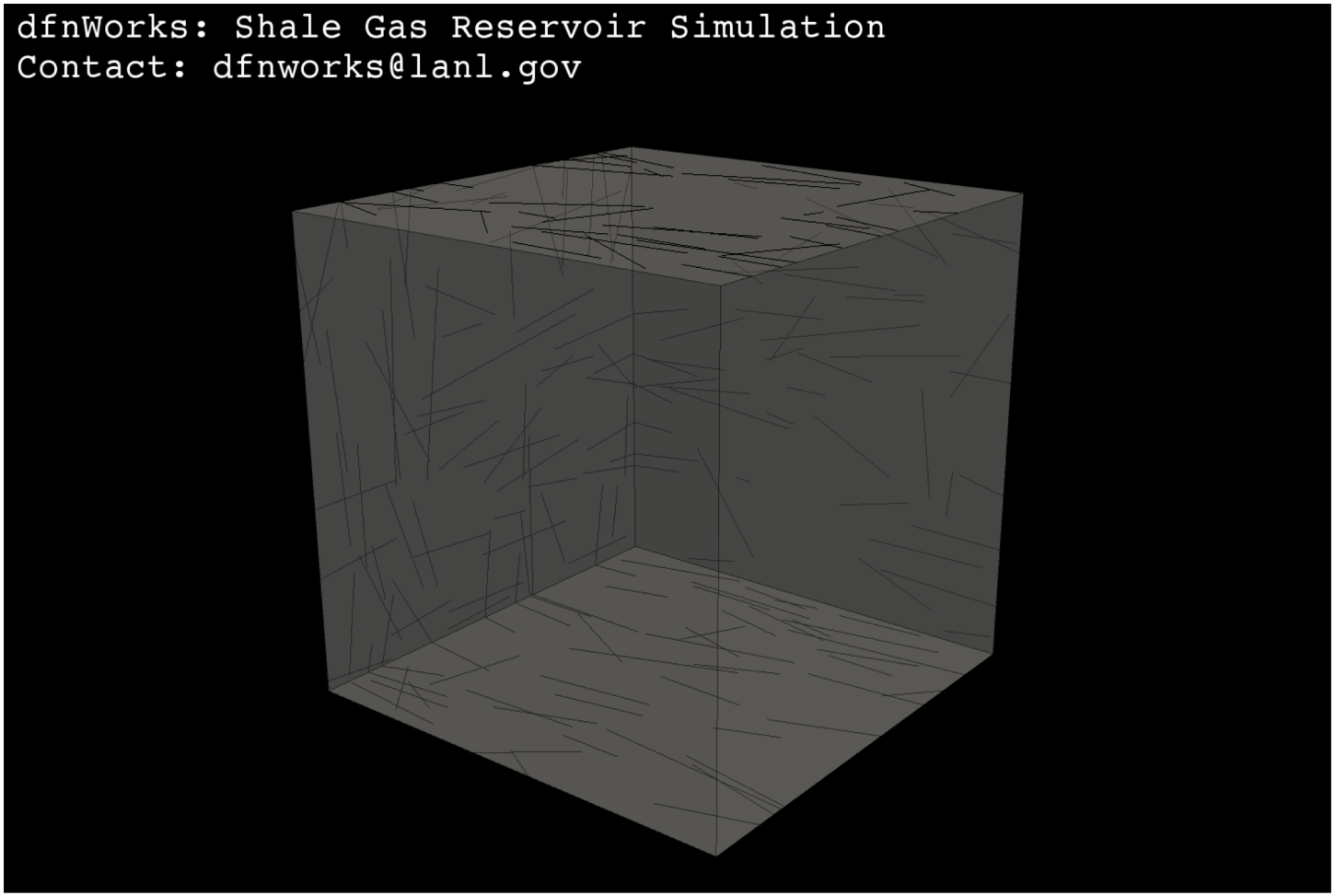
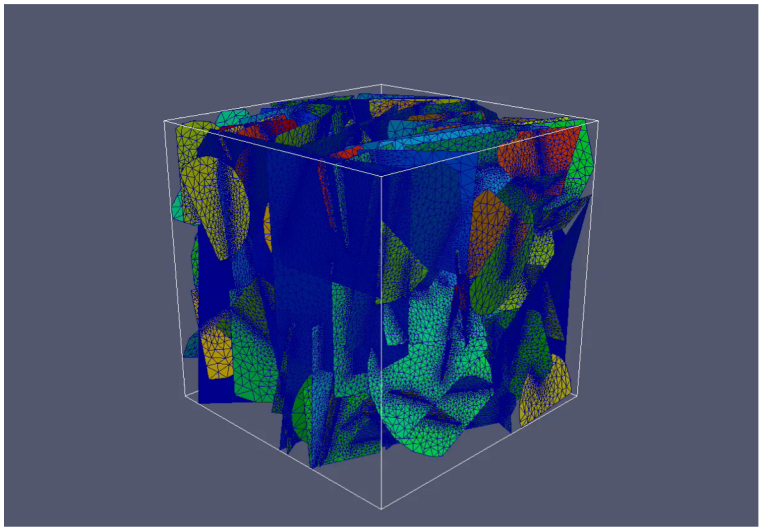
HPC Simulation of Production from a Fractured Shale



Internal investments continue to improve capability using graph-theory to capture relevant physics efficiently

Multi-platform Compatible (HPC & laptop) Modeling Suite for Discrete Fracture Networks



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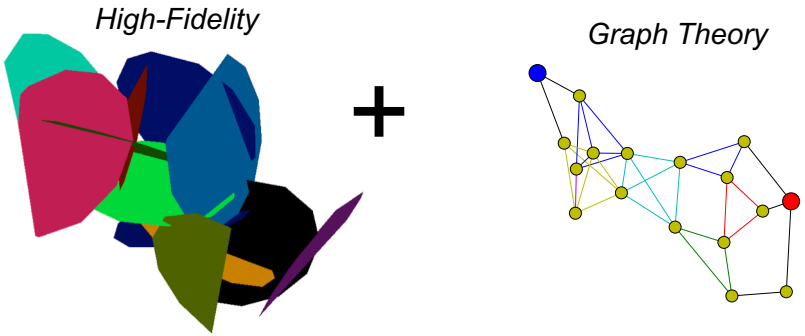
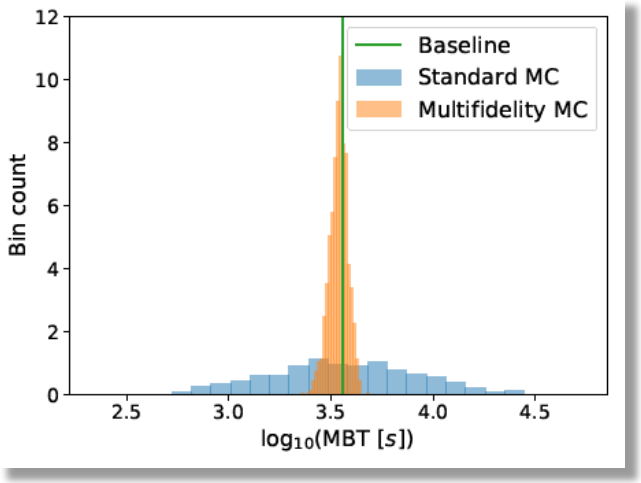
Multi-Fidelity Framework Combines Full Physics with ROM



For a fixed computational cost, multi-fidelity simulation can result in better precision relative to full-physics alone.



O'Malley et al. (in review)

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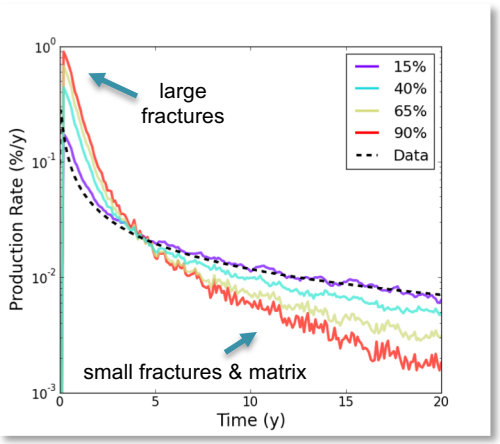
Elucidating Fundamental Controls on Hydrocarbon Production from Shale

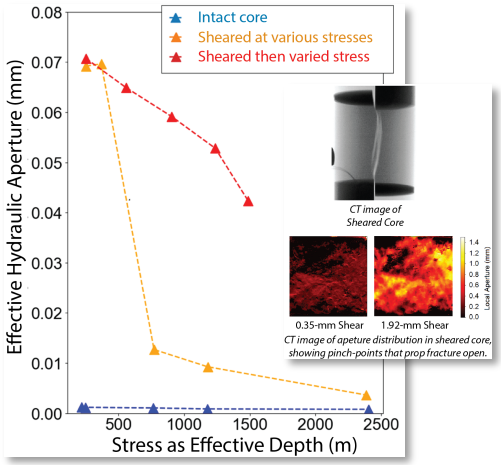
Hypothesis: The production of unconventional reservoirs can be predicted through physics-based processes in large fractures, small fractures, and matrix.

dfnWorks Simulation



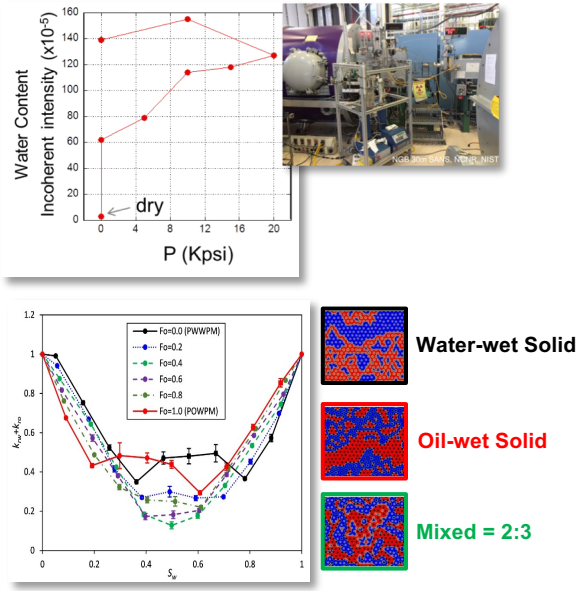
Karra, Hyman, et al.

Core-Scale Experiments



Carey, Frash, et al.

Pore-Scale Experiments + Simulation



Xu, Kang, et al.

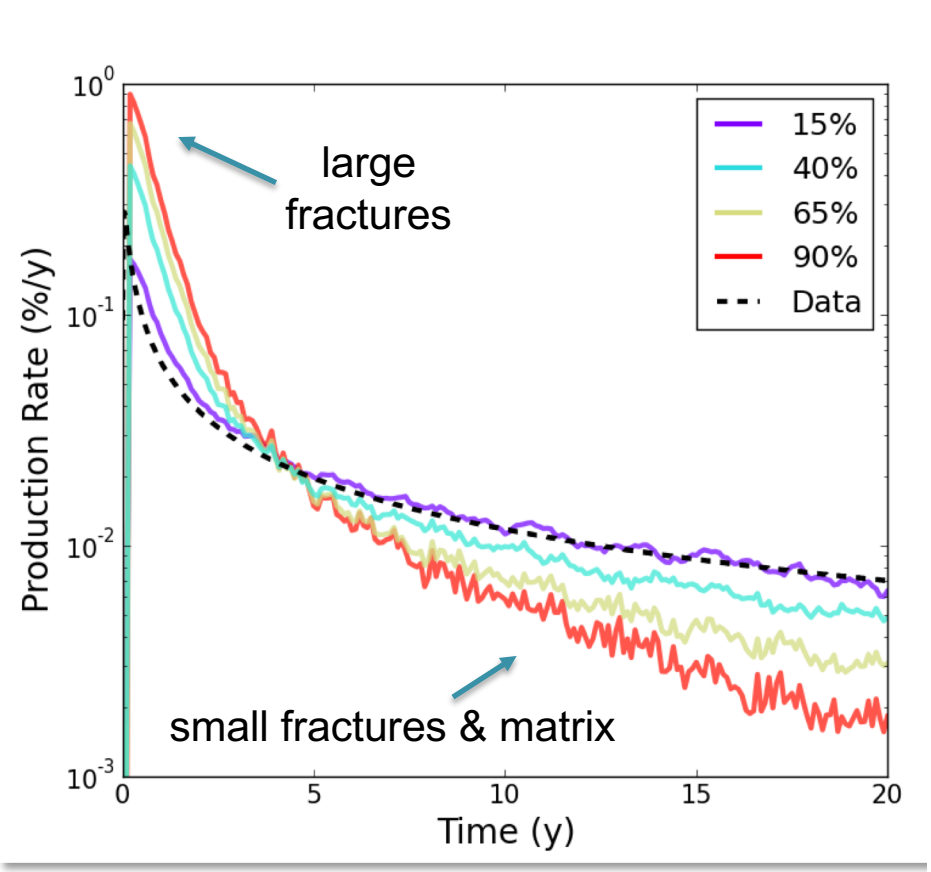
- Completed DFN tool development (main fractures plus tributary zones plus matrix)
- Demonstrated that near-term drains fractures, but mid-term requires tributary + matrix

- Completed development of experimental protocol to measure fracture-flow in-situ
- Determined permeability behavior as a function of stress and shear in carbonate-rich Marcellus

- Completed development of experimental apparatus to probe pores and fluids using neutrons
- Simulated pore-scale transport using Lattice Boltzmann to elucidate and refine transport phenomena in shale-matrix

Reservoir-Scale Simulation

Hypothesis: The production of unconventional reservoirs can be predicted through physics-based processes in large fractures, small fractures, and matrix.



Completed initial DFN tool development

- Added components to address tributary fracture zone and matrix
- Added pressure-dependent behavior for fractures

Applying toolset to explore initial use case

- Impact of pressure management strategies on ultimate total recovery at near-, mid-, and long-terms
- Incorporating data from core- and pore-scales

Future work

- Add multiphase flow and reactive transport to particle-tracking toolset

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Core-Scale Experiments

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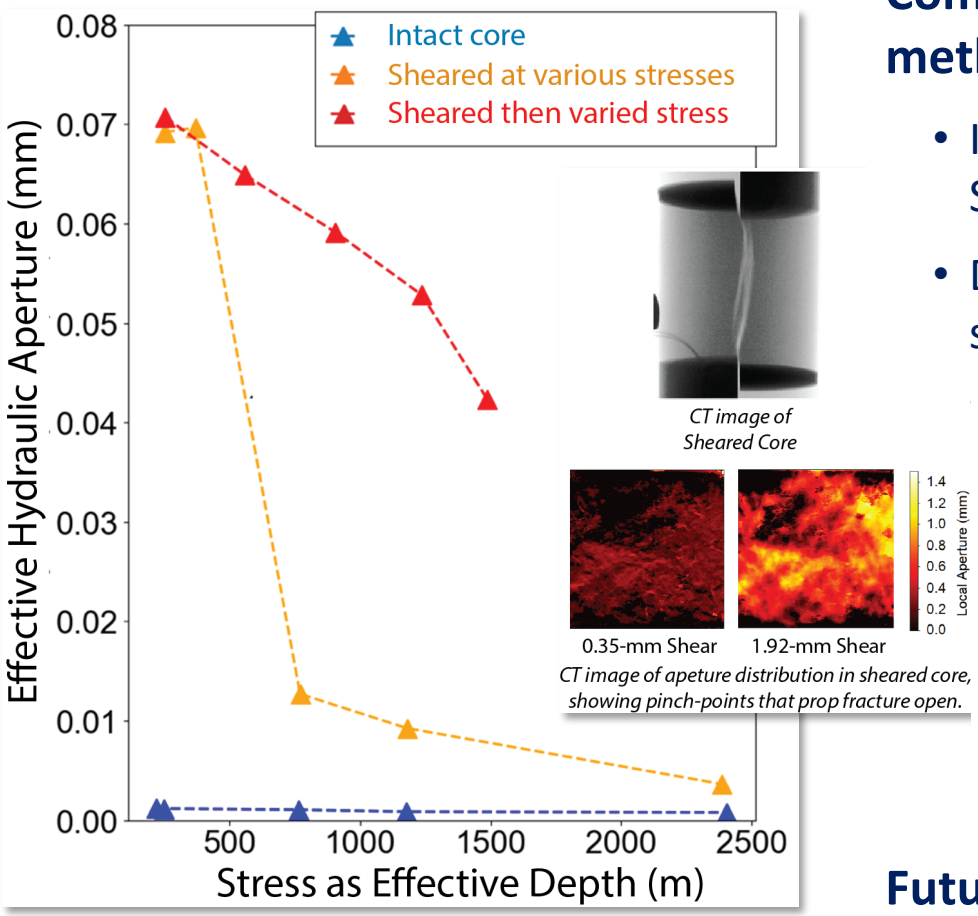

Completed development of core-scale methods

- Initial triaxial system built using Carbon Storage and LDRD funding
- Developed experimental protocol for studying fracturing and transport in

Applying toolset to explore initial use case

- Core scale experiments on set of Marcellus shale samples (carbonate-rich)
- Identified permeability behavior relevant to reservoir conditions

Future work

- Explore additional shales over a range of shale properties

Core-Scale Experiments

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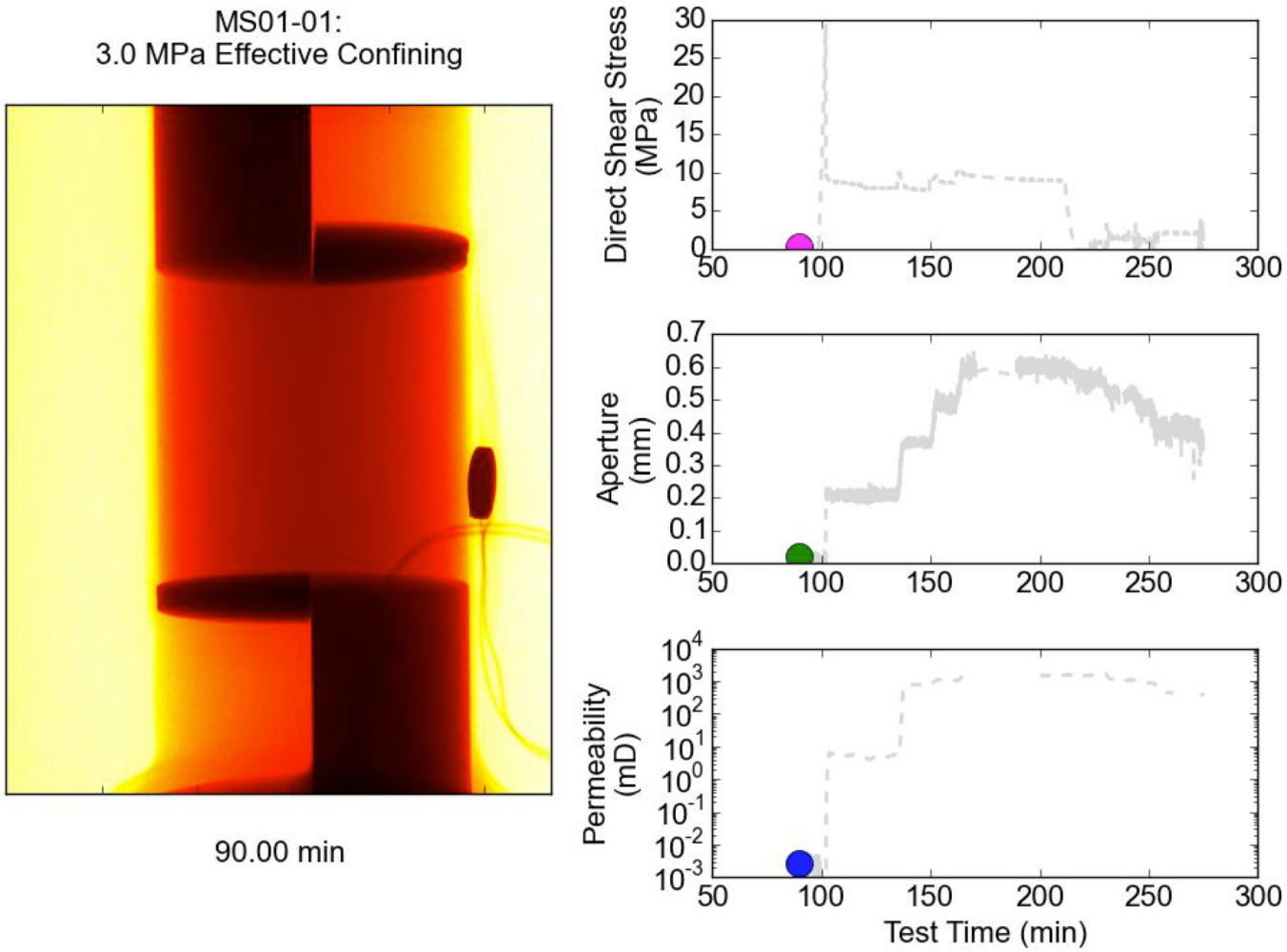

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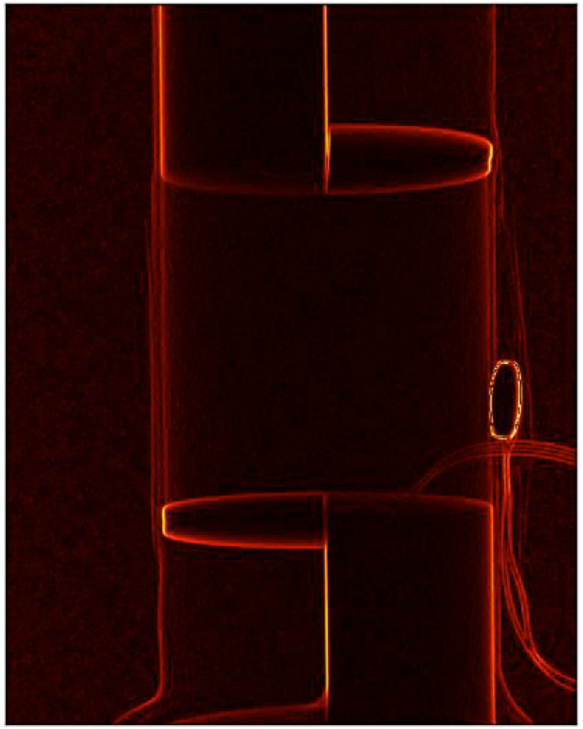

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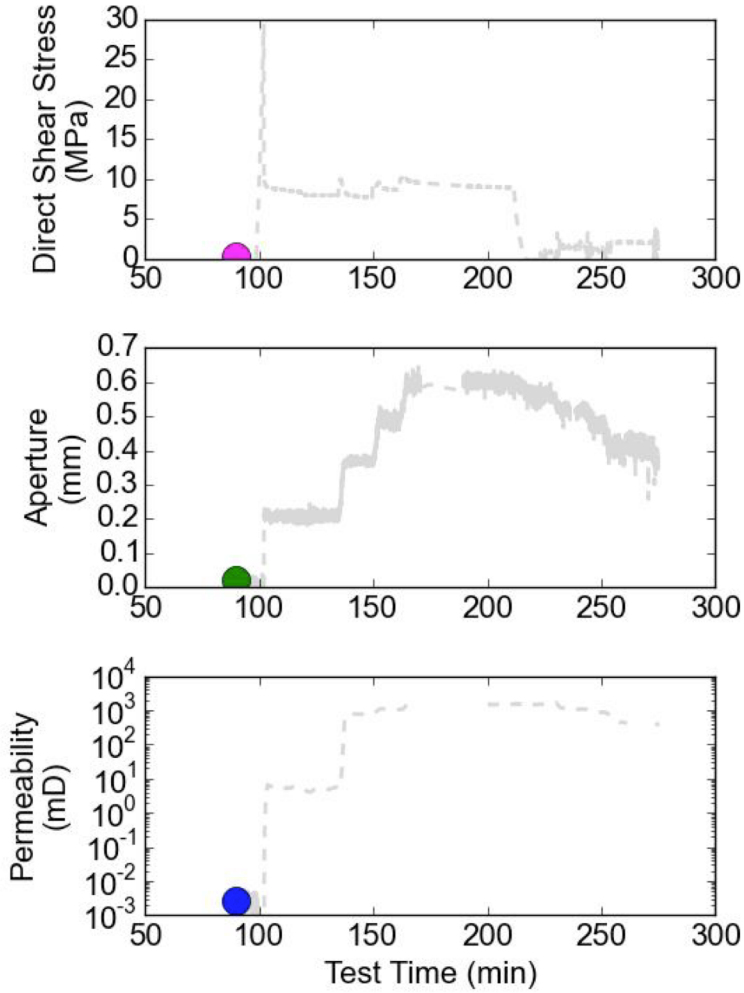

"Core"-Scale Experiments

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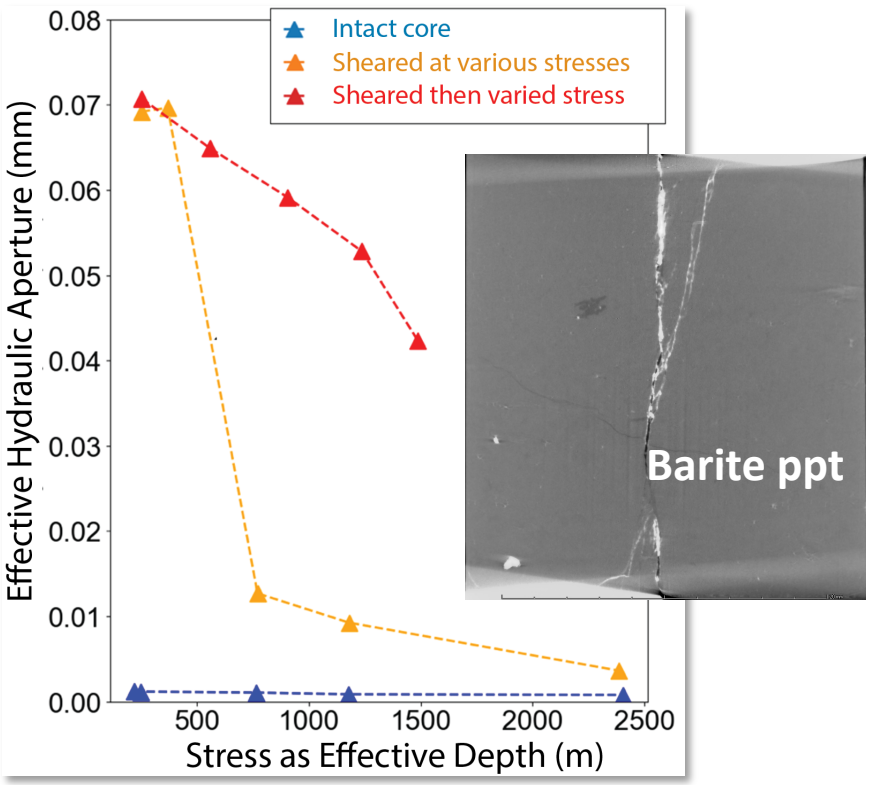

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- Microfluidics to define multiphase-flow effects in fractures

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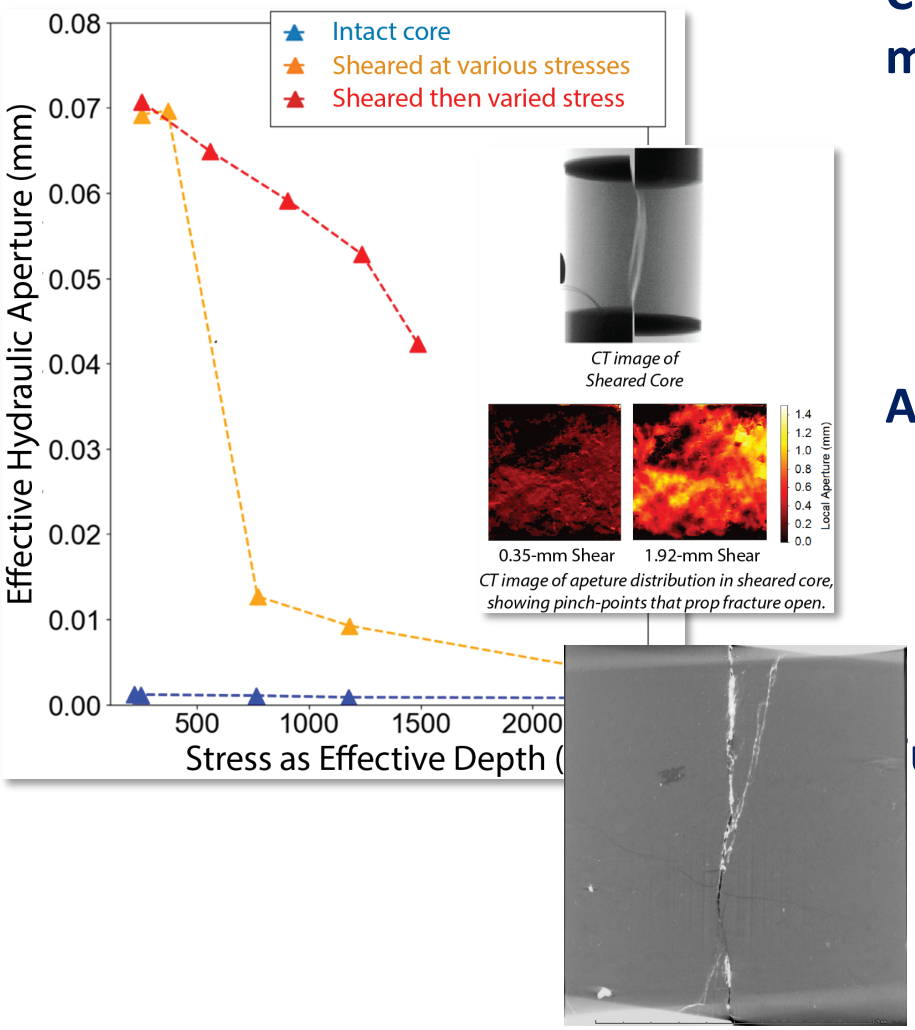

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Pore-Scale Experiments

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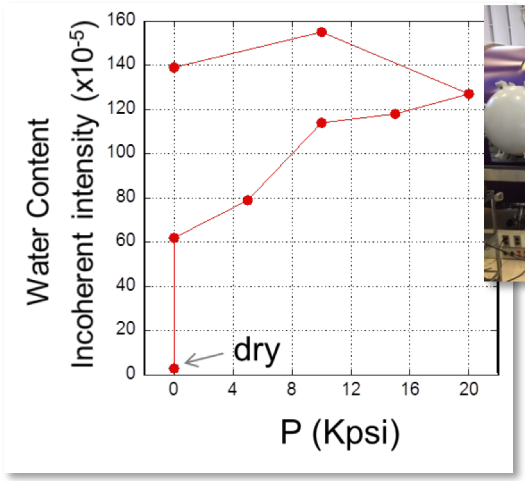
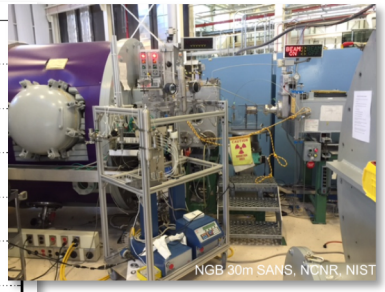
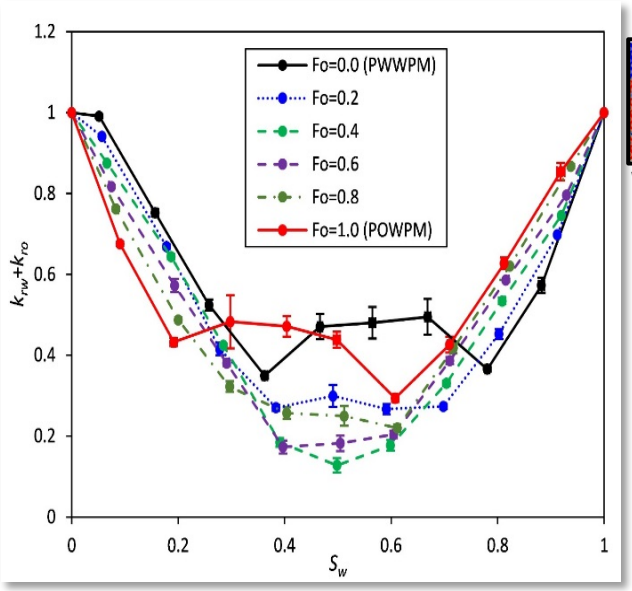
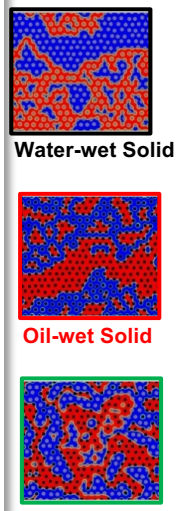








Completed development of experimental apparatus for neutron investigations

- Developed oedeometer for simulating pore pressure (500 bar) and overburden-induced stress (100 bar)

Applying toolsets to explore pore-scale phenomena

- Small-angle neutron scattering experiments on water/gas movement
- Lattice-Boltzmann simulations of transport phenomena in realistic pores and fractures

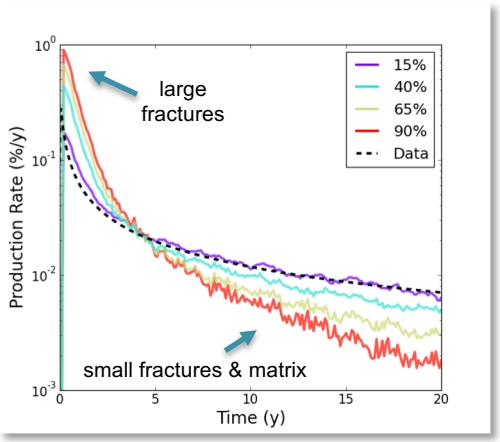
Future work

- Develop empirical relationships that can be used in reservoir-scale simulations

Relevance to CSP

Hypothesis: The production of unconventional reservoirs can be predicted through physics-based processes in large fractures, small fractures, and matrix.

dfnWorks Simulation



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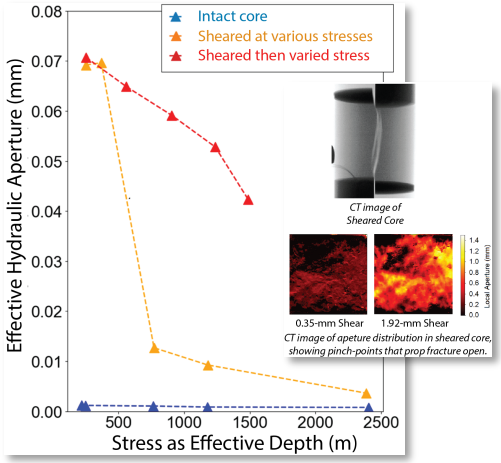
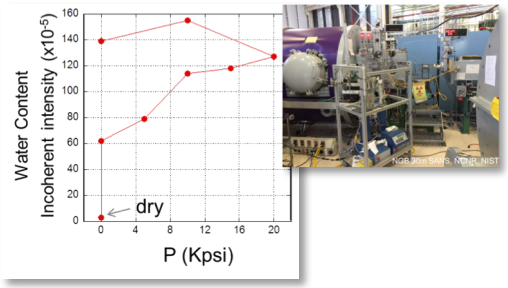
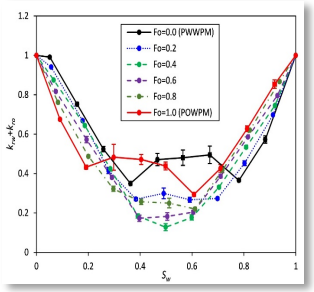
Core-Scale Experiments

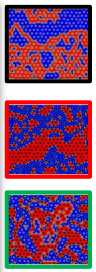


Carey, Frash, et al.

Pore-Scale Experiments + Simulation







Xu, Kang, et al.

- Simulation of transport phenomena in shale caprocks to improve understanding of long-term containment
- Fracturing behavior of shales to inform assessments of integrity after stress
- Storage behavior of shales