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Title: Mechanistic Approach to Analyzing and Improving Unconventional Hydrocarbon Production

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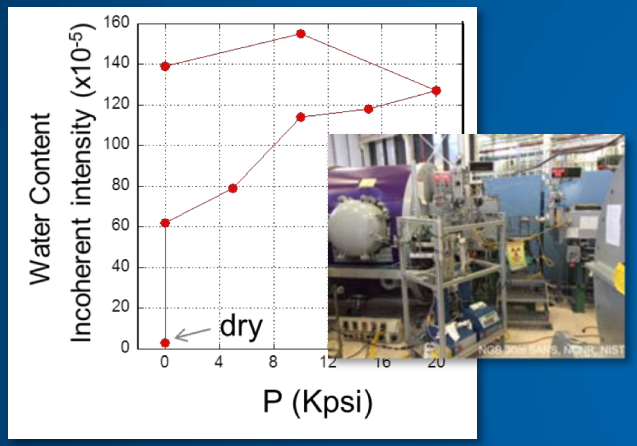
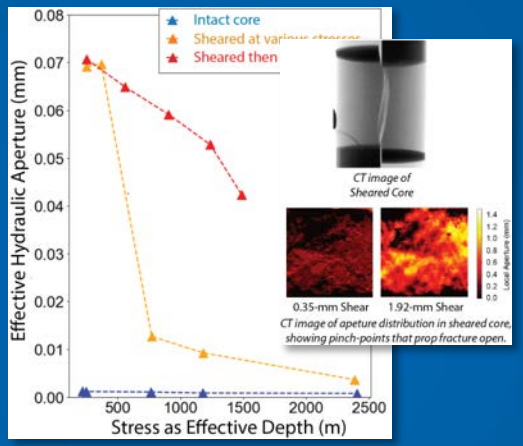
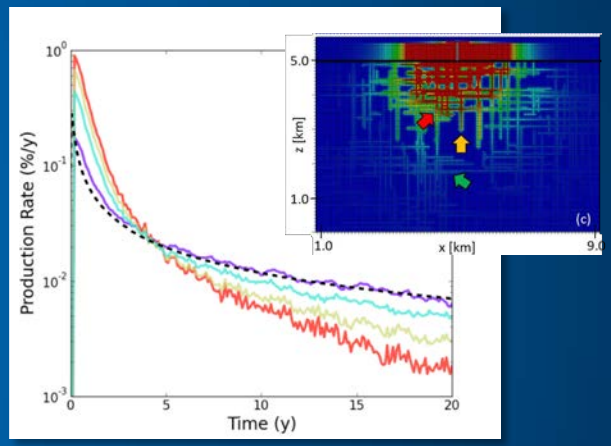
Mechanistic Approach to Analyzing and Improving Unconventional Hydrocarbon Production

Pore-Scale → Fracture-Scale → Reservoir-Scale







Bill Carey, Luke Frash, George Guthrie, Qinjun Kang, Satish Karra, Nataliia Makedonska, Phong Nguyen, Dan O'Malley, Hari Viswanathan, Nathan Welch, Hongwu Xu with contributions from Gilles Bussod, Jeffrey Hyman, Rajesh Pawar, Gowri Srinivasan

75 Los Alamos NATIONAL LABORATORY EST. 1943

2019 DOE FE Fundamental Shale Progress
March 6, 2019

NNSA National Nuclear Security Administration
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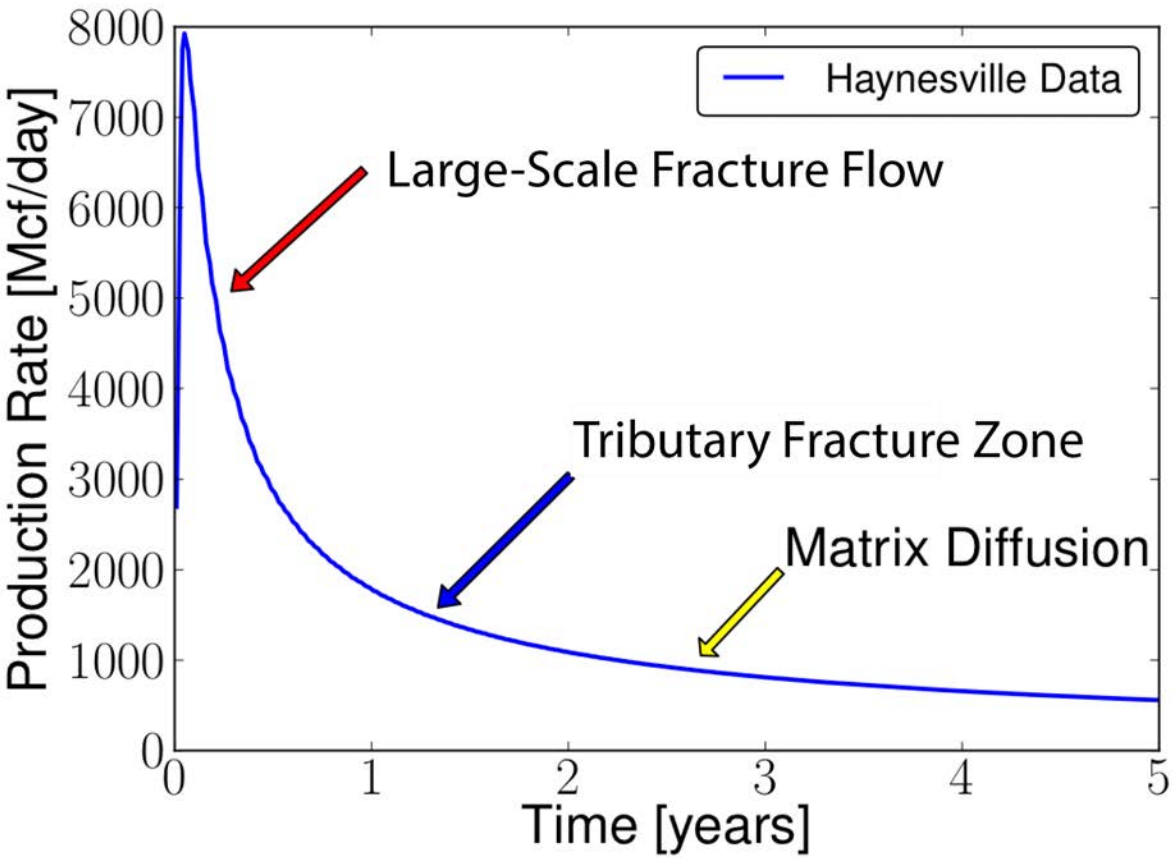
Can we mechanistically simulate production as a means to optimize production?

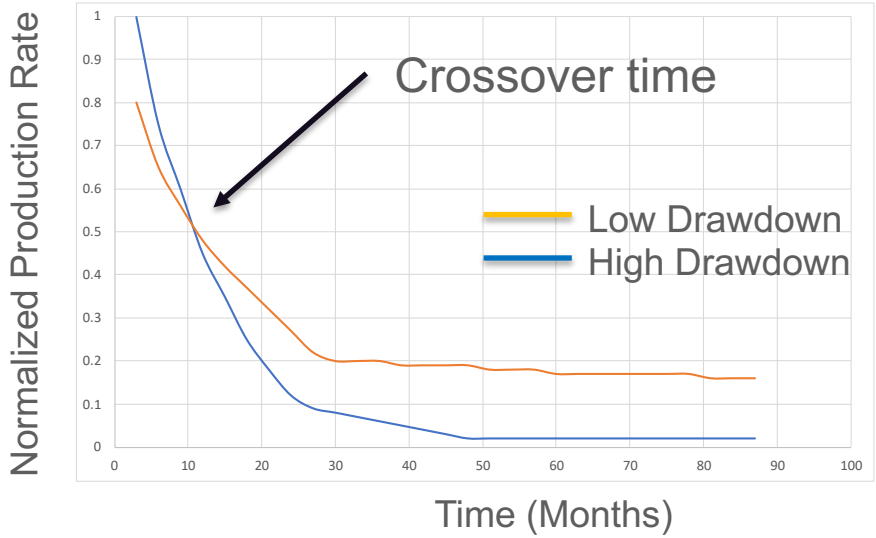


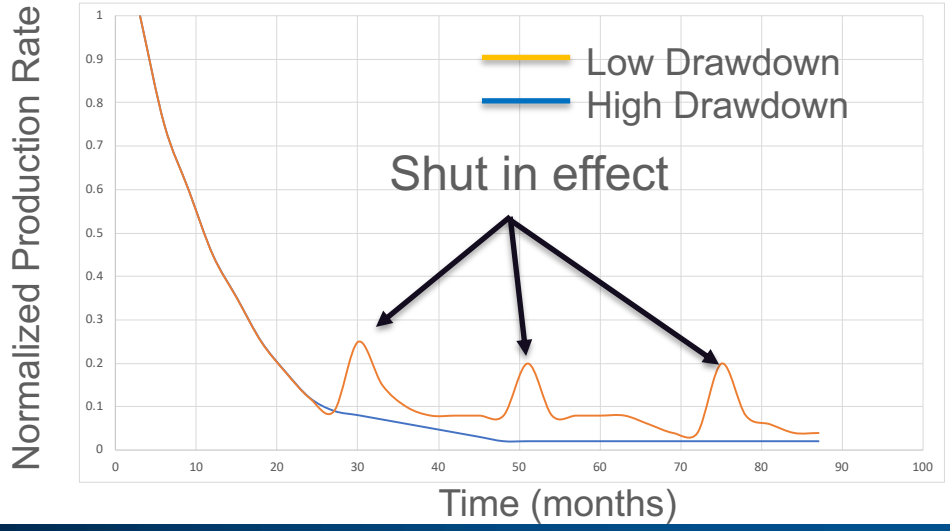
- 20% from early times (<1 yr) and 80% at later times
- Both early and late time are critical for improving production
- Early times controlled by connectivity between generated and natural fractures
- Late time due to interaction between matrix and small fractures

Hypothesis: Production curves reflect physical and chemical phenomena that change with time

Research Goal:
Optimize Production through Improved Pressure Management

Conceptual Model





Anecdotal Evidence

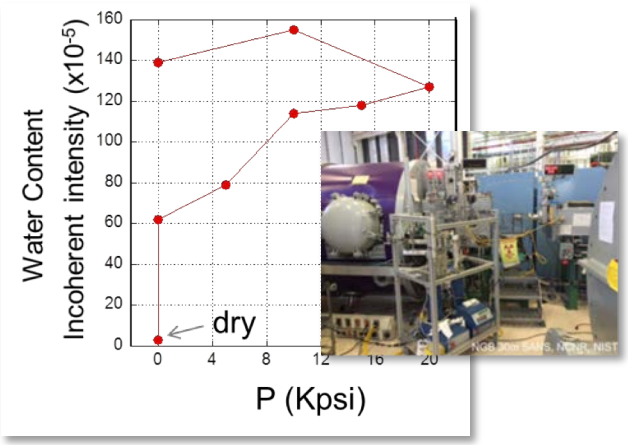
- Operators report that producing slower or using pressure maintenance enhances total production
  - What mechanisms control pressure-production behavior?
  - What controls the crossover time?
- Operators report that shutting in a well increases production
  - How does shut-in increase production?
  - Does increased production last over the lifetime of the well?
  - When is shut-in detrimental to productivity?

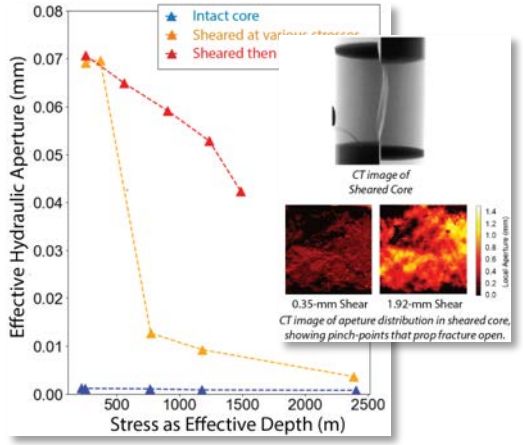
Value Proposition

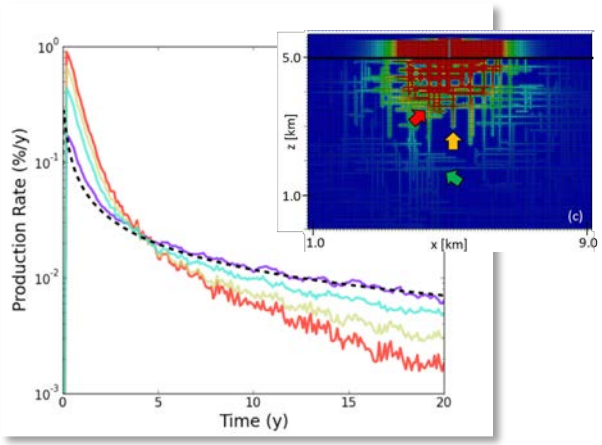
- Optimizing drawdown, shut-in time and pressure cycling/maintenance will significantly increase recovery

Research Approach:
Develop physics-based analysis and predictions of production

Pore-Scale → Fracture-Scale → Reservoir-Scale







Task 5
Hongwu Xu
Qinjun Kang

Task 4
Bill Carey
Luke Frash

Task 3
Satish Karra
Hari Viswanathan

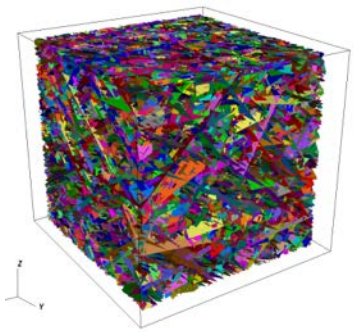
Task 6: Integration
Hari Viswanathan
Team

Achieve DOE Goal:
Efficient and Environmentally Sound Use of Fossil Fuels: More Recovery from Fewer Wells

Work Flow for Reservoir-Scale Analysis of Pressure Management Strategy

Computationally intensive grids (big data, large run times) → **Efficient Machine Learning Graph Emulators with Uncertainty Quantification**

High Fidelity Fracture Models
1 cell has 10^6-10^{10} dof



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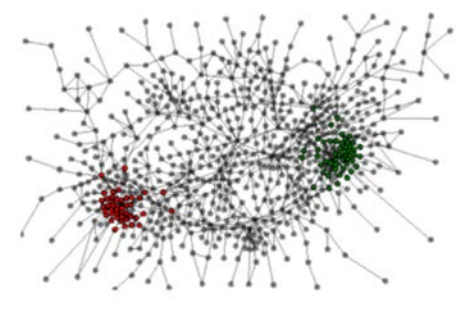
Equivalent Graph Representation retains Geometry and Connectivity
10^3-10^7 degrees of freedom



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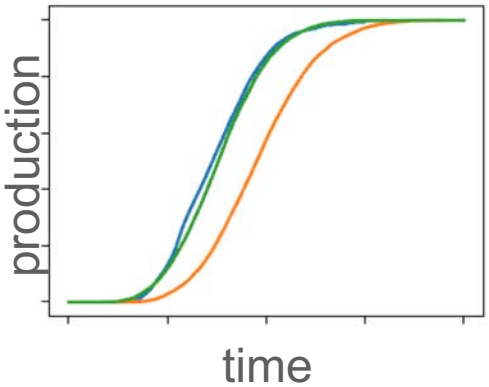
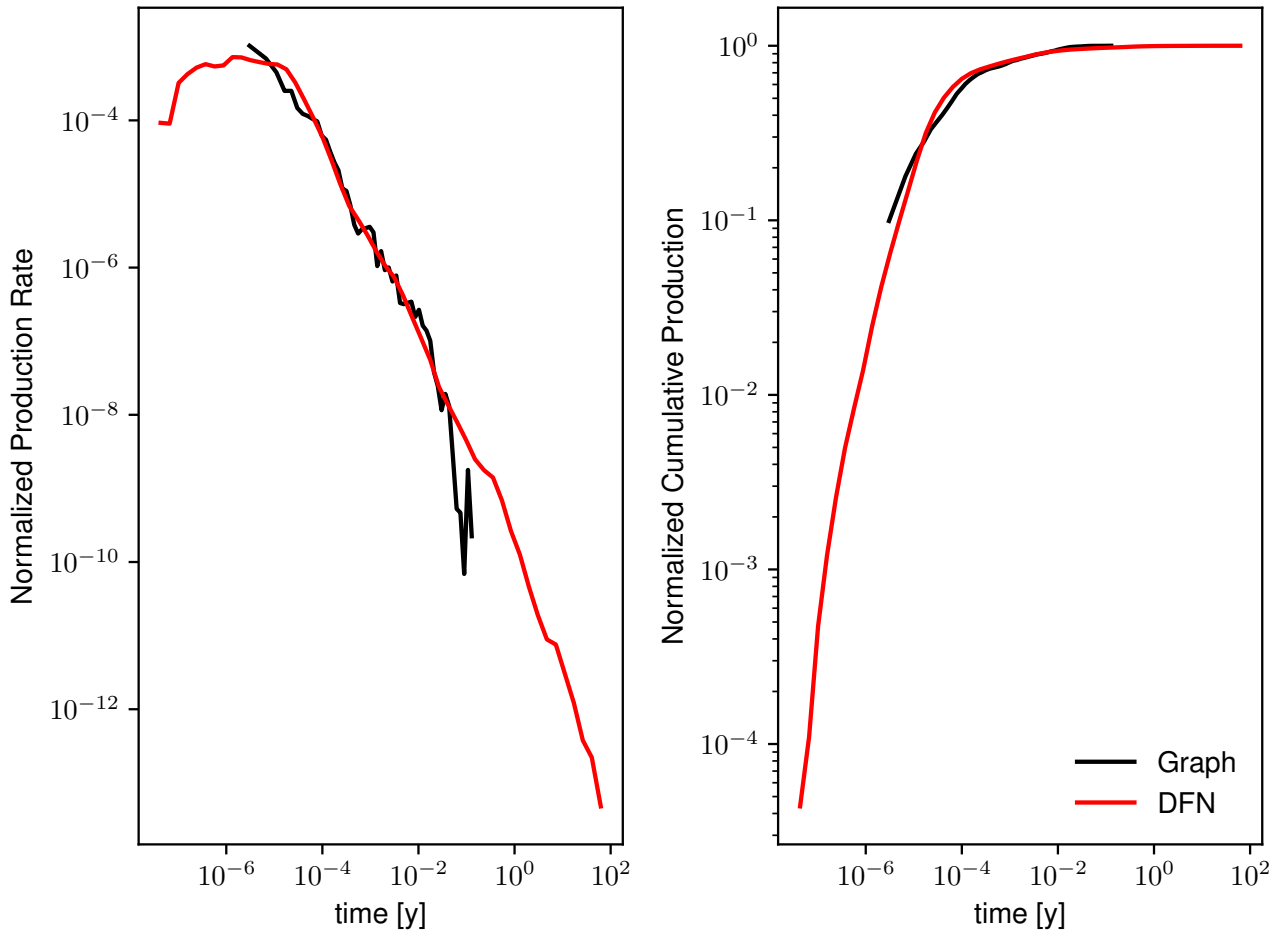
Quantity of Interest: Production Curve



Graph G(size, length, location, orientation, betweenness centrality, eccentricity …)

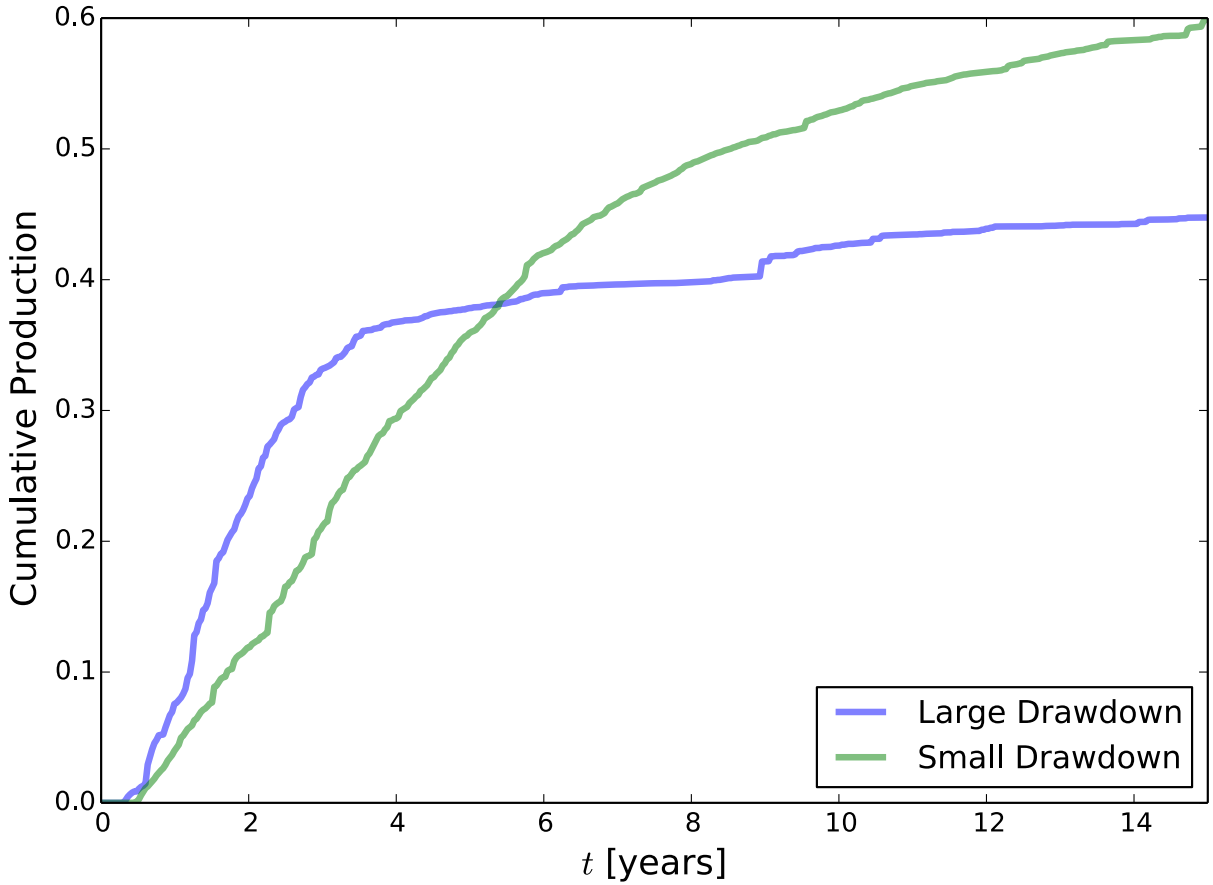
G. Srinivasan, J.D.Hyman, D.Osthus, B.Moore, D.O'Malley, S.Karra, E.Rougier, A.Hagberg, A.Hunter, and H. Viswanathan. Quantifying topological uncertainty in fractured systems using graph theory and machine learning. Nature Scientific Reports, 2017.

Verification of Graph-based Reduced Order Model for Production Simulations



Graph 3 Orders of Magnitude Faster Allowing for Robust Uncertainty Quantification

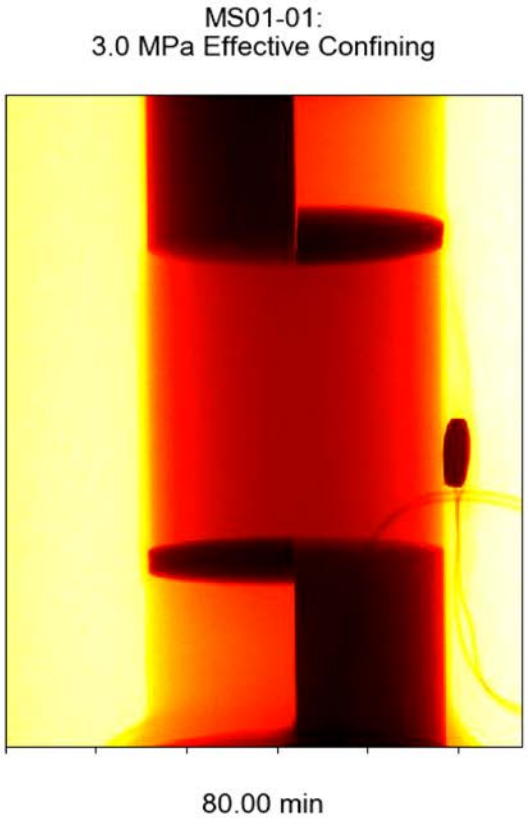
Proof of Concept: Simulating High and Low Drawdown Cases

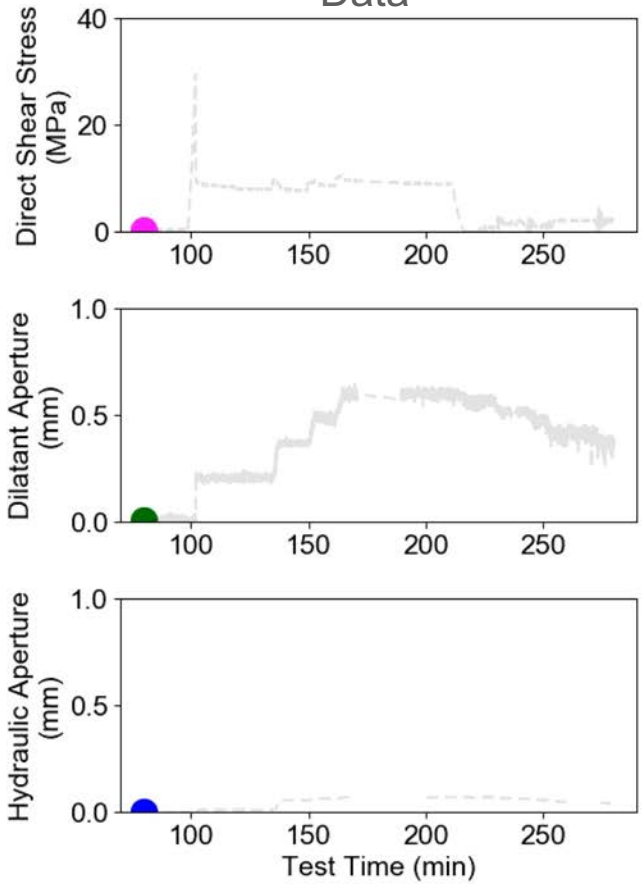


Next Step: Use pressure aperture relationship from experiments to inform simulations

Work Flow for Lab-Scale Analysis of Pressure Drawdown

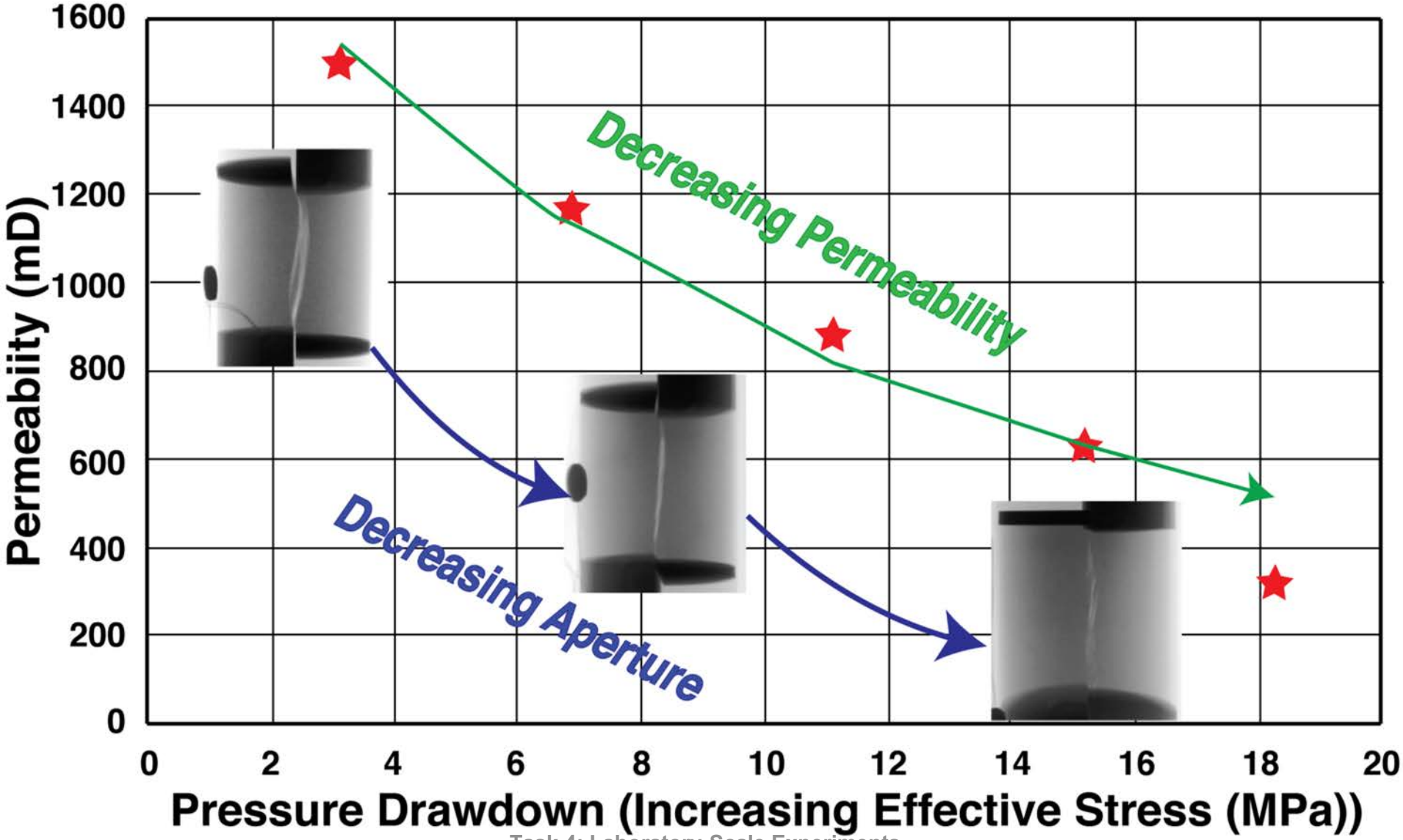
Triaxial Direct-Shear Coreflood → X-ray Radiography → Stress-Aperture-Permeability Data



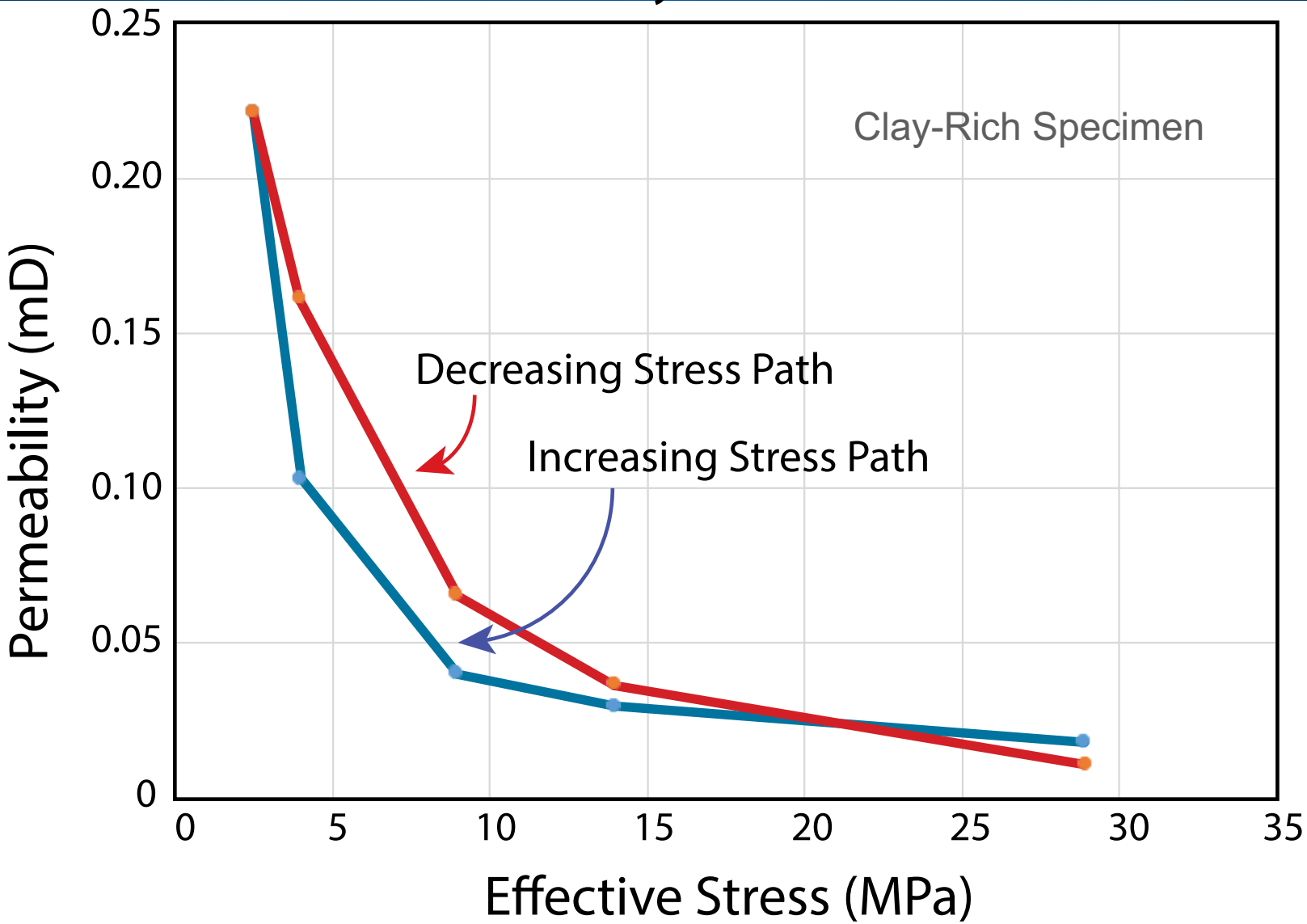


Pressure Drawdown Results in Loss of Aperture and Permeability–Results for Marcellus Shale

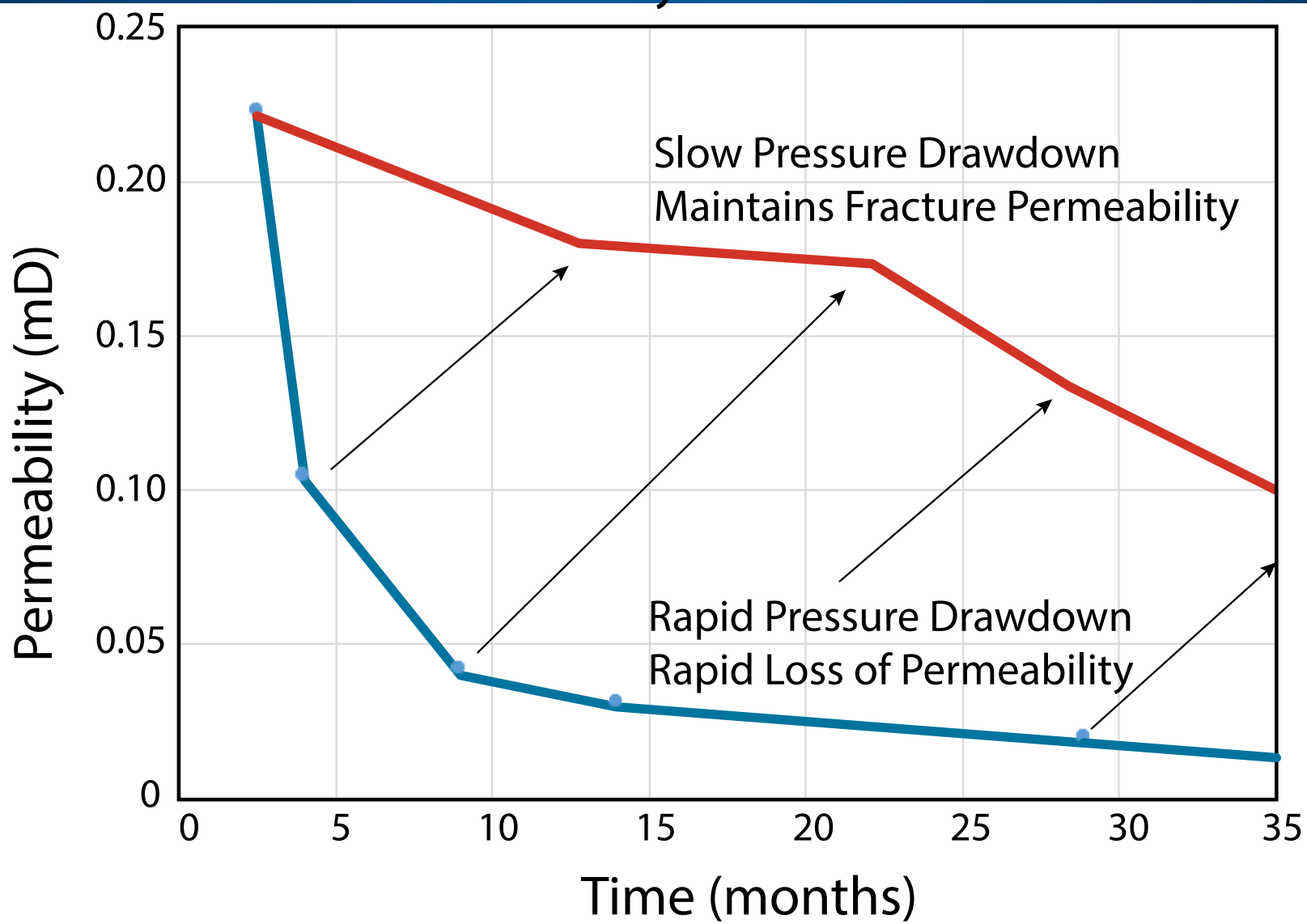
Frash et al. 2017 IJGGC



MSEEL: Post-Fracture Stress-Permeability Relationship

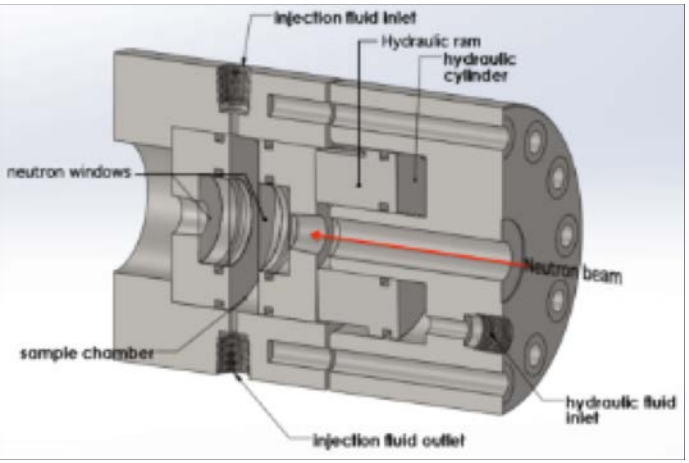


MSEEL: Pressure Management Strategy using Experiments



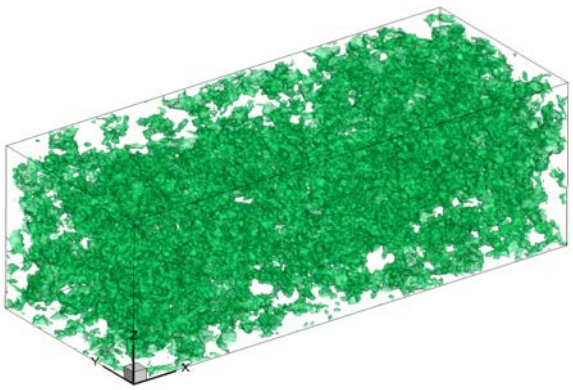
Work Flow for Pore-Scale Analysis of Pressure Impact on Oil Recovery from Shale Matrix

Neutron small-angle scattering of fluids distribution in pores → Microfluidics study of matrix-fracture communication → Lattice Boltzmann modeling of pore-scale processes



LANL-designed neutron-based **flow-through compressional cell** stresses (100 bar).

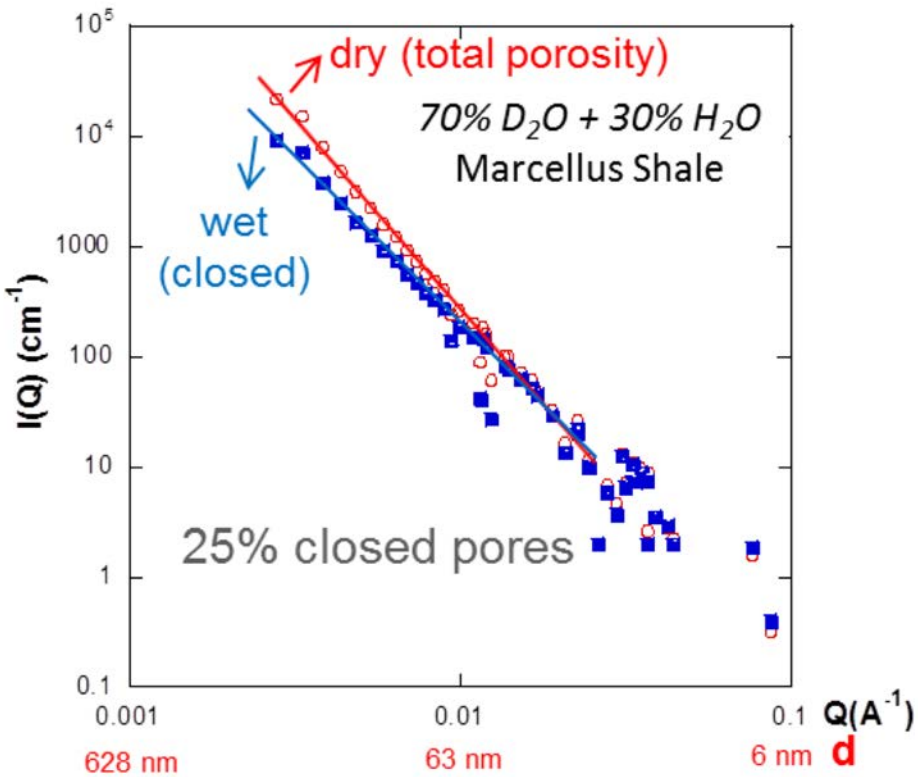
High-pressure/temperature microfluidics laboratory



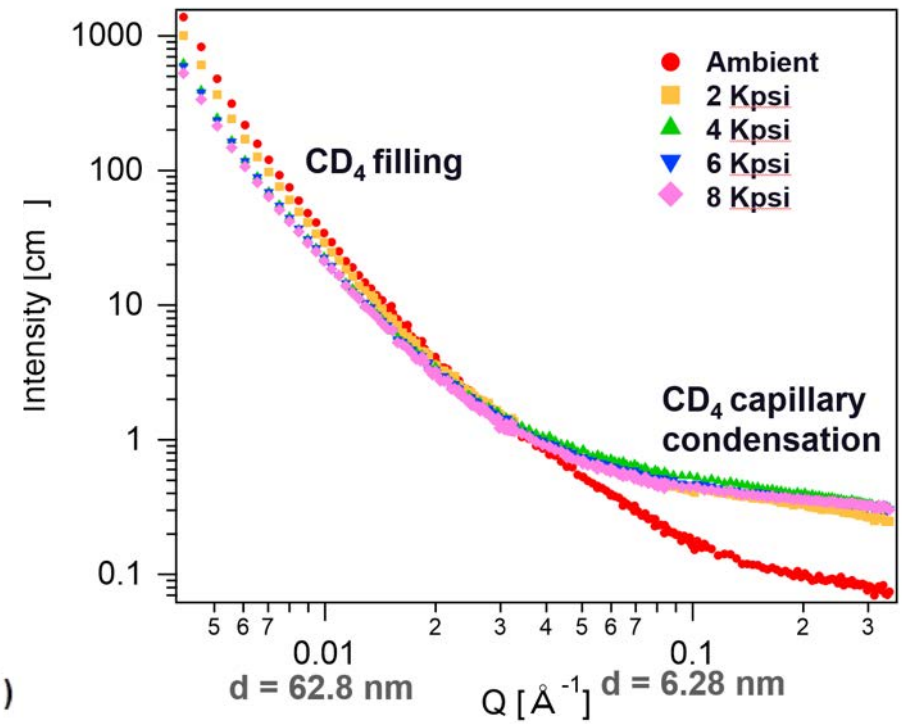
3-D representation of pore-structure in shale from CT data

Neutron Analyses of Pore-Scale Controls on Hydrocarbon in the Shale Matrix

Capillary Condensation of methane at elevated pressure increases reservoir hydrocarbon capacity

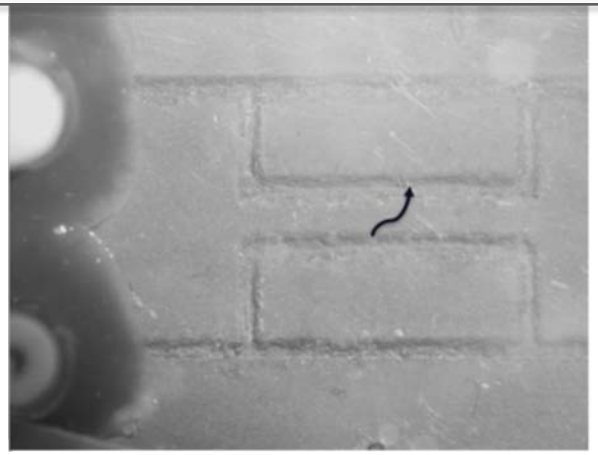


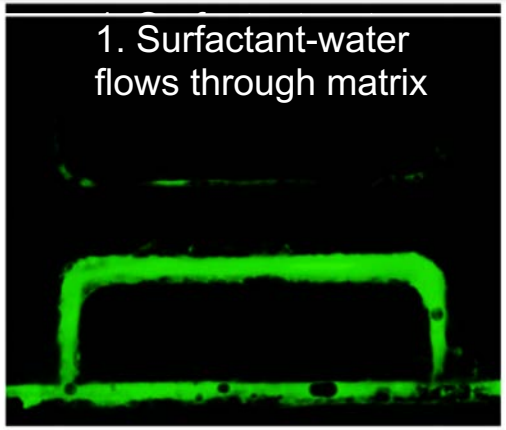
Capillary Condensation of methane at elevated pressure increases reservoir hydrocarbon capacity

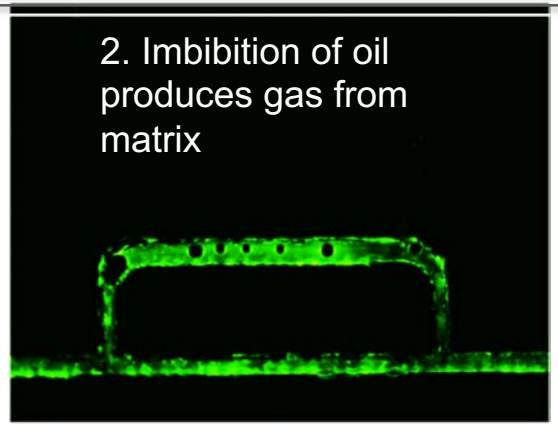


Microfluidics Reveals Matrix-Fracture Communication and Multiphase Hydrocarbon Recovery Processes

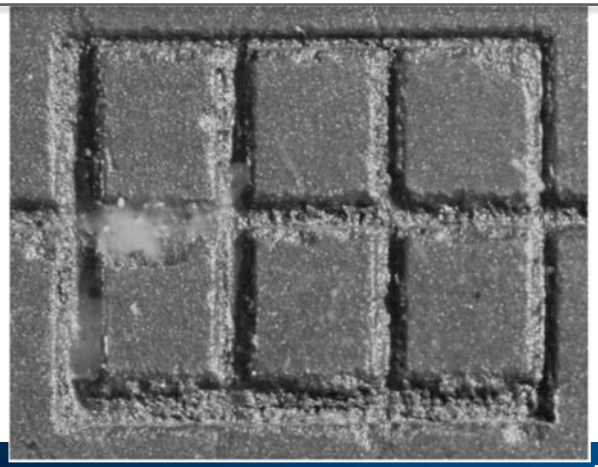
Rate of Hydraulic Fluid and Oil Transport Between Fracture and Matrix

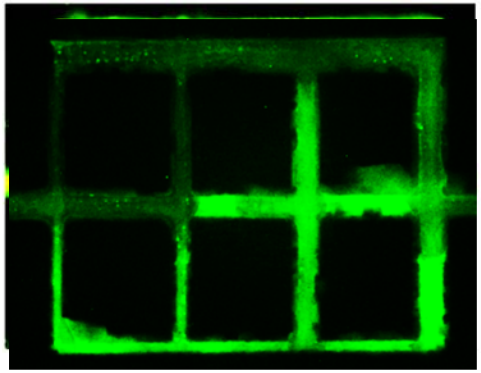


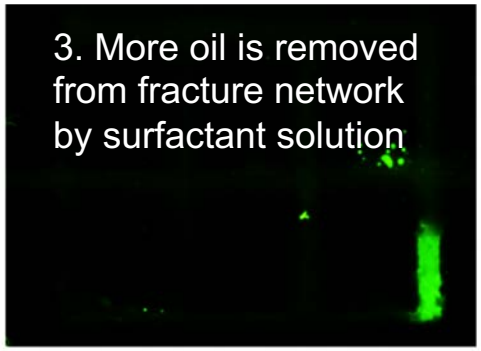




Recovery of Hydrocarbon from Fracture Networks with and without Surfactant

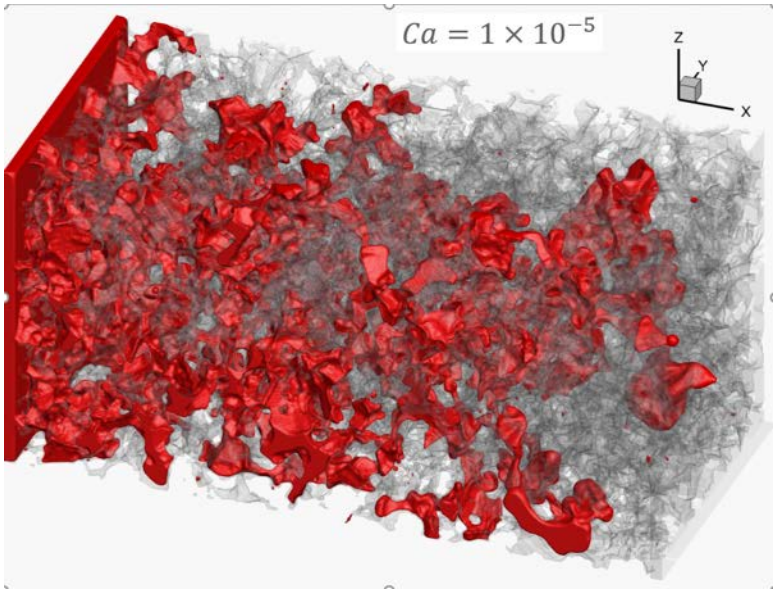




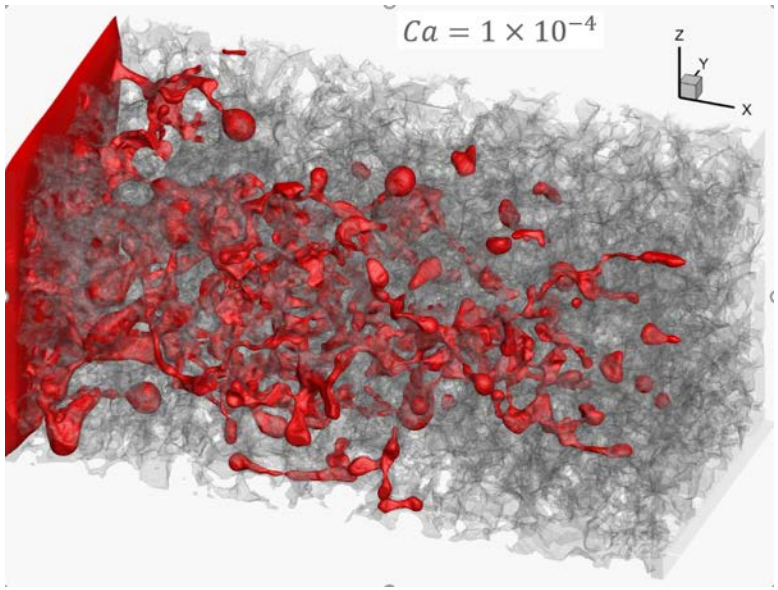


Lattice Boltzmann Analysis of Pressure Gradient Impact on Hydrocarbon Production

Low pressure gradient = Greater recovery



High pressure gradient = Lower recovery

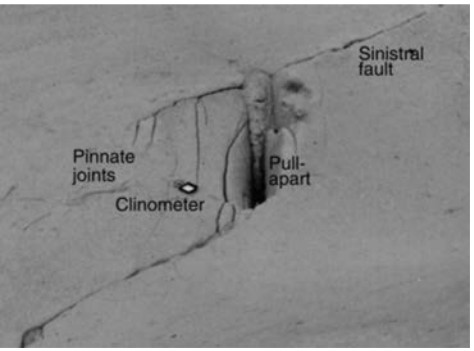


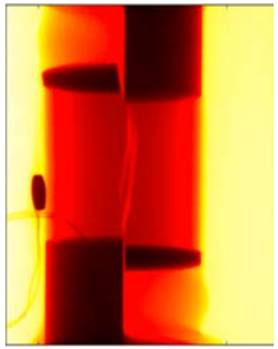
- Pore-scale numerical simulations can provide functional relationship between sweeping efficiency and pressure gradient

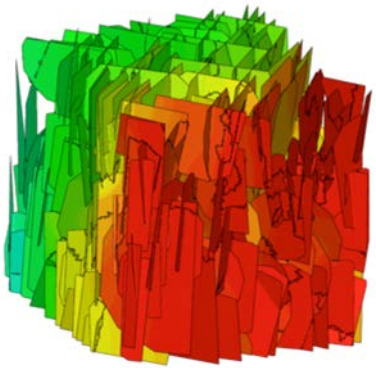
A lower pressure gradient (left) leads to capillary fingering and higher sweeping efficiency than the case of viscous fingering caused by a higher pressure gradient (right)

Project Framework for Prediction of Fracture Networks

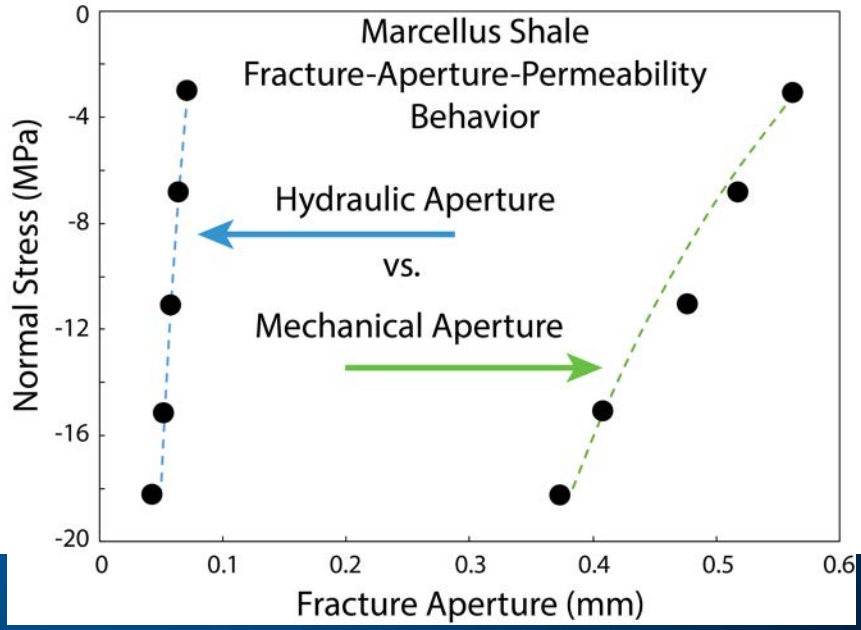
Field → Lab → Simulation







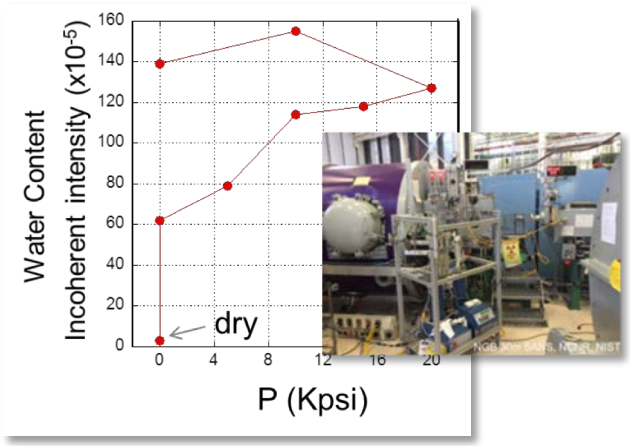
- **Predict fracture mechanical aperture from fracture length and displacement**
  - Literature plus experimental observations
- **Predict changes in fracture mechanical aperture from stress changes**
  - Analysis of experimental data
- **Predict hydraulic aperture (permeability) from fracture aperture**
  - Cubic-law, experimental data, pore-scale models



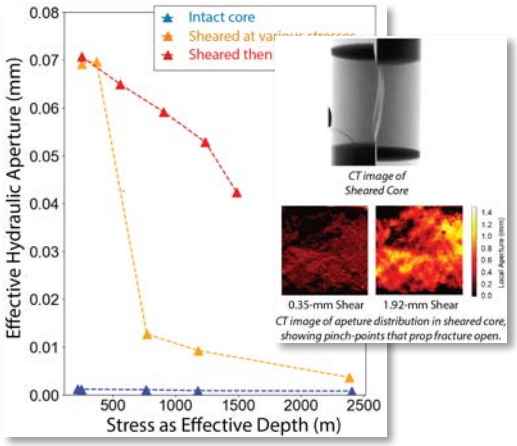
Conclusions:
Optimized Production through Pressure Management

The production of unconventional reservoirs can be enhanced through experimentation and physics-based modeling of hydrocarbon behavior in complex fracture networks.

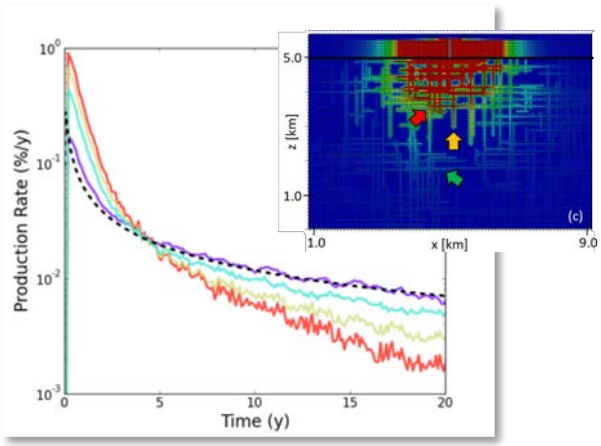
Pore-Scale



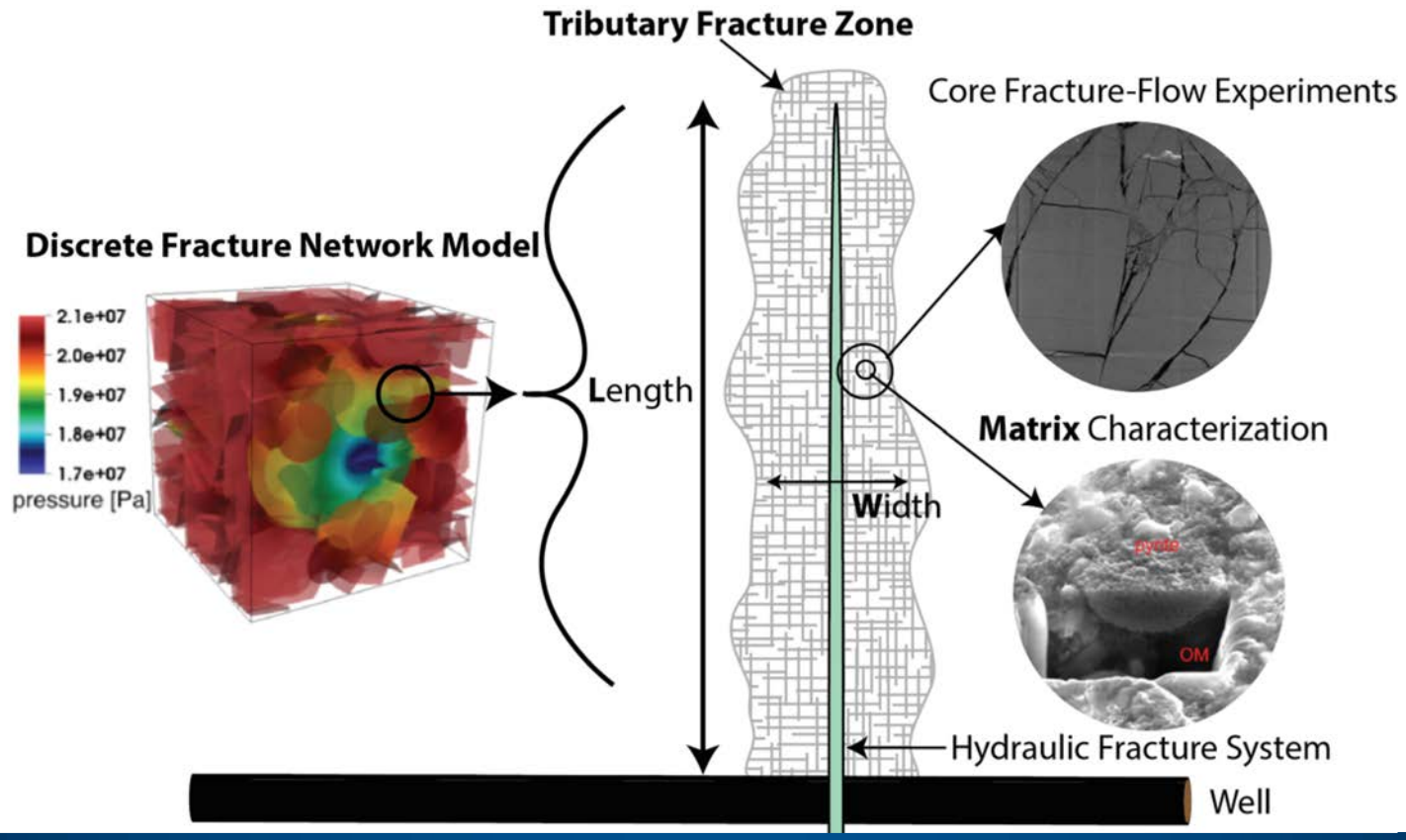
Fracture-Scale



Reservoir-Scale



- Pore-scale studies show how pressure gradients control fluid mobility and fracture-matrix communication
- Coupled fracture studies with x-ray imaging allows determination of impact of pressure drawdown on fracture permeability and ultimate recovery
- High-fidelity discrete fracture network modeling combined with machine learning demonstrates *cross-over:* potential higher cumulative production through pressure management

Acknowledgements

- US DOE Office of Fossil Energy and the National Energy Technology Laboratory. Projects FE-772-16-FY16 and FE-954-18-FY18
- Support and guidance from our Program Managers Bruce Brown and Steve Henry
- Apache Corporation for discussions and shale samples
- The ASSET team for discussions and helpful feedback