Mechanistic Approach to Analyzing and Improving Unconventional Hydrocarbon Production

U.S. Department of Energy

National Energy Technology Laboratory

Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration:

Carbon Storage and Oil and Natural Gas Technologies Review Meeting

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Part 2: Reservoir-scale Fractured Systems Modeling

Presentation by Satish Karra

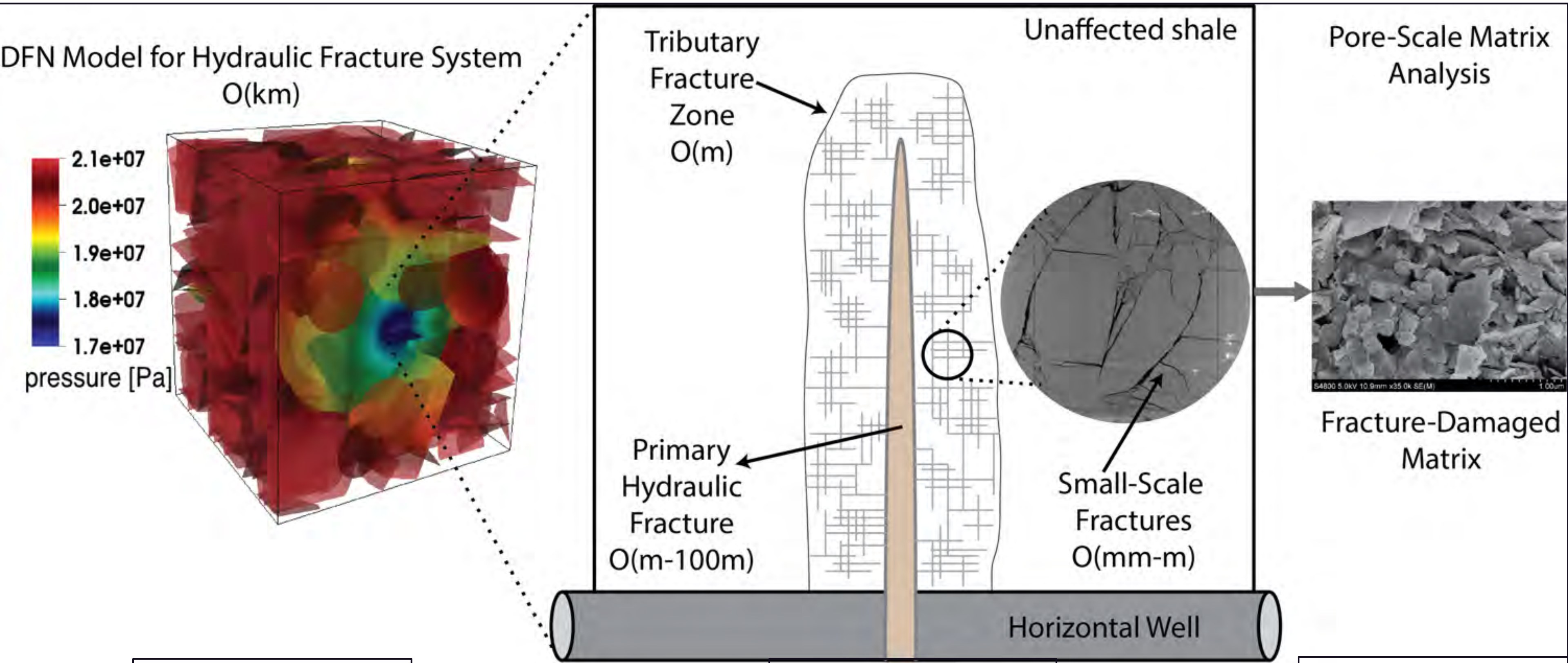
75 Los Alamos NATIONAL LABORATORY EST. 1943

NNSA National Nuclear Security Administration

Overview of Project

Target: Enable technological solutions to improve recovery efficiency through an improved fundamental understanding

Across Scales



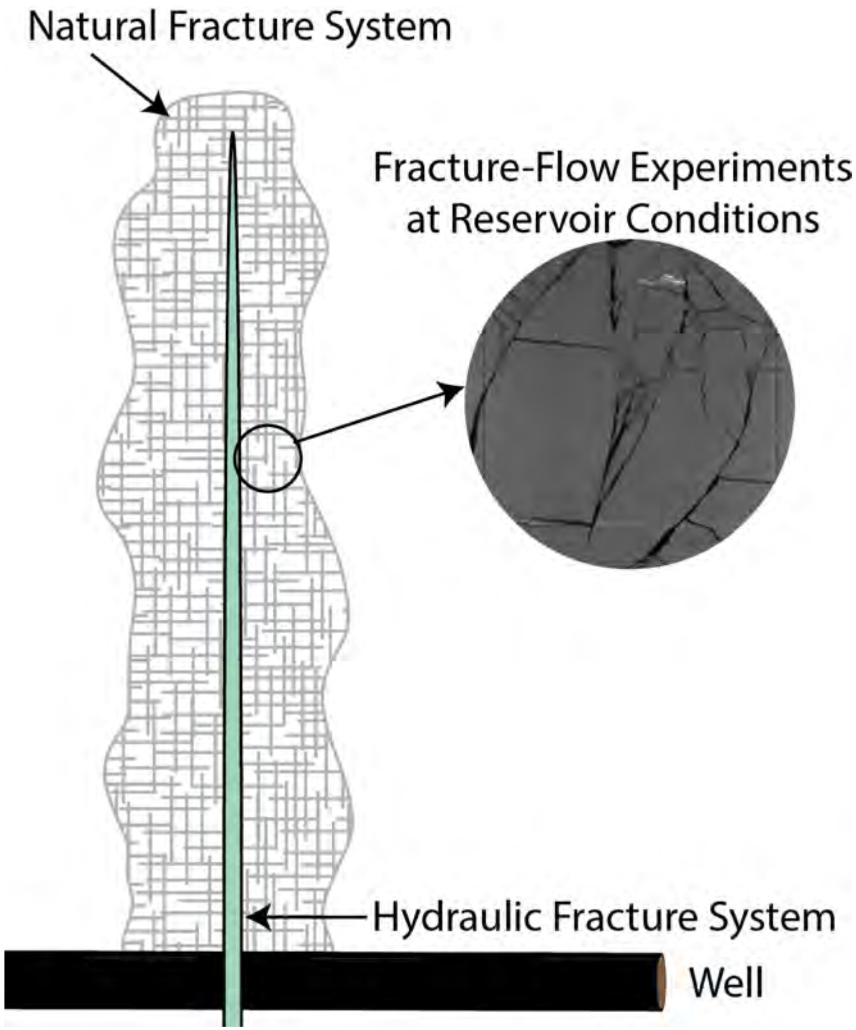
Karra @ 1:35

Carey @ 1:15

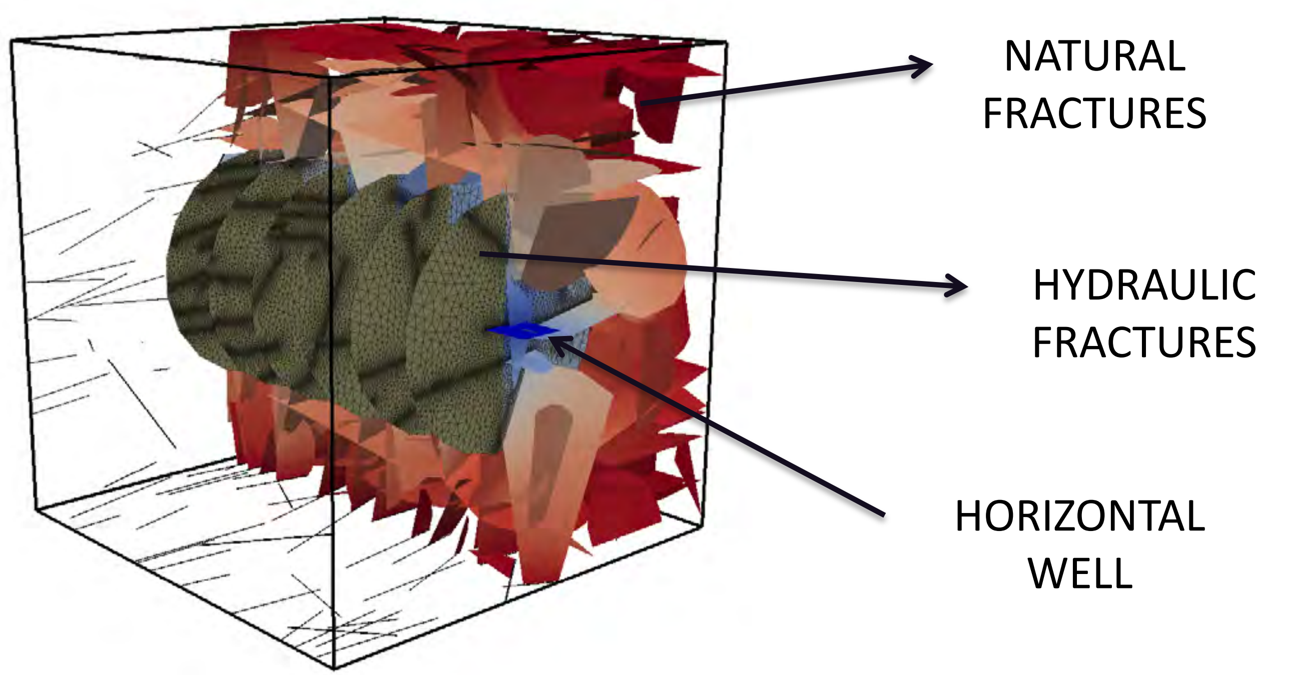
Kang @ 1:55

Technical Status: Reservoir-scale Fractured Systems Modeling

- Completed development of discrete fracture network tool for production curve calculations (large fractures + tributary fractures + matrix)
- Completed analysis of influence of fracture geometry/topology on production curve
- Incorporated effect of transient properties (e.g., aperture) in our DFN workflow

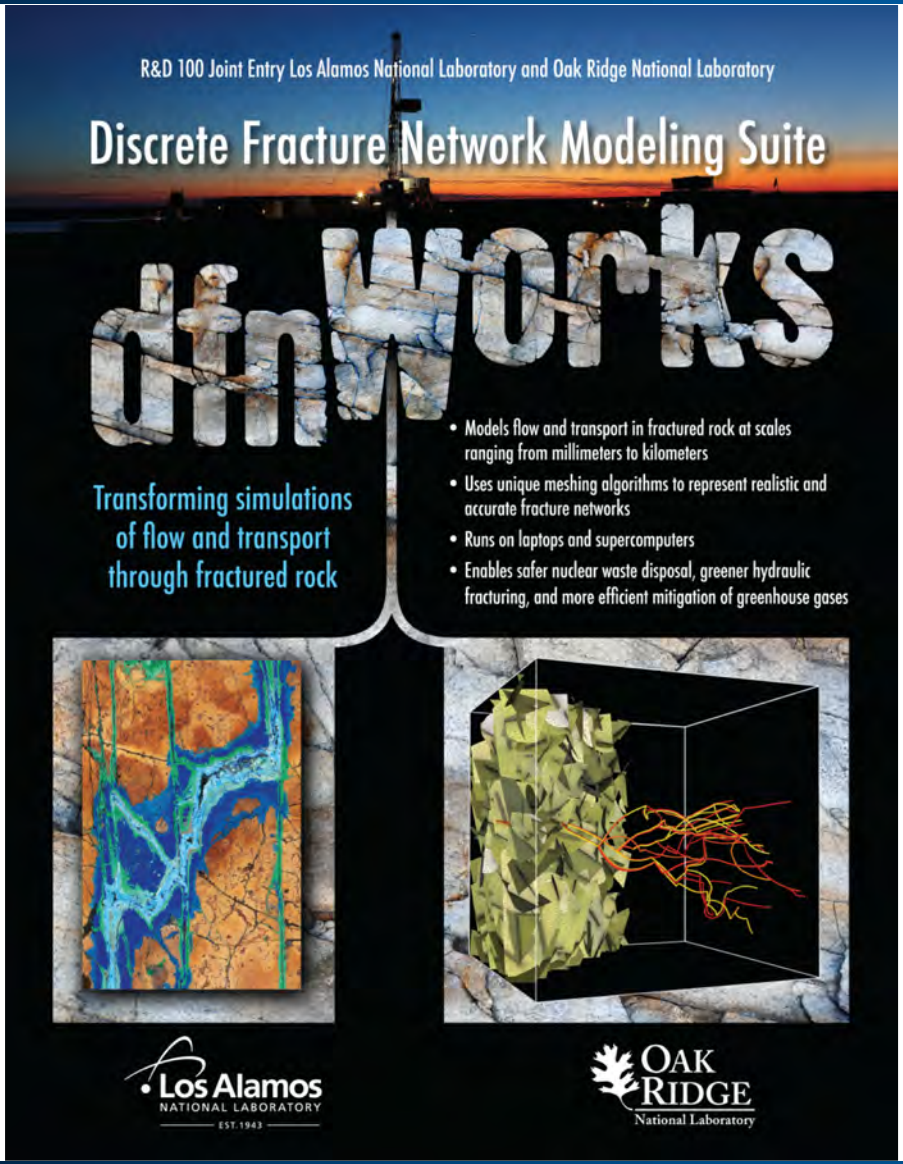


Modeling Approach: Discrete Fracture Network (DFN) Modeling



200m x 200m x 200m
383 fractures – horizontal well, 6 hydraulic fractures
DFN statistics from upper Pottsville formation [Jin 2003]

dfnWorks R&D100 Winner in 2017



» Federal Technology Winner 2017

» Models flow and transport in fractured rock at scales from millimeters to kilometers

» Uses unique meshing algorithms to represent realistic and accurate fracture networks

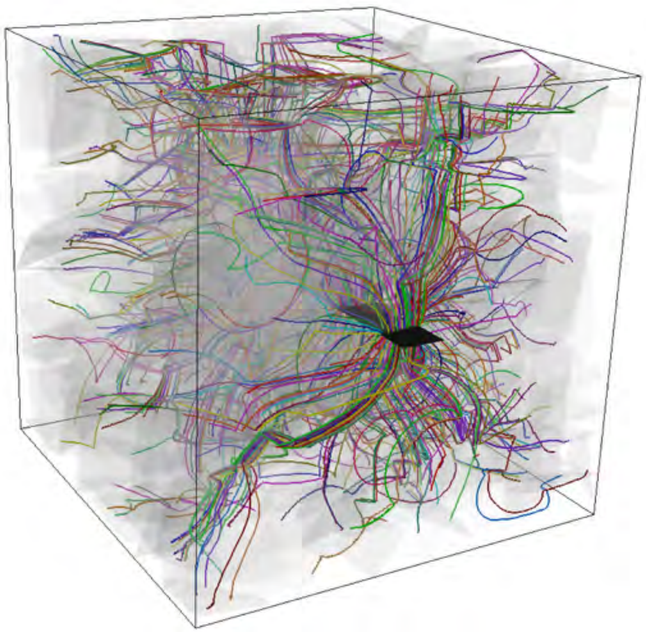
» Enables modeling of nuclear waste disposal, oil & gas extraction from shale, mitigation of greenhouse gases and nuclear nonproliferation

» Validated against site data from sites like Aspo, Sweden

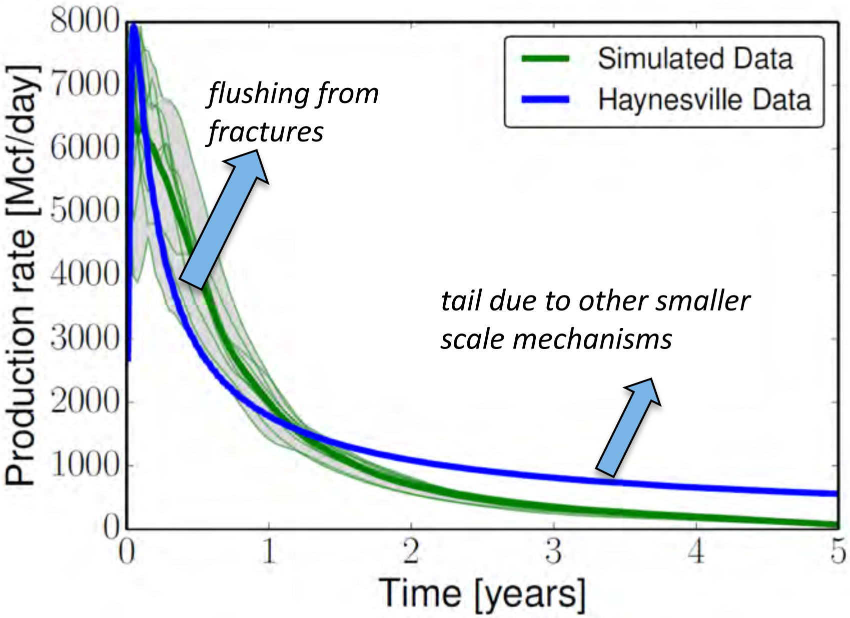
» Next version of dfnWorks will include graph-based methods for visualization and reduced order model simulations

Initial HPC Calculations of Production

Hydrocarbon Particles Flowing to the Well



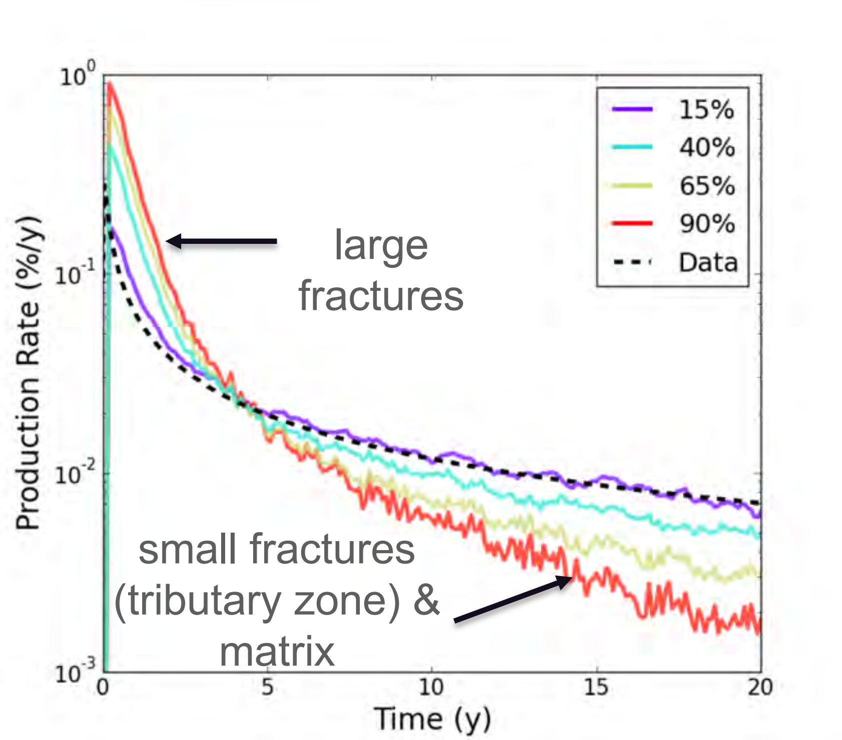
Production Curve



Karra et al. WRR 2015

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

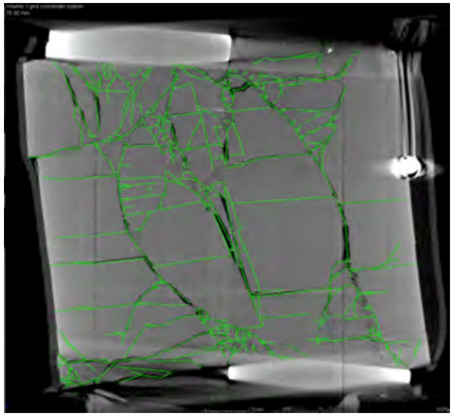
Tributary Fracture Zone and Matrix Incorporation



Lovell et al. WRR 2018

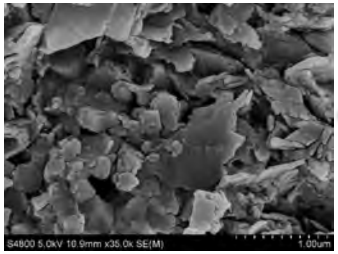
- Completed DFN tool development (main fractures + tributary zones + matrix)
- Demonstrated that near-term drains fractures, but mid-term requires tributary and matrix

Carey et al (Task 4)



Tributary zone fracture stochastics from triaxial experiments

Carey et al. 2015, J Unconv. O&G Res.



SEM image of shale obtained from Sichuan Basin

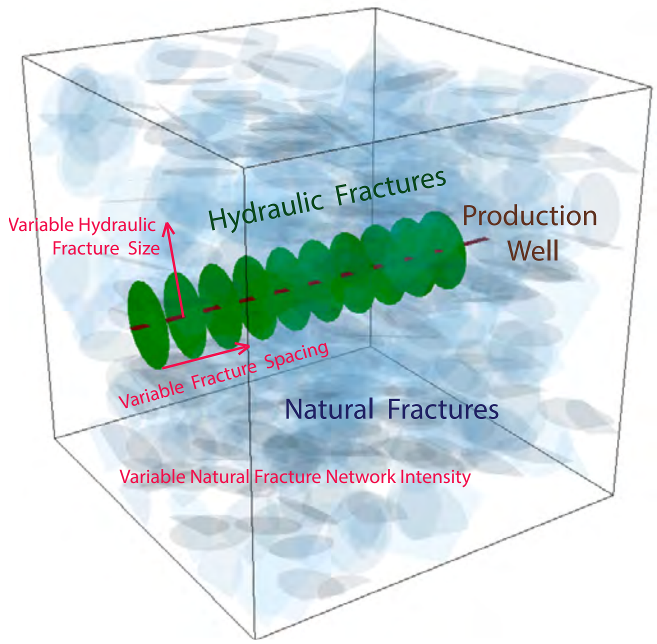
Markov Chain Monte Carlo (MCMC) method

Chen et al. (2015) Sci. Reports; Chen et al. (2015) Fuel; Karra et al. (2015) WRR

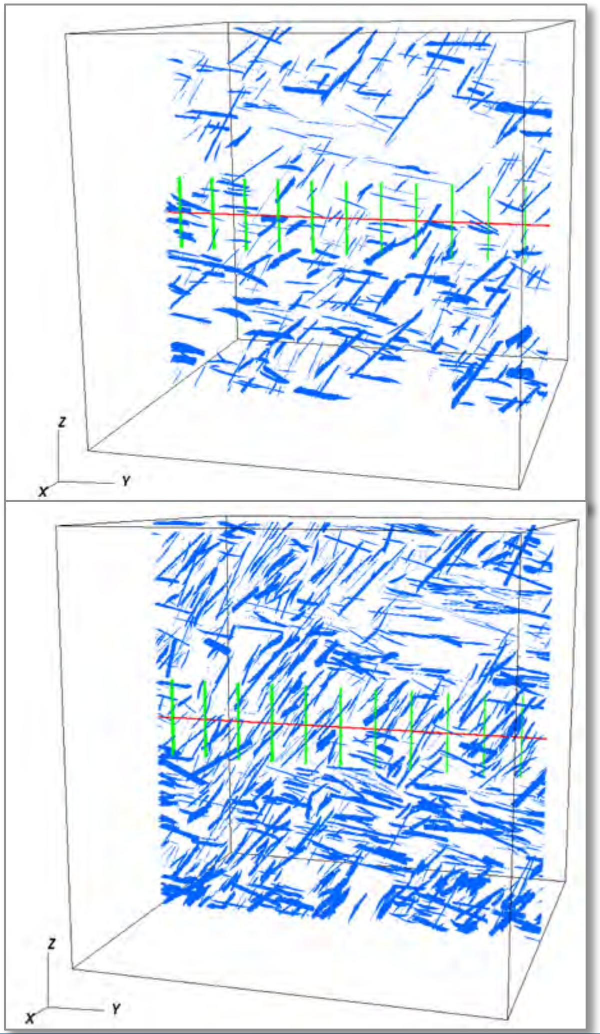
Xu, Kang, et al (Task 5)

Can site-specific stimulation strategies increase recovery efficiency or result in smaller but effective stimulations?

Hypothesis: The production of hydrocarbon from a fracture network does not vary linearly with spacing (# of stages) and size of hydraulically generated fractures



Example Natural Fracture Network Intensities (blue) Relative to Hydraulic Fractures (green) Spaced at 45-m

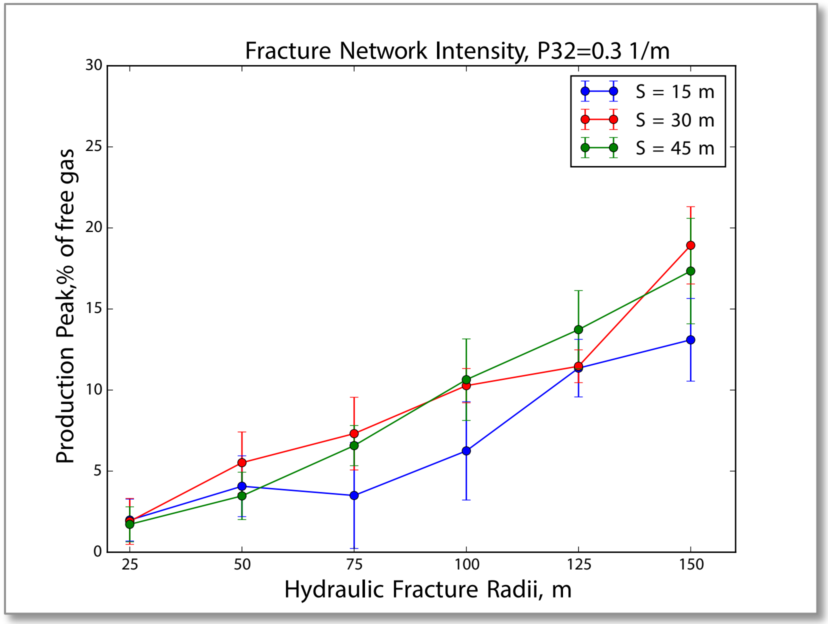


Approach

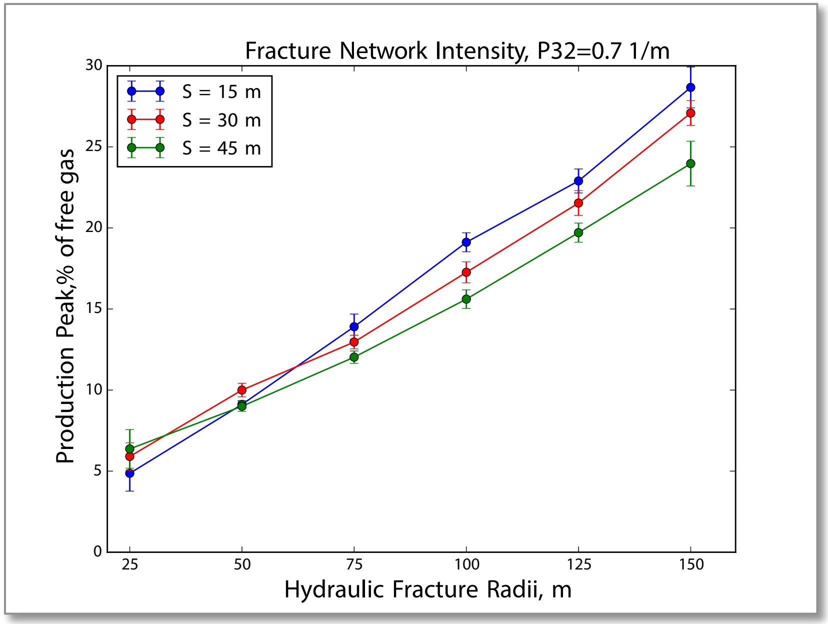
- Multiple scenarios (480 cases) by varying hydraulic fracture extent and spacing as well as natural fracture density
- Quantified uncertainty

Influence of Geometry/Topology of Fracture Network

sparse natural network



dense natural network

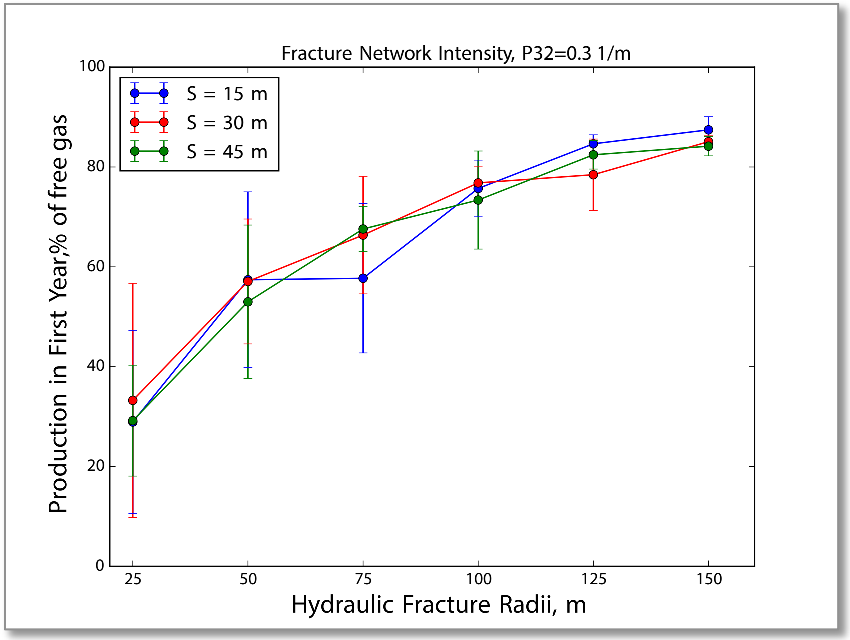


Key Finding

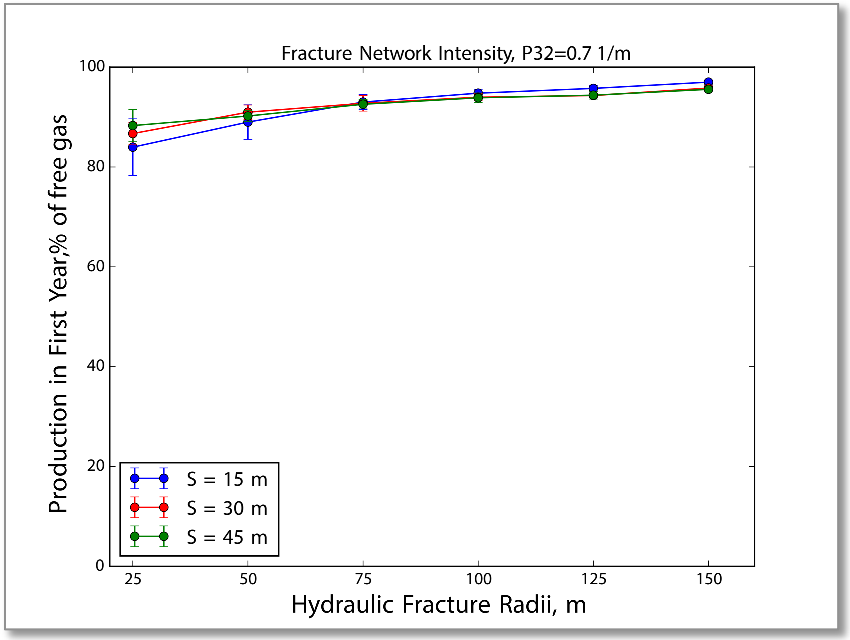
Production peak increases with hydraulic fracture size for any natural fracture intensity

Influence of Geometry/Topology of Fracture Network

sparse natural network



dense natural network

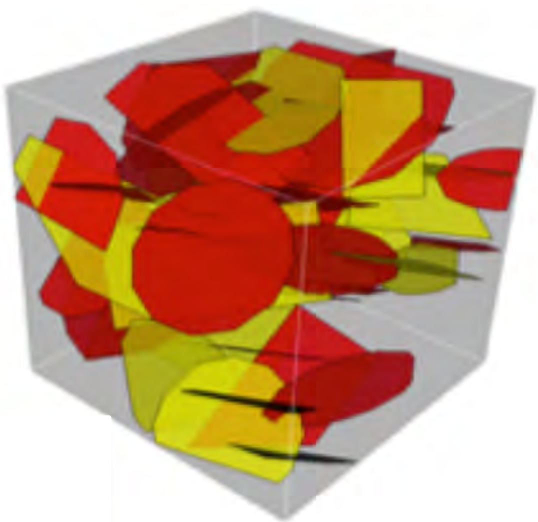


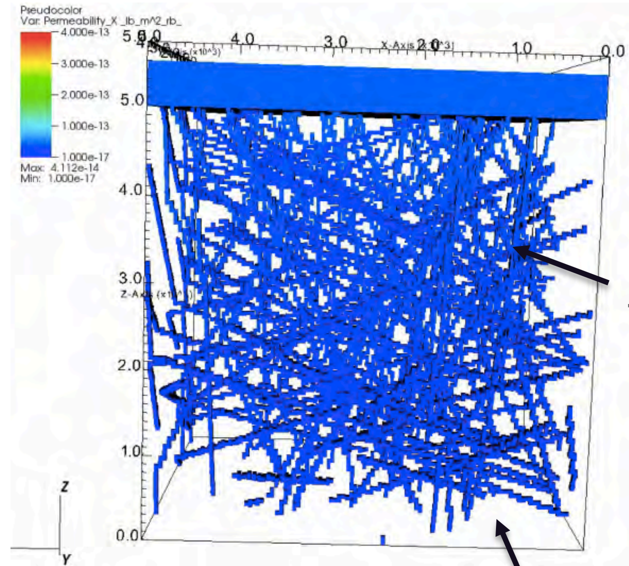
Key Findings

- Production increases with increase in size of hydraulic fractures for sparse natural fracture network only
- No significant effect of hydraulic fracture spacing

Task 3.2: How does spatio-temporal evolution of aperture influence reservoir pressure?

Hypothesis: To optimize production, one must balance pressure gradient and fracture closure





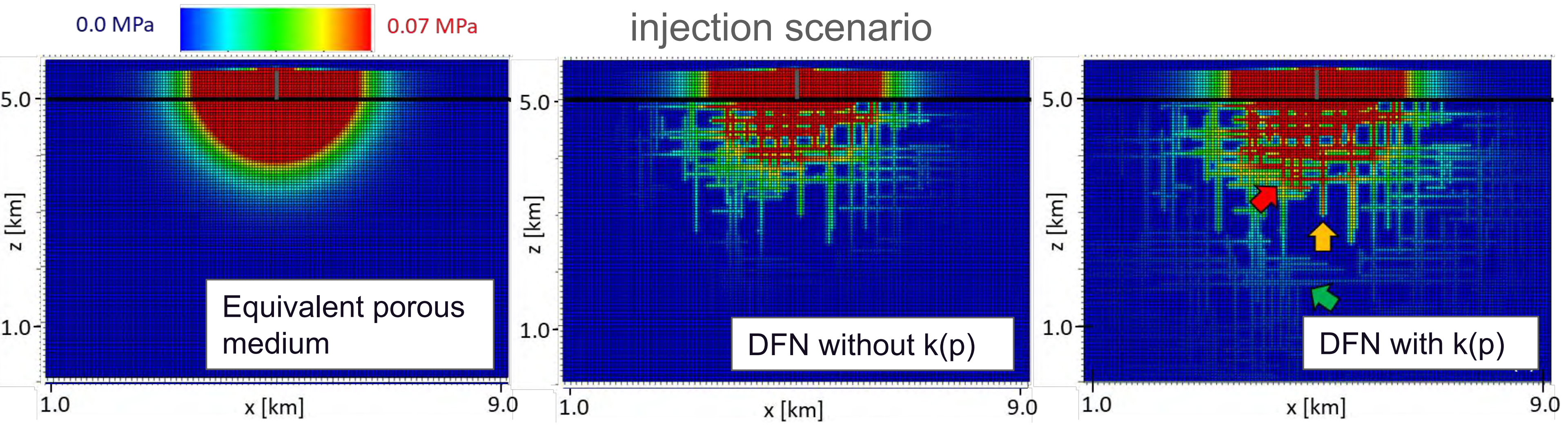
blue - fractures

white space - matrix

Approach

- DFN mapped to 3D mesh
- permeability, porosity are f(stress(p)) – Bandis model in fractures

Spatio-temporal evolution of fracture properties



Key Findings

- DFN simulations show due to pressure-aperture relationship, pressure diffuses to a larger extent
- This behavior has implications for designing pressure management (e.g., pressure cycling), and we have the tools to model the behavior

Accomplishments to Date

- Developed a DFN modeling based capability dfnWorks with mechanistic models for transport processes to evaluate production curves
- Built a database of 480 DFN datasets with varying fracture geometry/topology and evaluated the corresponding production curves
- Performed analysis on the DFN-production curve datasets
- Incorporated time- and spatial- dependence of fracture properties in our DFN workflow for pressure management strategies

Lessons Learned

- **DFN + matrix – challenging mesh generation problem**
  - –Currently we map DFN into a 3D cells
  - –Extreme refinement
  - –Computationally intensive
  - –Need planar mesh coupled with volume mesh
  - –LANL internal LDRD investment to overcome this

Synergy Opportunities

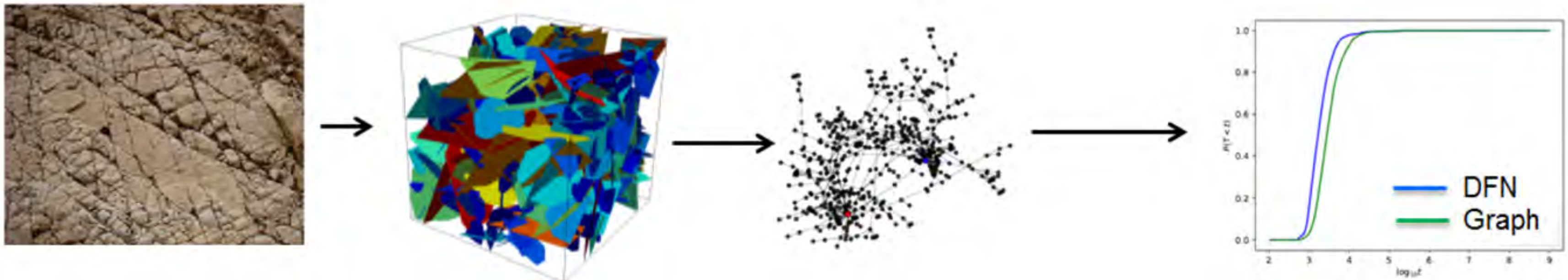
- In addition to Bill's points
- UC Boulder on flow-geomechanics in fractured system modeling for injection-induced seismicity
- GEOS team at LLNL

Key Findings

- Demonstrated that near-term production is due to free gas from fractures, but mid-term requires tributary and matrix
- Increase of hydraulic fracture size increases production peak
- Cumulative production increases with increase in hydraulic fracture size for sparse natural networks only
- No clear and significant effect is observed with more hydraulic fracturing stages
- Shown that identifying the natural fracture density is critical for optimizing a fracking operation
- Due to transient fracture properties (e.g., aperture), one can use pressure management strategies to improve production

Future Directions

- Pressure management (e.g., cycling) strategies on production with the tools we have developed
- ROMs for production as a function of fracture parameters such as staging and natural fracture density
- Graph-based machine learning models (from DFN) for production for real-time calculations in the field built-on ongoing LANL LDRD investments



Fractured Rock at Field Site | High Fidelity Physics-based DFN Simulation | Graph-based ML Emulator runs 10^4 times faster than DFN | Emulator closely match high fidelity simulation cumulative production

Karra, S., O'Malley, D., Hyman, J. D., Viswanathan, H. S., & Srinivasan, G. (2018). Modeling flow and transport in fracture networks using graphs. Physical Review E, 97(3), 033304.

Work presented at LANL Machine Learning in Geosciences Workshop 2018.

Appendix

Benefit to the Program

- **Recovery efficiencies for shale-gas reservoirs remain low, despite being economic (motivation)**
- **Elucidating the controls on gas production (at a site) can lead to new strategies to optimize recovery efficiency (benefit) through**
  - Measurement of the permeability and multiphase flow behavior in small-scale fractures comprising the tributary fracture zone
  - Improving the efficiency of hydraulic fracturing through production curve analysis
  - Determination of key mechanisms controlling unconventional oil and gas migration
  - Development of tools to analyze production cures and thereby enhance hydrocarbon production

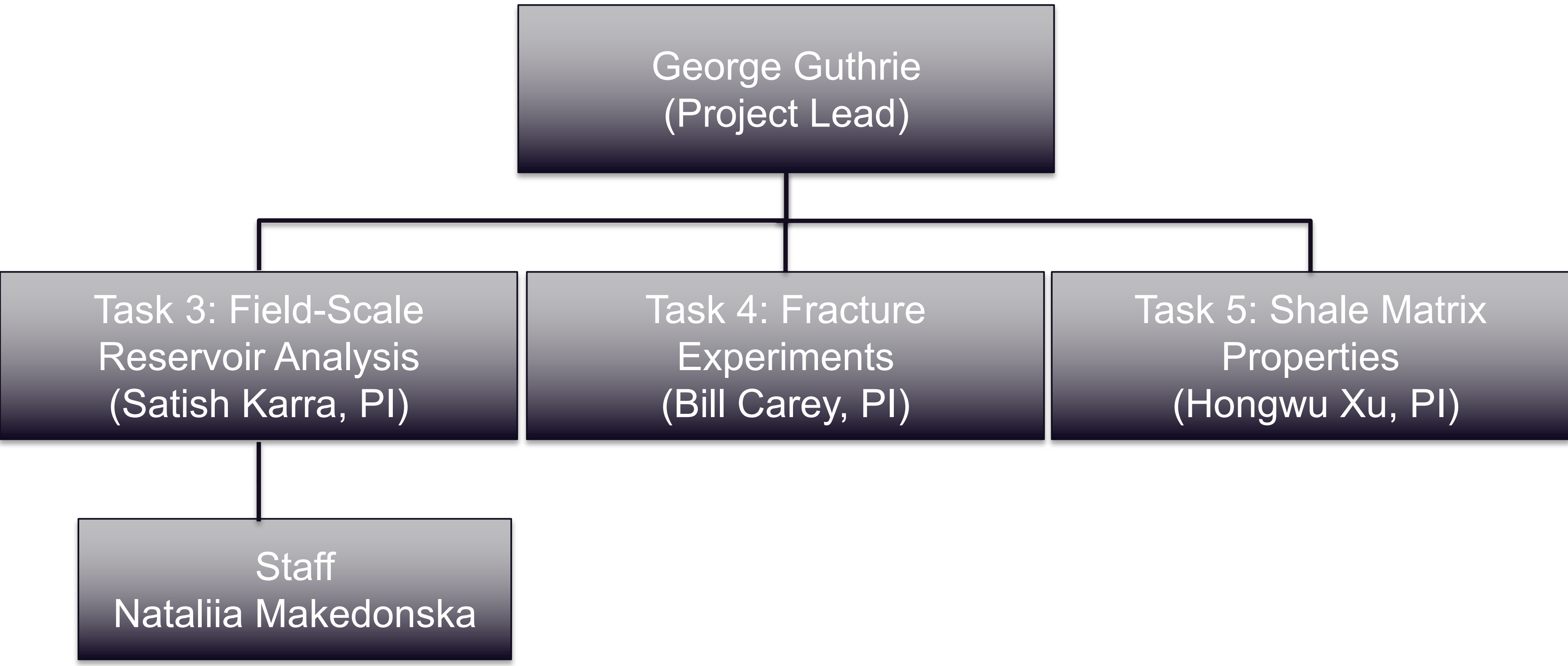
Project Overview
Goals and Objectives

- **Develop models for multiscale processes**
  - Incorporate processes such as free hydrocarbon flow in large-scale fractures, tributary zone fractures and the matrix into *dfnWorks* discrete fracture network framework

- **Identify the influence of fracture geometry/topology on hydrocarbon production**
  - Using the capability in the above goal, evaluate and analyze production curves for various fracture network scenarios controlled by parameters such as natural fracture density, hydraulic fracture size and spacing.

- **Evaluate the influence of time- and spatially- varying fracture network properties**
  - Incorporate models for time- and spatially- varying fracture properties such as aperture and evaluate the influence on production

Organization Chart



Gantt Chart

	Gantt Chart	FY16		FY17				FY18					
Task #	Task	Q 3	Q 4	Q 1	Q 1	Q 2	Q 4	Q 1	Q 2	Q3	Q 4	Product	Dependencies
3.0	Large-scale fracture controls on hydrocarbon production in the Marcellus shale												Start requires results from 2.1
3.1	Impact of fracture-network geometry/topology									complete		Report detailing the impact of geometry/topology on reservoir behavior	Report will be submitted by August 31, 2018
3.2	Impact of fracture-network properties											Report detailing the impact of time- and space-varying fracture geometry properties on reservoir behavior	Task will be complete in Q4 and report will be submitted at end of Q4.
3.3	Impact of density of fracture stages on production from a natural fracture network									complete		Report detailing the variation in production as a function of induced-fracture spacing for various characteristics of pre-existing fracture networks.	Report will be submitted by August 31, 2018

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