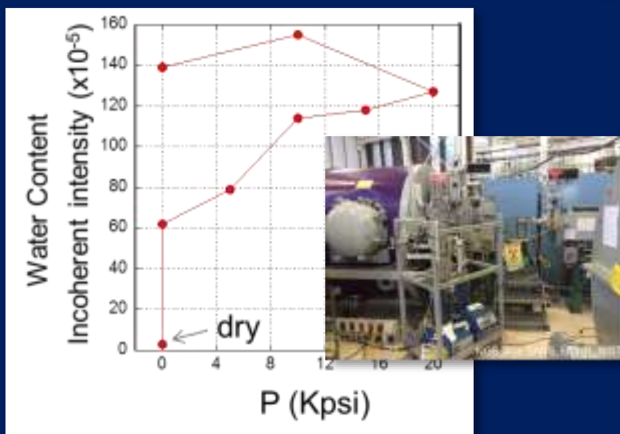
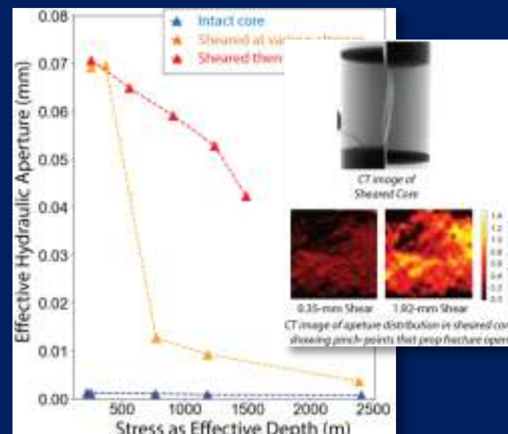
Mechanistic Approach to Analyzing and Improving Unconventional Hydrocarbon Production

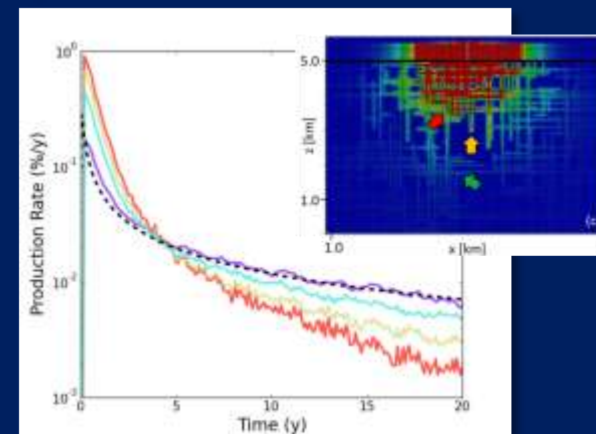
Hari Viswanathan

Program Manager: Bruce Brown

Pore-Scale → Fracture-Scale → Reservoir-Scale







Luke Frash, George Guthrie, Jeffrey Hyman, Qinjun Kang, Satish Karra, Nataliia Makedonska, Chelsea Neil, Matt Sweeney, Nathan Welch, Hongwu Xu

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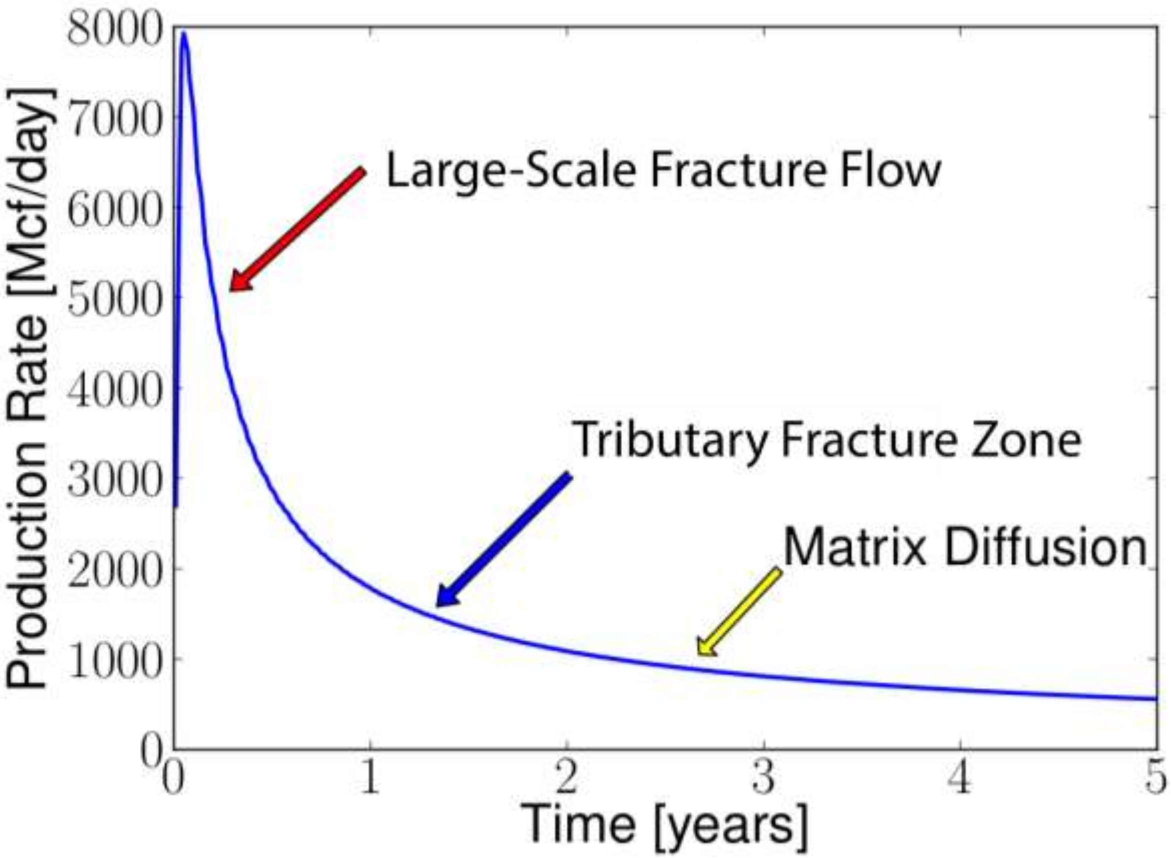
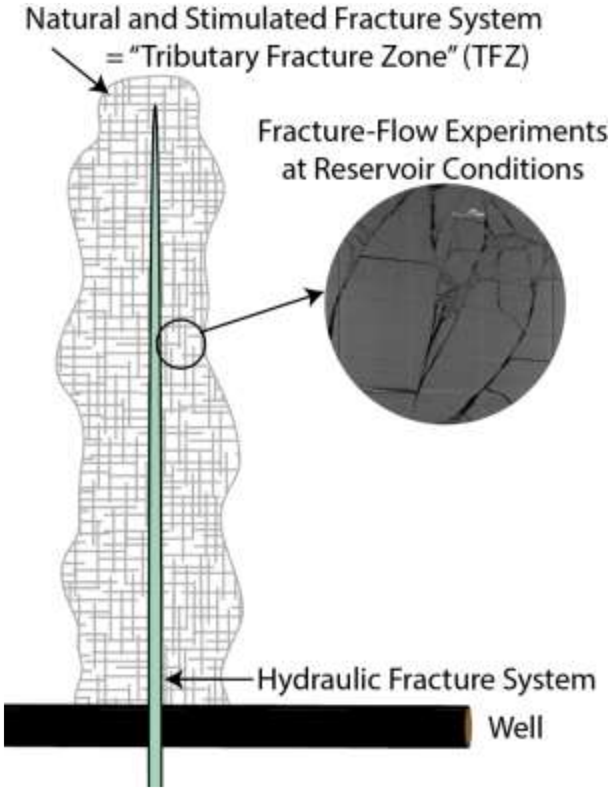
2020 DOE FE Fundamental Shale Review Meeting
October 16 2020

Overcoming Barriers to Production
Delivering Basin-Specific Optimization Strategies

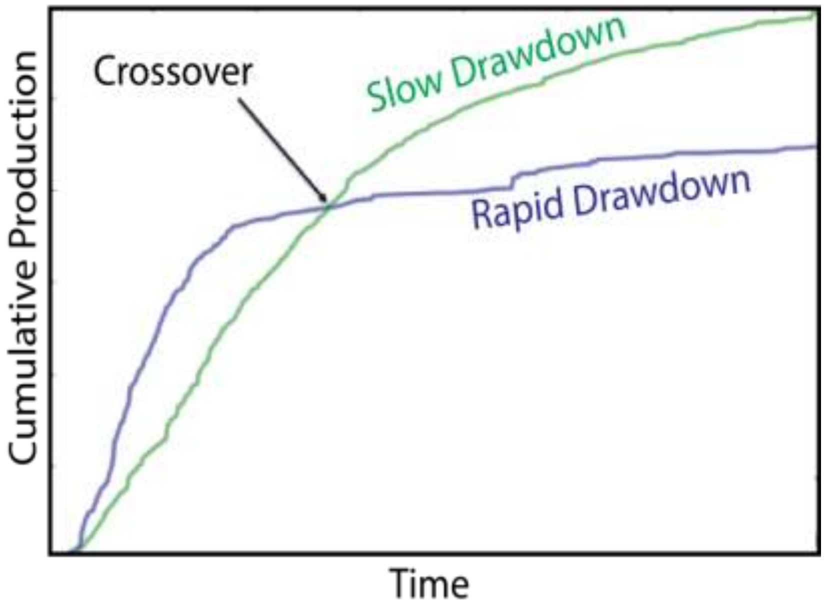
- Previous 5 years: Our platform for unconventional shale can predict pressure dependent gas production at the MSEEL-1 site making optimization possible.
- Next year: We will extend our approach to other DOE field sites (e.g. HFTS, Baaken) and continue to disseminate our results to industry (e.g. Chevron, Apache).



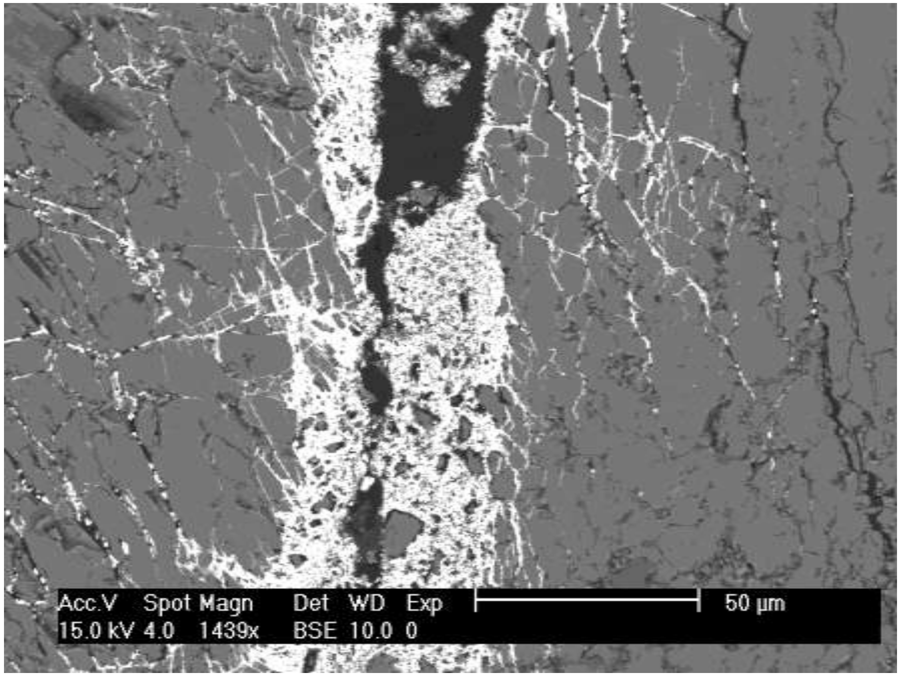


Barriers to Production

- **Premature closure of the stimulated reservoir volume**
  - Aggressive drawdown practices -> Learn to manage pressure to optimize production (LANL work)
  - Incompatible chemistry fouling fracture and matrix communication -> Tailor the working fluid to prevent fouling in fractures and matrix (e.g. SLAC work)



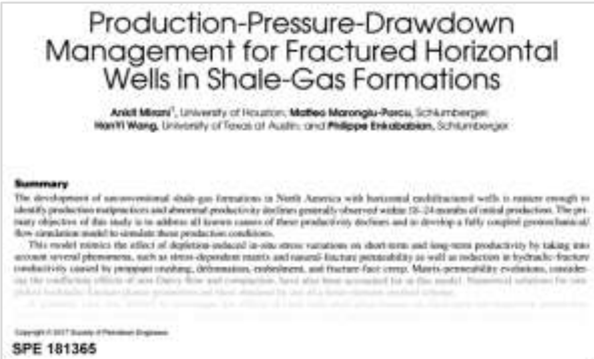
Aggressive pressure drawdown can close off parts of the reservoir



Barium carbonate fouls a fracture network
In a Los Alamos experiment

Use case: Pressure Management

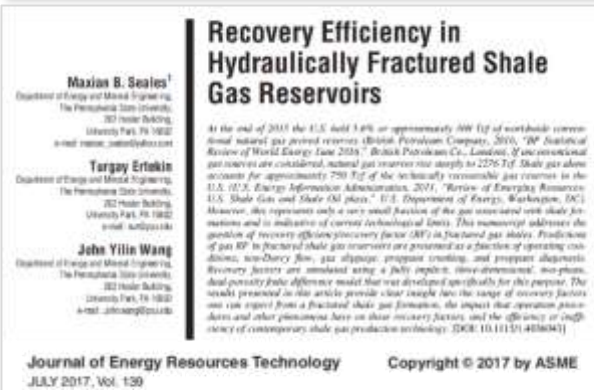
Slower drawdown can increase total recovery, but at the expense of reducing near term recovery.



Production-Pressure-Drawdown Management for Fractured Horizontal Wells in Shale-Gas Formations

Summary

SPE 181365



Recovery Efficiency in Hydraulically Fractured Shale Gas Reservoirs

Maxian B. Seales

Turgay Ertekin

John Yilin Wang

Journal of Energy Resources Technology JULY 2017, Vol. 139

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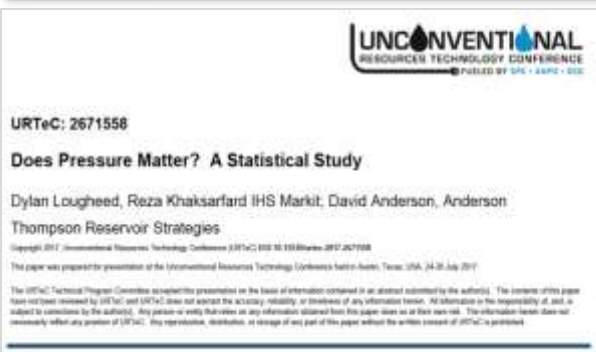
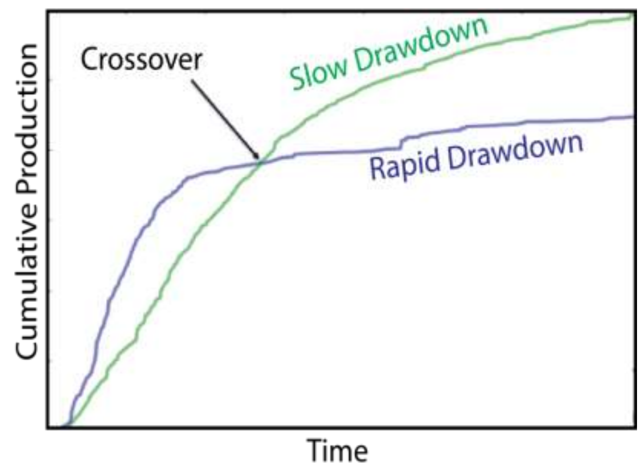


UNCONVENTIONAL RESOURCES TECHNOLOGY CONFERENCE

URTeC: 2671558

Does Pressure Matter? A Statistical Study

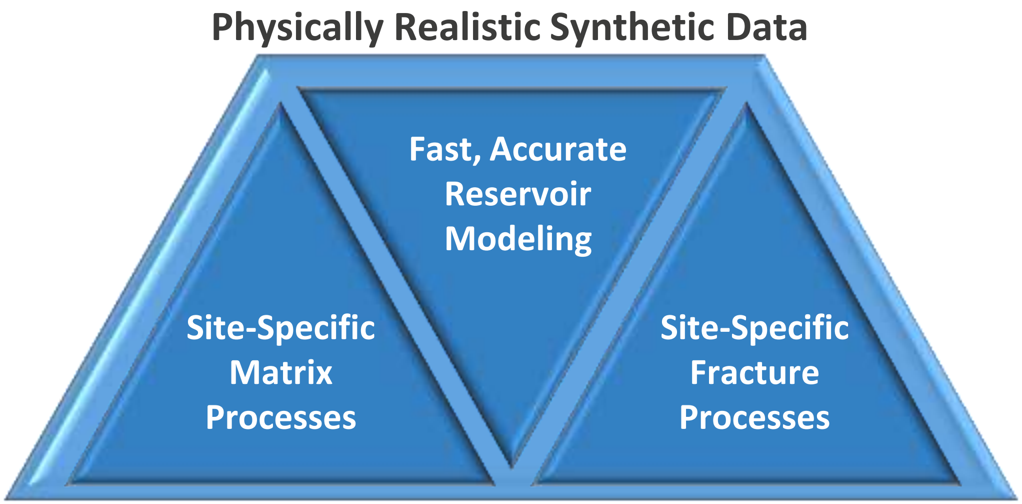
Dylan Lougheed, Reza Khaksarfard IHS Markit; David Anderson, Anderson Thompson Reservoir Strategies



- **Slower drawdown rates can lead to improved recovery efficiency in gas production from shale**
  - Anecdotal evidence from field experiences
  - Chemical signatures, consistent with known physical mechanisms
  - Recent simulation case studies showing effect
- **Yet, slower drawdown requires an operator to forego high near-term production for higher overall production.**
  - Uncertain site-specific characteristics/behavior (**risk**)
  - Unquantified **benefit**

A Mechanistic Reservoir Simulation Tool for Unconventional Reservoirs

Strategy: Develop a platform for an operator to optimize site-specific recovery of hydrocarbon (initially, gas), based on a combination of accurate site-specific synthetic data and real field data (when available).



Physical behavior of system described as a combination of fracture transport and matrix-scale transport

- Theoretical development and experimental characterization occurring through FE-30 investments

Fast, accurate reservoir-scale simulations using discrete-fracture network platform in combination with graph-based models & machine learning

- Initial development with LDRD
- Extension to gas in shales through FE-30

Ultimate goal—Scientifically based reservoir management strategies (and associated toolsets) for increasing recovery efficiency from shale.

Progression to Goals: Moving the Needle

LANL-LDRD; Fundamental Collaborative; SMART/MSEEL; FOA/TMSL; TCF

Matrix

- Validated LBM method to quantify gas transport (*D*) in matrix using real nanostructures; up to 100x ΔP effect
- Developed neutron method (SANS) to probe open/closed nanopores; measured open/closed ratio (*C*) in MSEEL core
- Identified damage in matrix at can occur at high ΔP
- Probing pressure-dependent effects of transport in MSEEL core
- Probing geochemical impacts to nanoscale matrix transport
- Evaluating chemical methods to enhance matrix transport (*D*)

Fractures

- Developed core-scale method for measuring transport properties (aperture, permeability) at various stresses
- Developed & validated scalable, pressure dependent model for apertures (*b*) against experiments and Barton-Bandis for MSEEL core
- Demonstrated theoretical basis for pressure-dependent recovery efficiency
- Identified potential critical drawdown conditions that can close fractures; found MSEEL core may be near critical stress

Fast, Accurate Simulations

- Developed dfnWorks—an open source PC-to-HPC platform for accurate meshing and simulation on discrete fracture networks
- Incorporated detailed mechanisms for fracture & matrix into dfnWorks
- Integrated graph-based models with full physics model in dfnWorks to increase speed by a factor of 10^4
- Coupling dfnWorks and graph-based models to Golder's FracMan platform; path to commercialization and to integration with commercial fracture generating software

Reservoir Management

- Demonstrated proof-of-concept that pressure dependent effects (e.g., drawdown rates) can have significant impacts on recovery efficiency
- Developing libraries-based platform for integrating synthetic and real data for rapid history matching & forecasting
- Developing & calibrating a site model for MSEEL–I for using in predicting the pressure dependent behavior relative to recovery efficiency
- Potential field-validation test at MSEEL-I based on predicted pressure dependent production (e.g., based on changing drawdown)

Goals

Accurate, Basin-Specific Predictive Model for Matrix Transport

Rate = $C \bullet D \bullet \Delta P$

Accurate, Basin-Specific Predictive Model for Fracture Transport

$b = b_0 \bullet \exp[a \bullet \sigma_n']$

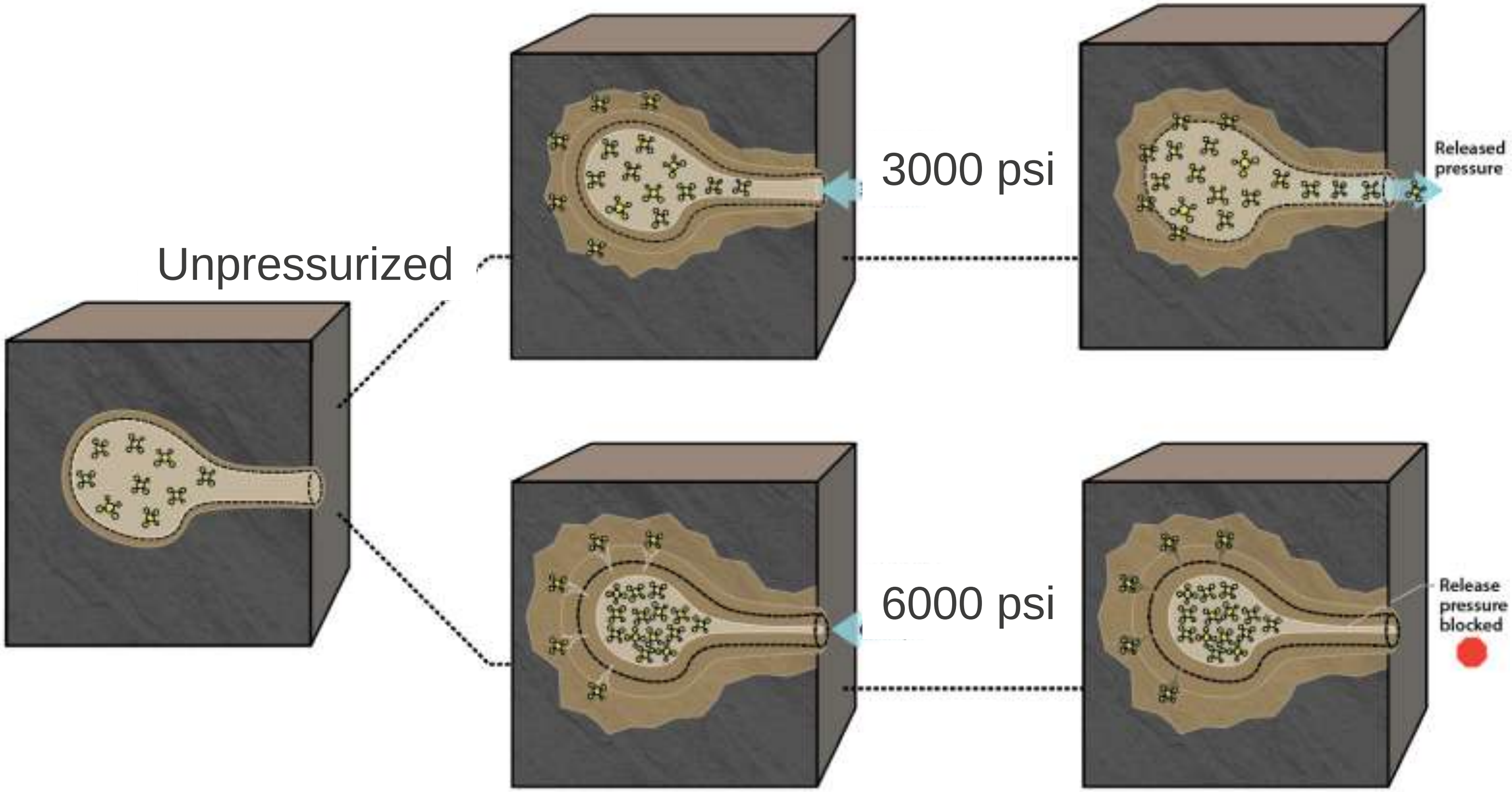
Calibrated Platform for Fast Generation of Site-Specific Synthetic Data

Field Validated Platform for Rapid Optimization of Pressure-Management

Matrix Controls on Production:

We are developing an accurate, site- (or basin-) specific predictive model for transport of gas through shale matrix: Rate = *C* • *D* • ΔP

We determined that matrix damage can occur at high ΔP
This impacts rate of production (*C* and *D*)
And is a Function of Reservoir History



Low pressure allows open pores

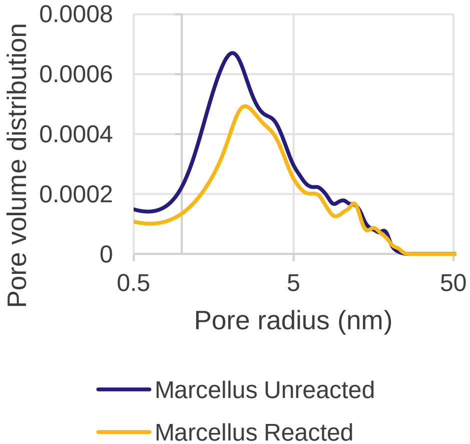
High pressure causes closed pores

Matrix Controls on Production:

We are developing an accurate, site- (or basin-) specific predictive model for transport of gas through shale matrix: Rate = $C \bullet D \bullet \Delta P$

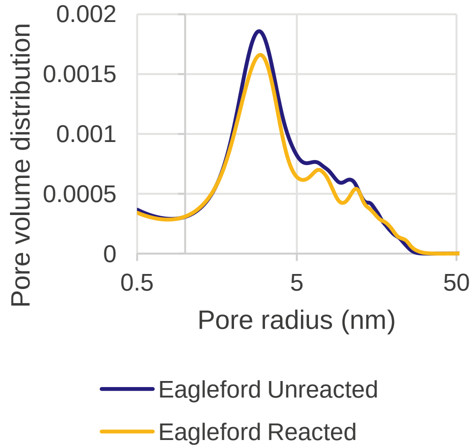
Impact of barite precipitation on matrix porosity
Collaboration with SLAC using small angle neutron scattering

Marcellus shale



Porosity decreased by 13.48%

Eagle Ford shale



Porosity decreased by 14.01%

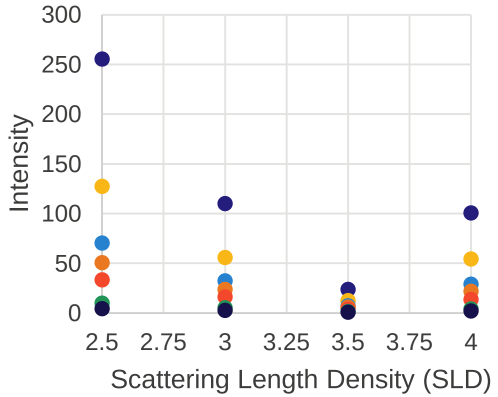
- SANS experiments on Marcellus and Eagle Ford shales following reaction with barite promoting fluids
- Both shales lost ~14% of their porosity due to barite precipitation
- Marcellus shale loses most porosity at ~2.2 nm
- Eagle Ford shale loses porosity more uniformly

Matrix Controls on Production:

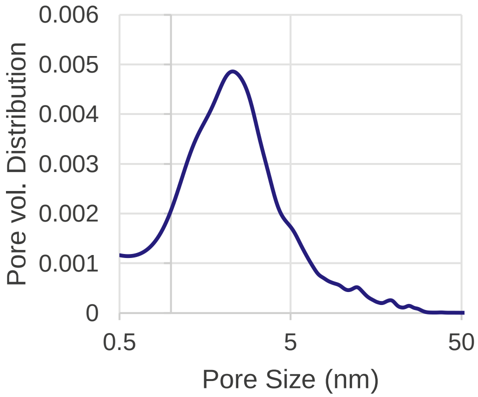
We are developing an accurate, site- (or basin-) specific predictive model for transport of gas through shale matrix: Rate = *C* • *D* • ΔP

Analysis of kerogen pore structure
Collaboration with SNL using small angle neutron scattering

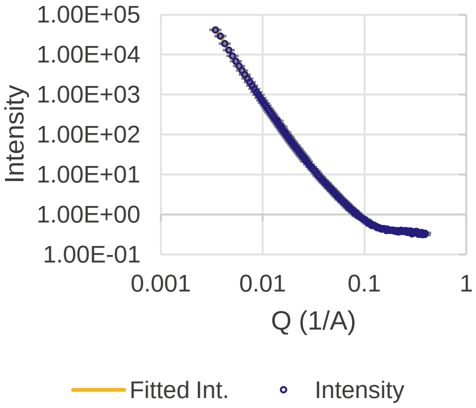
Contrast matching



Pore size distribution



Fitted intensity from PSD



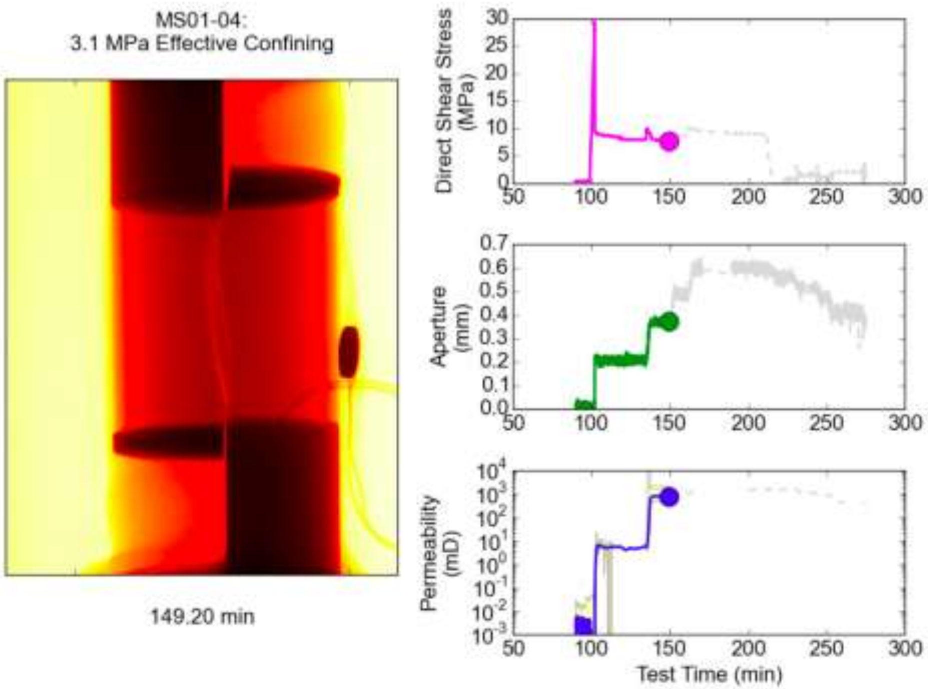
- Differentiates between pores occurring in kerogen and clay
- Provides insight on the maturity of the shale (gas rich, oil rich)
- Discovered kerogen pore sizes range from 1-5 nm which SANS can interrogate but are below resolution of most methods

Tributary Fracture Controls on Production

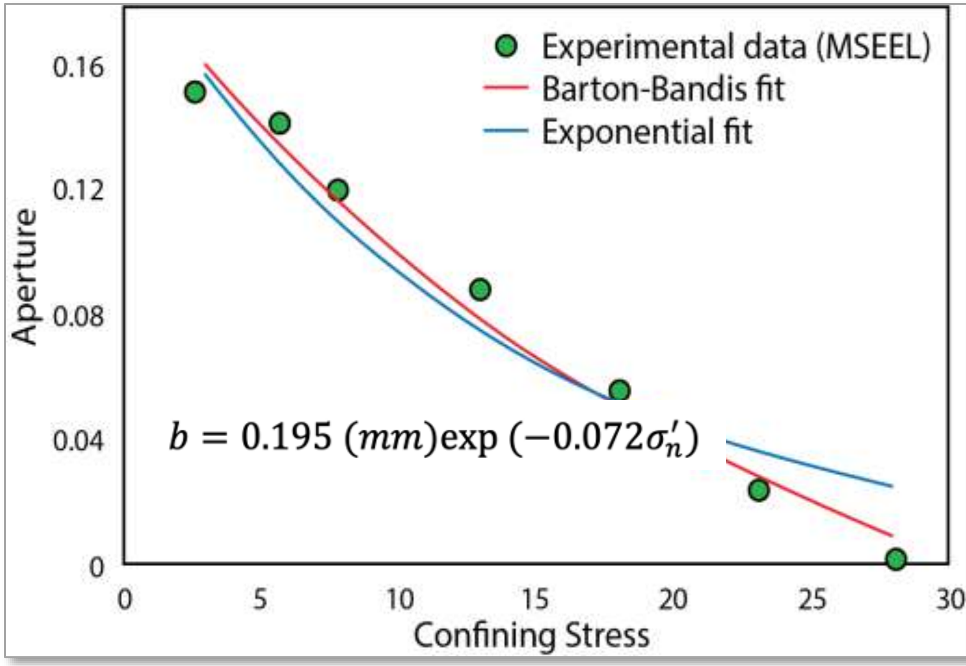
We are developing an accurate, site- (or basin-) specific predictive model for fracture transport: $k_{eff} = b^2/12$, where $b = b_0 \cdot \exp[a \cdot \sigma_n']$

Developed & validated scalable, pressure dependent model for fracture aperture (*b*) based on experiments on MSEEL core

Example experiment on MSEEL at 3 MPa



Summary showing fit of MSEEL data

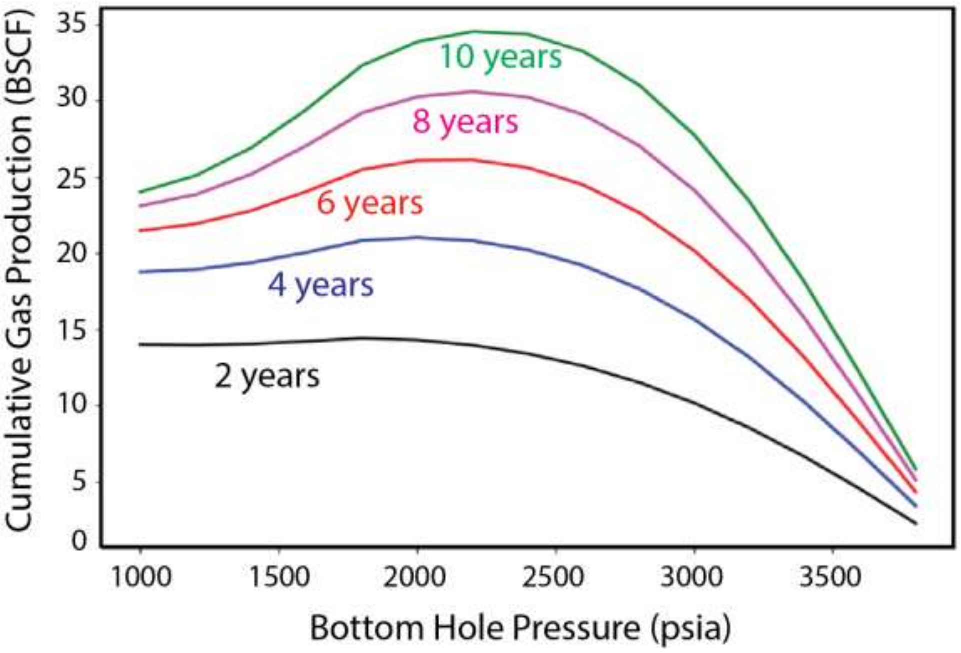


Tributary Fracture Controls on Production

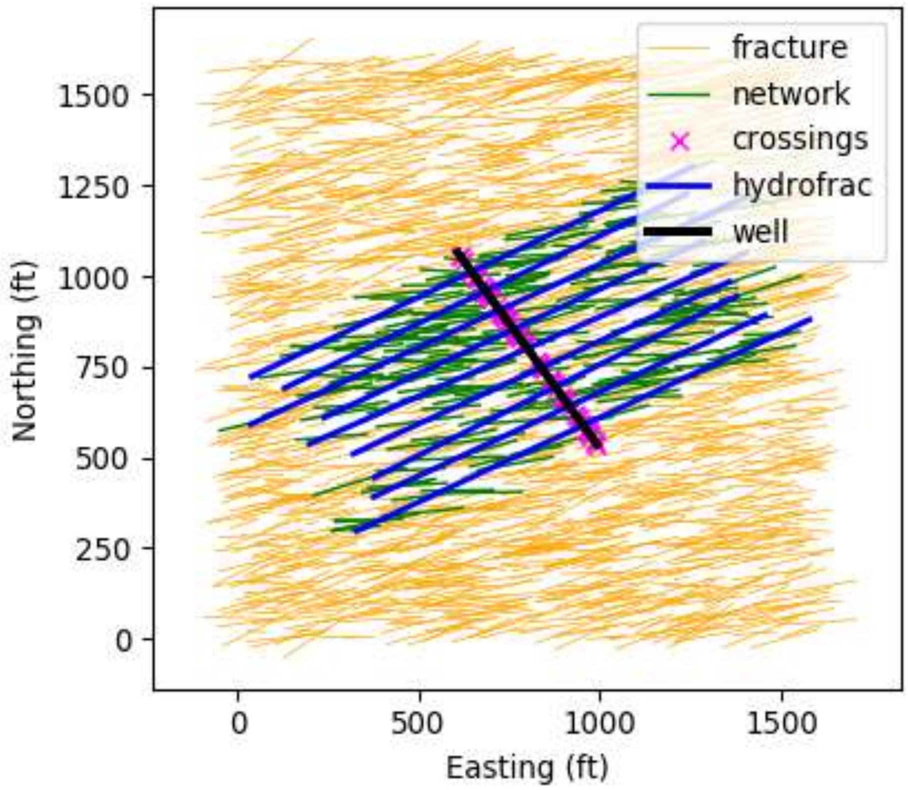
We are developing an accurate, site- (or basin-) specific predictive model for fracture transport: $k_{eff} = b^2/12$, where $b = b_0 \bullet \exp[a \bullet \sigma_n']$

Created Reduced-Order Model to investigate drawdown conditions
Using experimental data, we identified potential critical drawdown conditions that can close fractures→MSEEL core may be near critical stress

Drawdown versus Production

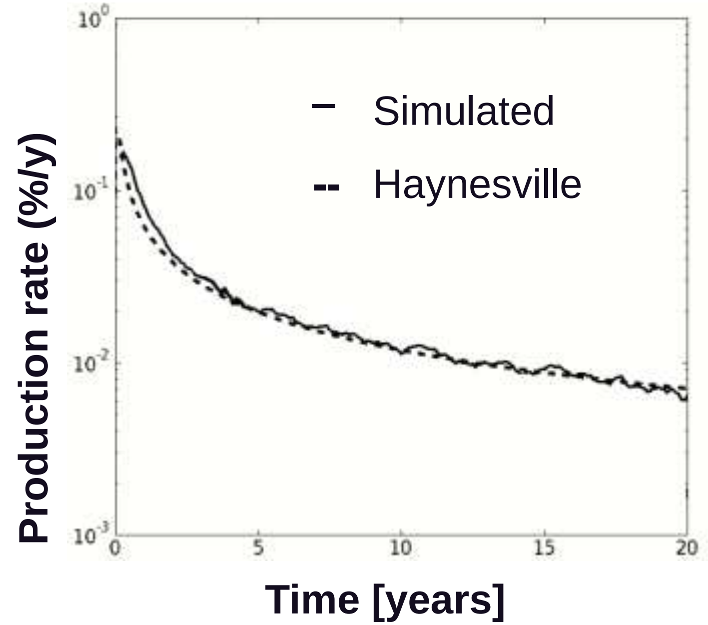


Reduced Order Model



dfnWorks:
Fast, Accurate Simulations of Unconventional Reservoir Performance

Incorporated detailed mechanisms based on experimental data for fracture & matrix into dfnWorks

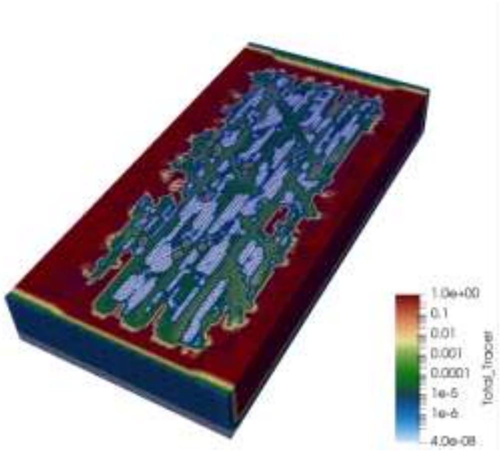


Year	1	2	5	10
% Fracture Production	99	95	75	40
% Matrix Production	1	5	25	60

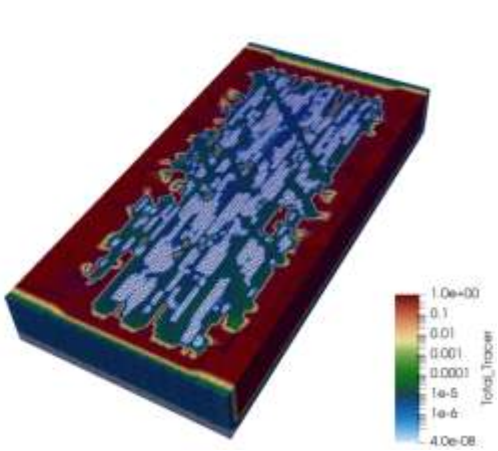
Fast, Accurate Simulations of Unconventional Reservoir Performance
Fracture closure as a function of drawdown strategies at MSEEL-1

- Simulation of the impact of pressure drawdown on complex fracture networks
- Utilizes Barton-Bandis model for aperture changes due to changing fluid pressure
- Results based on experimentally measured parameters

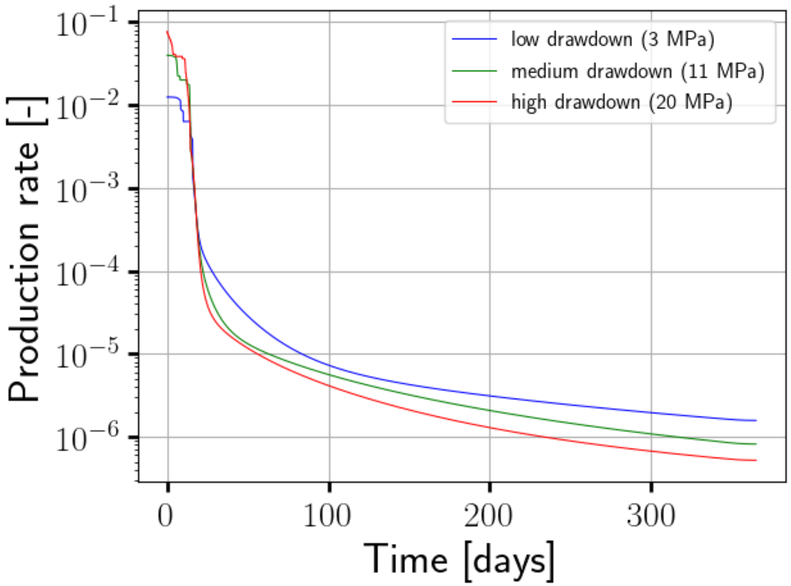
Low drawdown strategy: more contribution from entire fracture network



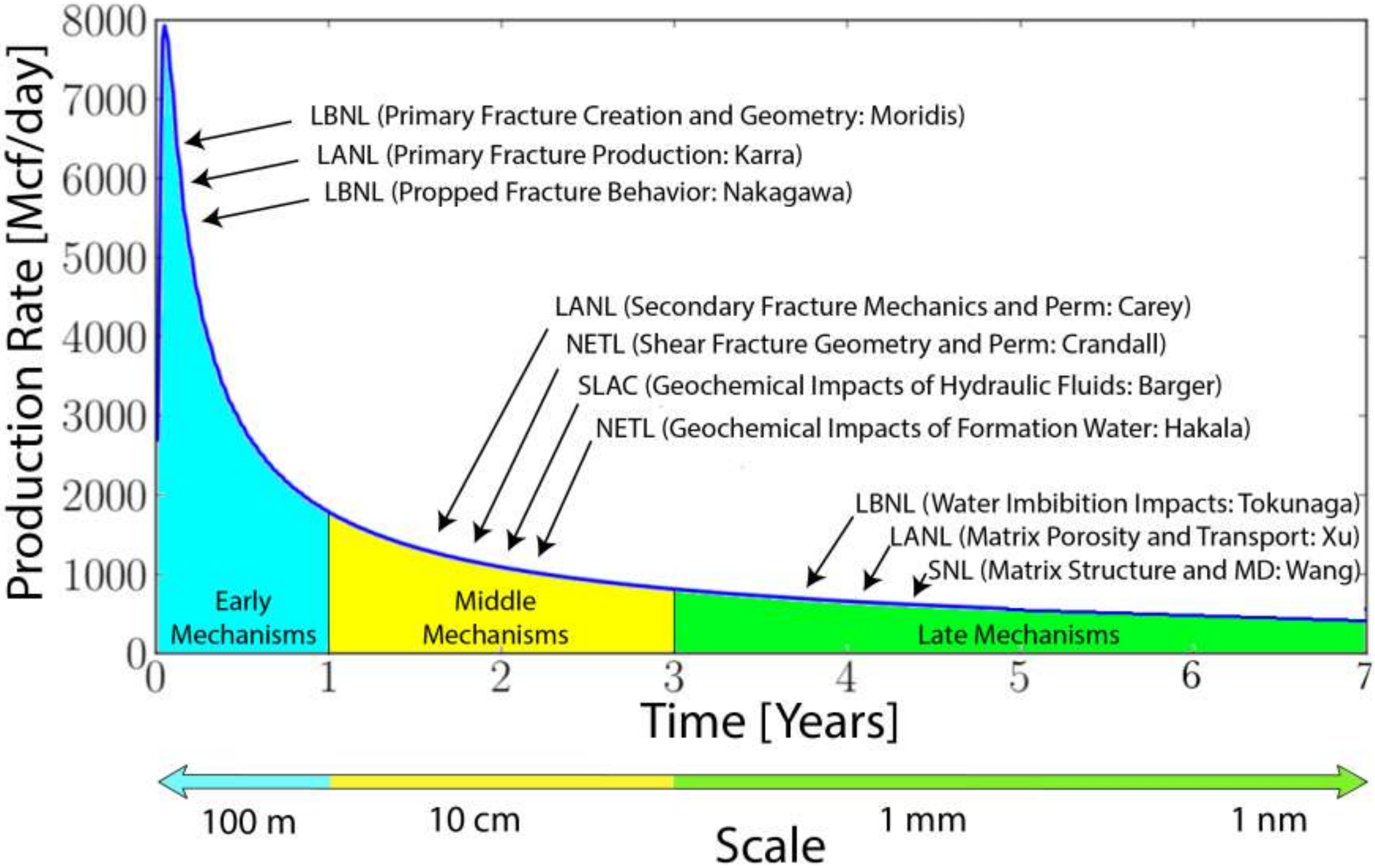
High drawdown strategy: less contribution from entire fracture network



Production for different drawdown scenarios



DOE’s Hydraulic Fracture Program Addresses Key Features of Production Curve Providing Path to Improved Recovery



FY21 Proposed Work: Other basins and 2nd order effects for Pressure Management in Gas-Dominated Systems

- **Apply pressure management strategy beyond the Marcellus to other DOE field sites such as HFTS and Baaken sites**
  - **Experimental characterization of pressure sensitivity of nanopore system**
  - **Experimental measurements of pressure sensitivity of fractures**
  - **Numerical tool development for optimizing productivity**
- **Incorporate geochemical mechanisms impacting permeability and production into unconventional reservoir platform**
  - **Measure the impact of geochemical processes (e.g. barite precipitation) on nanopore structure and hydrocarbon transport in shale matrix using SANS experiments and LBM simulations**
  - **Experimental study of barite precipitation in dynamically fractured core: impact on matrix-fracture communication**
- **Integrate pricing models (net present value, capital costs, hydrocarbon prices, etc.) with reservoir optimization tool to develop efficient economical analyses**

Goals for our Research Program

- FY25: Industry broadly adopts the new DOE approach
- FY24: Platform is commercialized and/or licensed
- FY22-24: Industry gains confidence in the approach through multiple field-validation tests
- FY 21: Platform is tested on other basins to demonstrate robustness of the approach