Numerical and Laboratory Study of Gas Flow through Unconventional Reservoir Rocks

RPSEA Piceance Basin Tight Gas Research Review

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Presentation Outline

- Challenges and our research activities
- Our RPSEA project and collaborators
- Preliminary results
- Goals and objectives

Background

- In very tight reservoir rocks, both **measurement techniques** and our **understanding of the physics** are being challenged
- Our group's research activities focus on **pore-scale physics and flow** using direct simulation and experiments
- Specifically, we investigate what makes unconventional rocks unconventional
  - **Surface interaction**
  - **Non-continuum slippage**
  - **Heterogeneity in pore structure and rock-fluid interactions**

Our RPSEA Project

- RPSEA 09122-29 – 02/2011 – 02/2014
  - Use **nanofluidic chips** and single-molecule detection techniques to visualize fluid flow in nano-sized pores
  - Combine core flooding test and SEM imaging to correlate fluid flow in tight rocks to pore structures
  - Develop **pore-scale numerical models** to provide information that cannot be easily obtained from experiments, such as three-dimensional motion of fluids
- Our Team
  - **Missouri University of Science & Technology** – B. Bai (core flooding), Y. Ma (single-molecule detection)
  - **Colorado School of Mines** – X. Yin (pore-scale models), K. Neeves (nanofluidic chips)

Traditional laboratory studies

- Pulse-decay permeability measurement
- Mercury porosimetry
- Linear core flooding
- Ultra-centrifuge
- PVT (CSM)

A CMS-300 Pulse-Decay Permeameter

These equipments allow us to study

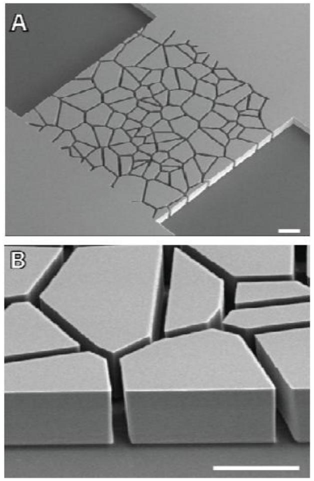
•Porosity and permeability
•Storage capacity and transport
•Multiphase flows and formation damage

Non-traditional laboratory studies

- What makes flow in unconventional reservoir rocks unconventional?
  - **Surface interactions**
  - **Non-continuum slippage**
  - **Heterogeneity in surface properties**
  - Fractures and cracks
  - In-situ stress
  - …

This list is probably far from complete.

Some of these effects can be studied using micro (right) and nano-scale (below) porous media analogs constructed on silicon / polymer chips



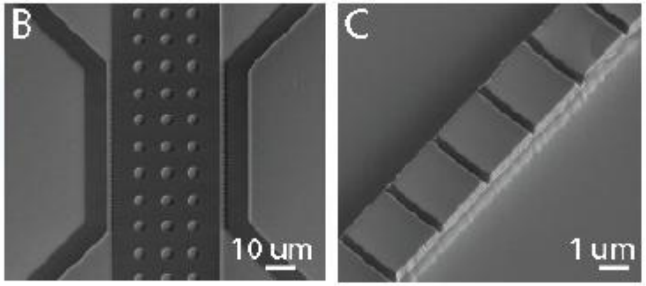
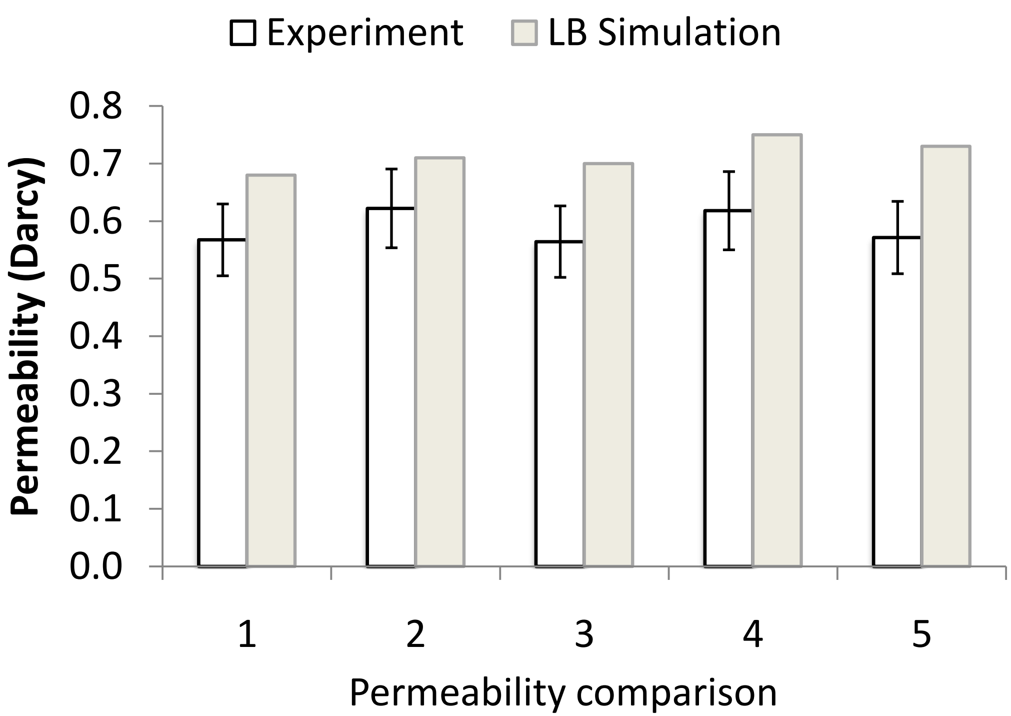
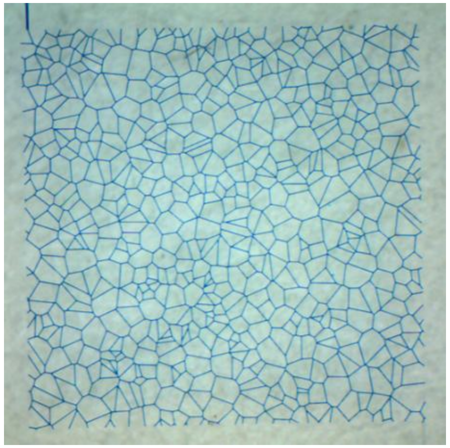


Photo courtesy of Keith Neeves Chemical Engineering Colorado School of Mines

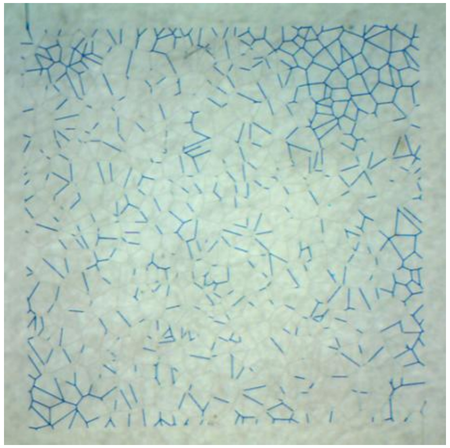
Preliminary results from micro-chip experiments





Air-water two phase flow test: Left: The geometry is initially saturated with water

Below: Air is injected in the lower left corner forcing water out of the channels



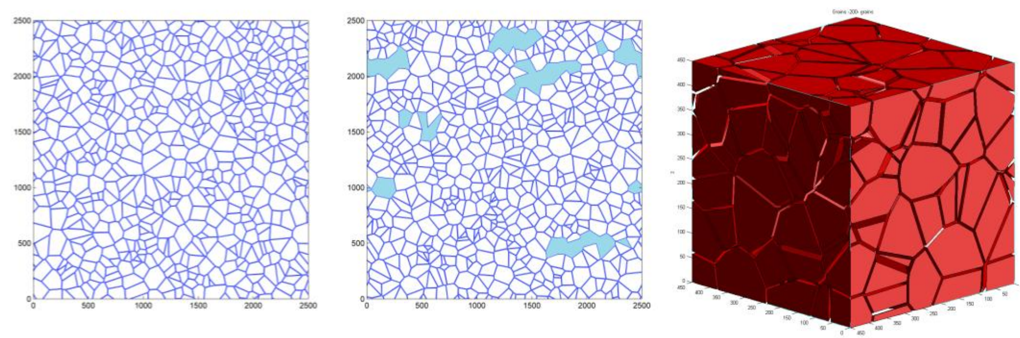
Data and photo provided by Keith Neeves and Melissa Wu , Chemical Engineering, Colorado School of Mines

Simulation of micro- and nano-scale flows

- Numerical tools have been and are being developed to study fluid flow with non-continuum effects in nano-sized pores

Experimentally measured ϕ and k and pore structure

⇨



Representative porous media geometry models

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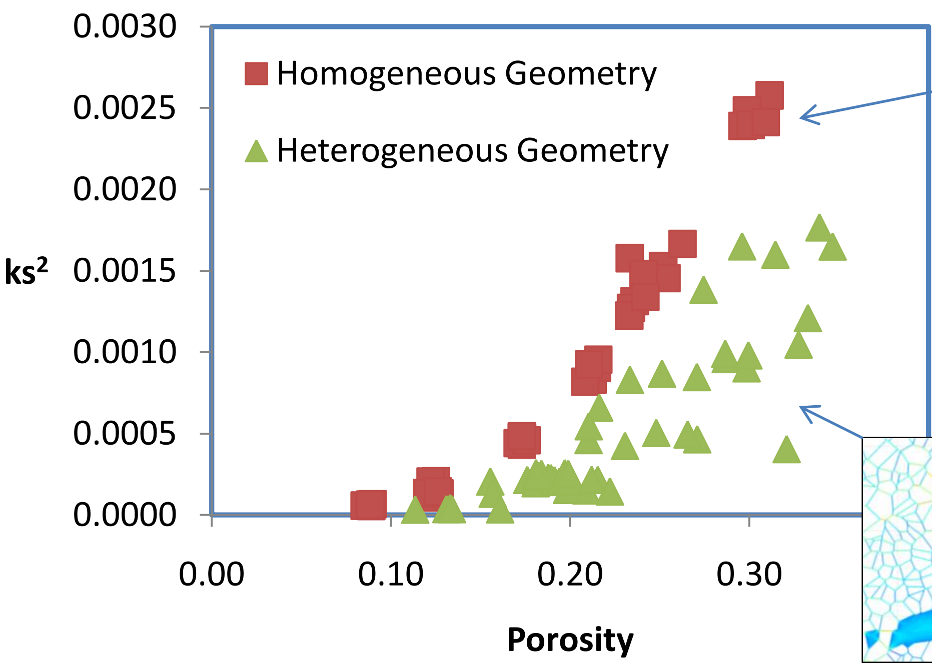
Direct numerical simulation models:
•Lattice-Boltzmann (for Navier-Stokes)
•DSMC (for non-continuum flows – being developed)

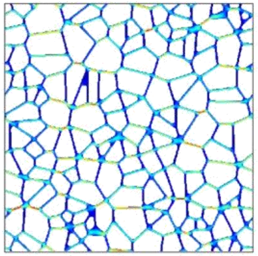
⇦

Pore structure
Relative permeability
Effect of stress
Adsorption / Desorption

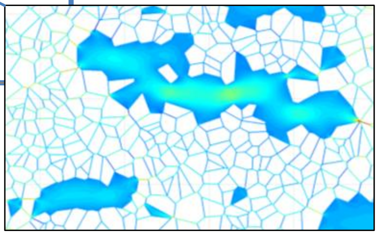
Preliminary results from pore-scale modeling

- **Porosity-permeability relation** is the key to rock typing and understanding geomechanical effects on fluid flow





Ideal, channelized geometry – porosity-permeability shows a strong correlation



More realistic, heterogeneous geometry – porosity-permeability shows large scattering

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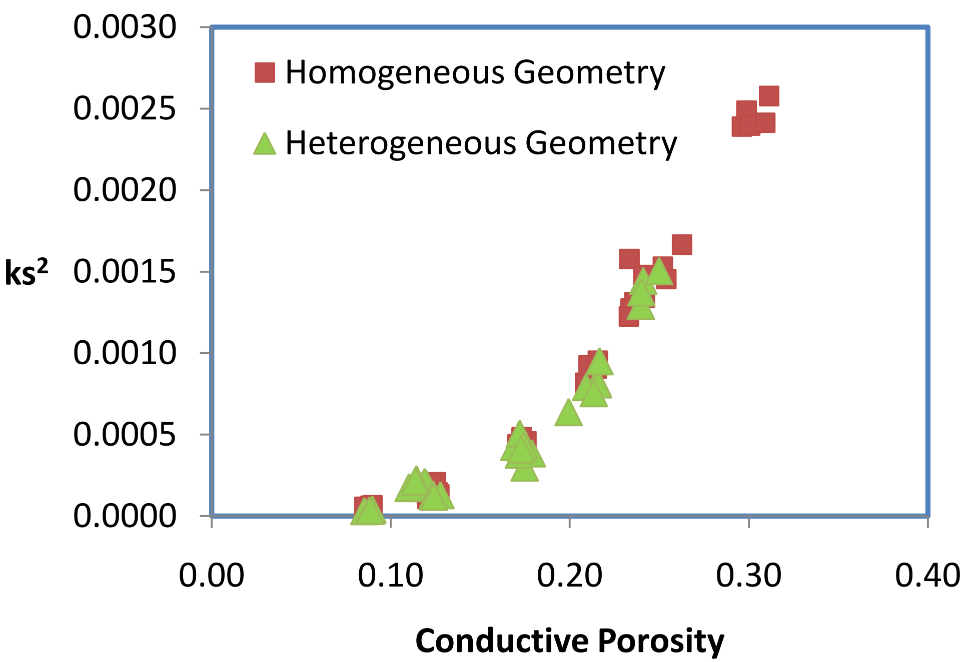
Preliminary results from pore-scale modeling

- A **universal porosity-permeability correlation** can be developed by recognizing that the **large pores do not contribute to permeability**



- These data are from our scoping studies using 2D geometries
- 3D simulations and experiments are underway
- Such a correlation can be used to determine the geometry of pores from bulk measurement without resorting to image analysis

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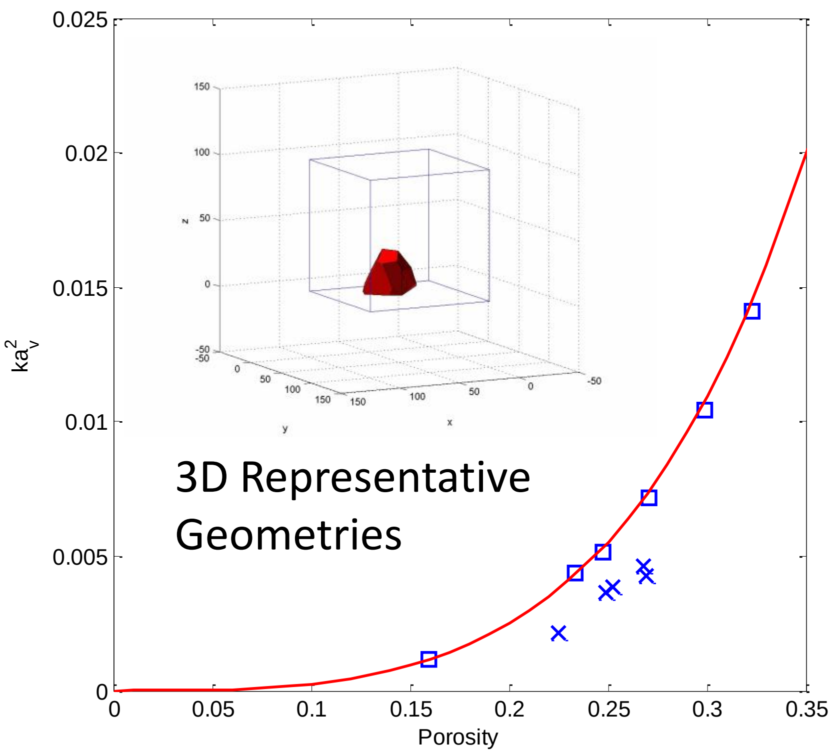
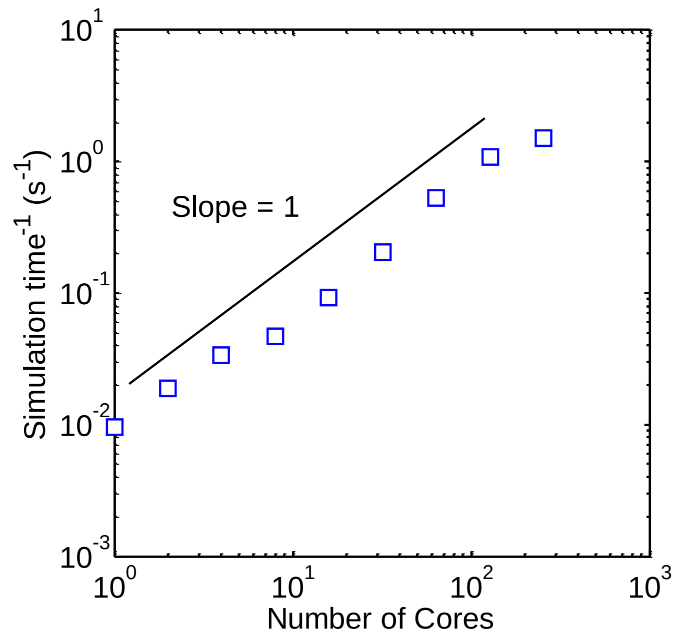
Parallelized, 3D pore-scale simulator



3D Porosity-Permeability Data



3D Simulator Parallel Speedup

Goals and objectives

Simulations with controlled geometries and assumed physics

Micro- and nano-fluidic experiments with controlled geometries and real physics

Core-scale experiments with real geometries and real physics

Increasing level of reality

The combined approach will significantly improve our understanding of fluid flow on nano-scale and unconventional reservoir dynamics

Acknowledgements

- **Collaborators**
  - Baojun Bai, Yinfa Ma (MUST)
  - Keith Neeves (CSM, ChemE)
  - Qinjun Kang (Los Alamos National Lab)
- **Students**
  - Feng Xiao (PE)
  - Lei Wang (PE)
  - Melissa Wu (ChemE)
- **Funding**
  - RPSEA

Simulated vs. measured permeability

- Simulation of flow through digital cores from CT-scan
  - CT and experimental data from Imperial College
  - Numerical simulations are done in CSM

	A1	BSS	C1	F42A	S1	S2
Porosity	42.9	19.6	23.3	33	14.1	24.6
Resolution	3.85	5.345	2.85	9.996	8.683	4.956
K (exp)	7,220	1,286	1,102	59,000	1,678	3,898
K (sim)	8,675	1,507	1,192	59,331	2,006	4,076
% error	20.2%	17.2%	8.1%	0.6%	19.6%	4.6%