Research Proposal

Nanoscale Flow and Transport: Pore-scale Experiments and Numerical Simulations

Xiaolong Yin, Colorado School of Mines

Challenges on the Nano-Scale

Fundamental laws for storage and transport are challenged

Conventional

- Storage – pore volume + phase behavior = Gas/Oil in Place
- Transport – pressure driven + Stokes flow = Darcy's law

Unconventional

- Storage – pore volume + surface adsorption
- Storage – surface-fluid interaction modifies fluid properties and phase behavior
- Transport – non-continuum effect (slip)
- Transport – other mechanisms (diffusion)

Scope of Proposed Research

Objectives

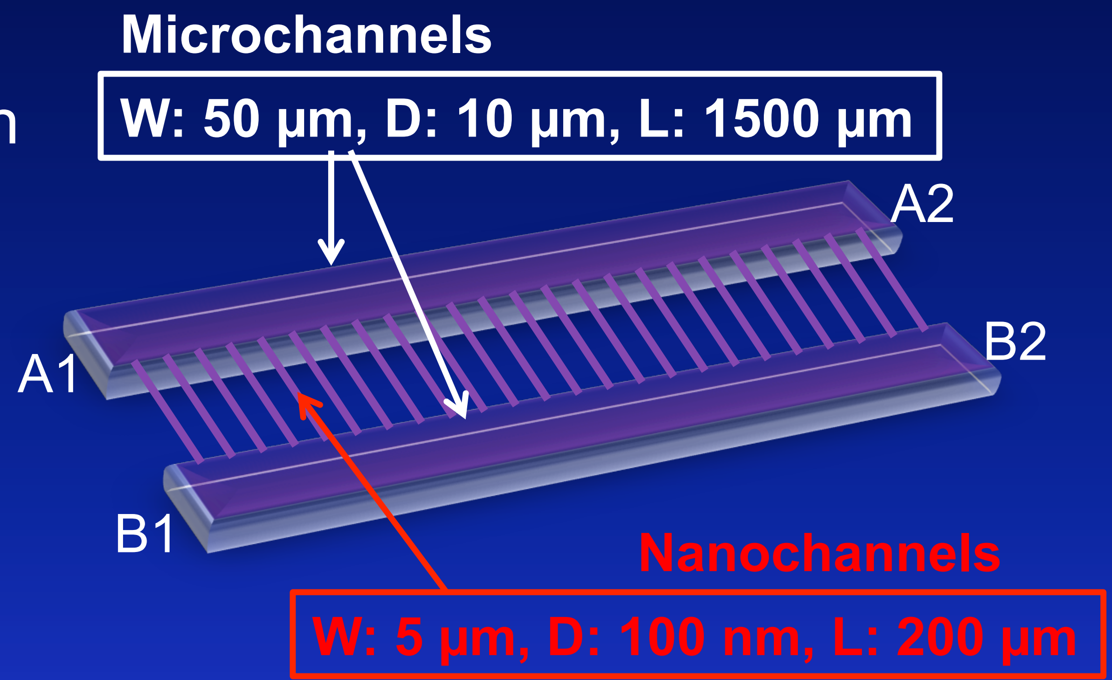
- Make (direct) observations and measurements
- Provide numerical and experimental data needed for the development of constitutive relations

Approach

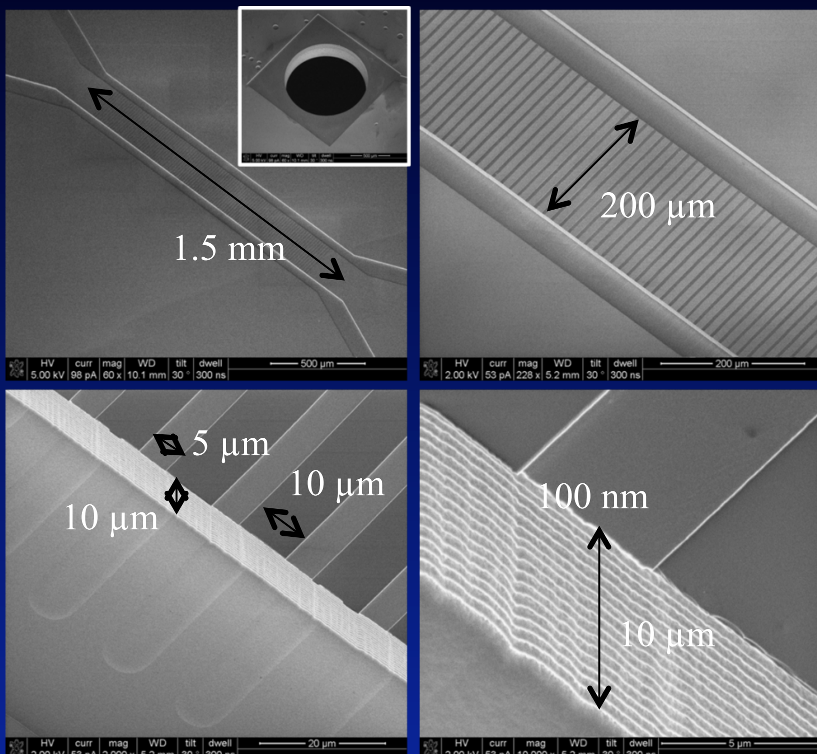
- Phase behavior and flow experiments in controlled environments (e.g. nanofluidics)
- Use direct observations to verify / calibrate indirect measurements
- Use numerical simulations to isolate the mechanisms and to provide model parameters

Experiments

- Nanofluidic models are fabricated using **silicon and pyrex** – direct observation is possible
- The channel depth can be made to 30nm
- A1, A2, B1, B2 are connected to fluid injection / production ports



SEM Image and Air-Water Drainage



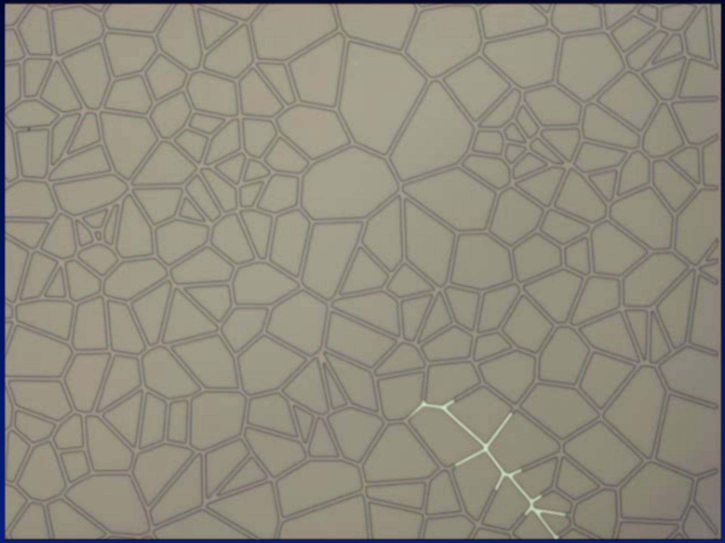
Nanochannels arranged in parallel

Water ↓

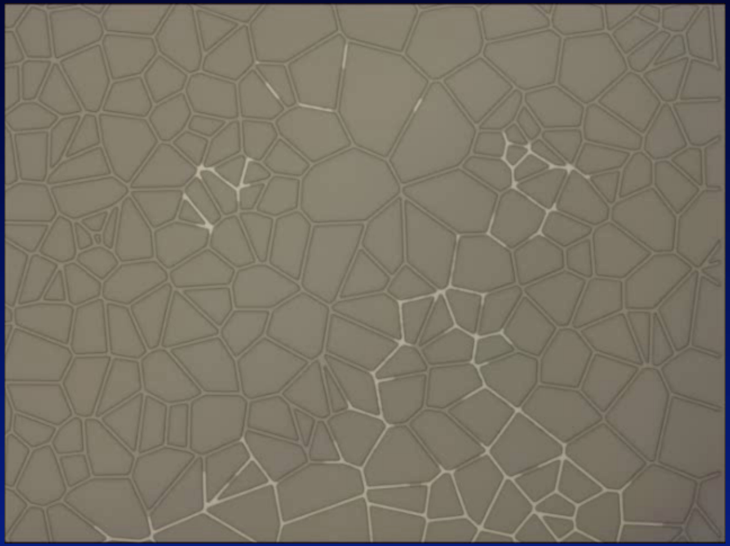
Air ↓

Pressure difference = 135 psia
Threshold pressure = **120 psia**
Above threshold pressure, saturation decreases with increasing pressure difference

Nano-Networks and Evaporation



IPA (isopropyl alcohol) evaporation in 300nm deep channels (5x)



IPA (isopropyl alcohol) evaporation in 30nm deep channels (2x)

Numerical Simulations

- Phase behavior
  - Multi-component lattice Boltzmann method

- Mobility of single- and multi-phase fluids
  - $Kn < 0.001$ – Lattice Boltzmann method
  - $0.001 < Kn < 0.1$ – Lattice Boltzmann method w/ slip
  - $0.1 < Kn$ – Direct simulation Monte Carlo

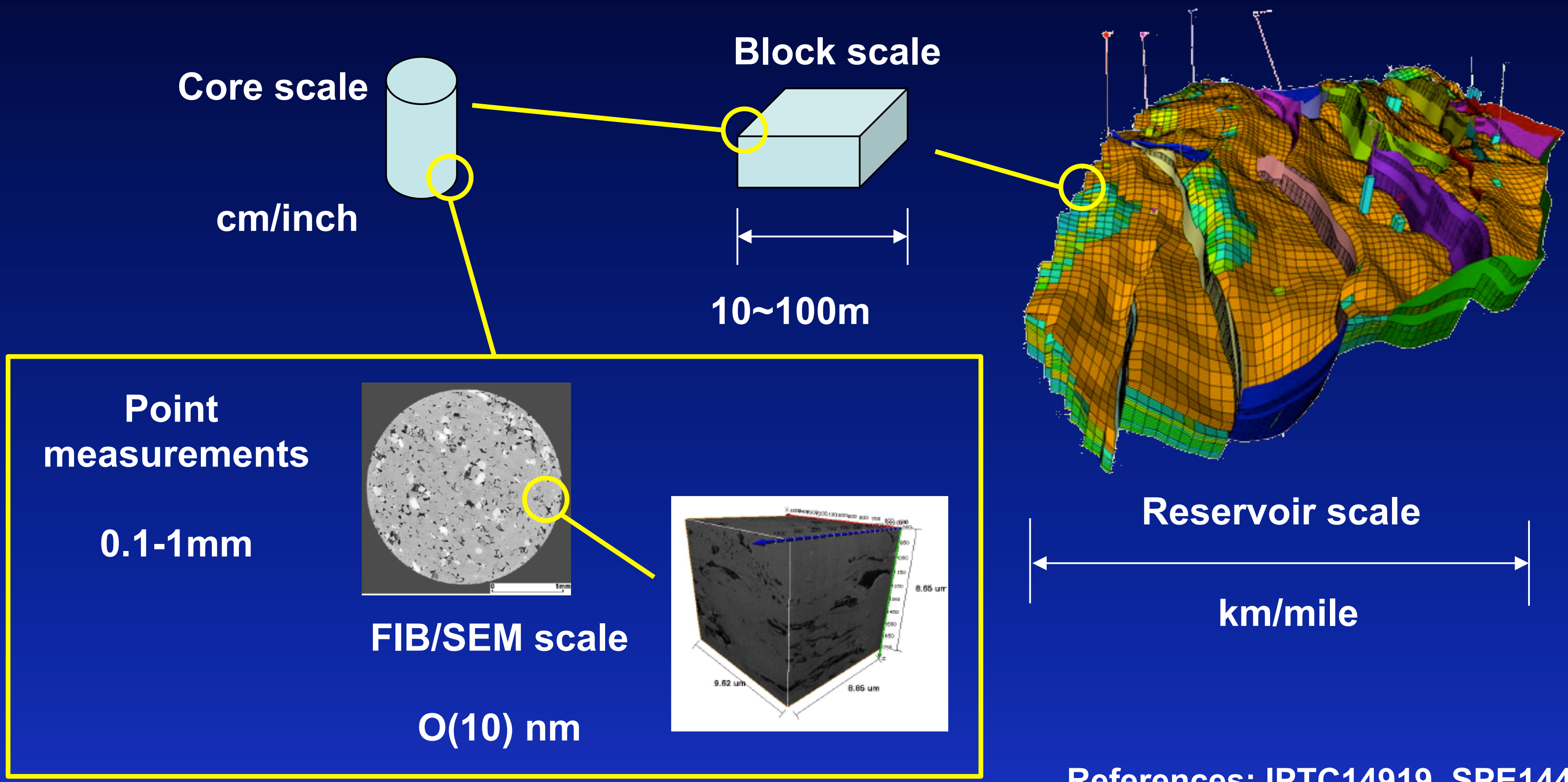
- **Validate the physics**
- **Extract constitutive relations**
- **Simulate relevant processes in real geometries**

Plan

Topics	Data to be Obtained
Phase Behavior	• Multicomponent hydrocarbon mixture phase boundaries • Effect of surface properties • Effect of pore size distributions
Single-phase transport	• Apparent permeability of hydrocarbon liquids and gases as a function of confinement and surface properties • Confirmation and characterization of osmotic effects (size dependent transport)
Multiphase transport	• Visualization of water-oil displacement on the nanoscale • Effect of additives and chemistry on water-oil displacement efficiency • Gas-EOR

Attack the Problem of Scales

- (Verified) simulations can directly upscale nm-scale phenomena to μm/mm-scale effective properties



References: IPTC14919, SPE144050

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