Pore/Molecular-Scale Measurements

MODELING PHASE BEHAVIOR IN CAPILLARY TUBE

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Outline

- Objective
- Model Description
- Results
  - Bubble point suppression
  - Effect of capillarity and IFT
- Discussion

Objective

- Calculate bubble point of a binary hydrocarbon mixture in a slit nanopore
- Incorporate effect of capillarity using Peng-Robinson EOS in flash calculation
- Address dependence of IFT on phase equilibrium using Parachors

Model Description

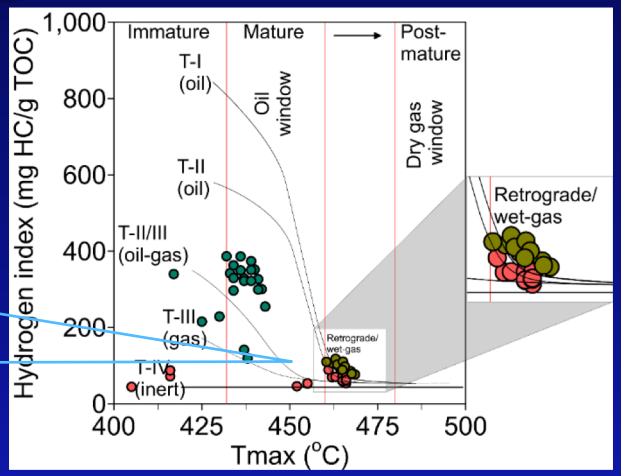
Five general categories of petroleum reservoir fluids:

Increasing chemical complexity

- Black oil
- Volatile oil
- Retrograde gas
- Wet gas
- Dry gas

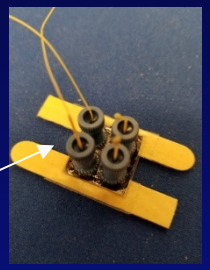
This model:
- C1:C7 = 90:10%
- C1:C7 = 10:90%
- C1:C3 = 90:10%
- C1:C3 = 30:70%
- C1:C3 = 10:90%

Niobrara mudrock system
(Source rock analysis)

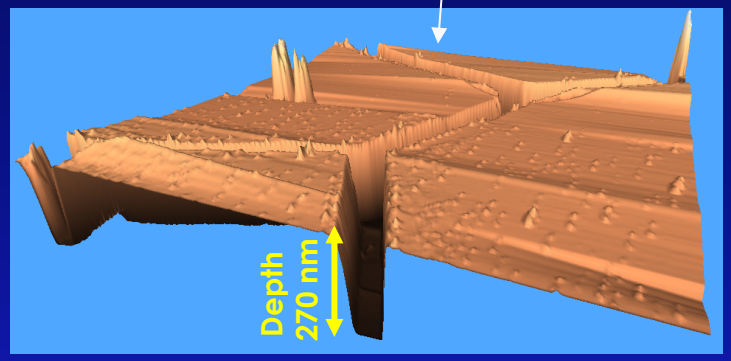


This model: dimensions of pore radius, r:
- r = 20 nm
- r = 50 nm
- r = 100 nm
- r = 150 nm
- r = 200 nm
- r = 500 nm

Condensation lab study w/ silicon nanochip
- Nanochannels
- D = 50~500 nm

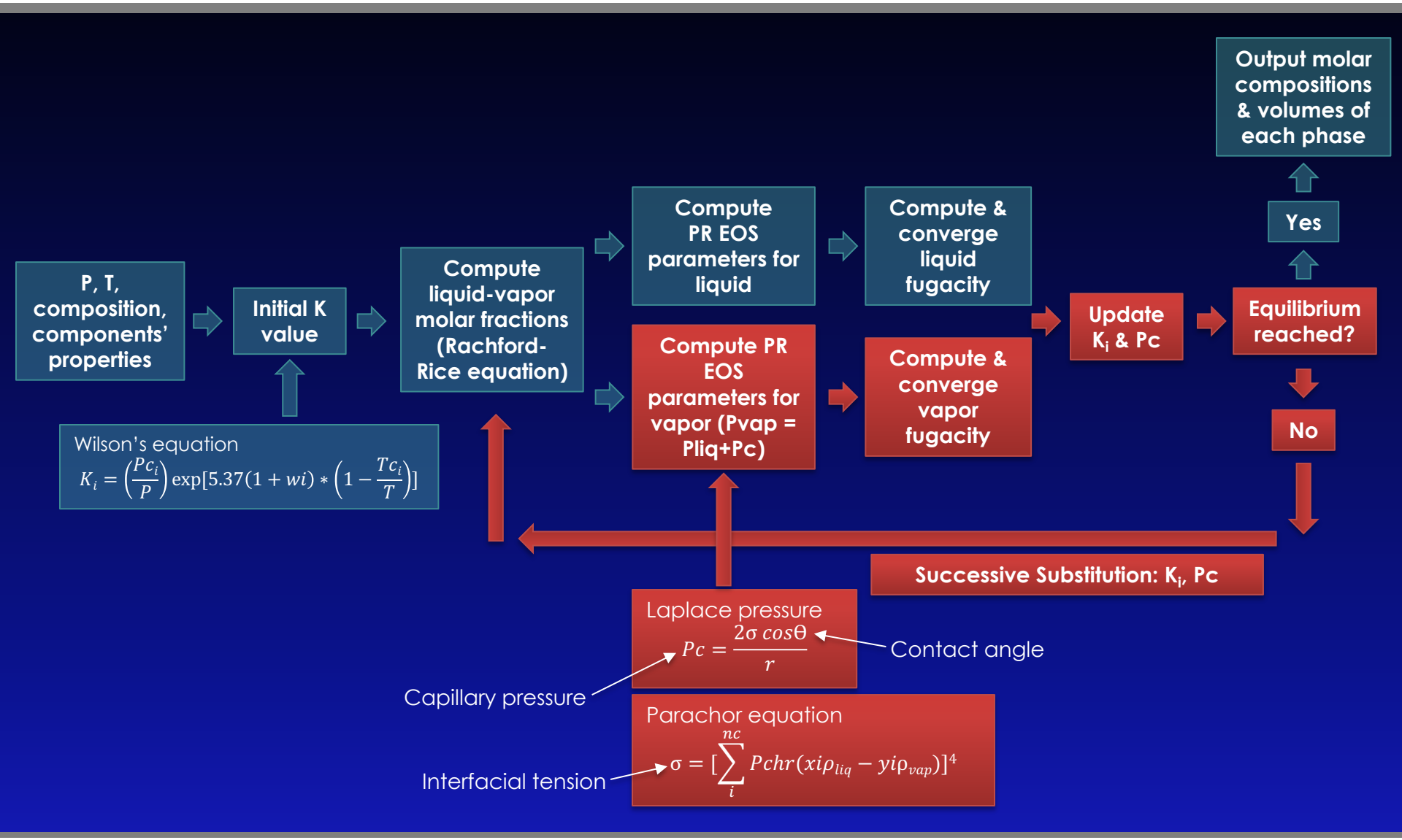


Silicon nanochip



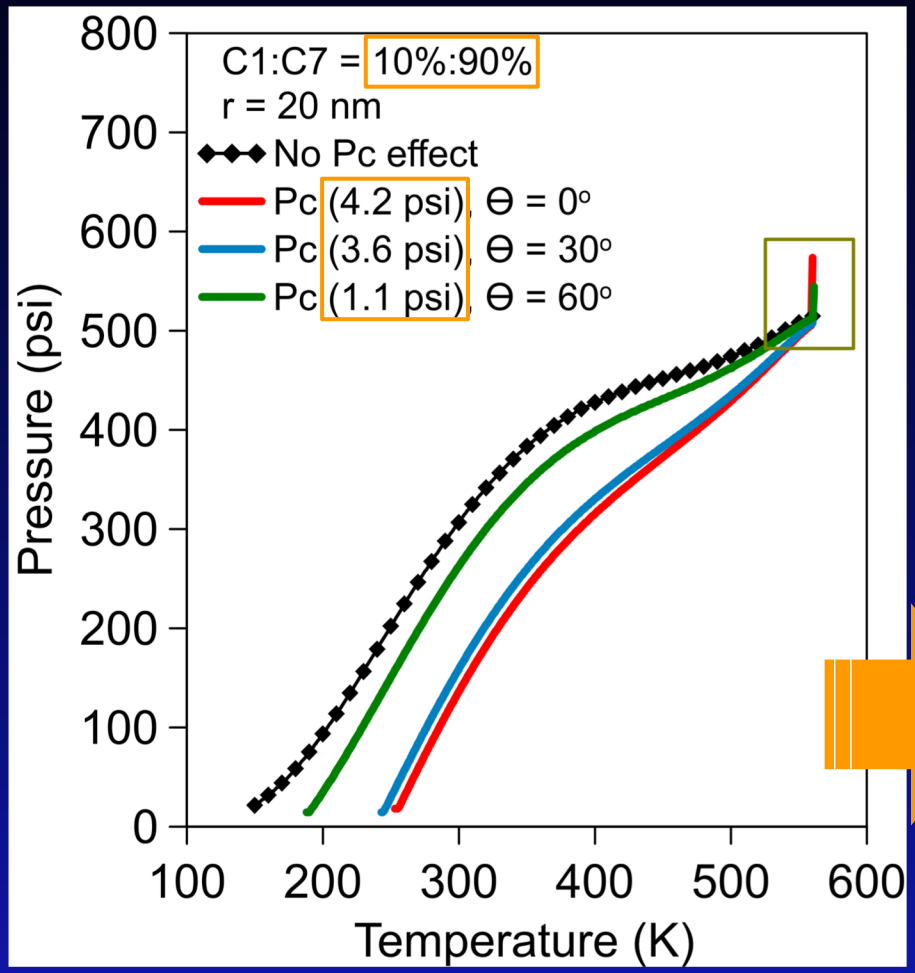
Profiled using the Atomic Force Microscope (AFM)

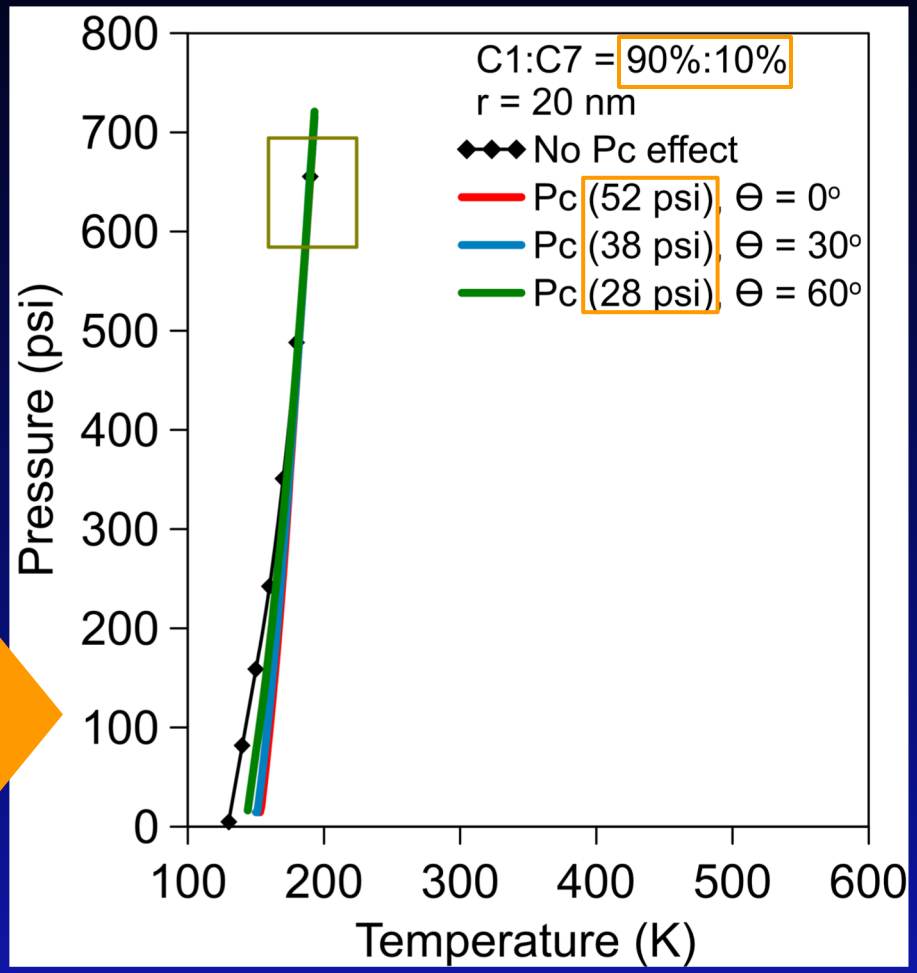
Flash Calculation Flowchart



Bubble-Point Pressure Lowering Dependence on IFT (C1:C7=10-90% & 90-10%)

Nanoconfinement effect due to capillarity





Bubble-Point Pressure Lowering Dependence on IFT (C1:C7=10-90%)

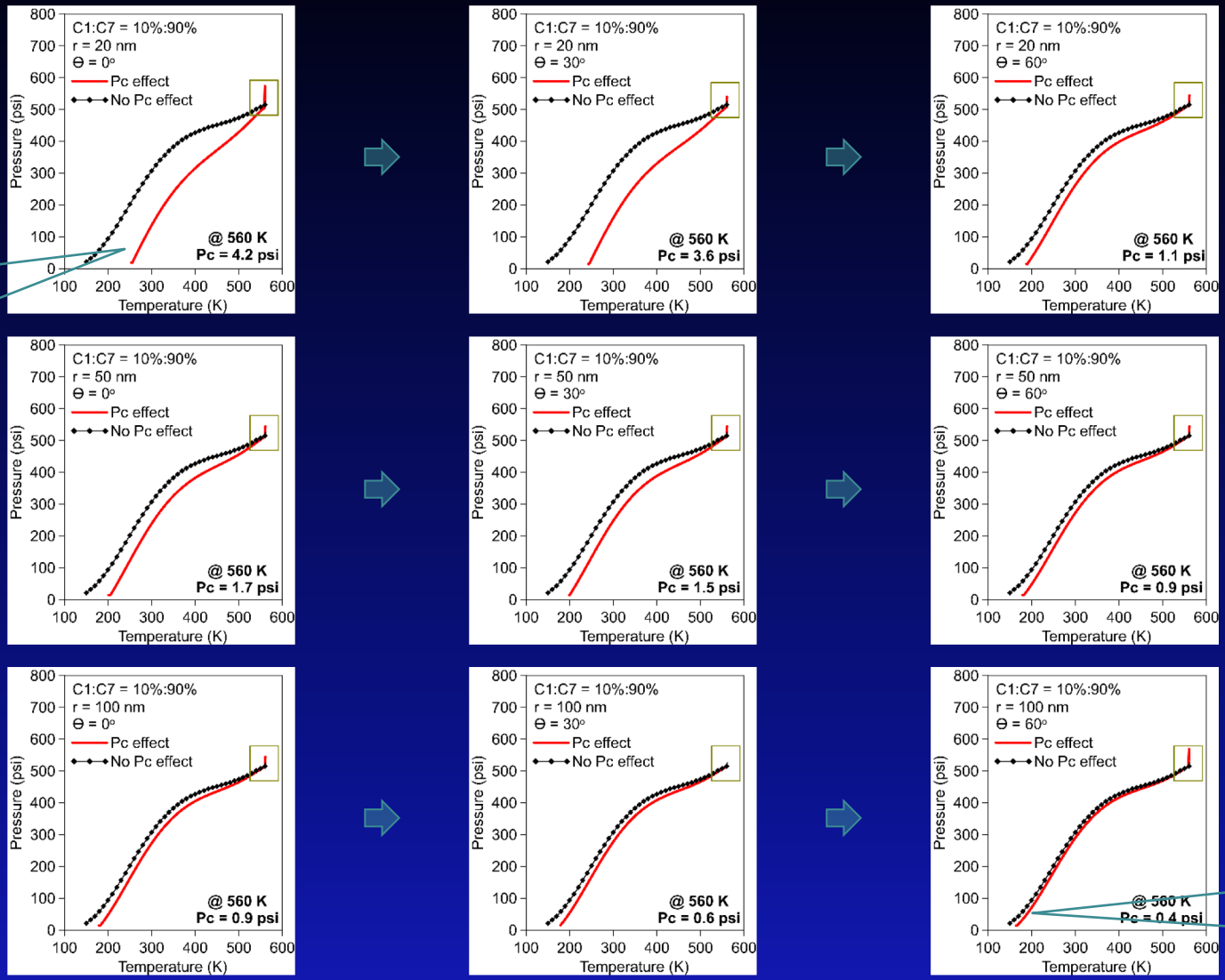
Impact of pore radius and contact angle on the capillary pressure

Increasing θ

Increasing θ

Increasing θ

Smaller r & θ
= Higher Pc
= Higher Pb
suppression



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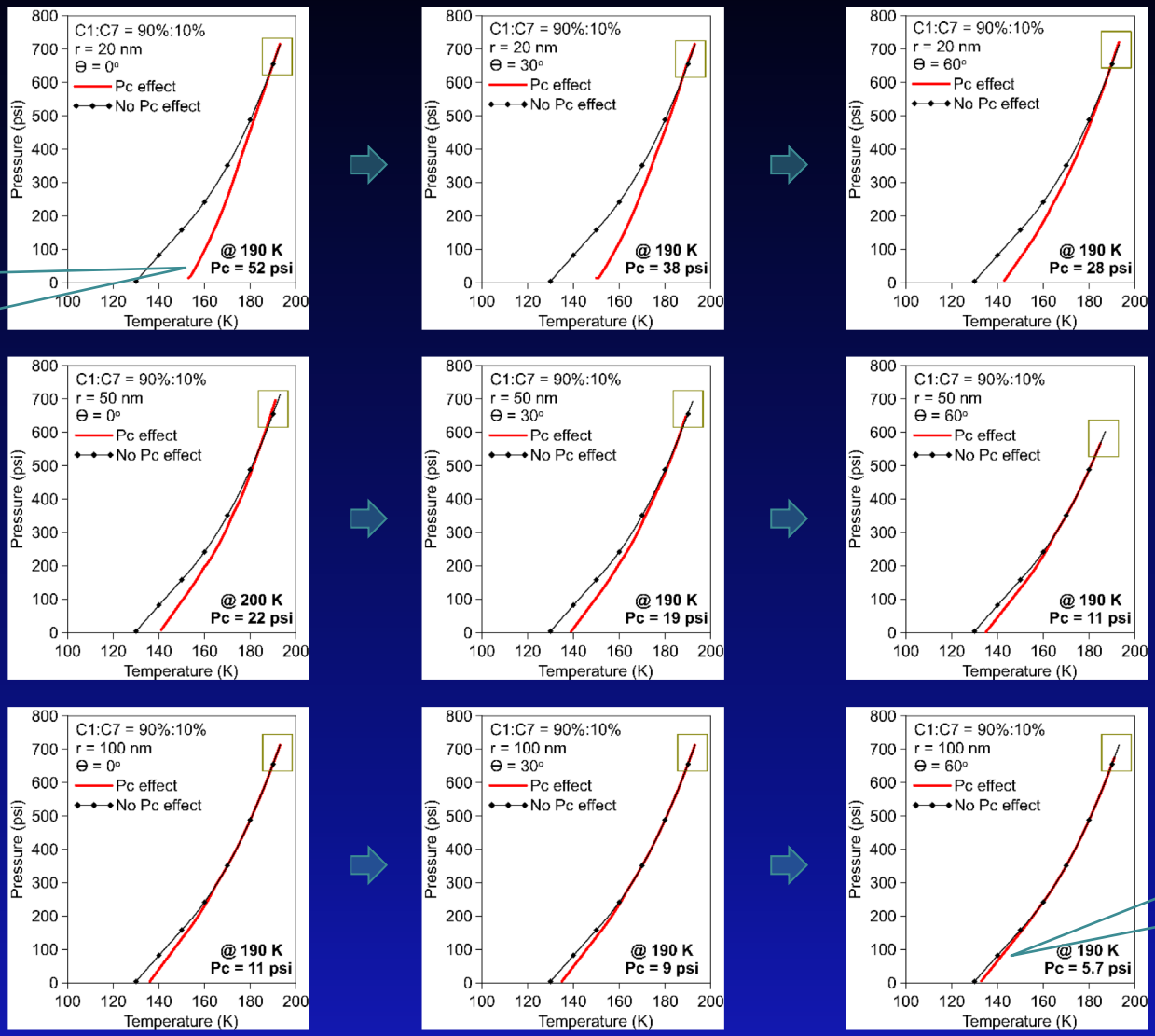

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Laplace pressure

$$Pc = \frac{2\sigma \cos\theta}{r}$$

Capillary pressure

Contact angle

Parachor equation

$$\sigma = [\sum_{i}^{nc} PCR(xi\rho_{liq} - yi\rho_{vap})]^4$$

Interfacial tension

Larger r & θ
= Lower Pc
= Lower Pb
suppression

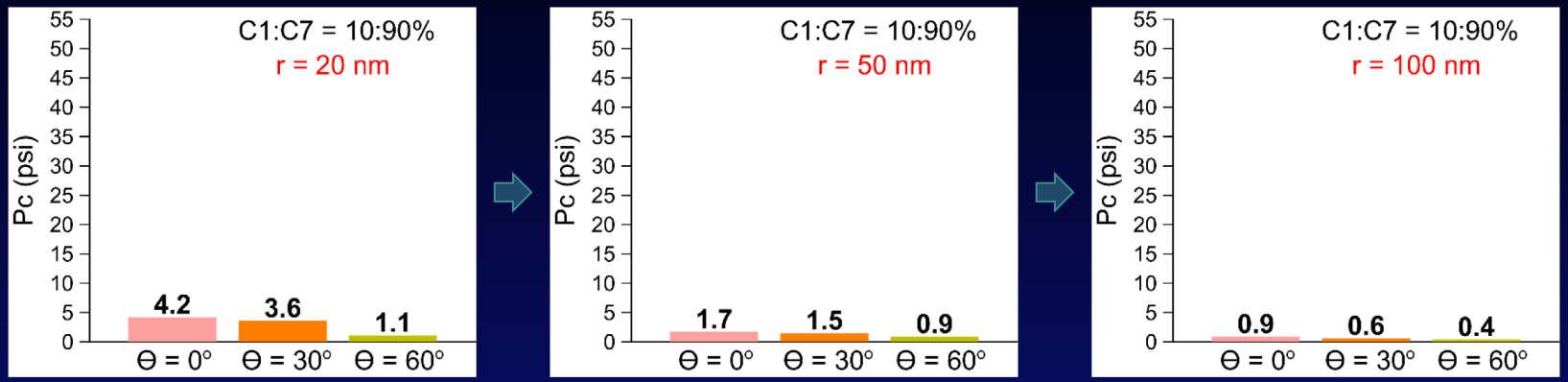
Bubble-Point Pressure Lowering Dependence on IFT (C1:C7=10-90% & 90-10%)

Capillary pressure vs. composition & contact angle

Fixed composition/changing pore radius & contact angle

Increasing r
Increasing ϴ

C1:C7
10-90%



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Increasing r
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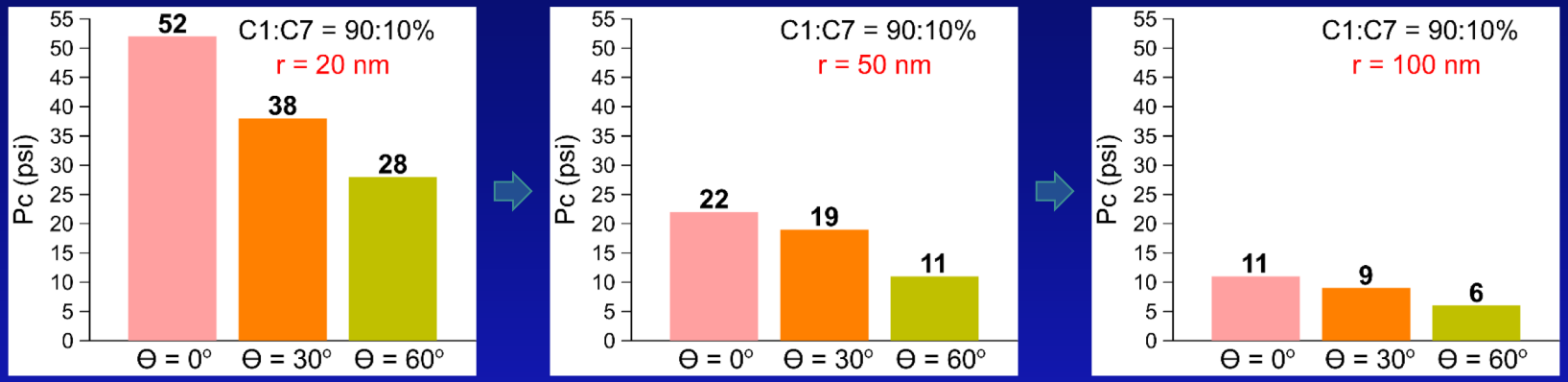
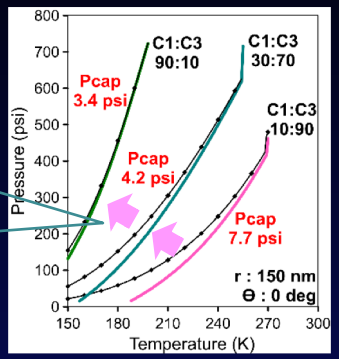
C1:C7
90-10%

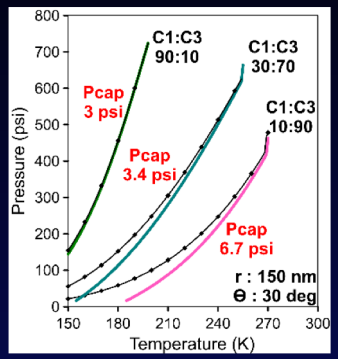


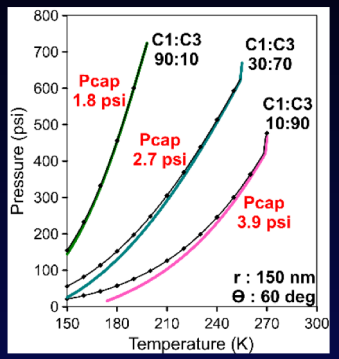
IFT Dependence on Phase Behavior (C1:C3=10-90%, 30-70% & 90-10%)

Capillary pressure vs. composition & contact angle

Lower phase density diff = lower Pc = lower Pb suppression





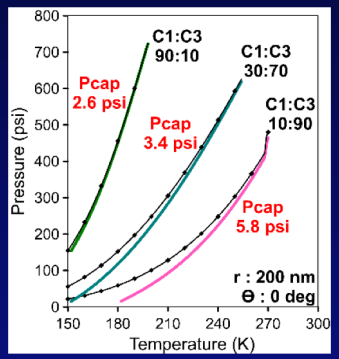


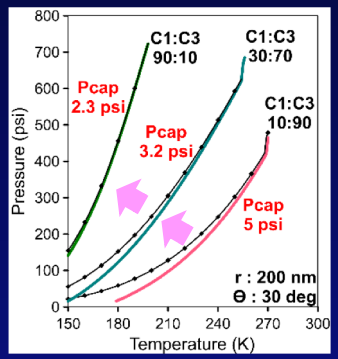
Laplace pressure

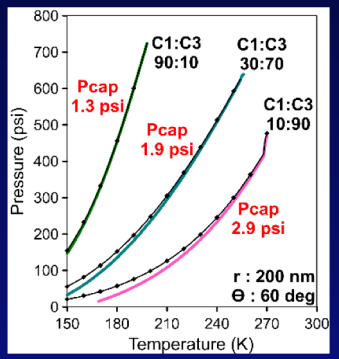
$$Pc = \frac{2\sigma \cos\theta}{r}$$

Capillary pressure

Contact angle



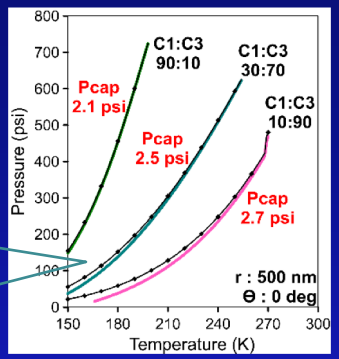


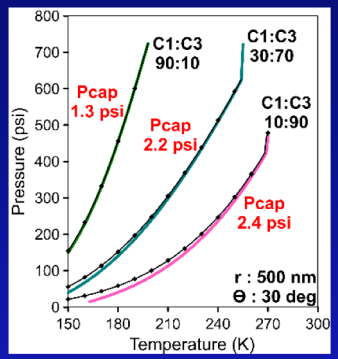


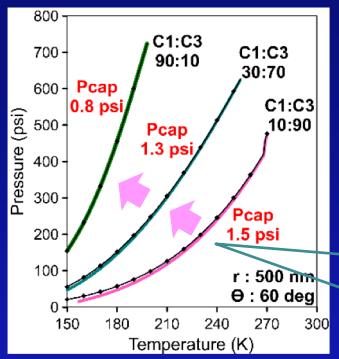
Parachor equation

$$\sigma = [\sum_{i}^{nc} PCR(xi\rho_{liq} - yi\rho_{vap})]^4$$

Interfacial tension







Larger r = lower Pc = lower Pb suppression

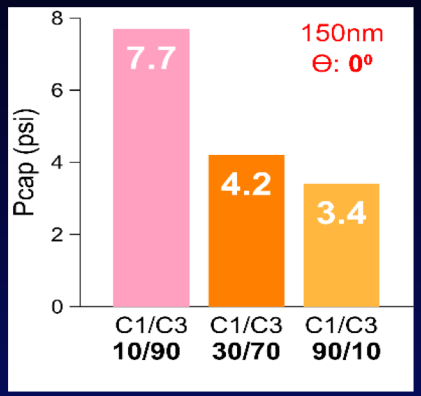
Larger Θ = lower Pc = lower Pb suppression

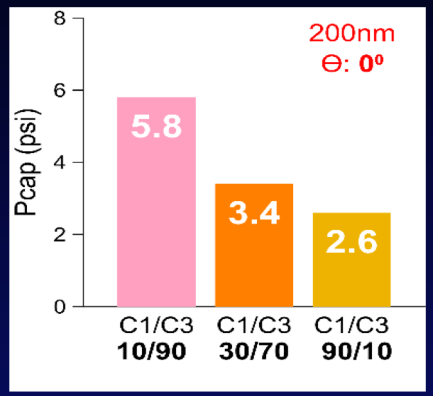
IFT Dependence on Phase Behavior (C1:C3=10-90%, 30-70% & 90-10%)

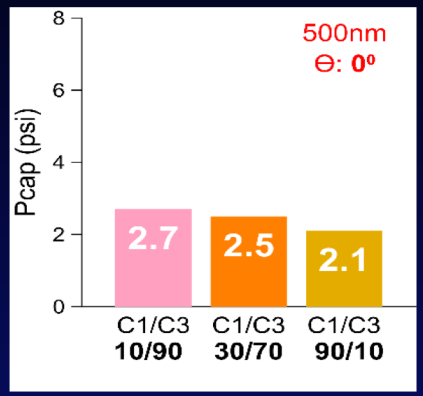
Capillary pressure vs. composition & contact angle

Fixed composition/changing pore radius & contact angle

Increasing r

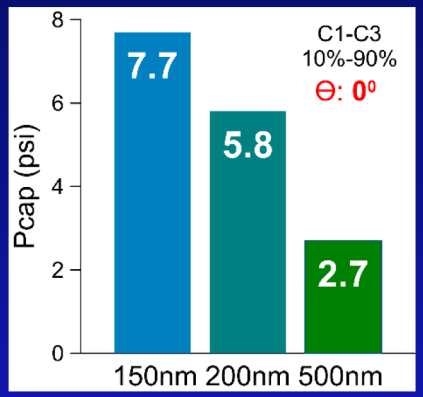


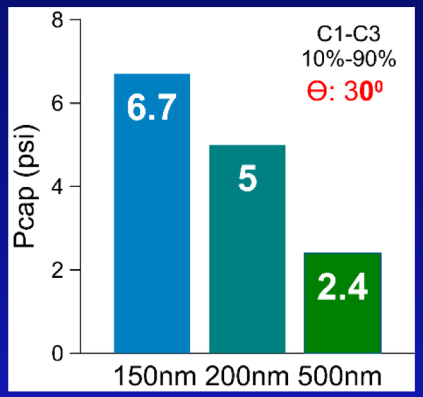


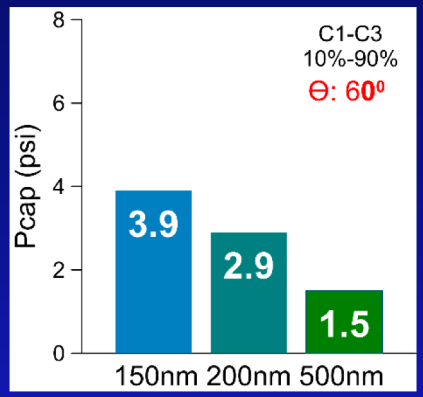


Fixed composition/changing pore radius & contact angle

Increasing Θ



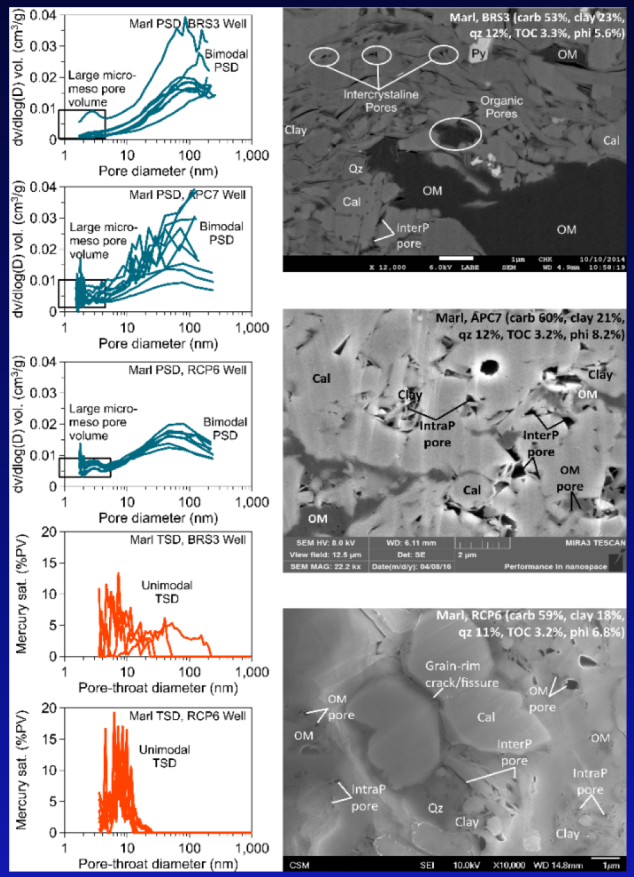




Pore-Size Distribution Effect in Shale Reservoir Phase Behavior

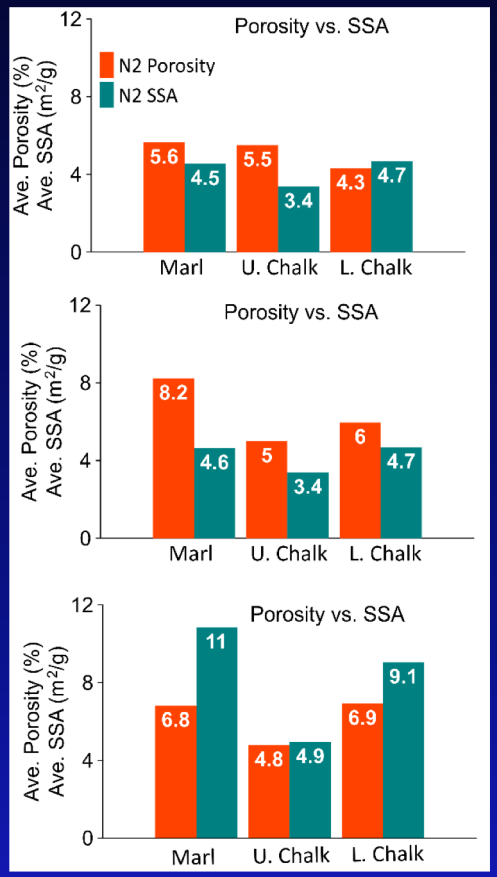
Micro-nano pore size distribution (PSD)
(Niobrara mudrock system)

- Micro-nano pore dominated matrix
- Clay-and organic matter associated finer pores
- Even smaller pore-throat sizes
- Large IFT/Pc due to the nano-confinement



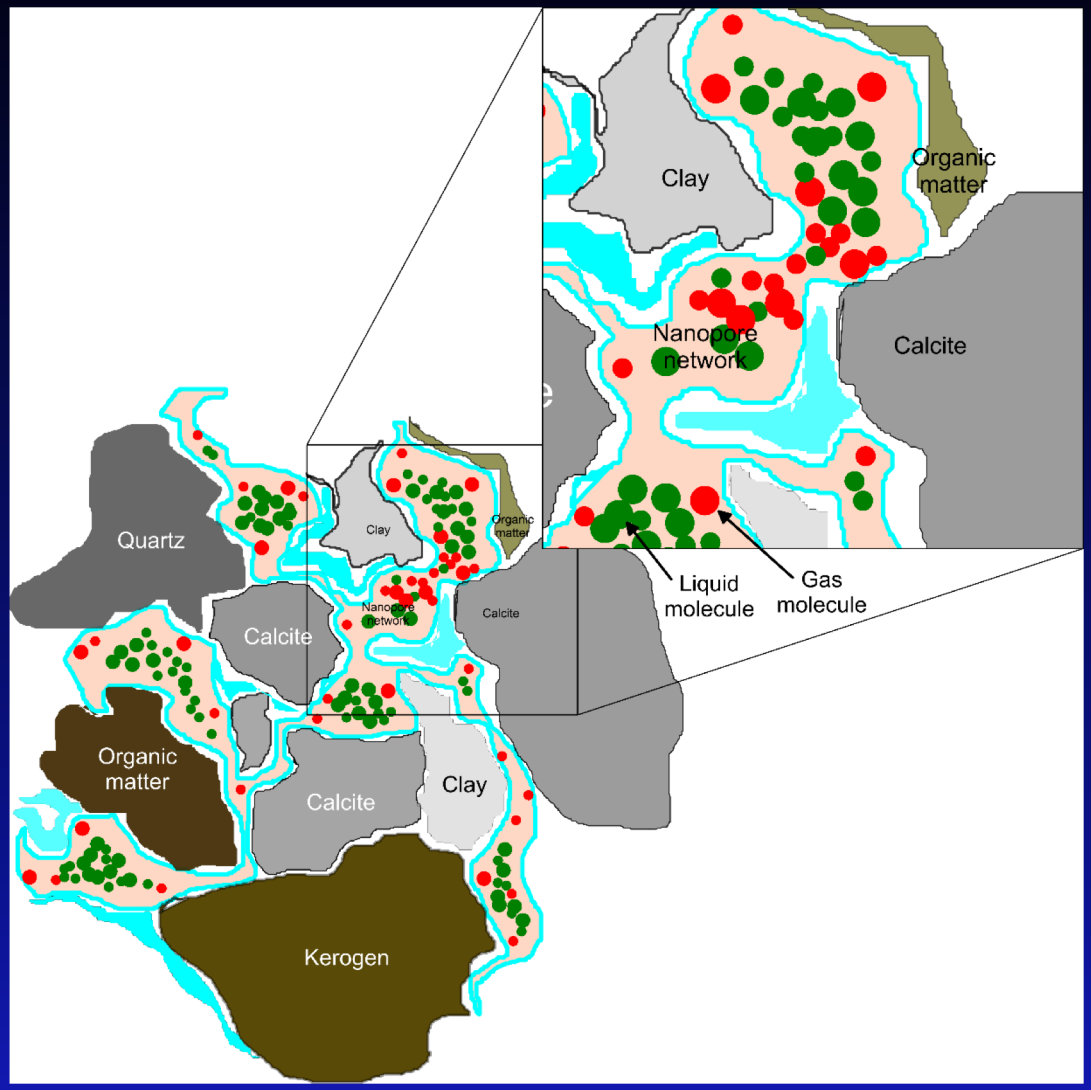
Nanopores vs. specific surface area
(Niobrara mudrock system)

- Strong link; micro-nano PSD/SSA
- Larger SA = stronger interface and higher IFT/Pc
- Finer pores = large capillary condensation effect (Kelvin equation)



Conceptual Shale Reservoir Pore Network Model

The origin of capillarity and IFT



Thank you