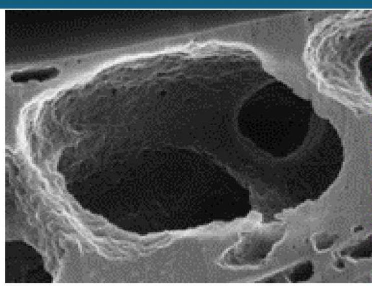
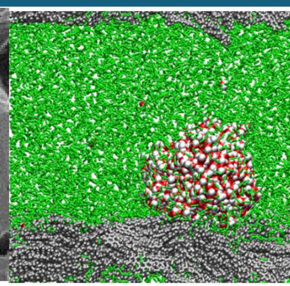
SAND2018-9235PE

Understanding Fluid Interaction and Transport in Unconventional Reservoirs: From Nanoscale to Wellbore Production





PRESENTED BY

Yifeng Wang

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Problem Statements

Sustainability of shale oil/gas production:

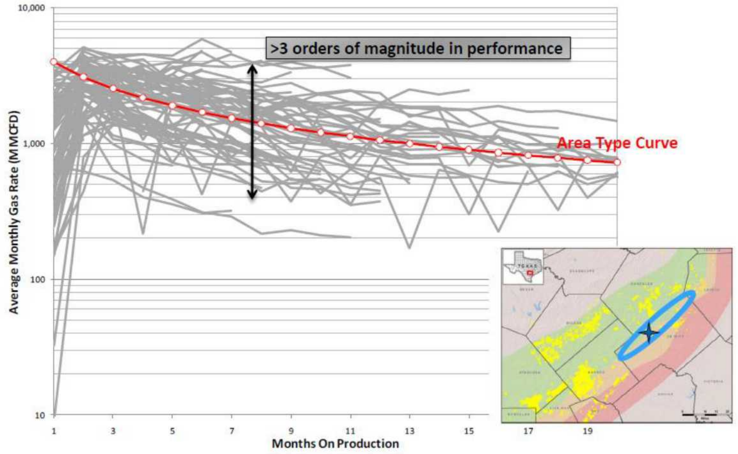
- Large variability and unexpected rapid decline in well production (up 95% reduction over first 3 years)
- New wells to be drill to maintain the supply, with increasing cost/well
- Low recovery rates (<10%), with little known about secondary gas recovery in "brown fields" (>90% of total gas reserve!!!).
- Long-term production projection largely empirical

Locating sweet spots, maximizing individual wellbore production while minimizing environmental impacts.

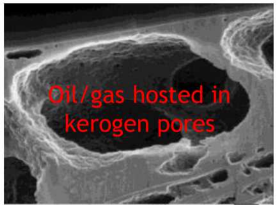
- Existing practice largely empirical.

Limiting step of oil/gas production:

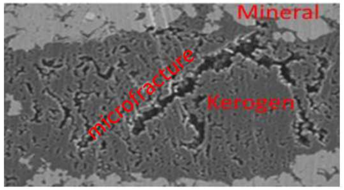
- Fluid interaction and transport in nanoporous shale matrix
- Knowledge drawn from conventional reservoirs is not applicable.
- Mechanistic understanding of oil/gas disposition and release in shale matrix is crucial for developing engineering approach to maximizing wellbore production and extending the production cycle.



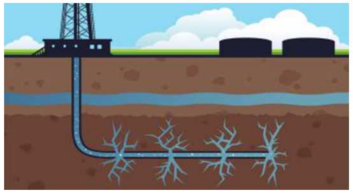
Robertson (2013)



Oil/gas release from kerogen pores (Pore size: nanometer scale)



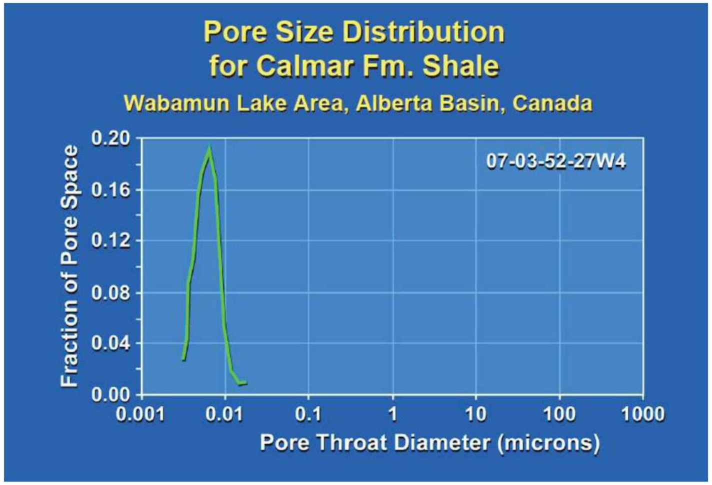
Fluids "flow" from kerogen via microfractures or connected pore networks (Channel size: micrometer scale)



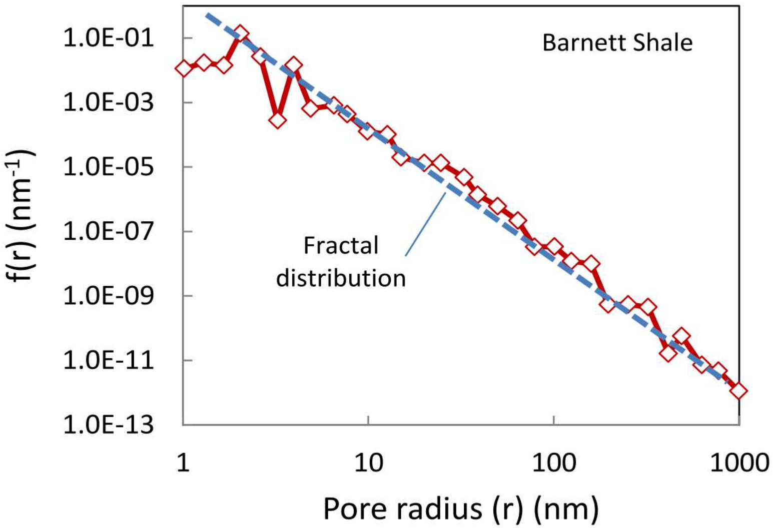
Fluids flow into hydraulic fractures then to production well
(Channel size: millimeters to decimeters)

Limiting step(s)

Shale as a nanocomposite material

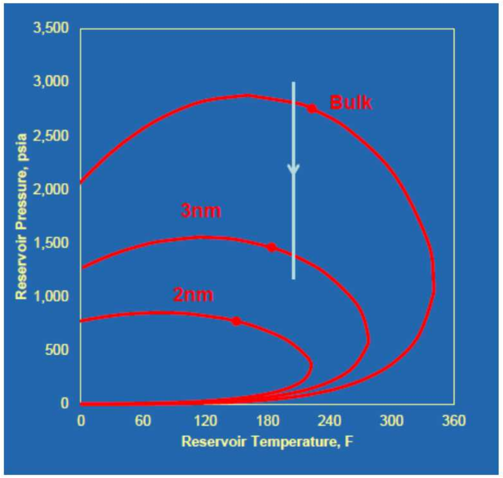


Bachu & Bennion (2006)

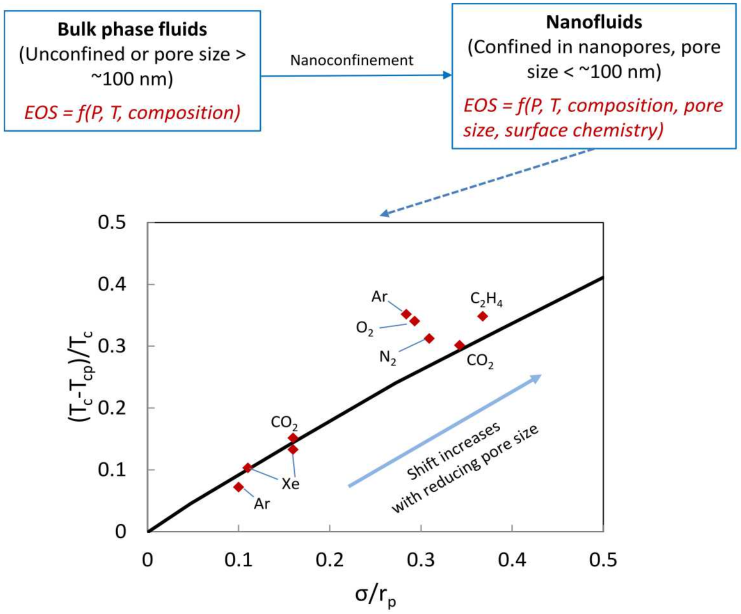


Clarkson et al. (2012)

Effects of nanopore confinement



Akkutlu, 2013

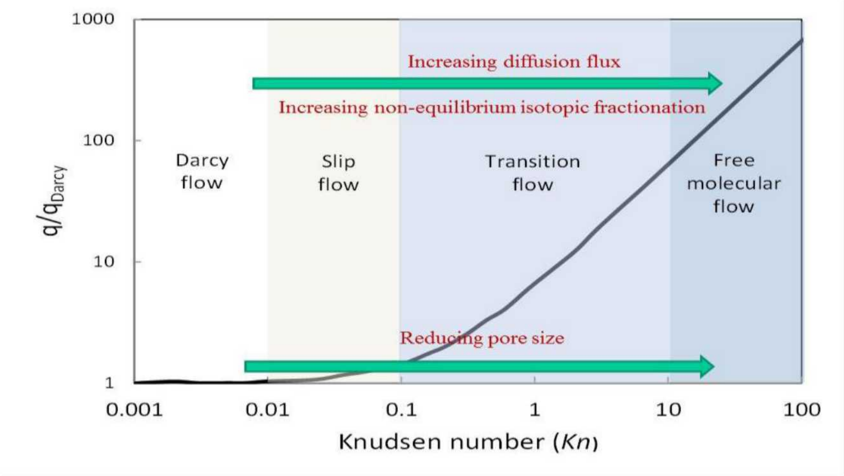


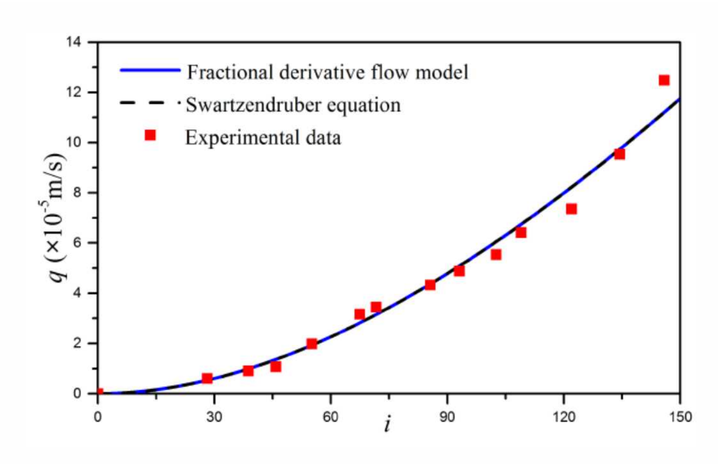
Wang (2014); Zarragoicoechea and Kuz (2004)

Rule of thumb: Chemical species under nanoconfinement behave drastically differently from those unconfined (i.e., those in bulk phase). Nanoconfinement modifies:

- Thermodynamic properties
- Kinetic properties
- Transport properties
- Others

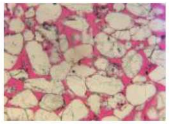
Emergent transport properties in nanopores: Isotopic fractionation

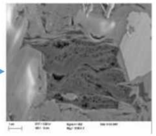




Zhou et al. (2018)

Conventional reservoir





SPE 124253 (2009)

Shale formation

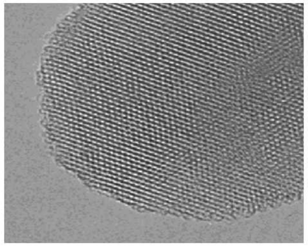
$$k_{app} = \frac{2r}{3RT}\left(\frac{8RT}{\pi M}\right)^{1/2} + \left[1 + \left(\frac{8\pi RT}{M}\right)^{1/2}\frac{\mu}{pr}\left(\frac{2}{\alpha} - 1\right)\right]\frac{cr^2}{8\mu}$$

M - Molecular weight

Mass dependent transport

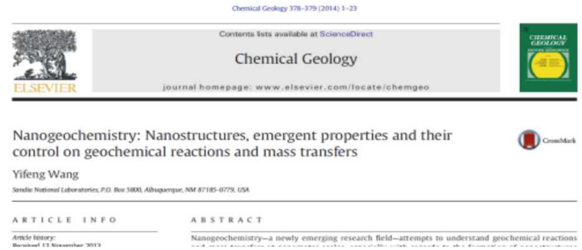
Wang (2018)

Capabilities for nanogeochemical and nanofluidic studies at SNL



Synthesis of nanoporous materials

Isolation of kerogen from Mancos shale



Chemical Geology 378–379 (2014) 1–23

Contents lists available at ScienceDirect

Chemical Geology

journal homepage: www.elsevier.com/locate/chemgeo

Nanogeochemistry: Nanostructures, emergent properties and their control on geochemical reactions and mass transfers

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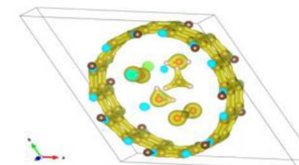
ARTICLE INFO

Article history:

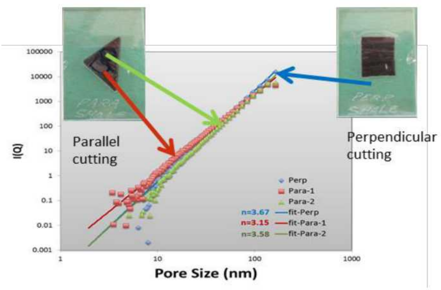
ABSTRACT

Nanogeochemistry—a newly emerging research field—attempts to understand geochemical reactions

Pioneering work in nanogeochemistry. Access to DOE Center of Integrated Nanotechnology



Density functional theory (DFT) modeling



Pore structure characterization

Field observations
- Core/outcrop sample collection
- Quantification of heterogeneities

Material characterization
- Pore structures: SANS, BET, TEM, SEM, etc
- Chemistry & mineralogy: XRD, XRF, etc

Sorption/desorption measurements
- Methane sorption/desorption on model materials
- Methane sorption/desorption under high P & high T
- Chemical/physical stimulations

Column experiments
- Diffusive fluxes
- Advective fluxes

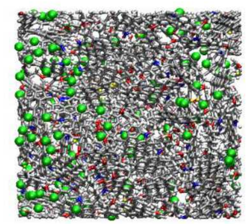
Gas disposition & release
- Gas in place (GIP)
- Gas migration from matrix into fractures
- Stimulated volume
- Gas for secondary recovery

Molecular dynamic (MD) modeling
- Binding energies of methane sorption
- Diffusion rates

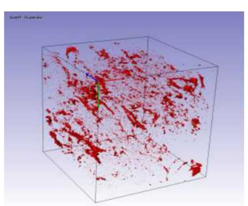
Nanoscience
- Effects of nanopore confinement on fluid thermodynamic properties
- Effects of nanopore confinement on methane transport (microfluidics in shale)

Upscaling
- Percolation theory
- Fractal representation
- Lattice Boltzmann modeling

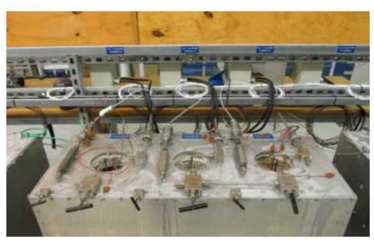
Predictive models
- Constitutive relationships
- Continuum models
- Reactive transport modeling



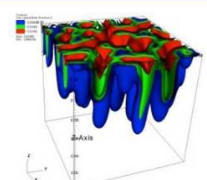
Molecular dynamics (MD) simulation



Pore structure characterization (FIB)

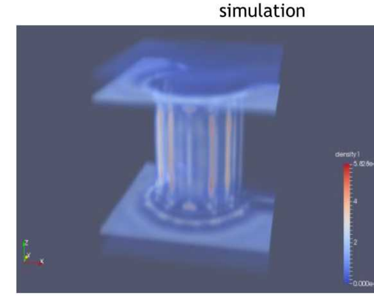


High pressure/high temperature sorption/desorption measurements



http://www.pflotran.org/applications.html

PFLOTRAN: Reactive transport modeling



TRAMANTO: Classical Density Functional Theory

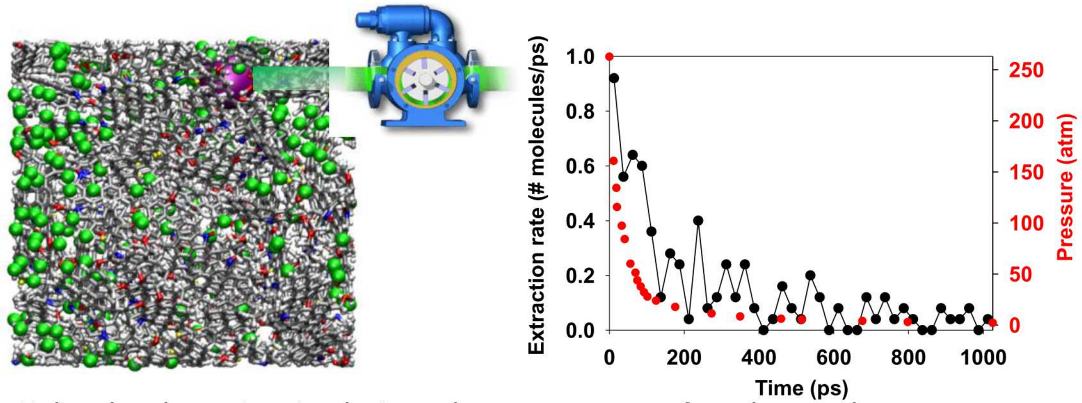
Fundamental Understanding of CH_4-CO_2-H_2O Interactions in Shale Nanopores under Reservoir Conditions (PI: Yifeng Wang)

Project Description

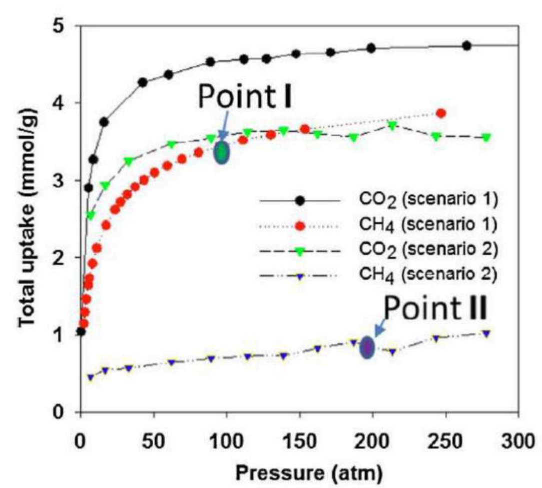
- This project aims to obtain a fundamental understanding of CH_4-CO_2-H_2O interactions in shale nanopores under high-pressure and high temperature reservoir conditions and integrate this understanding into reservoir engineering for efficient shale gas recovery and subsurface carbon sequestration.

Major Accomplishments and/or Deliverables (10 journal publications)

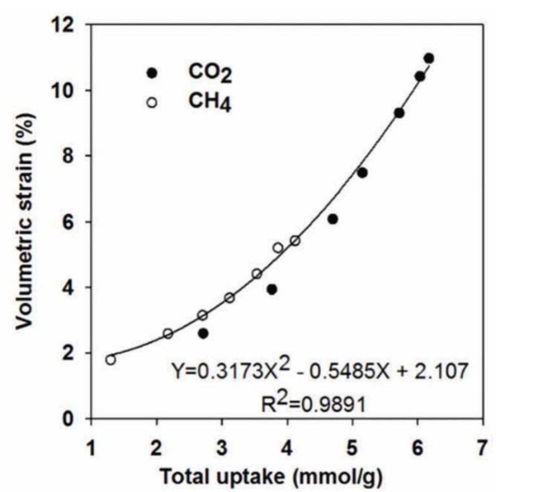
- Significant portion of CH_4 can adsorb to clay minerals.
- Wellbore production decline could be attributed to nanoscale gas disposition and migration in kerogen nanopores.
- Complex interactions may exist among CH_4-CO_2-H_2O components in kerogen nanopores.
- Existing kerogen models are inadequate in representing actual kerogen structures.



Molecular dynamics simulations show two stages of methane release from kerogen: A fast advective release of compressed free gas is followed by a slow diffusion of adsorbed gas (Scientific Reports, 2016, 6, 28053).

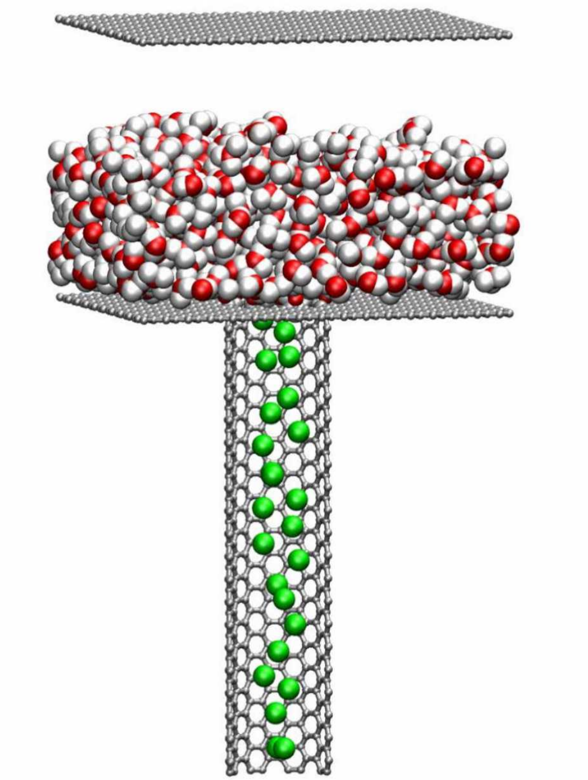


Preferential sorption of CO_2 by kerogen over CH_4 (Fuel, 2018, 220, 1-7)

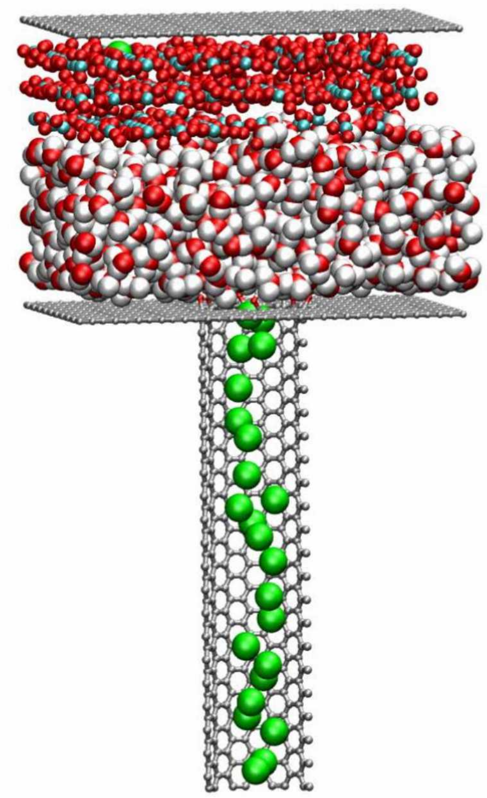


Volumetric strain of kerogen as a function of gas pressure and total gas uptake (Phys. Chem. Chem. Phys., 2018, 20, 12390-12395)

CH_4-CO_2-H_2O interactions in nanopores



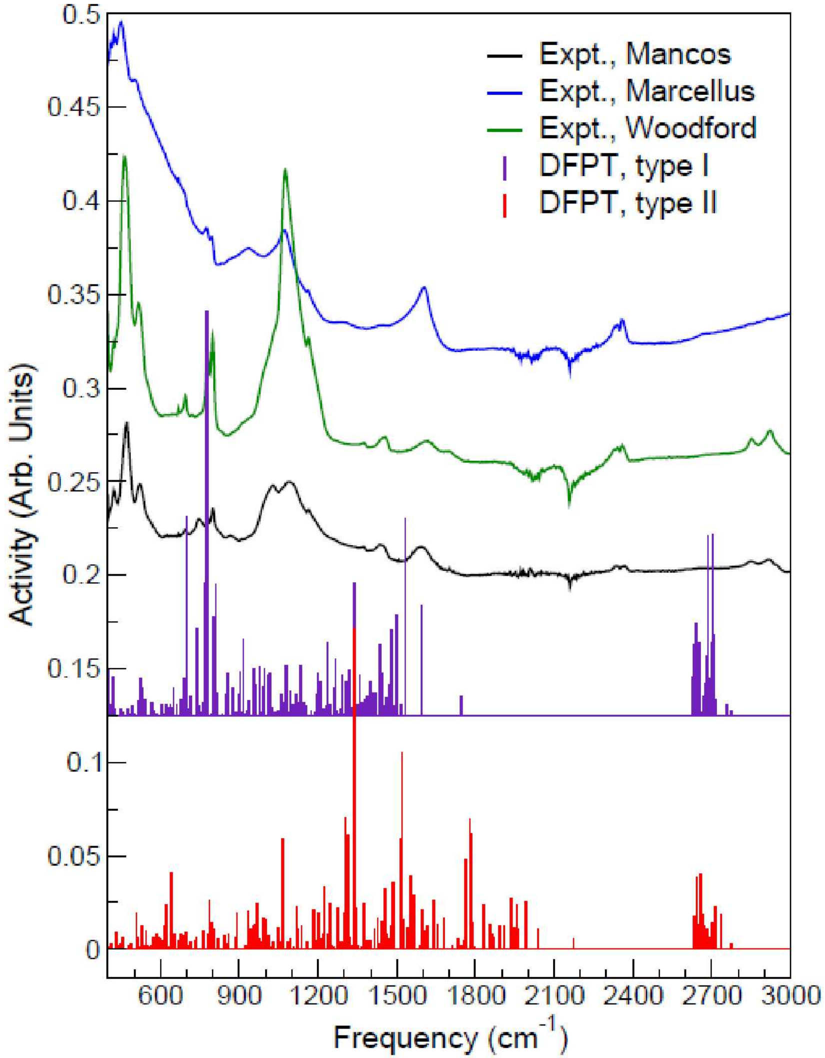
Water effect

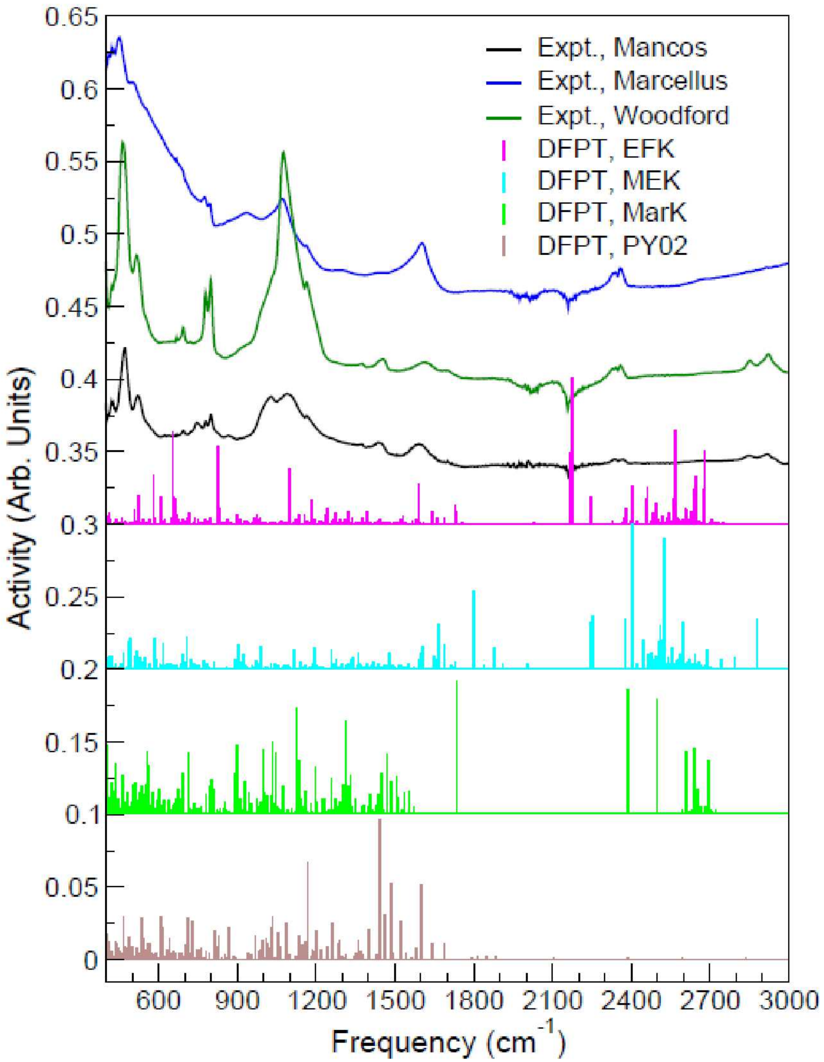


Assume that water thin films block the pore entrance.

CO_2 invades through water and replaces CH_4 in the nanopore.

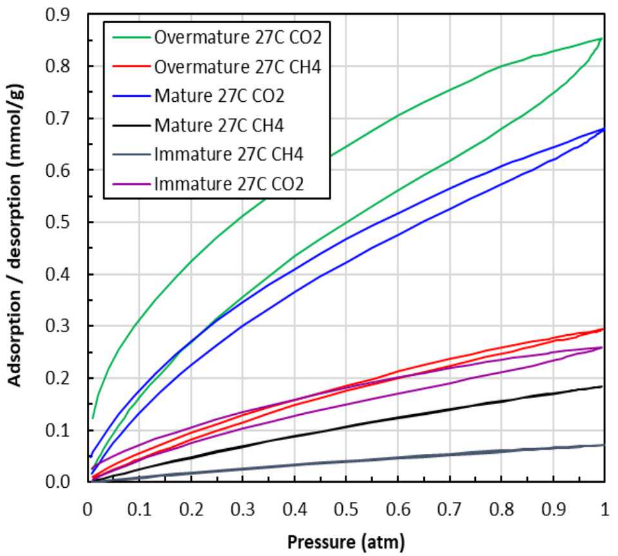
Are the existing kerogen models adequate?

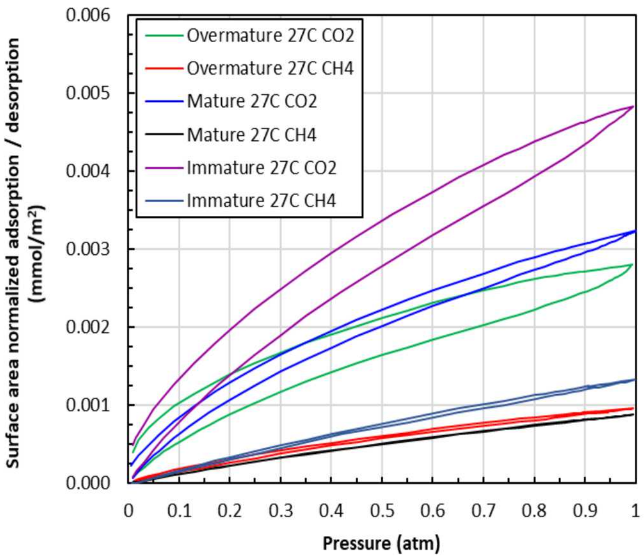


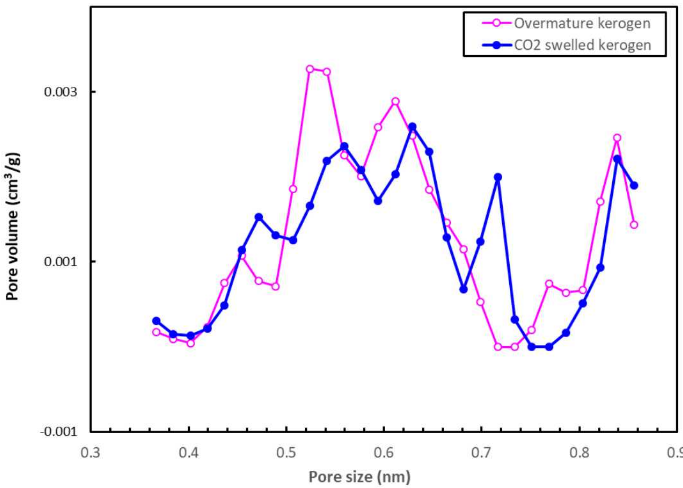


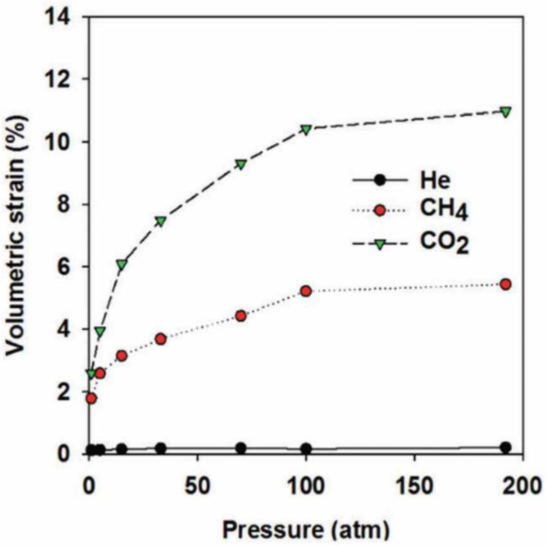
Scientific Reports, 2017, 7, DOI:10.1038/s41598-017-07310-9

Sorption-Desorption Hysteresis and Chemo-Mechanical Coupling (?)



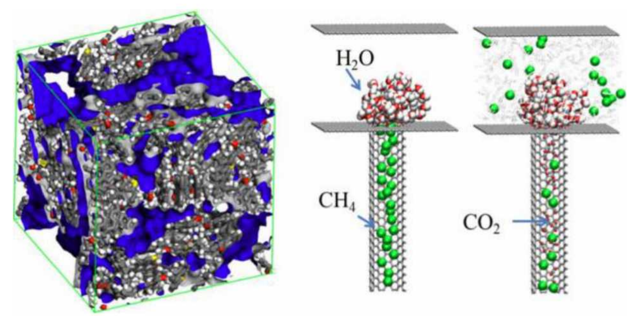


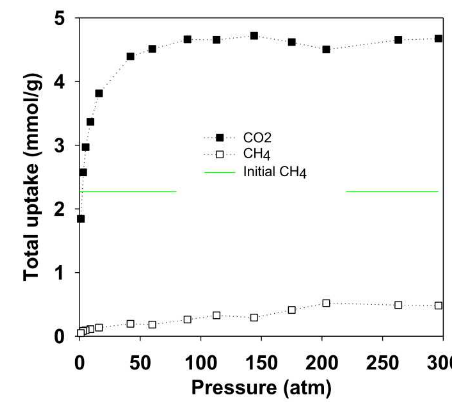


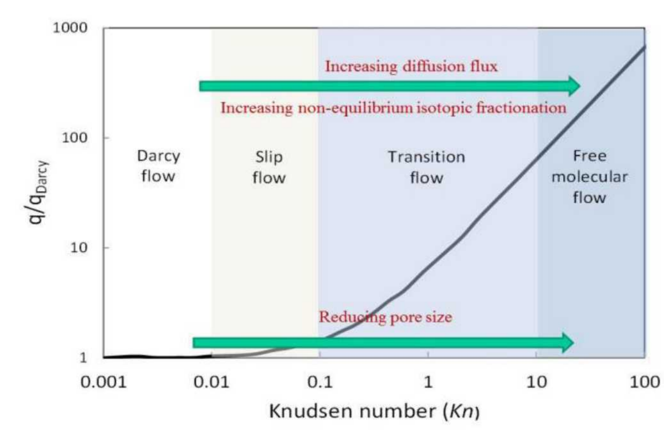


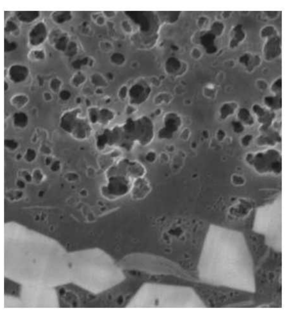
Publications

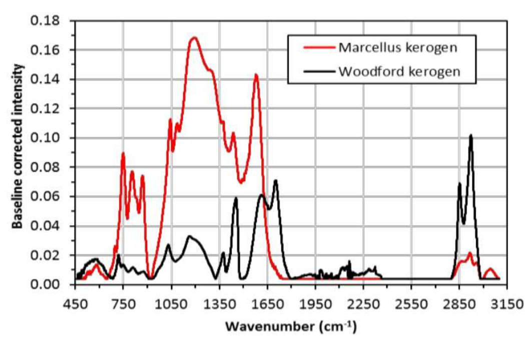
- Xiong, Y., Wang, Y. & Olivas, T. (2015) Experimental Determination of P-V-T-X Properties and Sorption Kinetics in the CO_2-CH_4-H_2O System under Shale Gas Reservoir Conditions: Part One, P-V-T-X Properties, Sorption Capacities and Kinetics of Model Materials for CO_2-CH_4 Mixtures to 125°C , **High Temperature Aqueous Chemistry**, HiTAC-II Workshop, Heidelberg, April 16, 2015.
- Ho, T. A., Criscenti, L. J. & Wang, Y. (2016) Nanostructural control of methane release in kerogen and its implications to wellbore production decline. **Scientific Reports** 6, 28053; doi: 10.1038/srep28053.
- Weck, P. F., Kim, E. & Wang, Y. (2016) van der Waals forces and confinement in carbon nanopores: Interaction between CH_4, COOH, NH_3, OH, SH and single-walled carbon nanotubes. **Chem. Phys. Lett.** 62, 22-26.
- Cristancho, D., Akkutlu, I.Y., Criscenti, L.J., Wang, Y. (2016) Gas storage in model kerogen pores with surface heterogeneities, **SPE**-180142-MS, DOI: 10.2118/180142-MS.
- Wang, Y. (2017) On subsurface fracture opening and closure. **J. Petrol. Eng.** 155, 46-53.
- Wang, Y. (2018) From nanofluidics to basin-scale flow in shale: Tracer investigations, In: **Shale Subsurface Science and Engineering** (in press, book chapter)
- Weck, P. F. Kim, E., Wang, Y. et al. (2017) Model representation of kerogen structures: An insight from the density functional theory. **Scientific Reports,** 7, DOI:10.1038/s41598-017-07310-9.
- Ho, T. A., Greathouse, J. A., Wang, Y, and Criscenti, L. J. (2017) Atomistic structure of mineral nano-aggregates from simulated compaction and dewatering. **Scientific Reports**, 7, 15286.
- Ho, T. A., Wang, Y., Criscenti, L. J. & Xiong, Y. (2017) Differential retention and release of CO_2 and CH_4 in kerogen nanopores: Implications to gas extraction and carbon sequestration. **Fuel,** 220, 1-7.
- Ho, T. A. Wang, Y. and Criscenti, L. J. Chemo-mechanical coupling in kerogen gas adsorption/desorption. **PCCP** (in press).
- **Book:** Wang, Y., **Nanogeochemistry: Emergent Properties of Nano-Scale Mineral Phases and Confined Fluids**, Elsevier (in preparation)







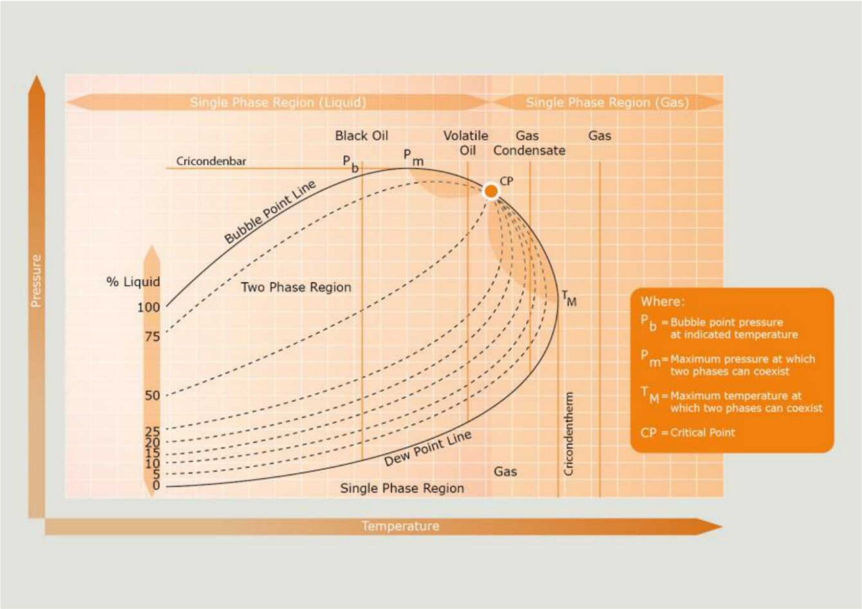


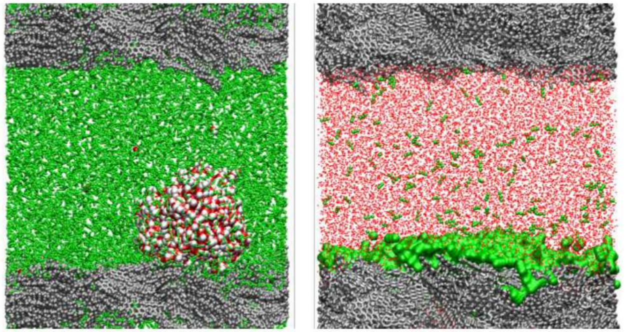


Understanding multi-component and multi-phase hydrocarbon fluid interaction and transport in shale matrix: From nanoscale to wellbore production (PI: Yifeng Wang)

Project Description

This project will use an integrated experimental and modeling study as well as field observations to fundamentally understand the disposition and release of complex hydrocarbon mixtures in a nanopore network of shale matrix and their transport from low-permeability matrix to hydrofracking-induced fracture networks in various reservoir types from black oil to dry gas.



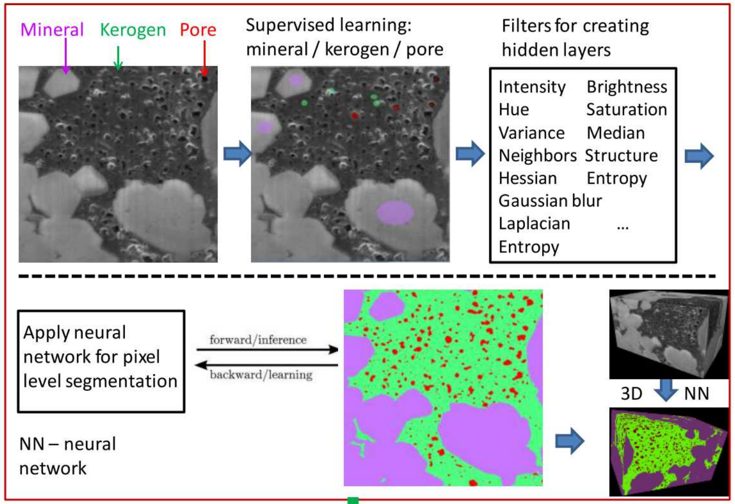


Phase separation in nanopores controls oil/gas movement in unconventional reservoirs.
Red and white - water; silver - kerogen; Green - CO_2

Ho et al. (2018) Nano Scale (in review)

- Expand our nanoscale understanding of fluid flows in shale matrix to wet gas and black oil reservoirs.
- Use machine learning to upscale nanoscale understanding and incorporate it into a reservoir simulator.
- Establish a scientific basis for a reliable prediction of wellbore production decline and for reservoir engineering optimization.

Physics-based Machine-Learning (ML) for Data Integration and Process Upscaling: A gray box approach



3D pore network and pore morphology

- 3D kerogen pore network
- Pore connectivity
- Pore size distribution
- Pore morphology
- Kerogen spatial distribution

Kerogen and shale properties (measurements)

- Density
- Maturity
- CO_2-CH_4 gas sorption
- Micro-FTIR / micro-Raman spectroscopy
- Auger Nanoprobe elemental analysis
- Nano indentation / Nano-mechanical property
- Imaging with artificial pyrolysis generated pores
- Imaging with artificial stress generated fractures
- Percolation or imbibition measurements

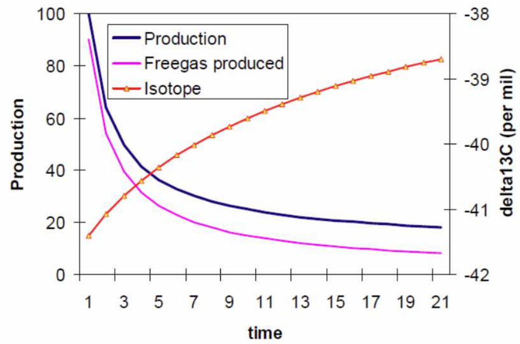
Kerogen properties (MD & cDFT simulations)

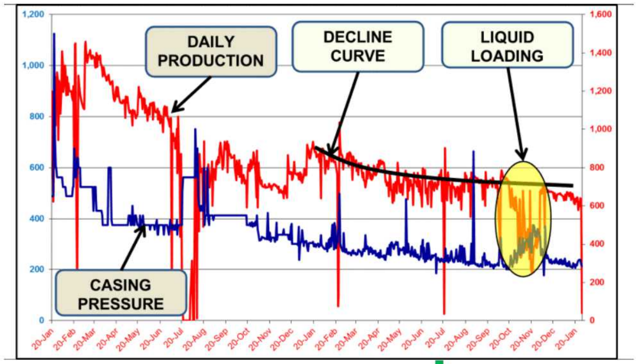
- CO_2-CH_4 gas sorption modeling
- DFT modeling infrared spectroscopy with maturity
- Atomistic modeling of stress generated fracture
- Thermal dynamic modeling of pore generation

Training dataset for deep learning → ML →

- Reduced order models
- Constitutive relationships

Using Real Time Gas Isotope to Model Gas Production Decline Curve





Reservoir simulator → Production curve

From REPSEA presentation: *Novel Gas Isotope Interpretation Tools to Optimize Gas Shale Production*; YongchunTang; PEERI

https://www.shaletec.com/files/Production-below-decline-curve.png

Research Team & collaborators

Name	Expertise	Role
Yifeng Wang	Nanogeochemistry	P.I., integration, reactive-transport model
Tuan Anh Ho	Molecular modeling	MD simulations
Philippe Weck	Molecular modeling	DFT and cDFT simulations
Guangping Xu	Experimental geochemistry	Material characterization, flow-through & imbibition experiments
Louise Criscenti	Geochemical modeling	MD simulations
Yongliang Xiong	High-temperature-high pressure geochemistry	Sorption-desorption measurements
Hongkyu Yoon	Lattice Boltzmann simulations	Pore network simulations
Stephen Verzi	Machine learning	Machine learning

External Collaborations