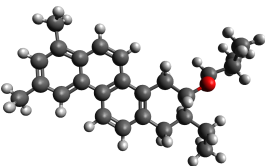


Felipe Perez

Enhanced Oil Recovery Technical Workshop

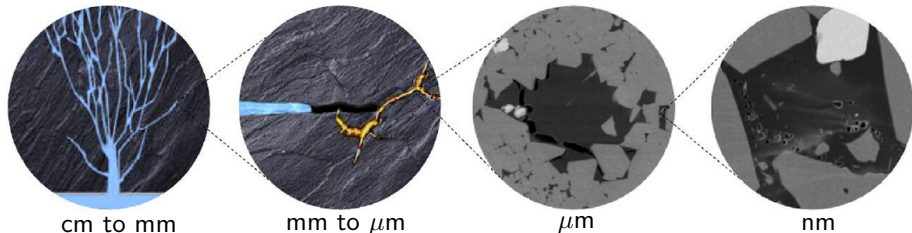
November 14, 2019

The University of Oklahoma



Molecular Signatures of Enhanced Oil Recovery in Shale Organic Pores

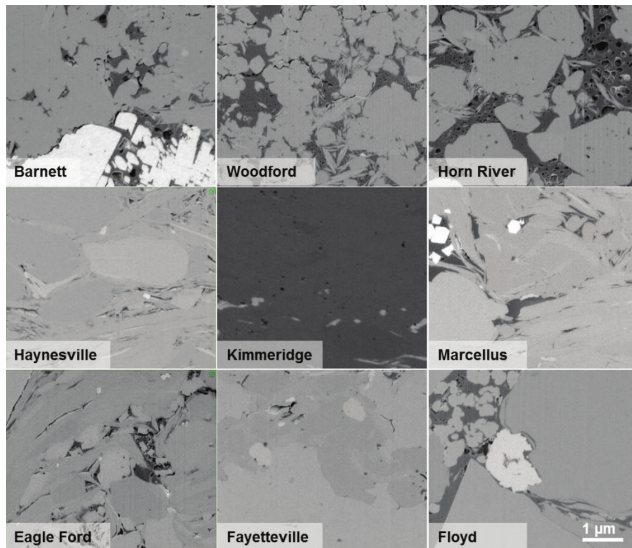
Where are hydrocarbons stored?



- Horizontal drilling and hydraulic fracturing have made oil and gas extraction possible in nanoporous shale plays.
- Hydrocarbon recovery from shale reservoirs is less than 10%.

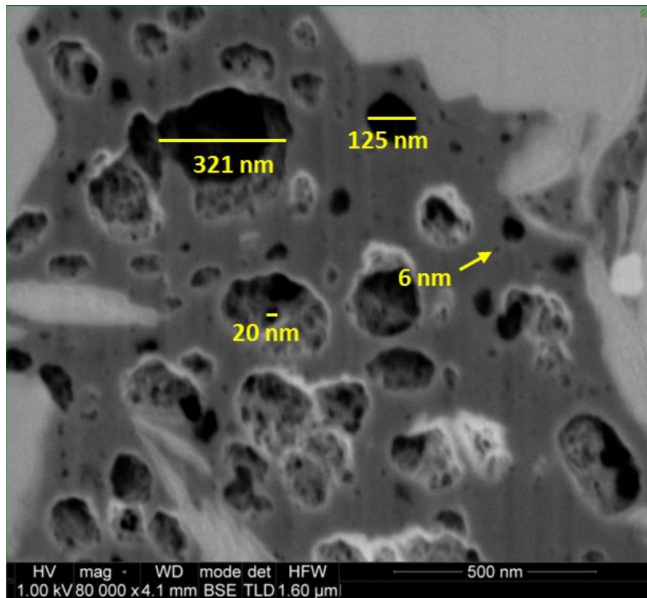
Modified from Huang and Zhao (2017)

Shale rocks in the U.S.



Taken from Curtis et al. (2010)

How large are the pores?



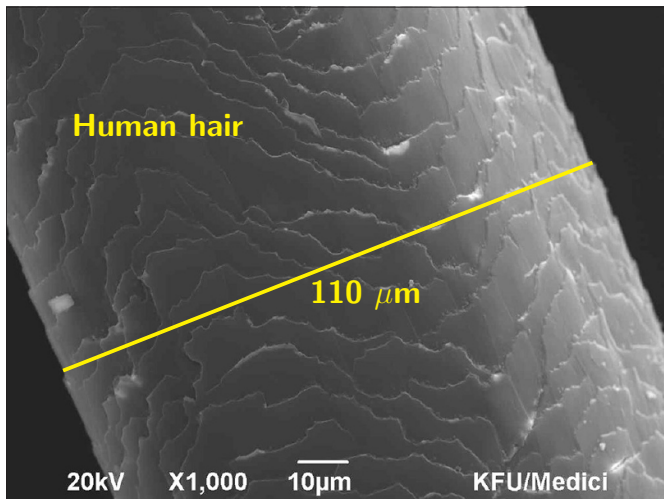
$$1 \text{ m} = 3.28084 \text{ ft}$$

$$1 \mu\text{m} = 10^{-6} \text{ m}$$

$$1 \text{ nm} = 10^{-9} \text{ m}$$

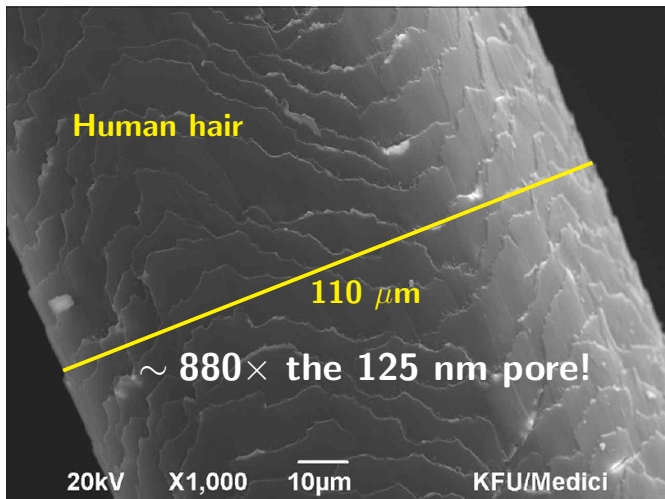
Modified from Curtis
et al. (2010)

Making sense of the scale



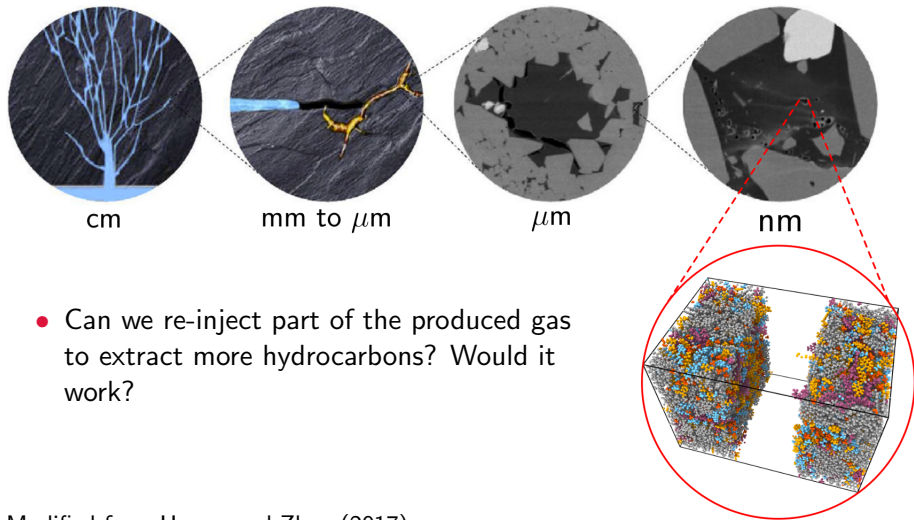
Modified from Alahmmed et al. (2017)

Making sense of the scale



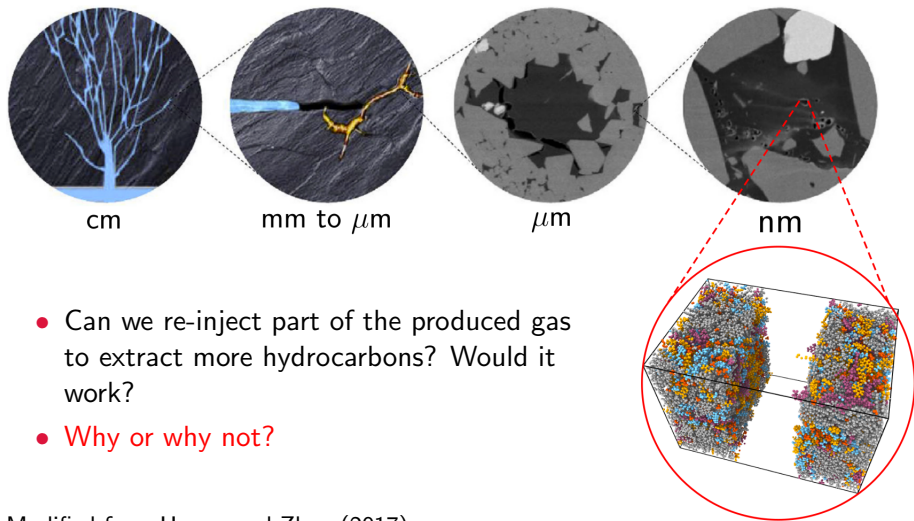
Modified from Alahmmed et al. (2017)

How can we recover more hydrocarbons?



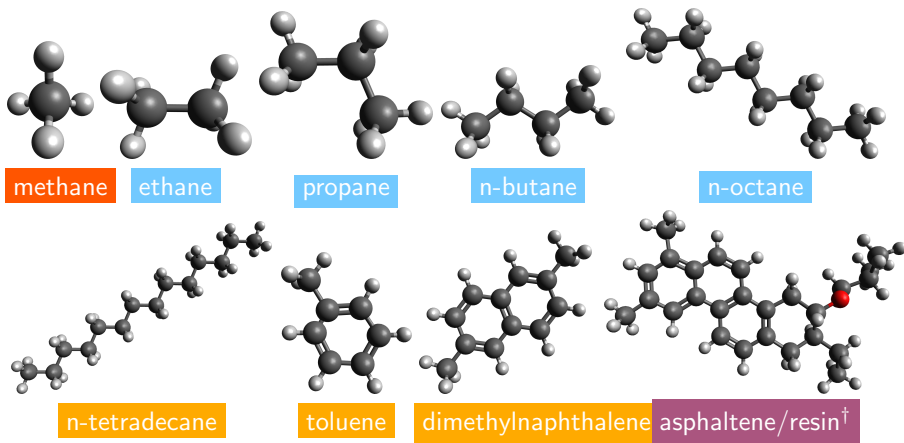
Modified from Huang and Zhao (2017)

How can we recover more hydrocarbons?



Modified from Huang and Zhao (2017)

Hydrocarbons (not at scale)



Color code:



Carbon



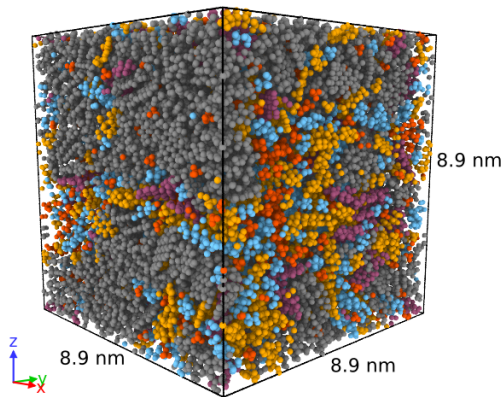
Hydrogen



Oxygen

[†] Ungerer et al. (2015)

Kerogen + black oil

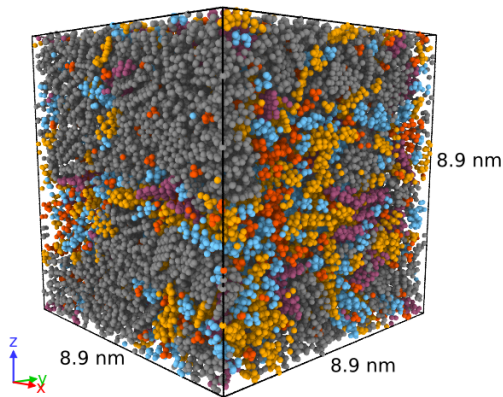


$T = 355 \text{ K (150}^{\circ}\text{F)}$ and $P = 300 \text{ atm (4400 psi)}$

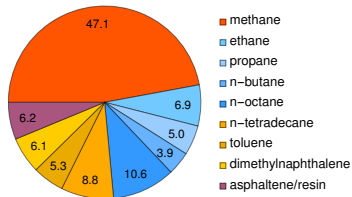
Color code:

- Kerogen
- Asphaltene/resin
- Heavy and aromatic species
- Intermediate species
- Methane

Kerogen + black oil



$T = 355 \text{ K (150}^\circ\text{F)}$ and $P = 300 \text{ atm (4400 psi)}$

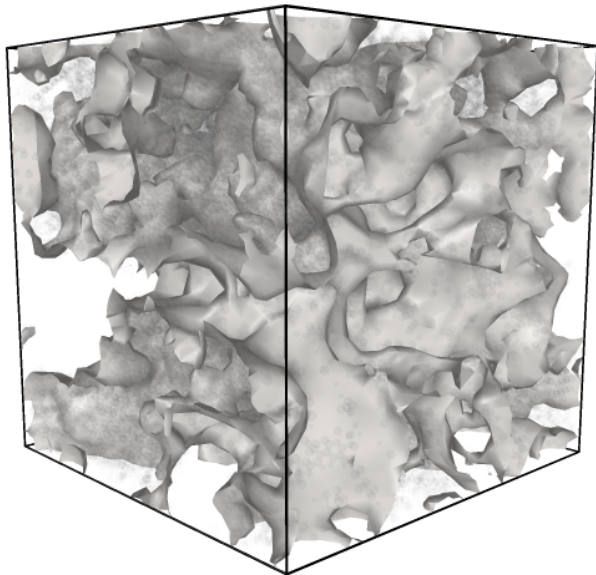


Black oil composition (mole fraction)

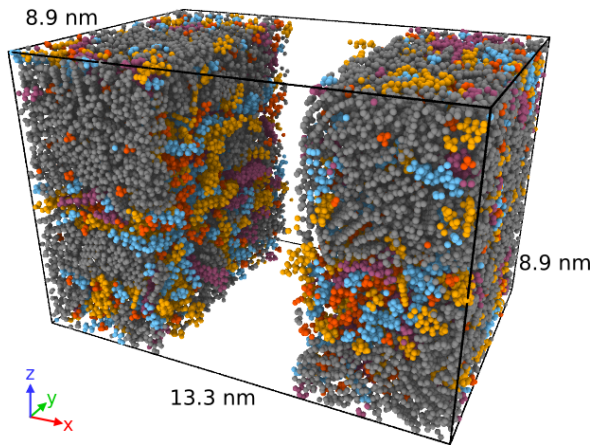
Color code:

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- Heavy and aromatic species
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- Methane

3D pore network



Kerogen + black oil + microfracture

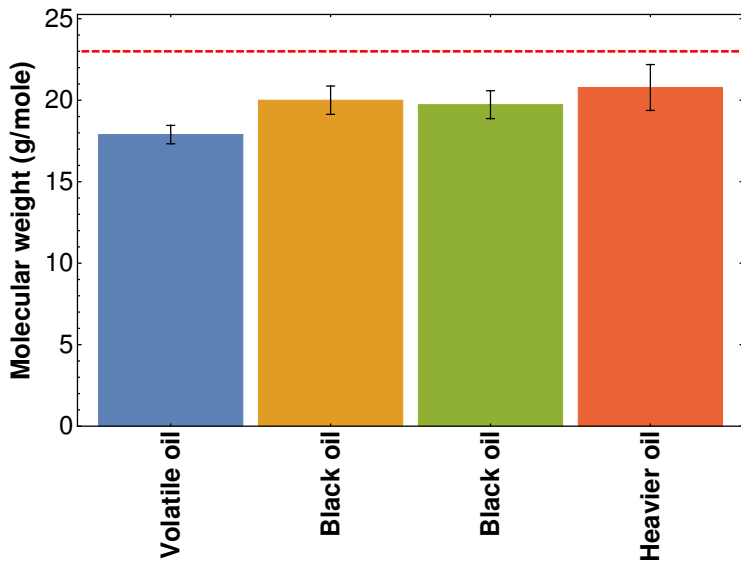


$T = 355 \text{ K (150}^\circ\text{F)}$ and $P = 300 \text{ atm (4400 psi)}$

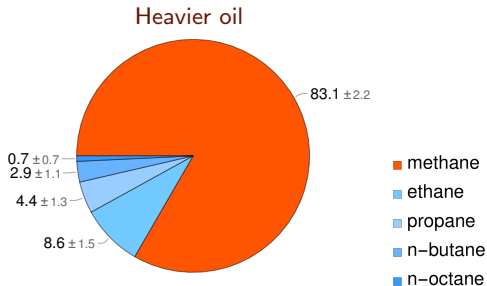
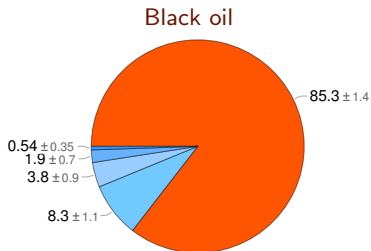
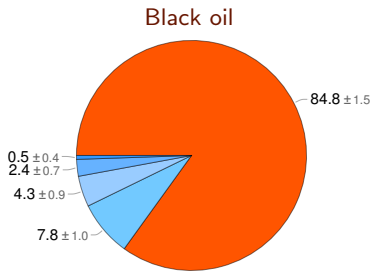
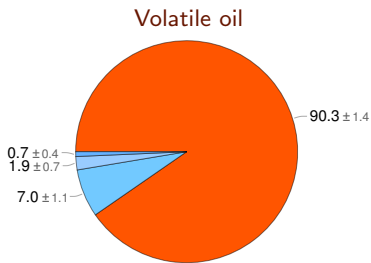
Color code:

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- Asphaltene/resin
- Heavy and aromatic species
- Intermediate species
- Methane

Produced fluids depend on in-situ fluid composition

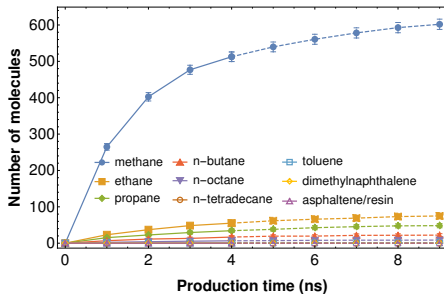


Not all species are produced

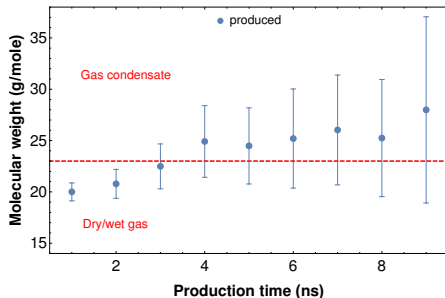


Production during primary depletion

Cumulative production per species

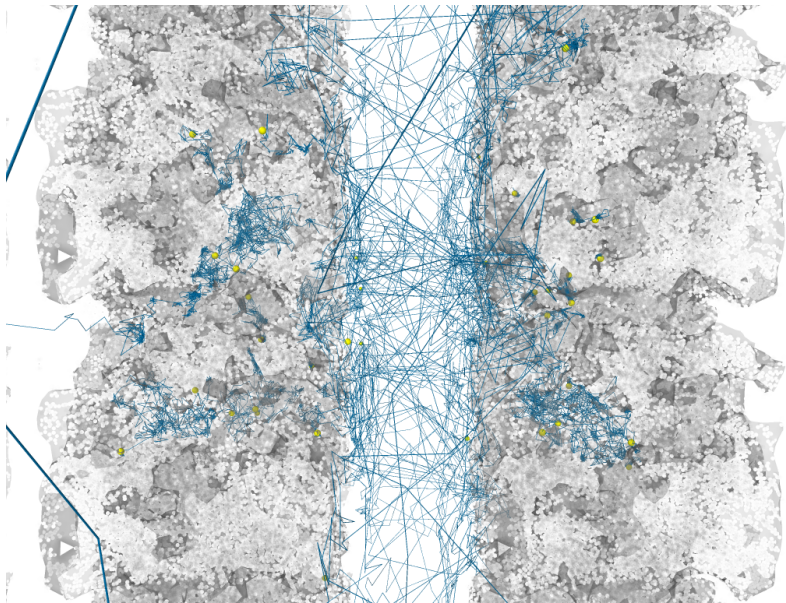


Produced fluid composition

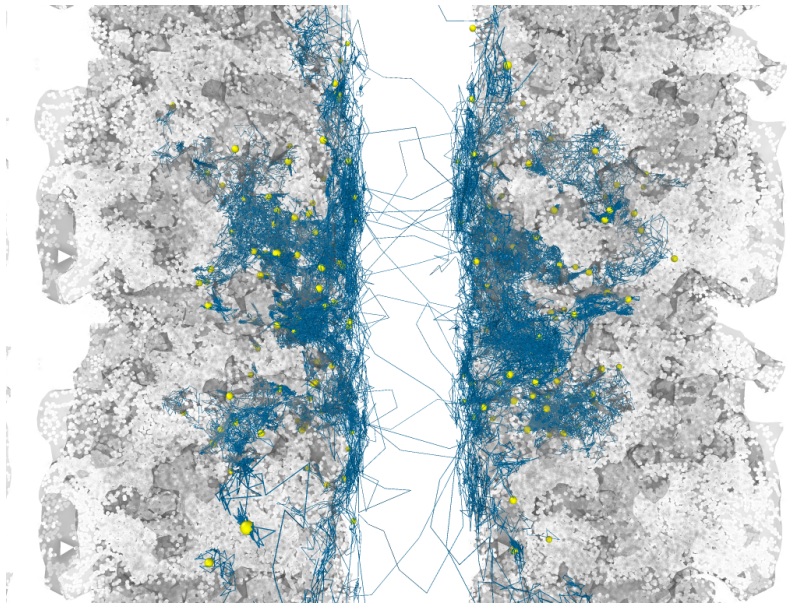


- The species produced during primary depletion are mostly methane, ethane, propane and n-butane.
- The molecular weight of the produced fluid increases with production time.

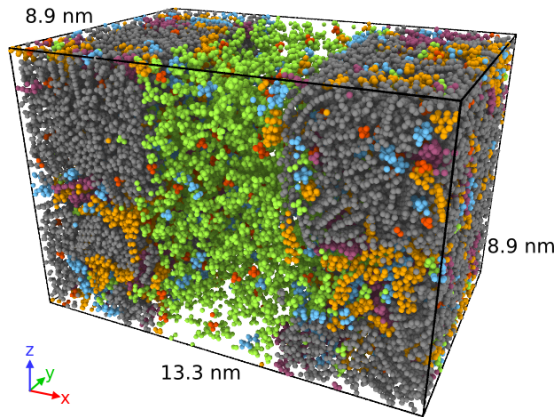
Non-produced n-butane molecules



Non-produced n-octane molecules



Kerogen + black oil + solvent

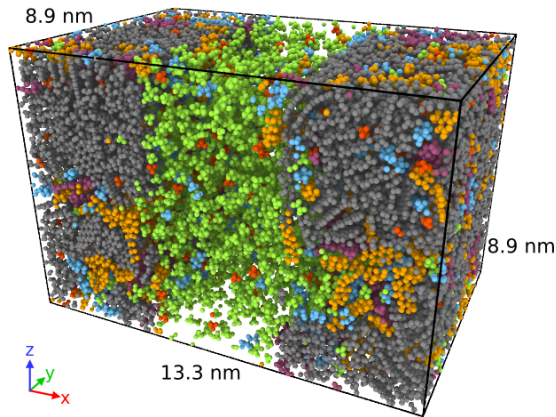


Solvent: $C_1:C_2$ mixture (72:28 mole fraction)
 $T = 355\text{ K}$ (150°F) and $P = 300\text{ atm}$ (4400 psi)

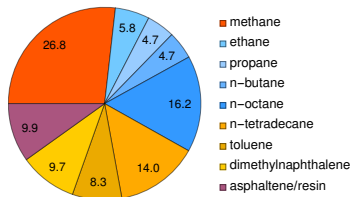
Color code:

- Kerogen
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- Heavy and aromatic species
- Intermediate species
- Methane
- Solvent

Kerogen + black oil + solvent



Solvent: $C_1:C_2$ mixture (72:28 mole fraction)
 $T = 355\text{ K}$ (150°F) and $P = 300\text{ atm}$ (4400 psi)

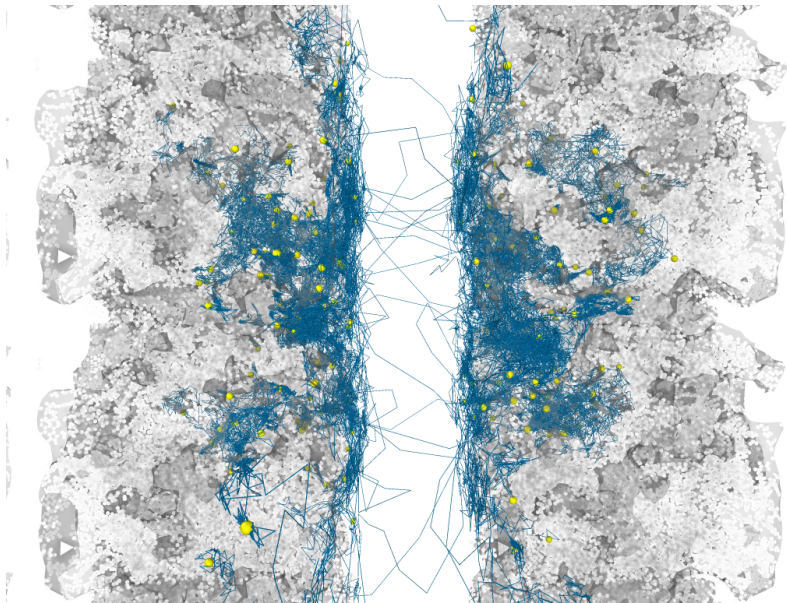


Remaining oil composition (mole fraction)

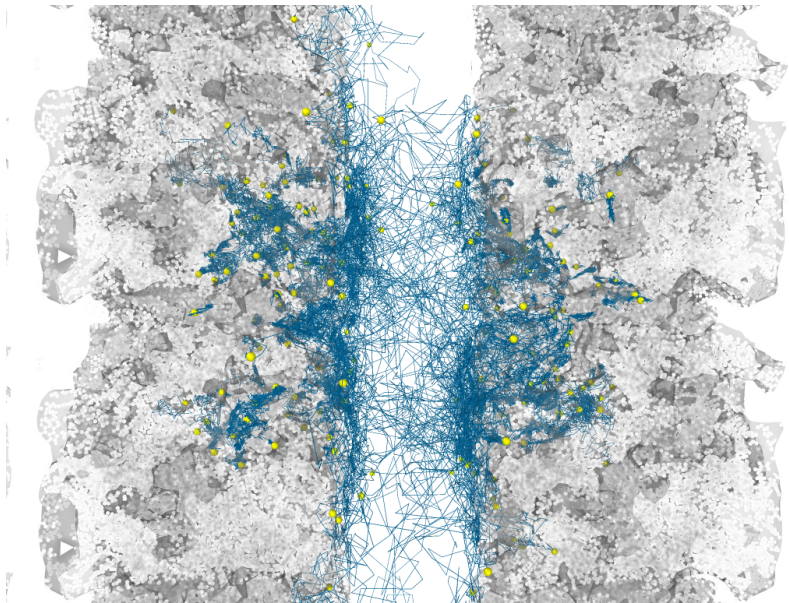
Color code:

- Kerogen
- Asphaltene/resin
- Heavy and aromatic species
- Intermediate species
- Methane
- Solvent

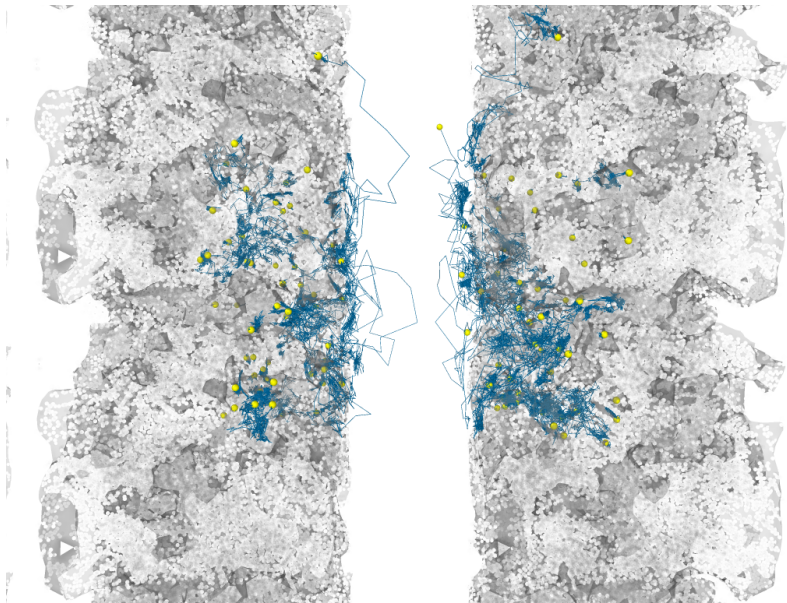
Non-produced n-octane molecules (no solvent)



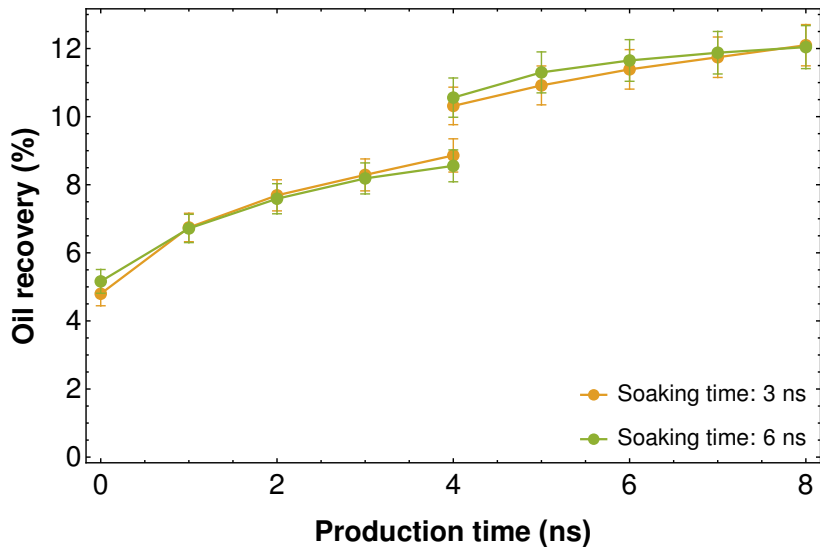
n-octane molecules (with solvent)



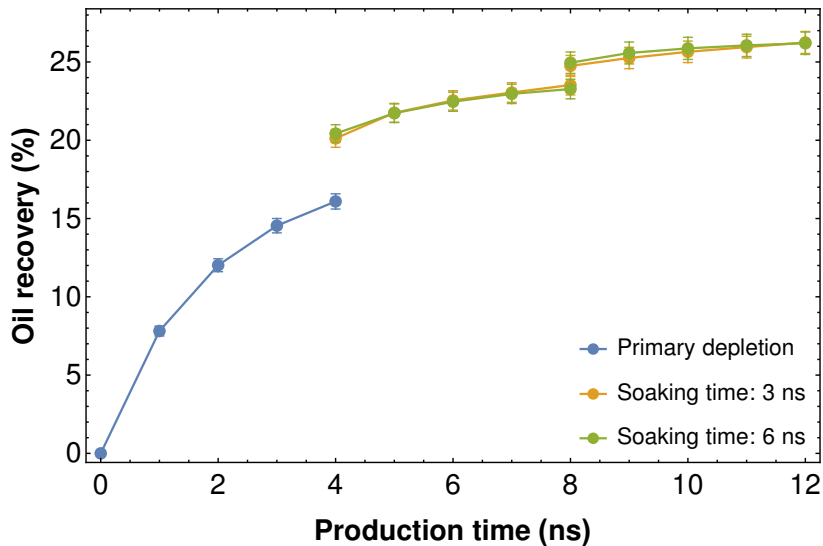
Dimethylnaphthalene molecules (with solvent)



Oil recovery during huff-and-puff



Overall oil recovery



Conclusions

- Molecular simulations agree with experimental observations.

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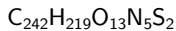
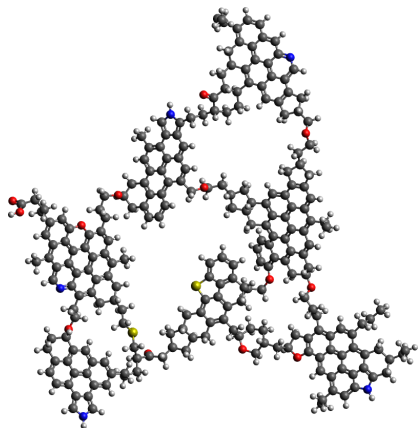
Acknowledgments

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- OSCER
- Dr. Deepak Devegowda
- Dr. Carl Sondergeld
- Dr. Chandra Rai
- Dr. Ali Tinni
- Mr. Sidi Mamoudou

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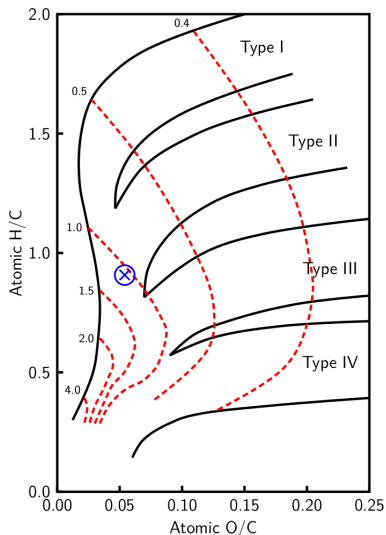
Kerogen type II-C



Color code:

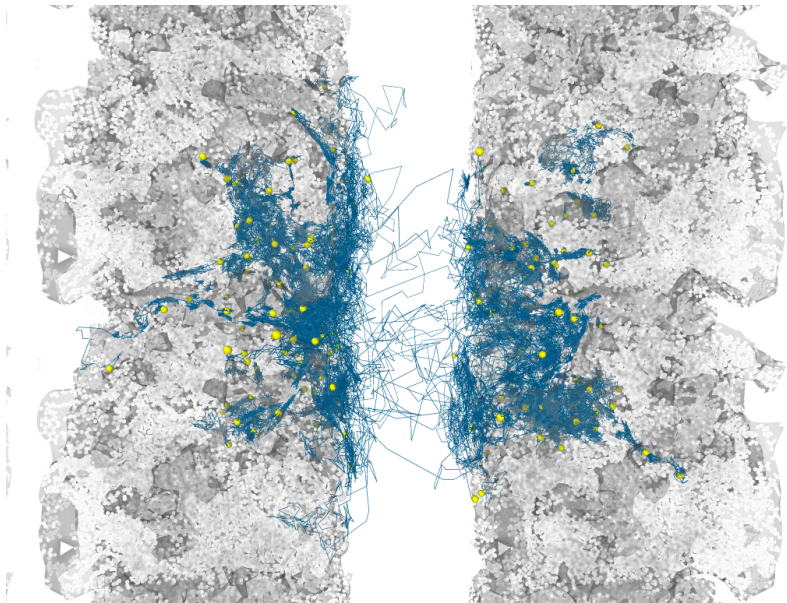
- | | |
|----------|------------|
| ● Carbon | ○ Hydrogen |
| ● Oxygen | ● Nitrogen |
| ● Sulfur | |

Ungerer et al. (2015)



After Seewald (2003)

n-tetradecane molecules (with solvent)



Toluene molecules (with solvent)

