Water Production in the Permian: Where is the water coming from?

Dr. David DiCarlo

Associate Professor, Hildebrand Department of Petroleum and Geosystems Engineering

The University of Texas at Austin

About myself and my group

- PhD Physics
- Researcher at Stanford
- Spent time at USDA-ARS
- Been at UT Pet Eng since 2007
- Interest in flow problems derived from the field

One example – three-phase flow

- Operators observe low residual saturations at Prudhoe Bay
- Design and perform experiments on simplified systems (oil and water in sandpacks)
- Results match that the controlling physics is layer formation caused by three-phase flow
- Companies have confirmation of why gas injection works in certain cases – makes decision making easier

Overview

- Use the same model for water production in unconventional formations
  - Water introduced by hydraulic fracturing
  - Water initially present
  - Water in heterogenous formations

Water introduced by fracturing – water block

- Hydraulic fracturing fluid invades into the rock matrix.
- The invaded fluid results in relative permeability reduction due to multiphase flow. This effect is known as the water block.

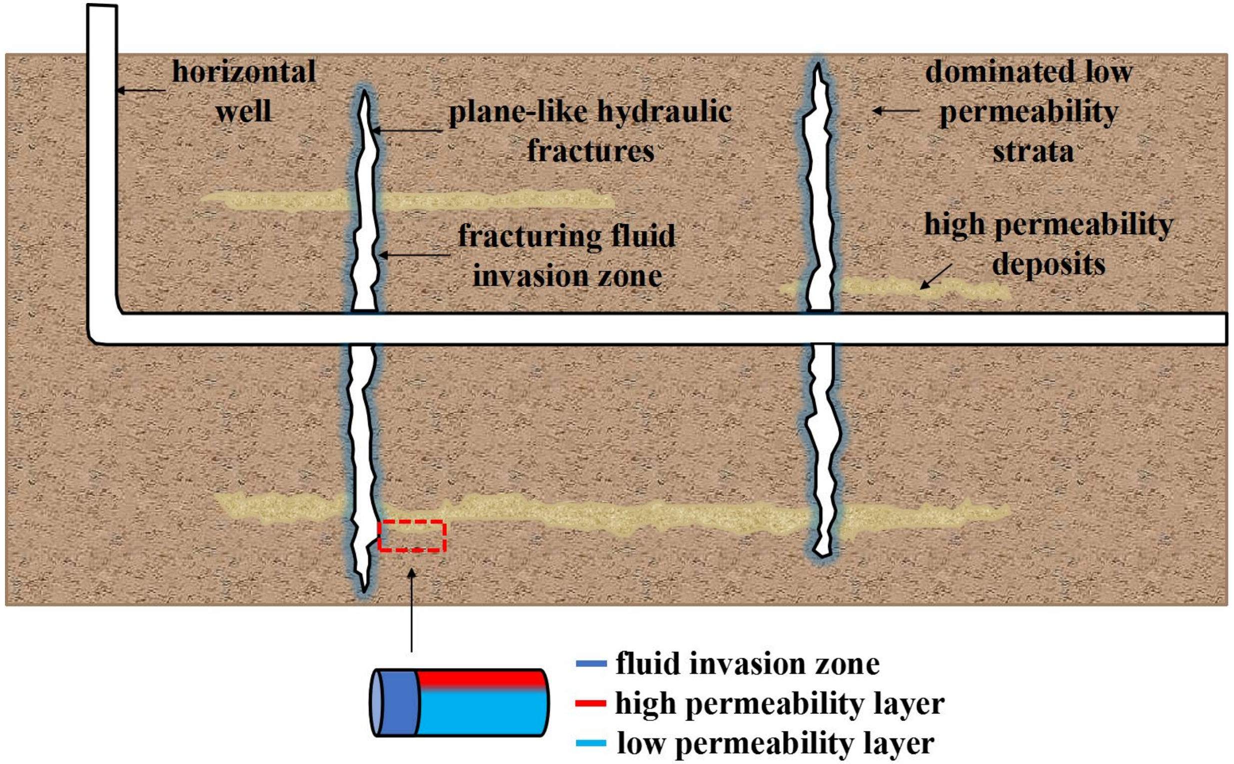
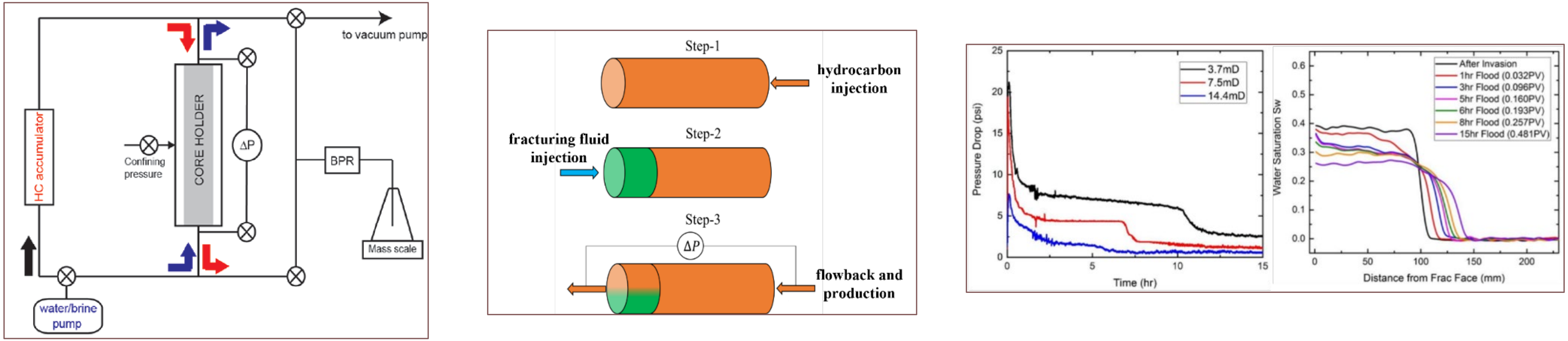


Figure 1. Schematic and the core representation of a reservoir after a fracturing treatment.

Water Block in Low Permeability Homogenous Rocks



(a) (b) (c)

Figure 3. Schematic of (a) coreflood set up, (b) coreflood sequence and (c) change of water saturation profile and pressure drop during flowback and oil production (Longoria et al., 2015; Liang et al., 2018; Luo et al., 2020)

Results:

- Injected water clears after a certain time by moving further into rock
- Clearance time scales as $K^{-1/2}$
- In the field this corresponds to 2-3 months

Example 2 – water block

- Operators develop combination of horizontal wells and hydraulic fracturing
- Question: how much is this hurting our current and eventual production?
- Design and perform experiments on simplified systems (water invasion and flowback in uniform rock cores)
- Results match that the controlling physics is water invading deeper into matrix caused by capillary forces
- Companies have confirmation that water can work just as well as miscible injectants – makes decision making easier

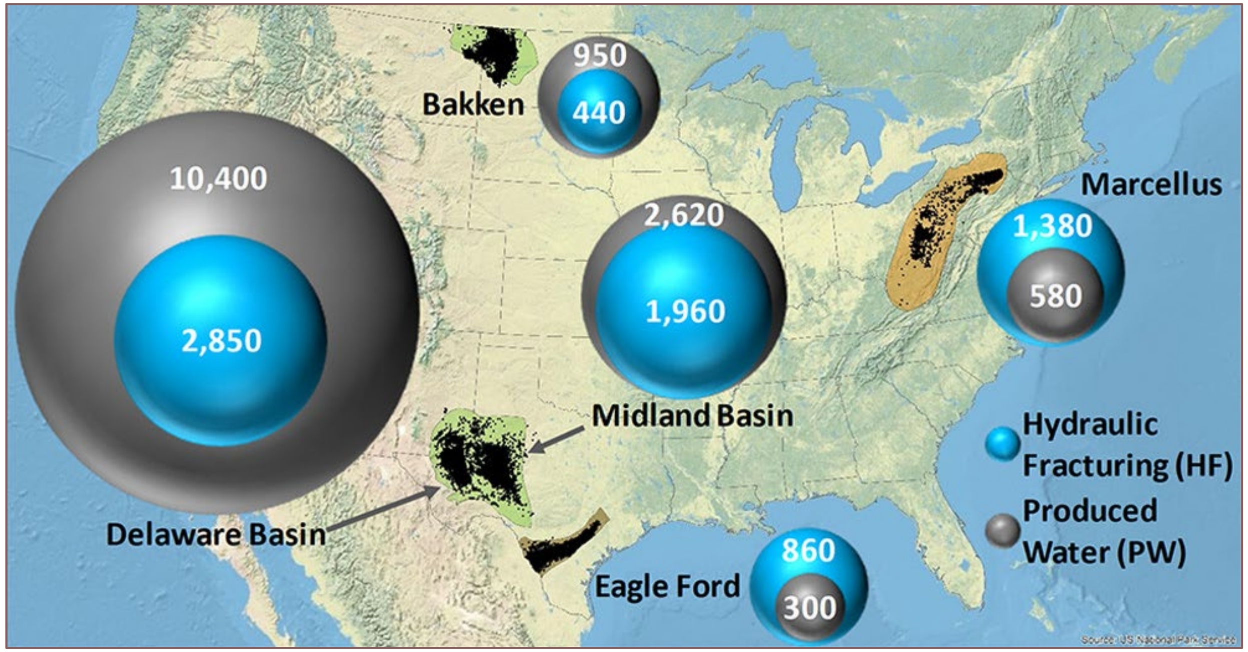
Current research objectives

Water blocks in the high water saturation heterogeneous low permeability formation.

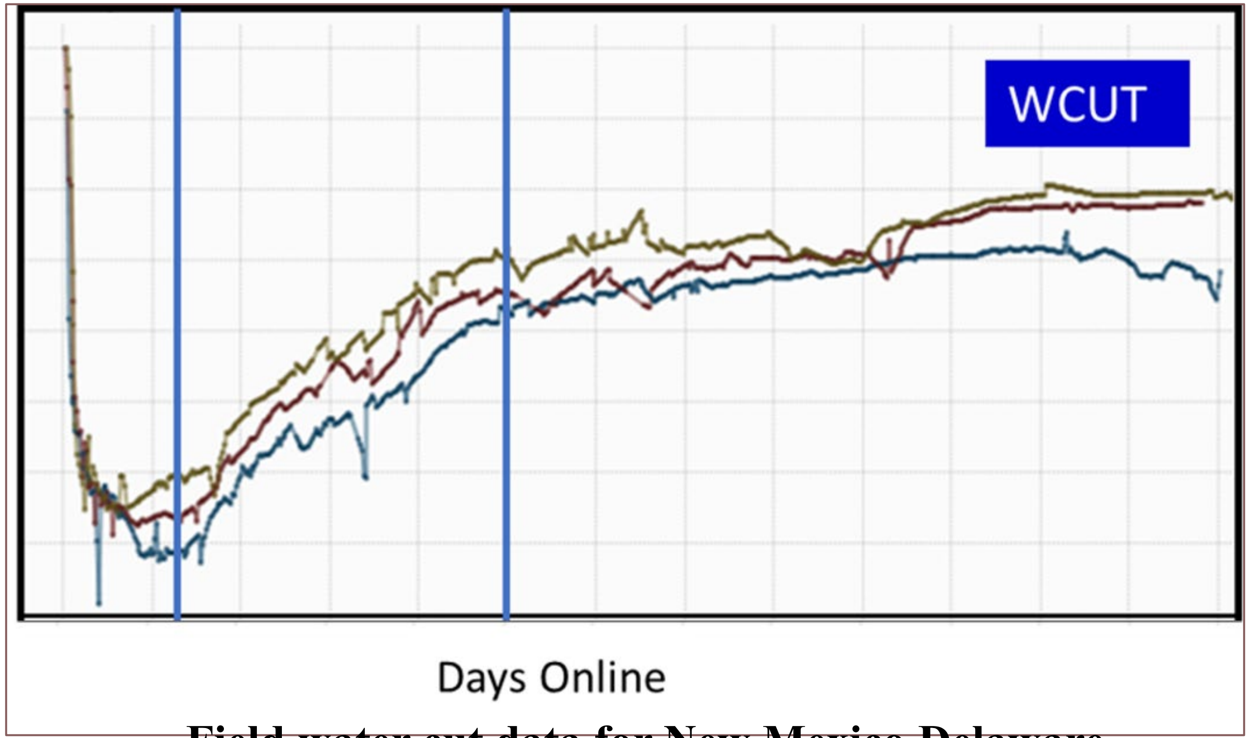
- Modeling water and oil production in the Wolfcamp formation: Insights from heterogeneous layered models. We employ simplified models to match and explain the basin-wide water cut trend.
- Study the physics and impacts of water blocks in heterogeneous low permeability rocks.

Modeling Production in the Wolfcamp Formation

- Motivation: massive water production in the unconventional oil basins.
- Increasing water cut trends after production – what is the source?

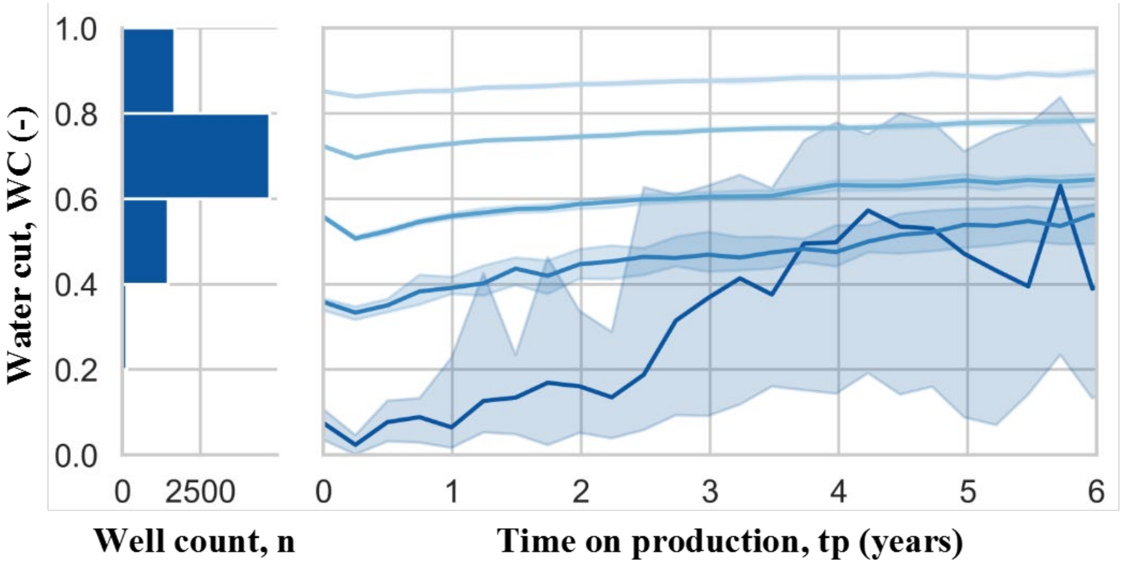


Water use and water production in billions of gallons, Scanlon et al., 2020



Field water cut data for New Mexico Delaware Basin Wolfcamp wells, Amadi et al., 2022

Can we get insight from production data?

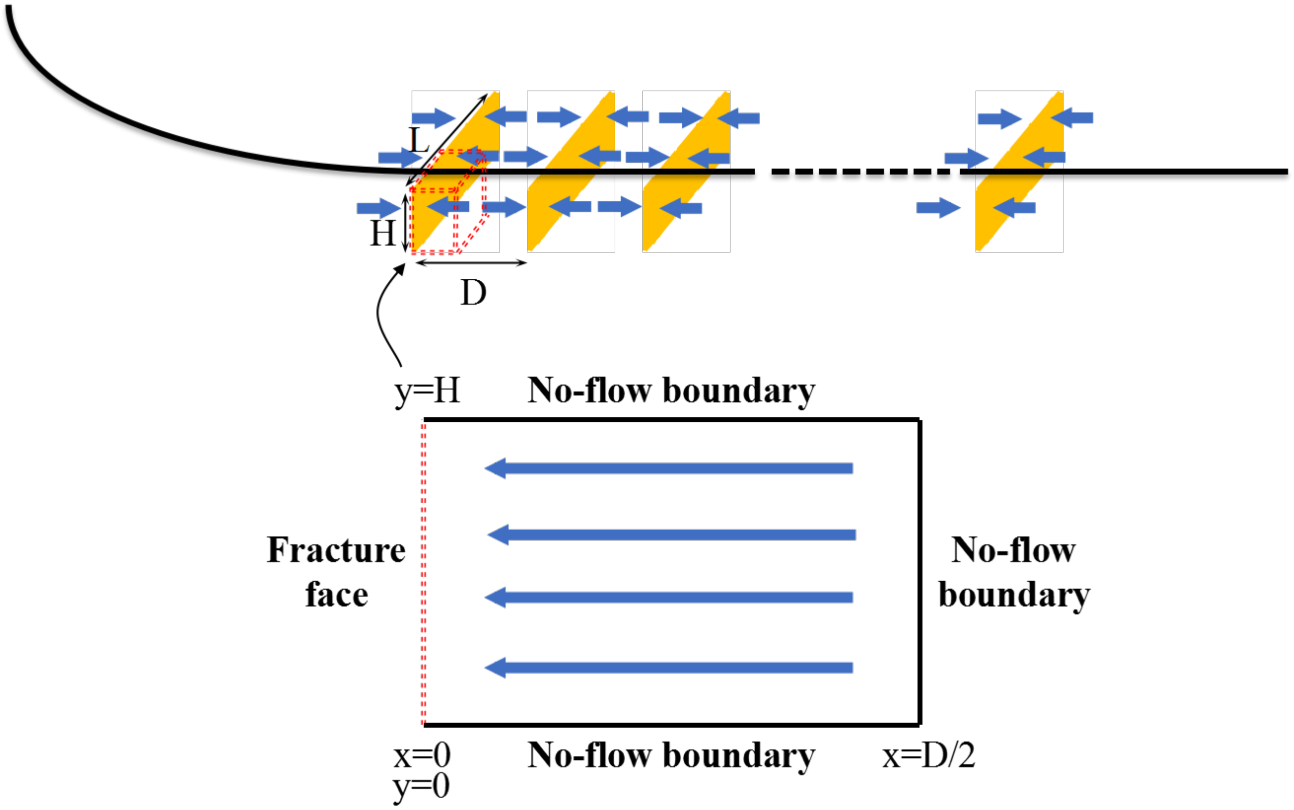


(a) (b)

- Most wells have high water cut
- Water cut changes with time – usually increases
- Primary production models are single phase flow – this is inherently two-phase flow

Modeling Production in the Wolfcamp Formation

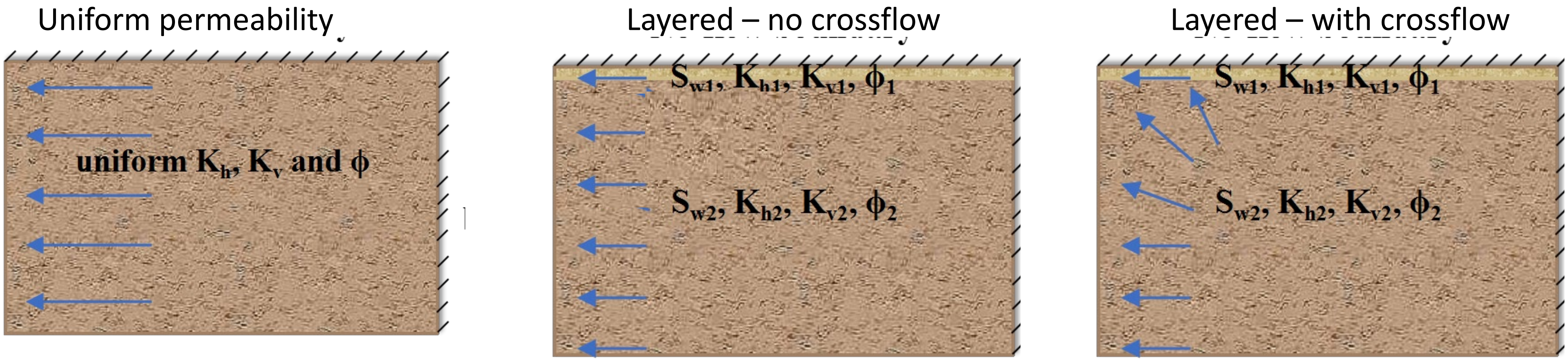
- Simplification of Reservoir Geometry: we use the simplified spatial model for a tight reservoir - parallel hydraulic fractures evenly spaced a distance D apart.



Schematic of a horizontal well with evenly spaced plane-like fractures. The length of each fracture is L, the height is H and the distance between fractures is D. The lower picture is the control volume of our model, which represents 1/2 of the hydraulic fracture.

Modeling Production in the Wolfcamp Formation

- Three different conceptualizations of reservoir

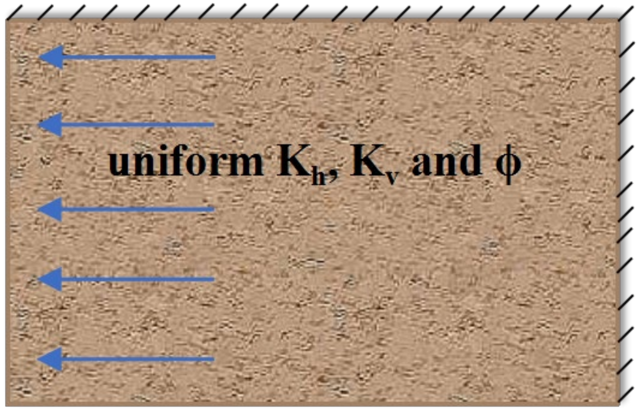


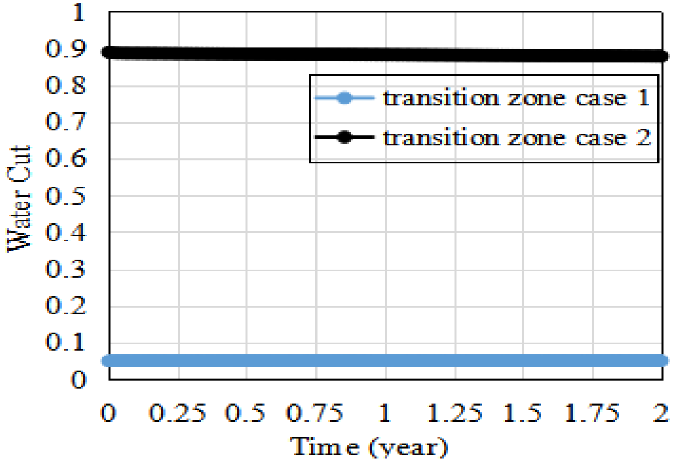
- Model oil and water production versus time
- Look for changes in water cut
- Do for three cases: water-wet, oil-wet, and mixed wet

Modeling Production in the Wolfcamp Formation

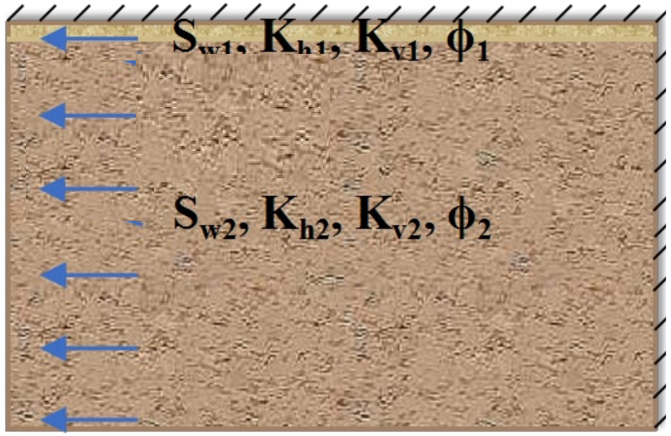
- Three different conceptualizations of reservoir

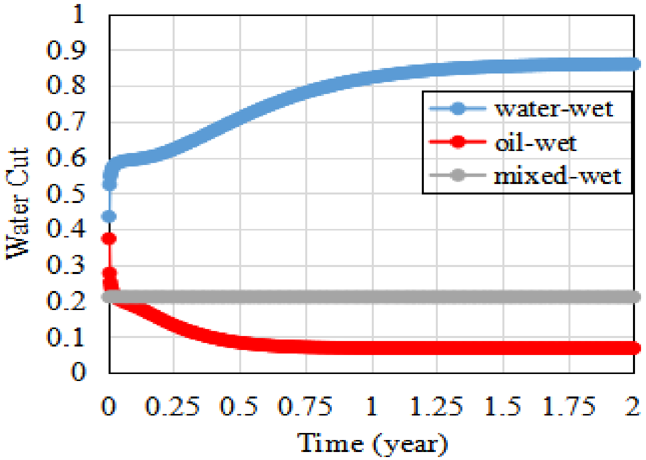
Uniform permeability



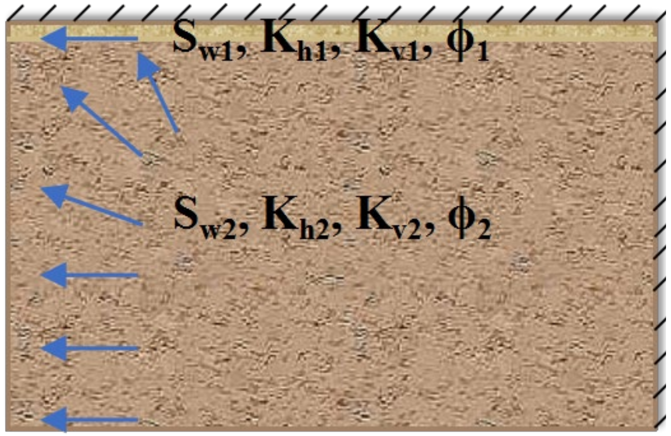


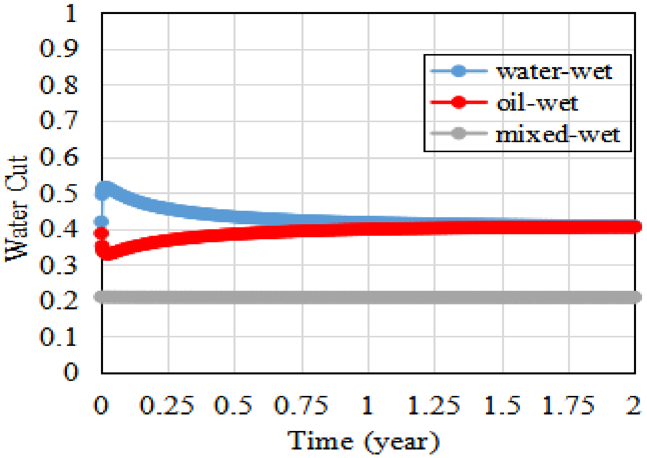
Layered – no crossflow



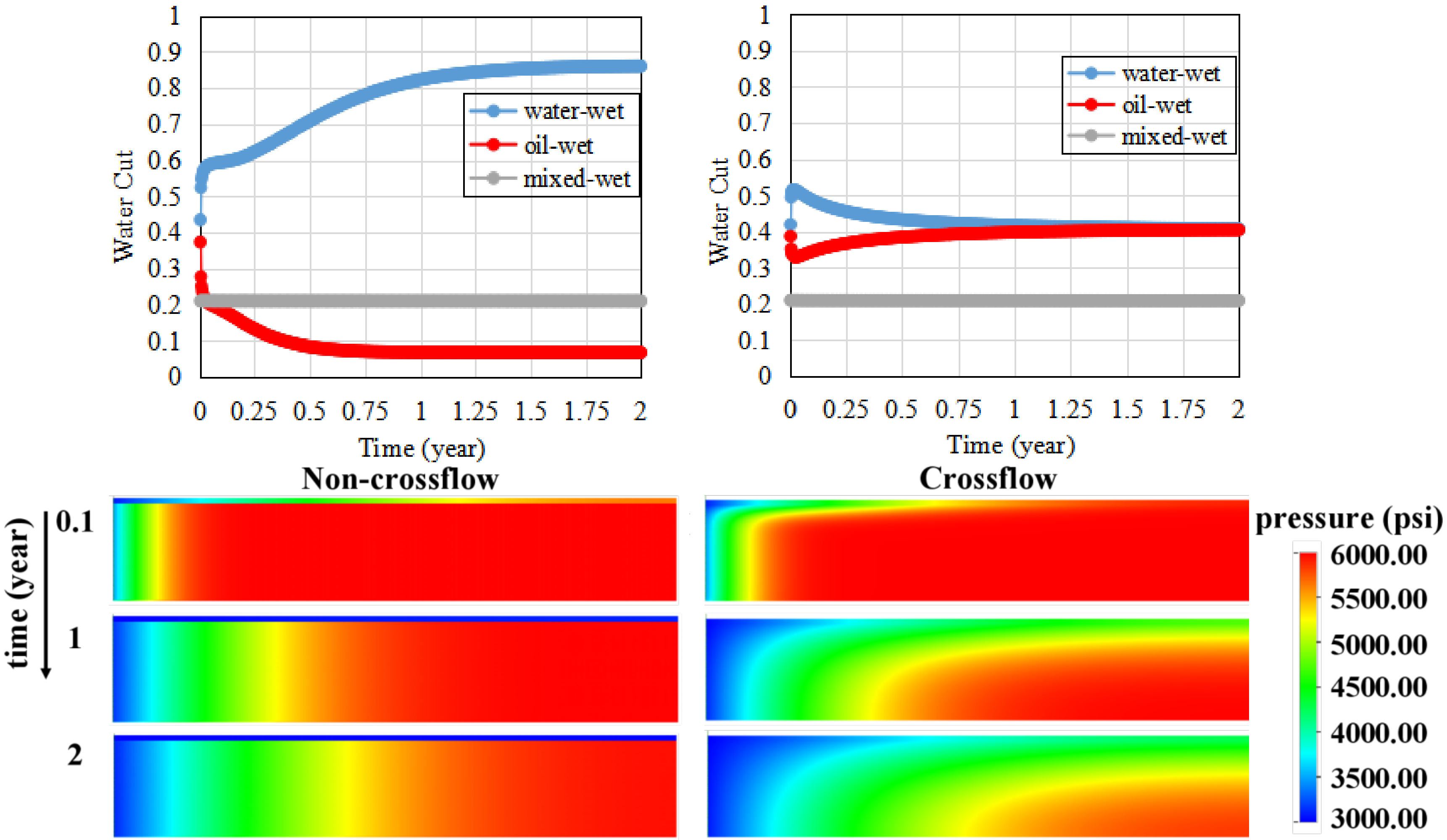


Layered – with crossflow



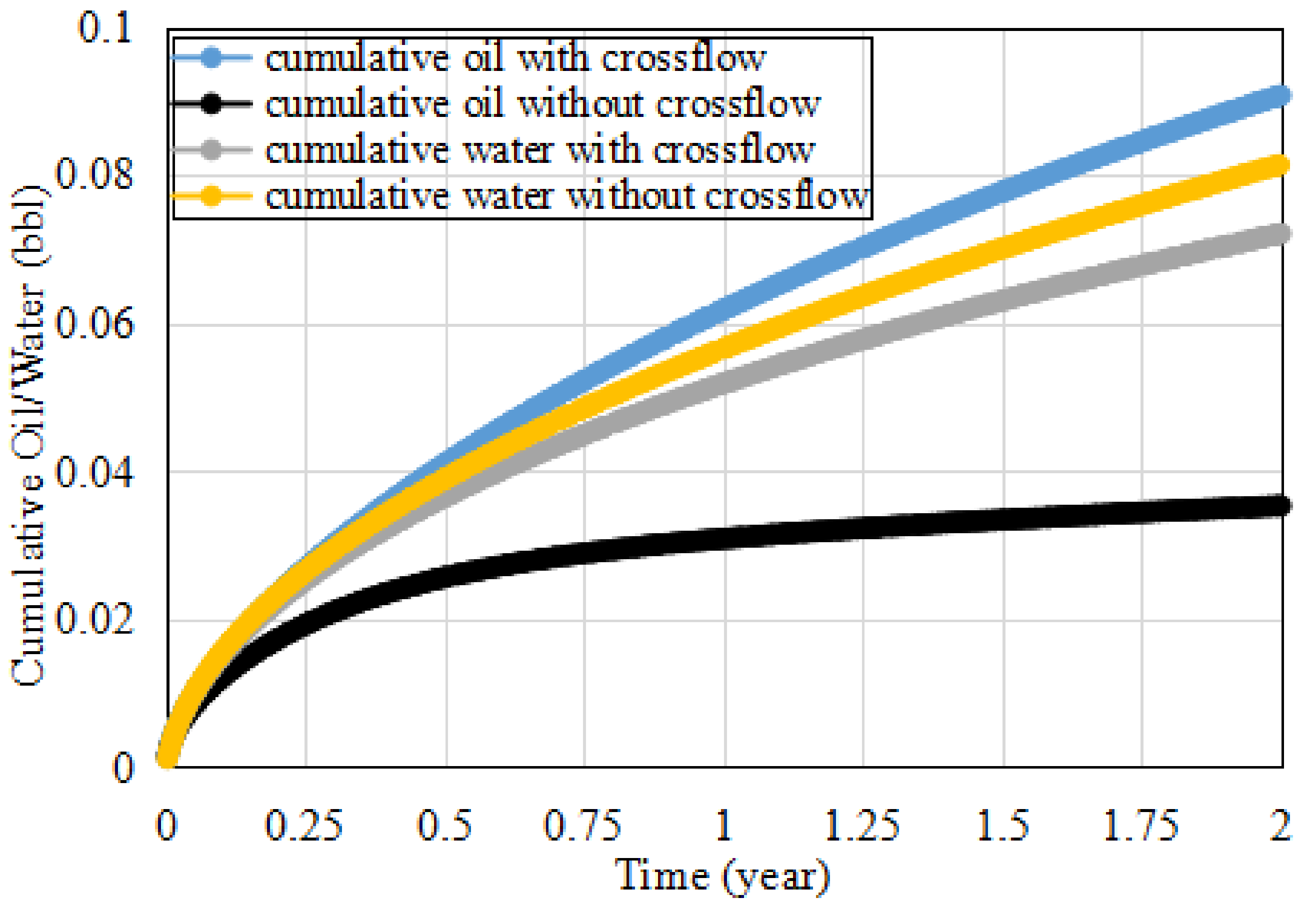


Effect of Crossflow on Pressure



- High perm layer drains fastest
- Crossflow allows pressure to remain high in high perm layer
- Longer production time

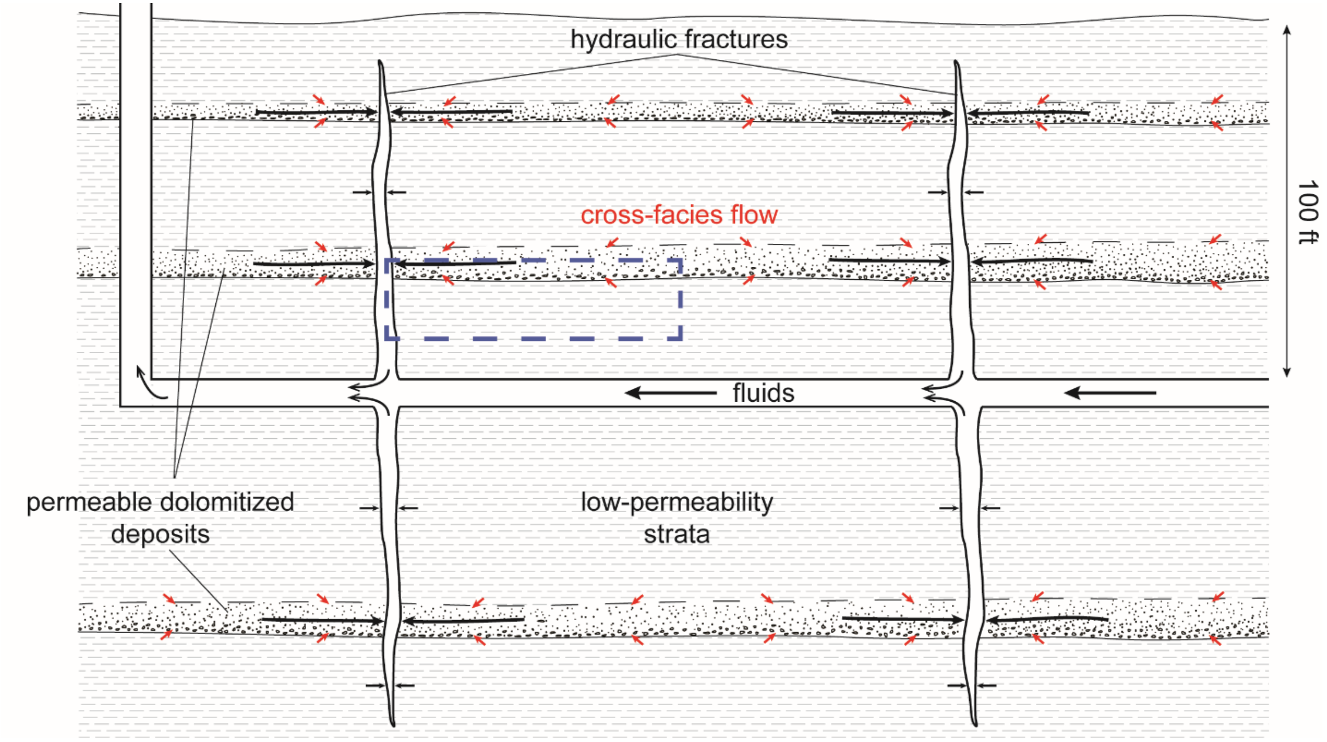
Effect of Crossflow on Cumulative Production



- Twice the overall production when crossflow occurs

Modeling Conclusions

- Layering with different permeabilities is essential to match production data
- Crossflow between layers significantly affects production in tight oil reservoirs.

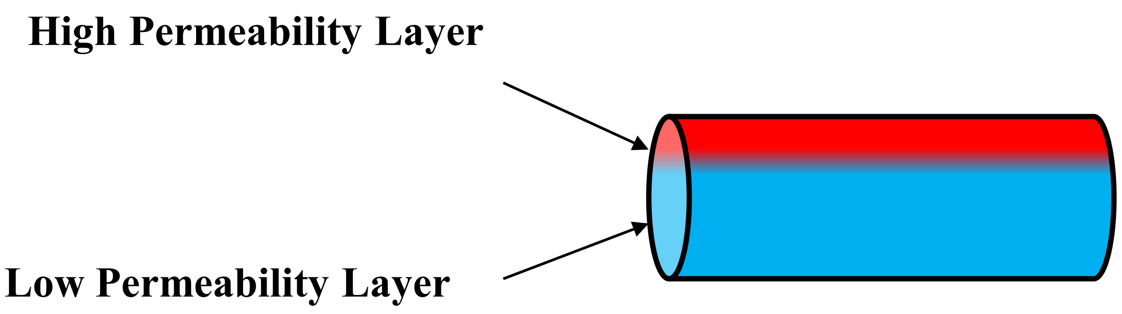


Perform experiments in layered media!

Schematic of a horizontal well with two plane-like fractures drilling into the heterogeneous upper Wolfcamp Formation (Ramiro-Ramirez, 2022).

Experiments in Layered Media

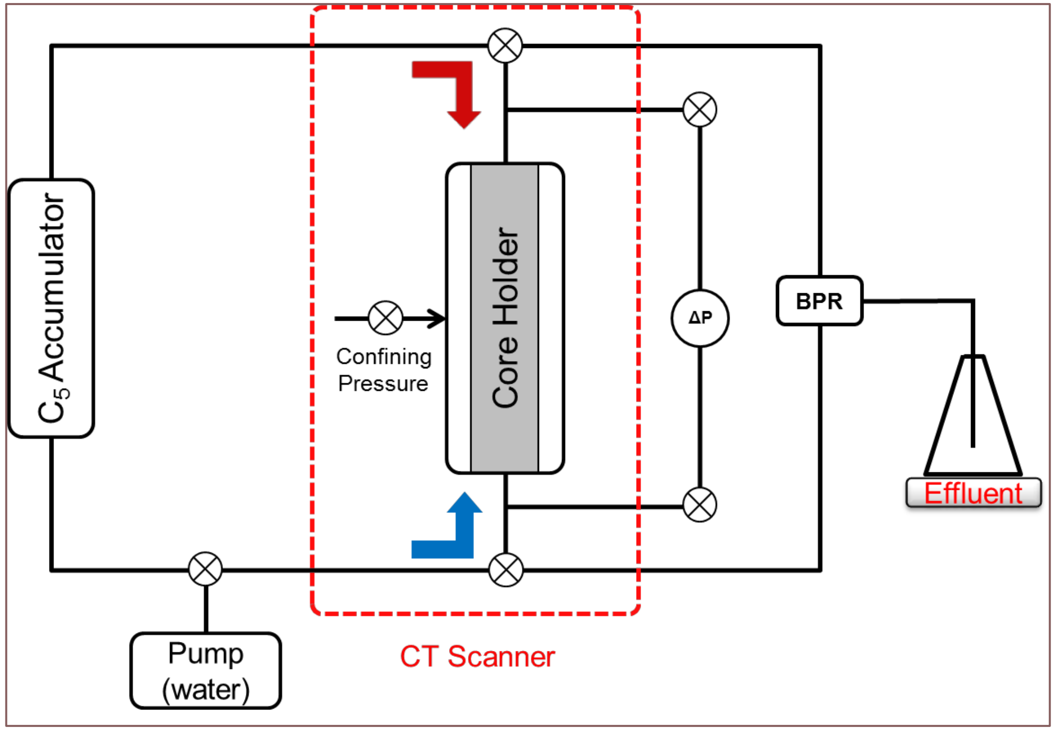
- Composite core: A composite core sample with the upper layer being high permeability (Berea Sandstone, 1/3 of the core, 50 mD) and the lower layer being low permeability (Texas Cream Limestone, 2/3 of the core, 6.9 mD).

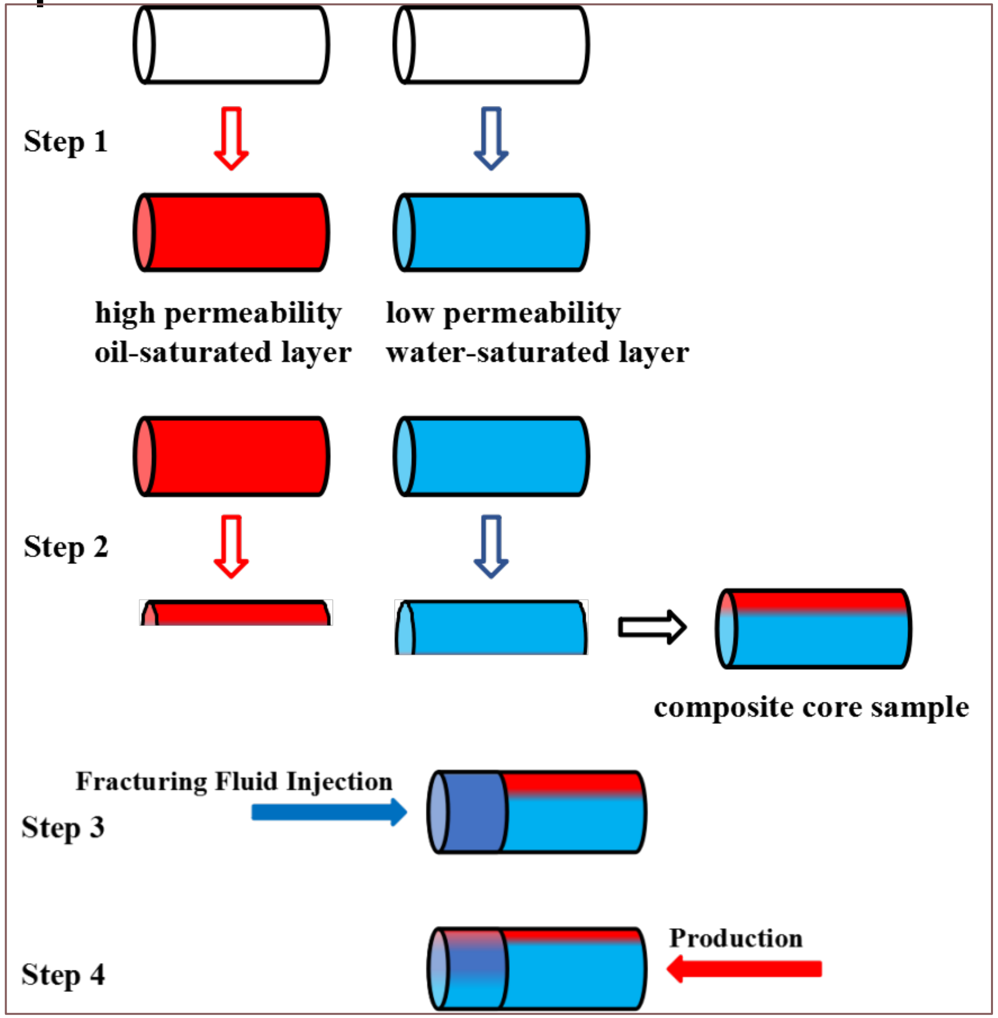


- Fluids: n-pentane and brine.
- Use CT scans and pressure drop measurements, we will observe in real-time the development of water blocks during fracturing fluid invasion, and their subsequent removal during production.

Experimental Schematic

- The experimental setup and coreflood procedures are shown below.





Materials and Methods

- Coreflood Procedure:

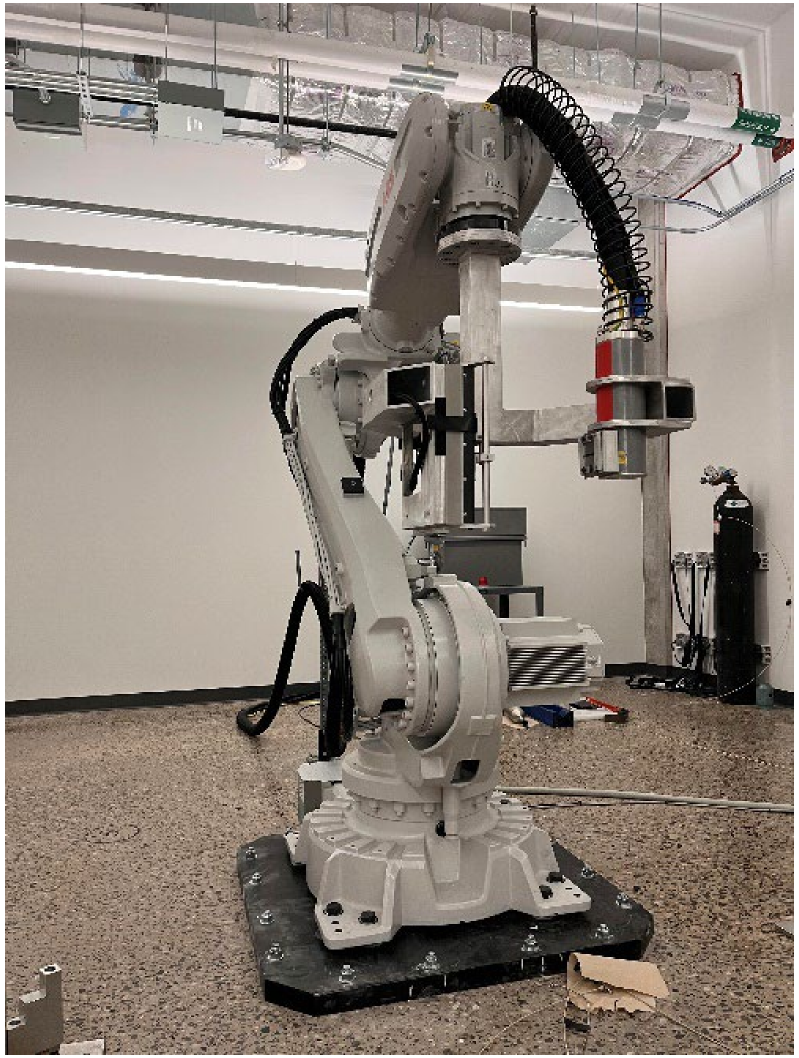
Step 1: Establishing initial reservoir saturation

Step 2: Composite core construction

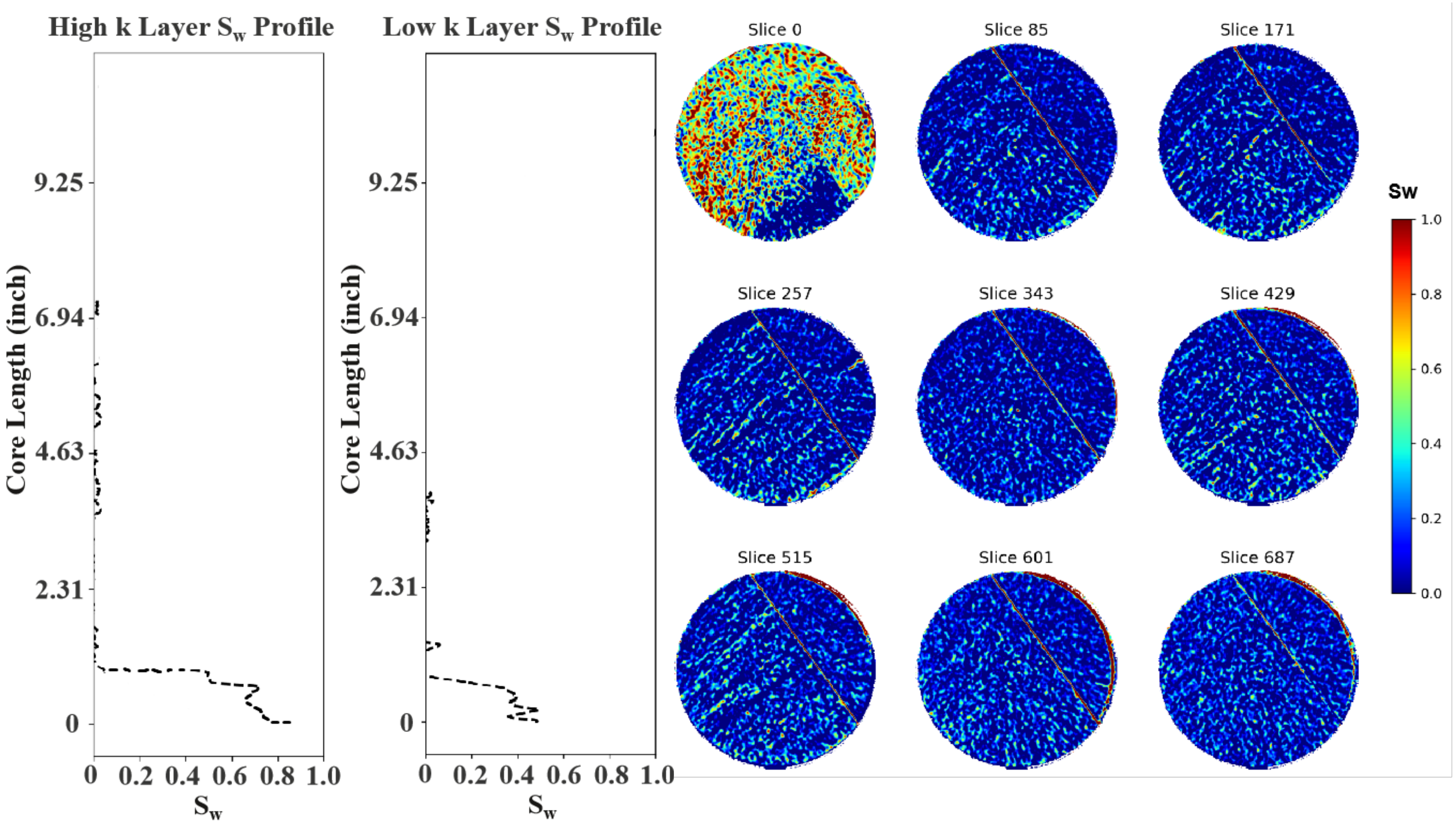
Step 3: Fracturing fluid invasion 3 CT scans

Step 4: Flowback and hydrocarbon production

7 CT scans were conducted during flowback.

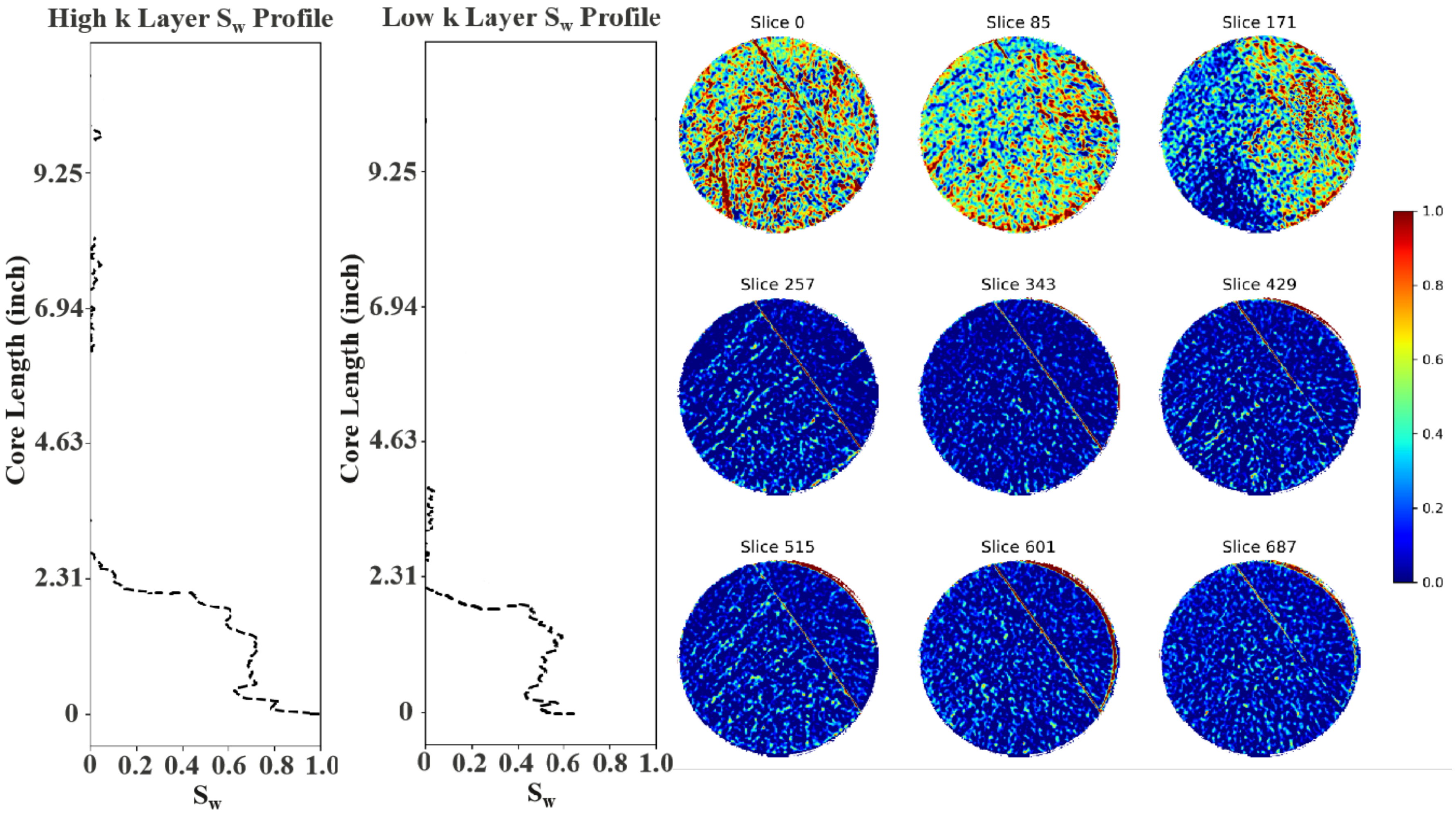


Fracturing Fluid Invasion – Early Time



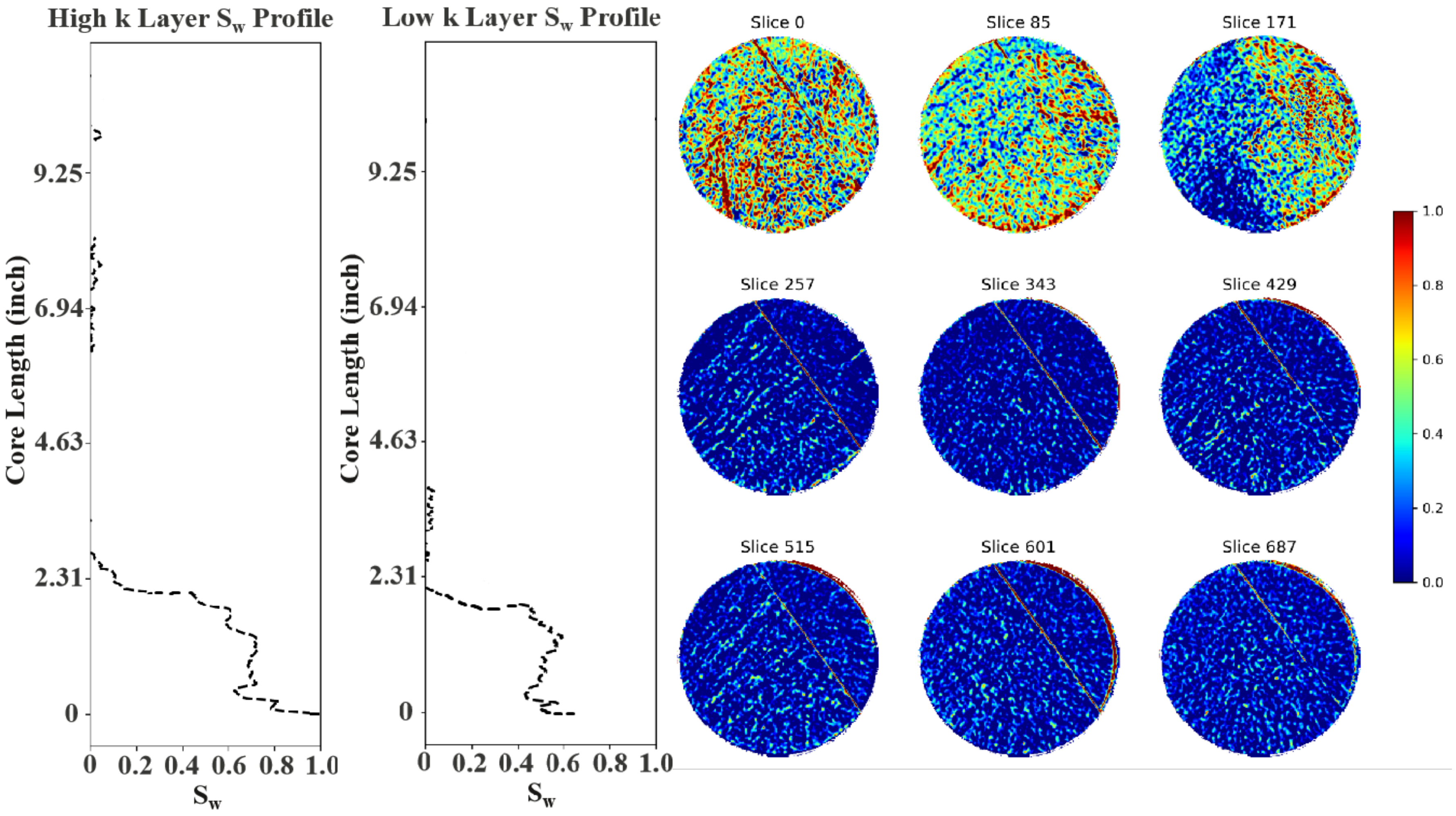
- The majority of fluid infiltrates the high permeability layer
- Low permeability layer remains incompletely saturated

Fracturing Fluid Invasion – Late Time



- Fracturing fluid propagation ceases approximately 2.3 inches from the fracture face
- Higher S_w within the middle of the core's high permeability layer

Fracturing Fluid Invasion – Late Time



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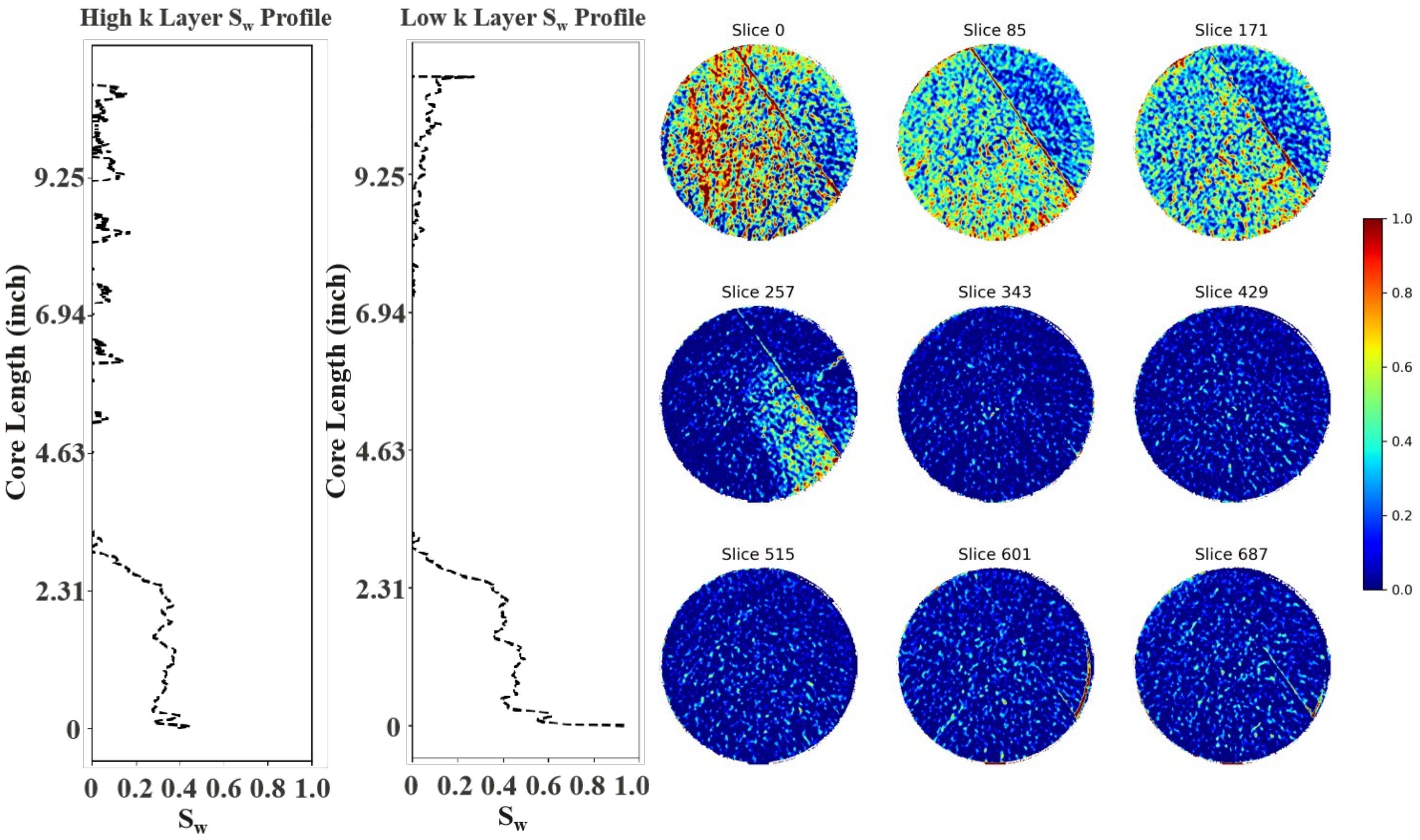
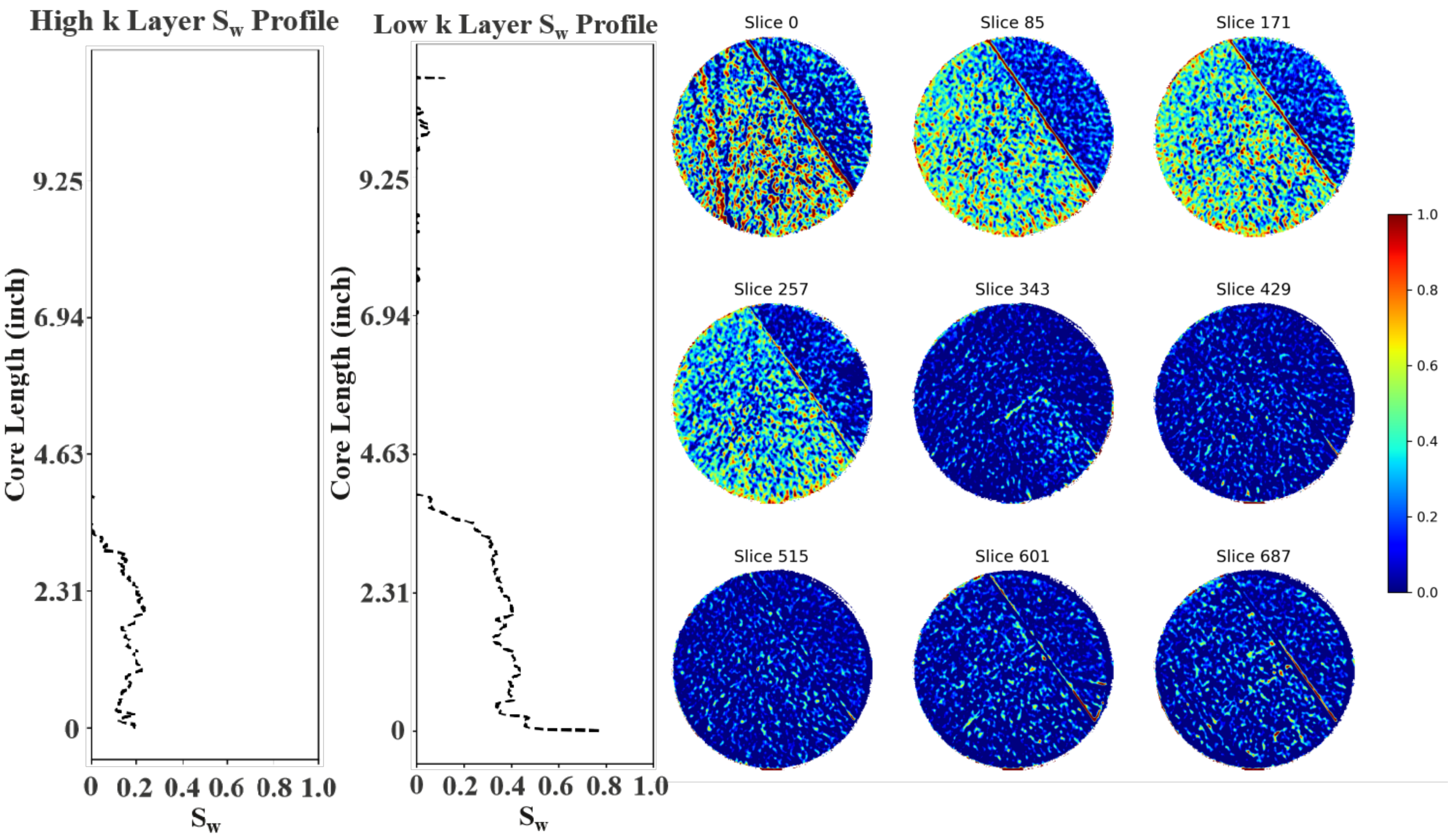
- Higher S_w within the middle of the core's high permeability layer

Production Phase – Early Time



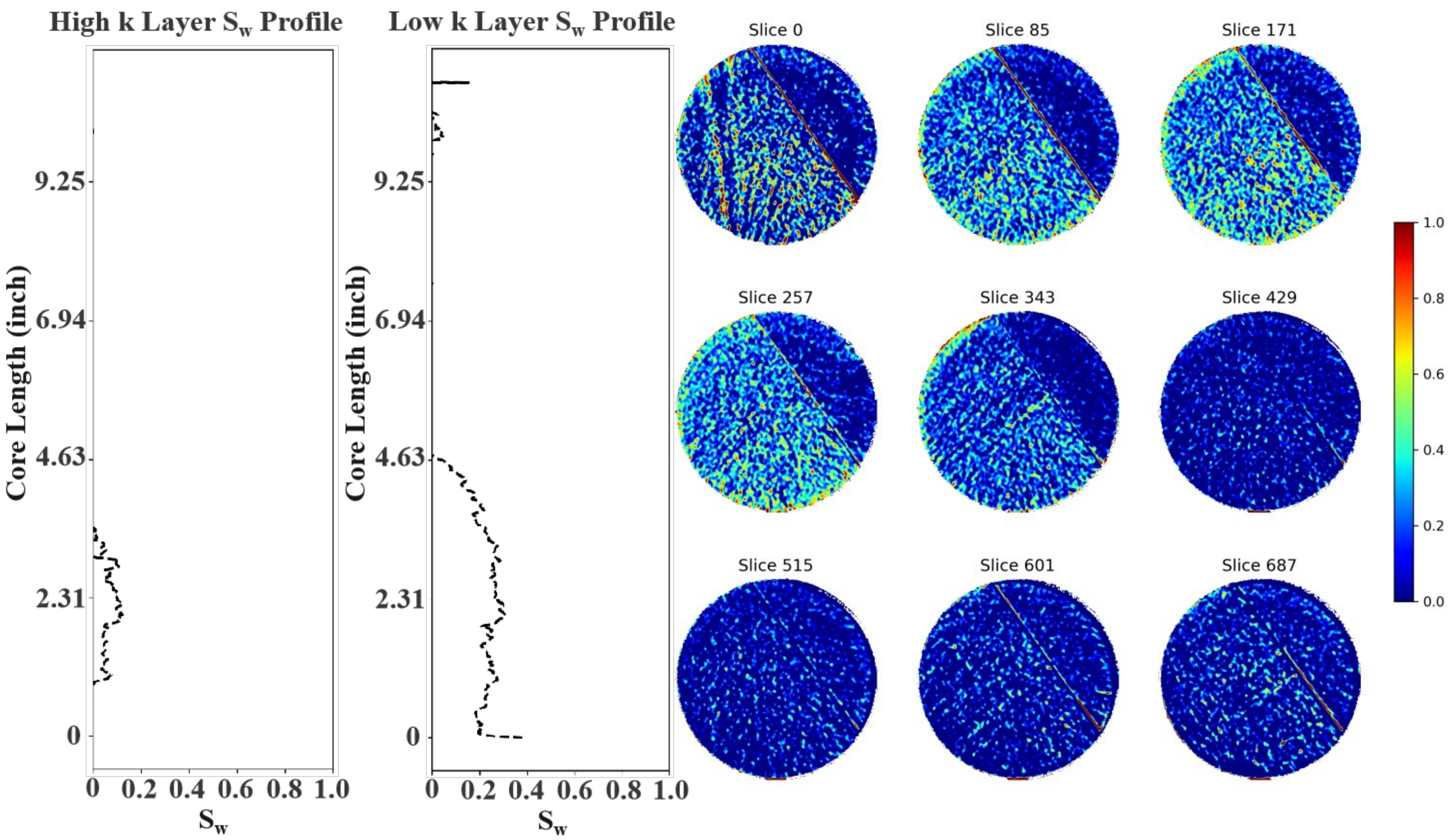
- High perm layer is the primary channel for flowback and oil production
- Low perm layer experiences minimal S_w reduction but deeper water migration

Production Phase – Middle Time



- Only a small fraction of fracturing fluid remained in the high perm layer
- S_w near the fracture face decreases in the low perm layer, while water imbibition within the core continues

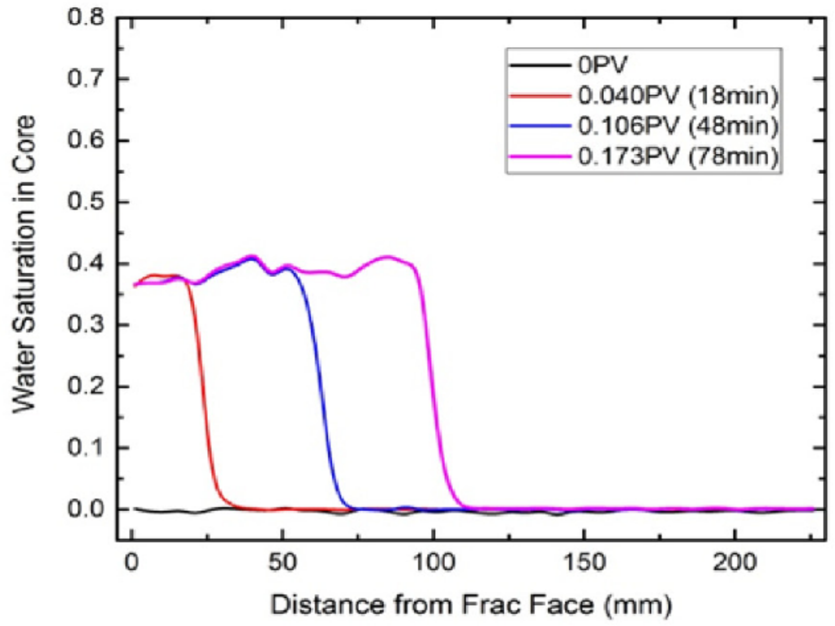
Production Phase – Late Time



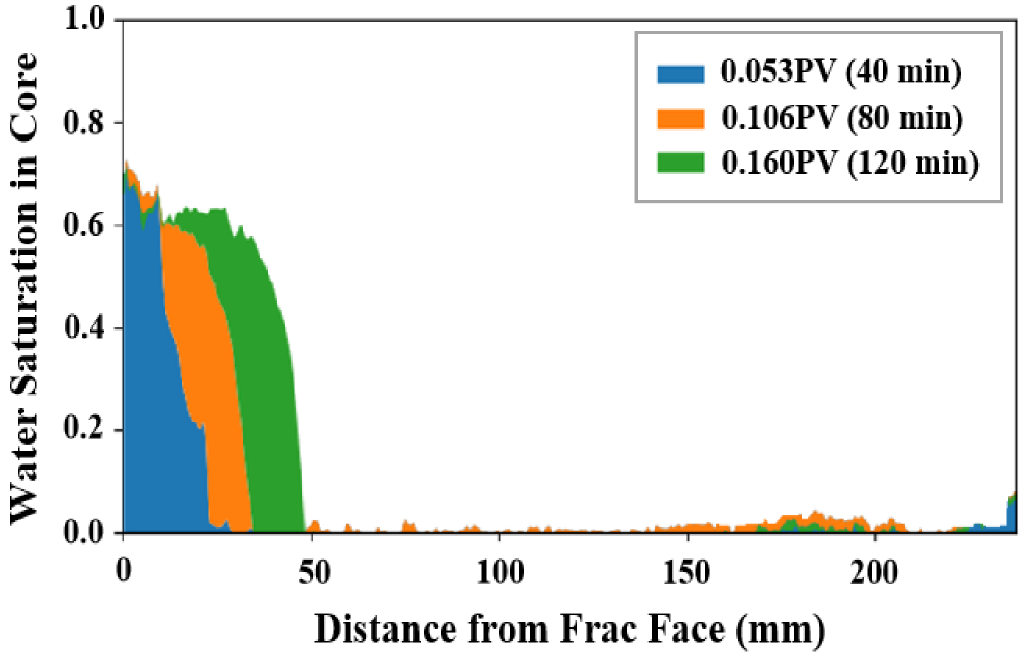
- S_w in the low perm layer is higher in the middle but lower at both ends of the core

Invasion Observations – Homogeneous vs Layered

Homogeneous



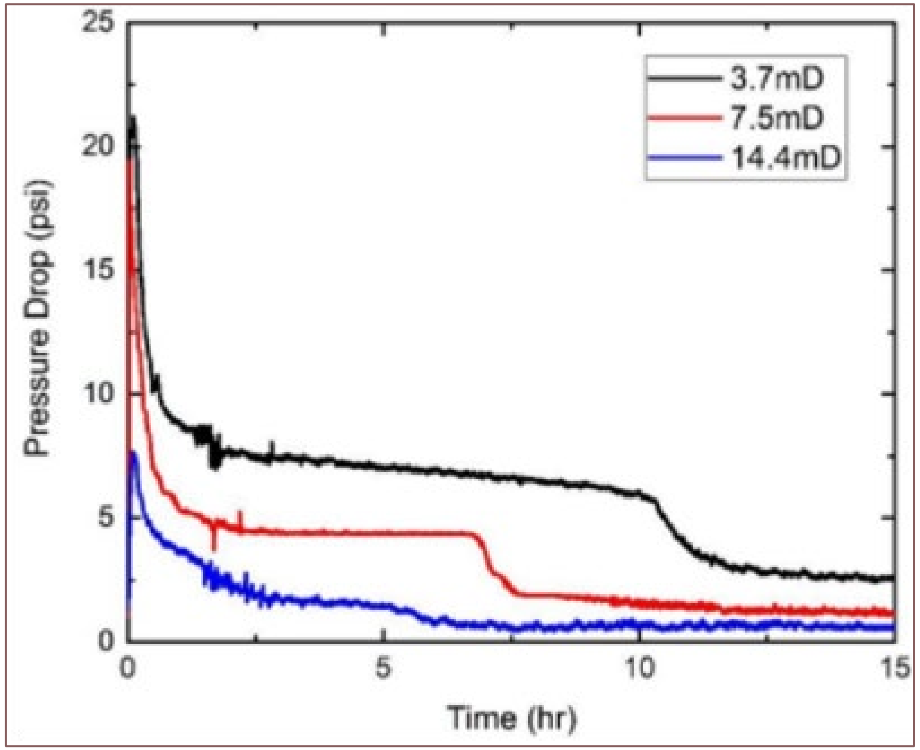
Layered



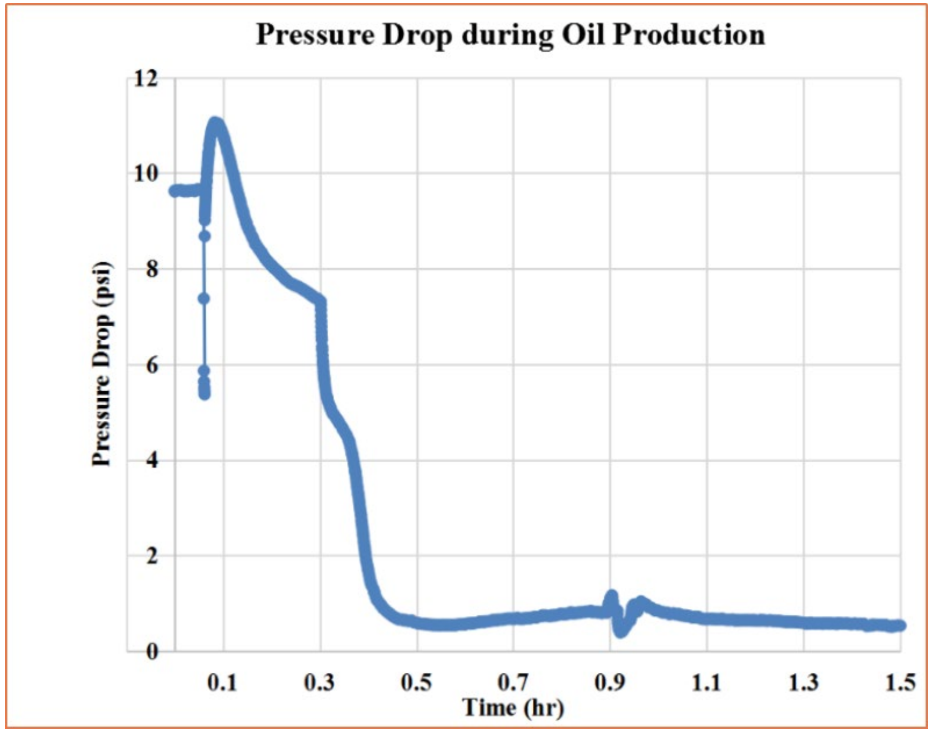
No difference when layers are averaged

Water Clearing Time – Homogeneous vs Layered

Homogeneous

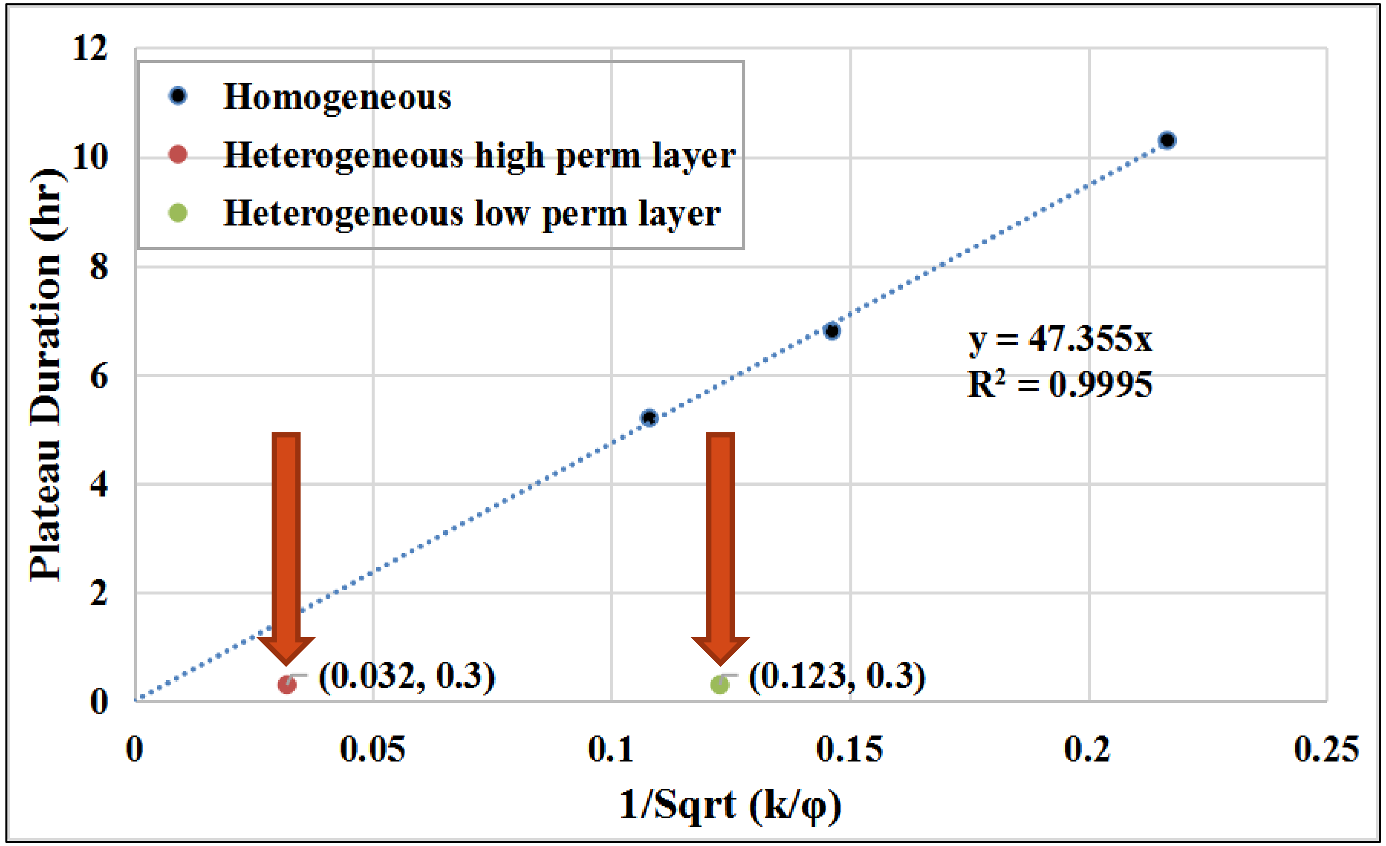


Layered



Much faster clearing times!!

Scaling to Field – Homogeneous vs Layered



When scaled with permeability, the clearing times are much faster

Experimental Conclusions

- The uneven water saturation distribution mitigates the effects of water blocks
- During flowback, water blocks in heterogeneous formations are less severe compared to homogeneous formations
- For water-wet case, production from heterogeneous unconventional reservoir formations is less susceptible to the adverse effects of water blocks

Summary

- Use field data, simple reservoir models, and experiments to estimate source of water production in unconventional formations
- Layered heterogeneity is key!
- Perform experiments in layered models to observe effect of water on oil production
- Crossflow helps mitigate water blocks
- Questions and observations are most helpful!