# Sandbox model results and implications for $CO_2$ migration and trapping

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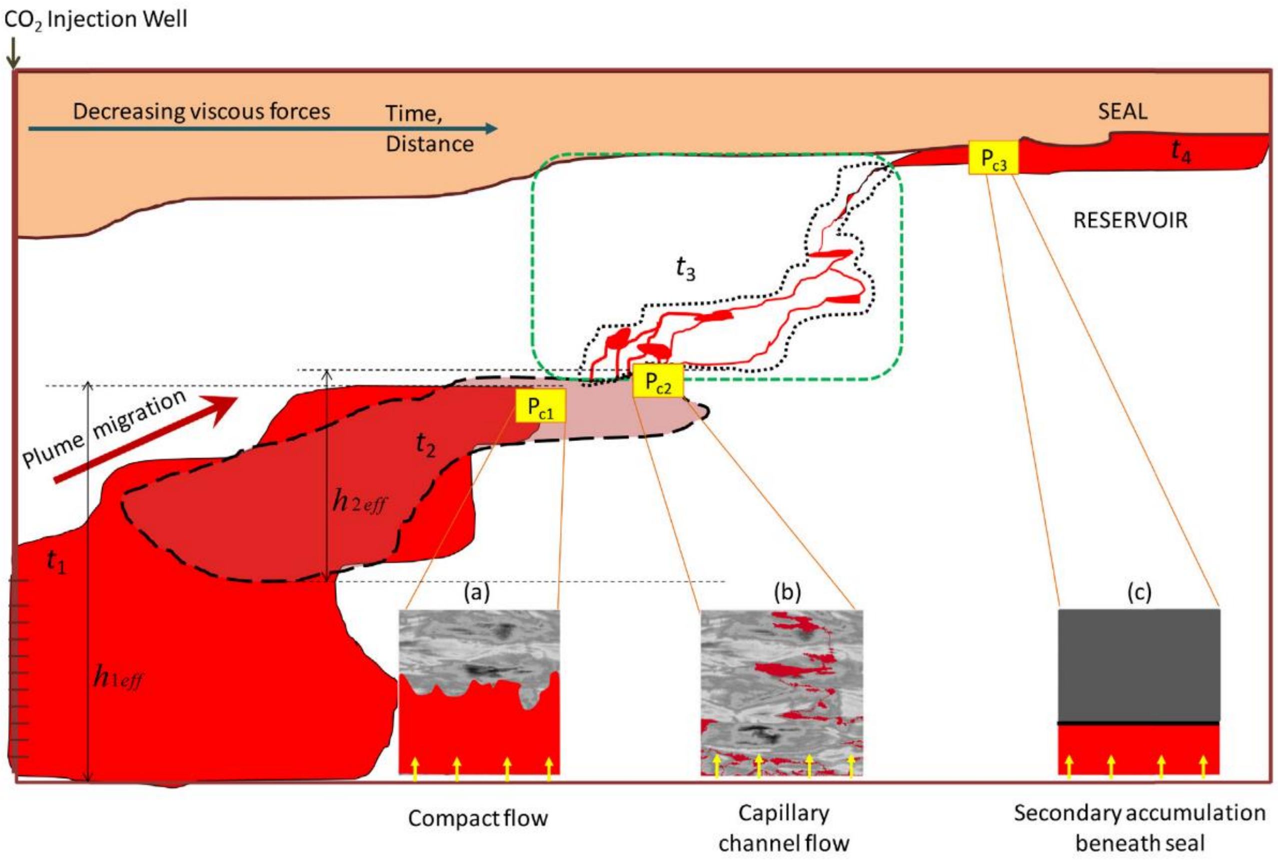
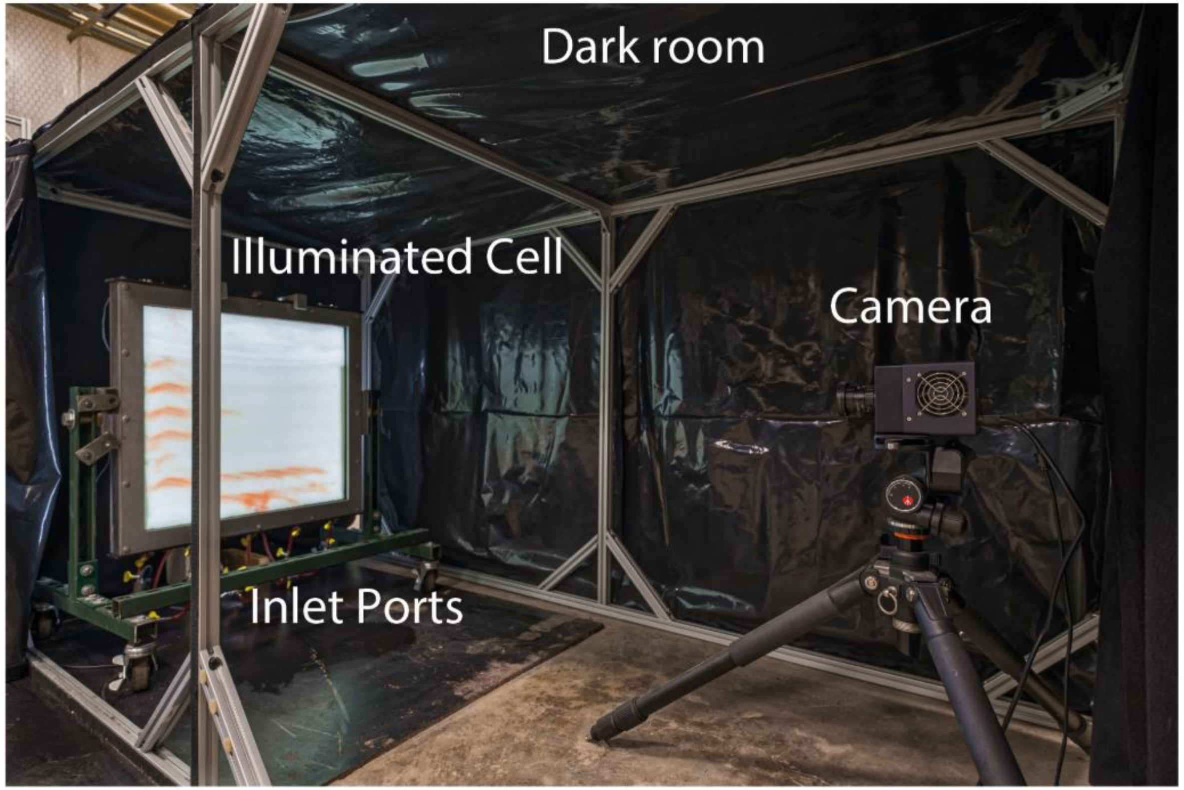
# The flow regime of $CO_2$ geologic storage is capillary- and buoyancy-dominated

- Spatially
  - Away from the injection well
- Temporally
  - During the entire post-injection period




Meckel et al., 2015

# Experiment: Intermediate-scale beadpack experiments have unique advantages

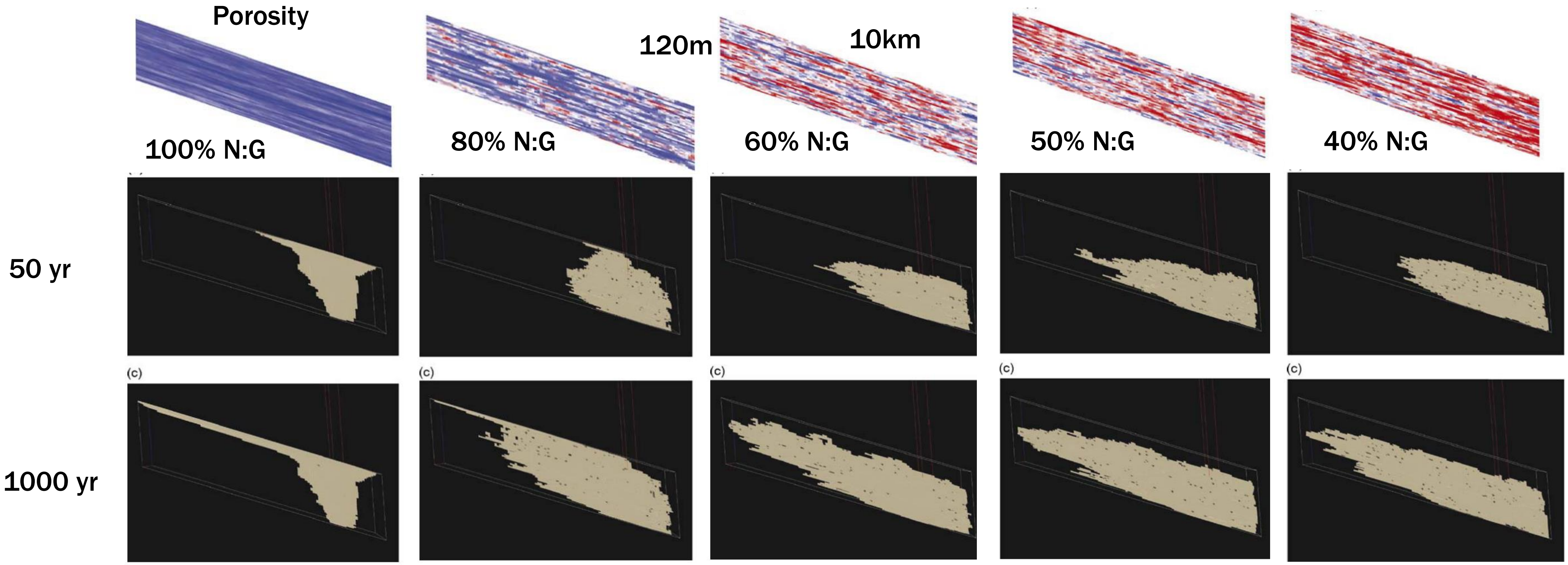



- Customizable domain
  - Different types and degrees of heterogeneity
- High-resolution imaging
  - Light transmission visualization
  - Both in time and space
- Buoyancy-driven flow
  - Most closely matches $CO_2$ geologic storage flow regime



Krishnamurthy, 2020

# Alternative confining system: composite confining system

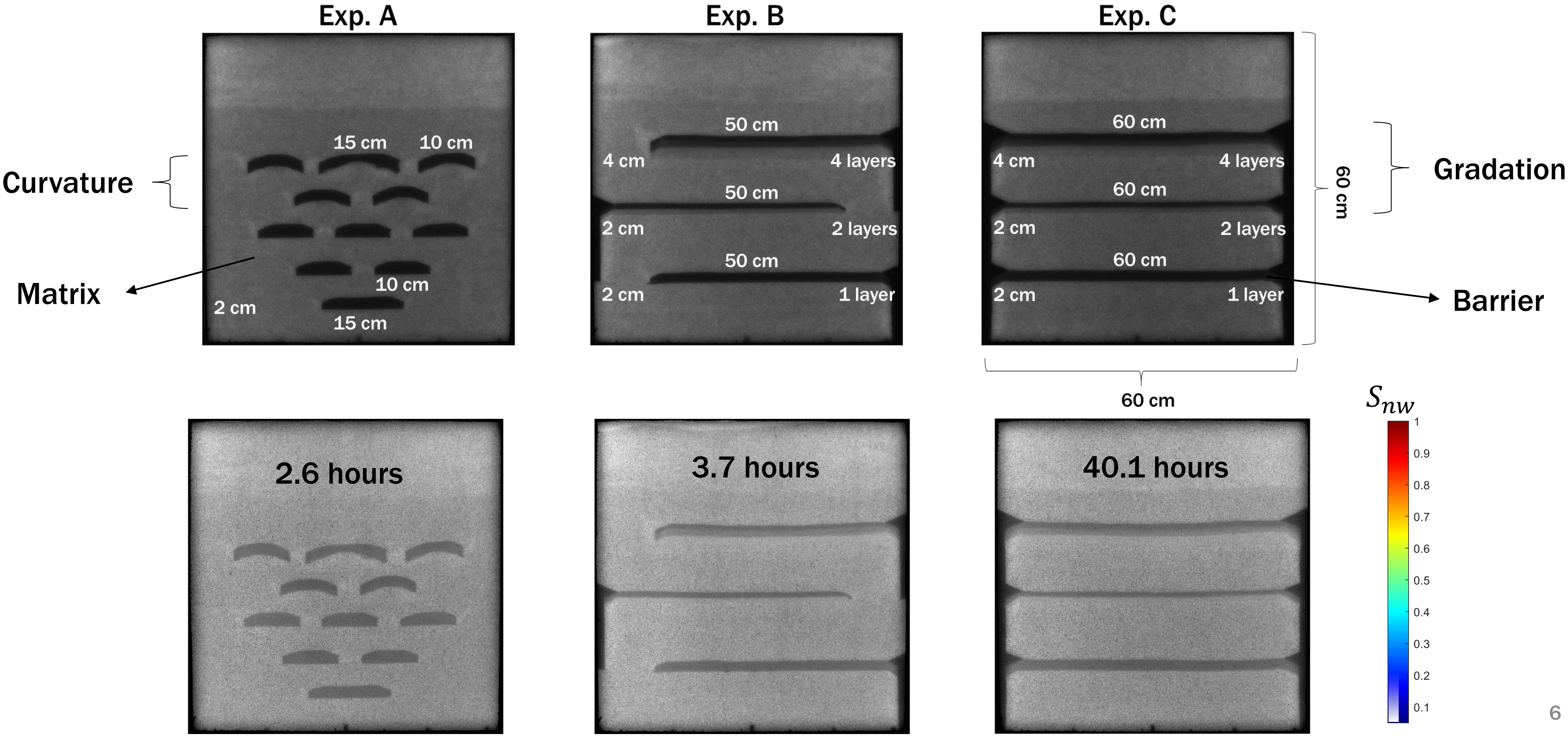



Flett et al., 2007

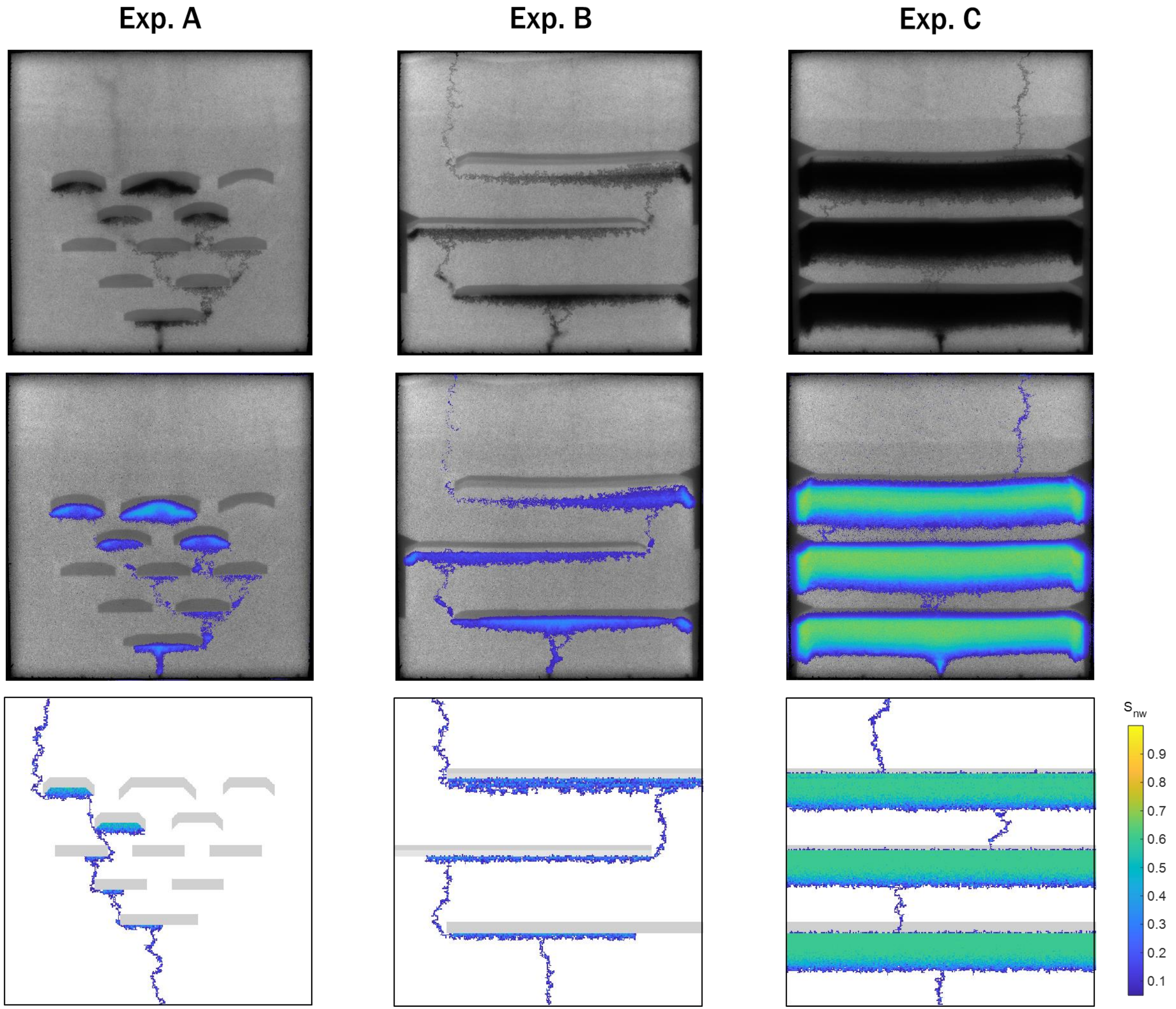
# What makes a good barrier?

- Which barrier properties affect the $CO_2$ retention capacity of the composite confining system
  - Barrier length
  - Barrier shape
  - Barrier gradation
    (Fining upward sequence)

# Experimental domains and results



# Saturation results at domain breakthrough

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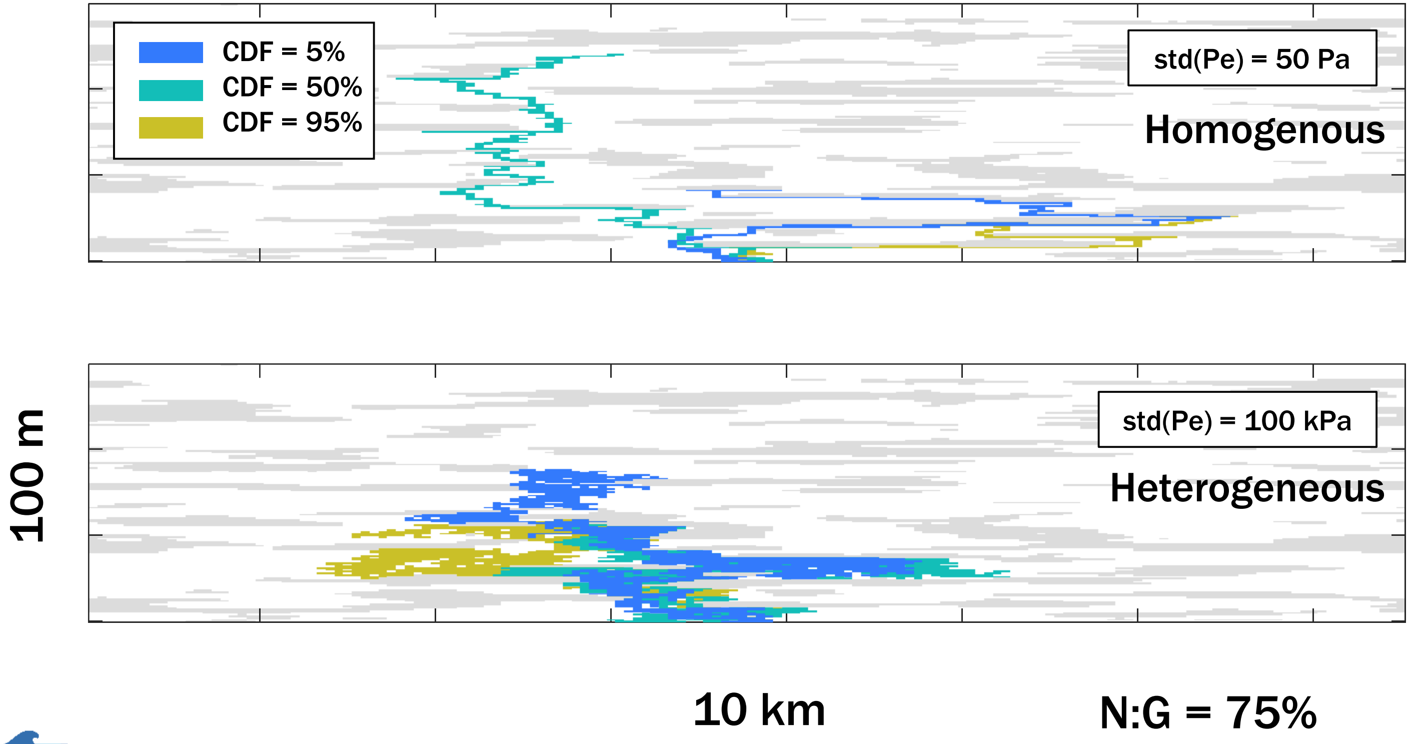
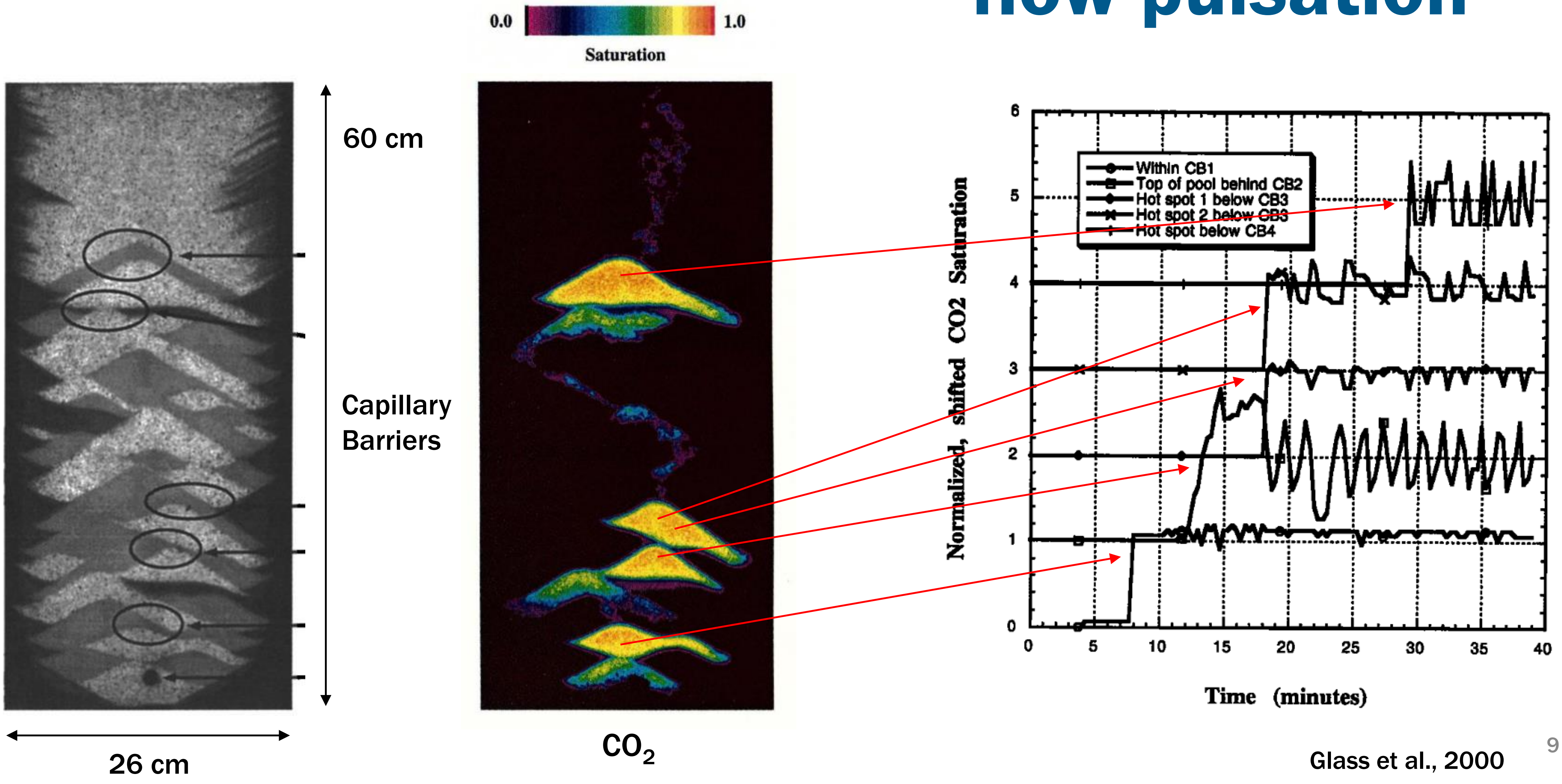
# Field-scale simulation as validation

- As long as the injected $CO_2$ amount does not exceed the storage capacity, plume vertical migration is contained.

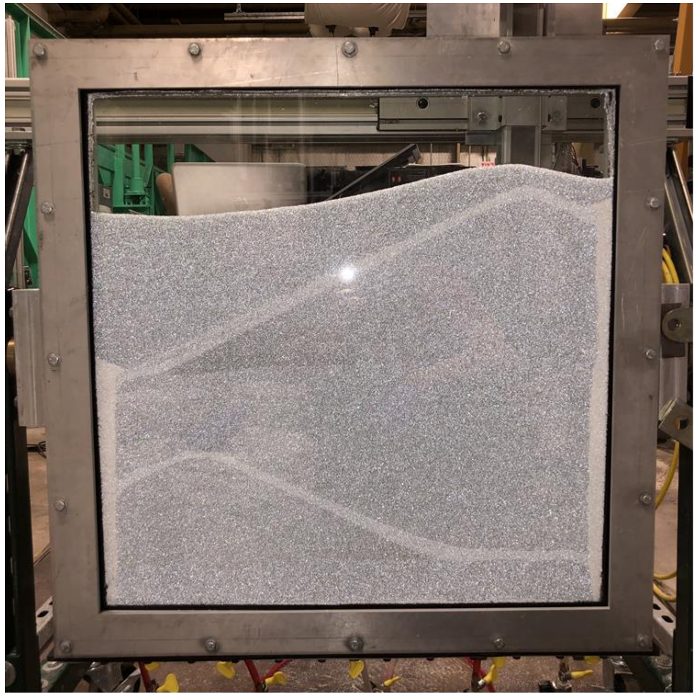


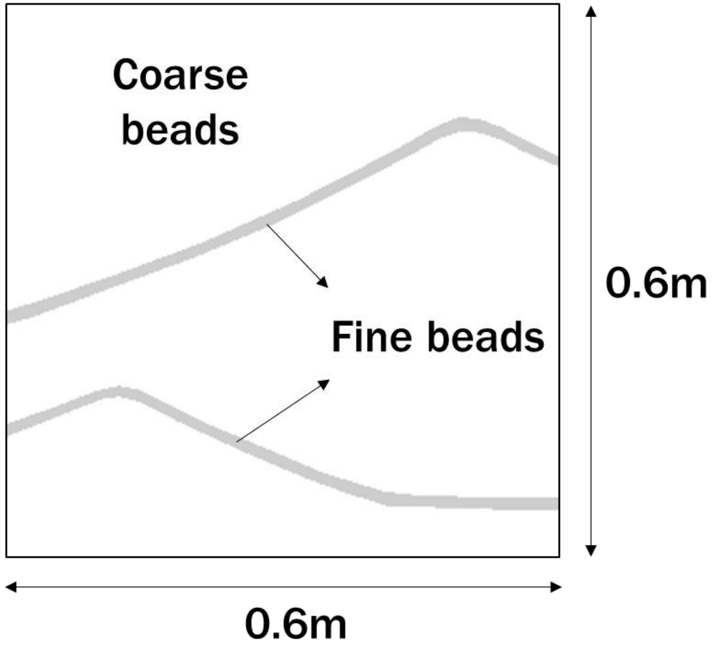
# Small-scale heterogeneity can also cause flow pulsation



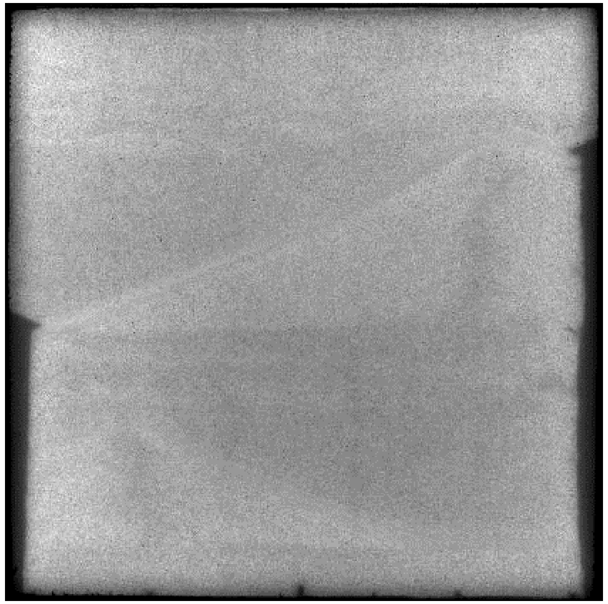

Glass et al., 2000

# Dynamic flow behavior: heterogeneity induced $CO_2$ flow pulsation

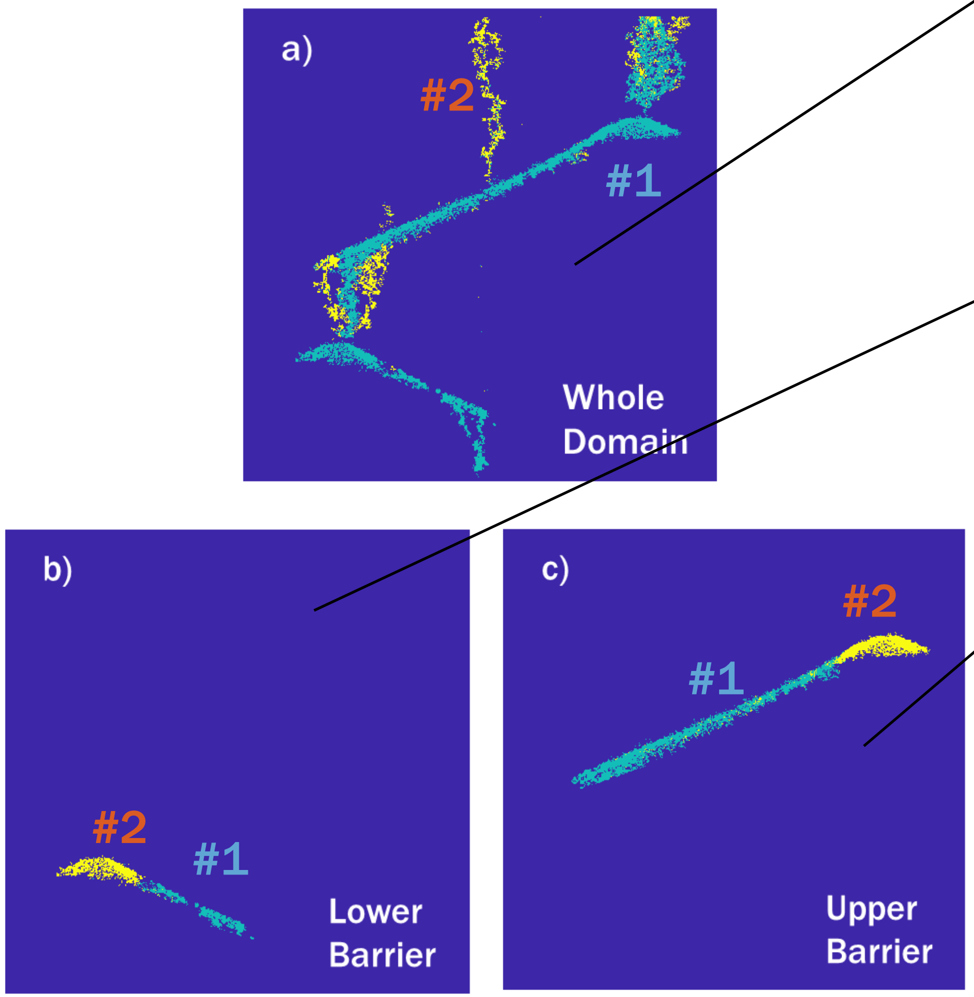


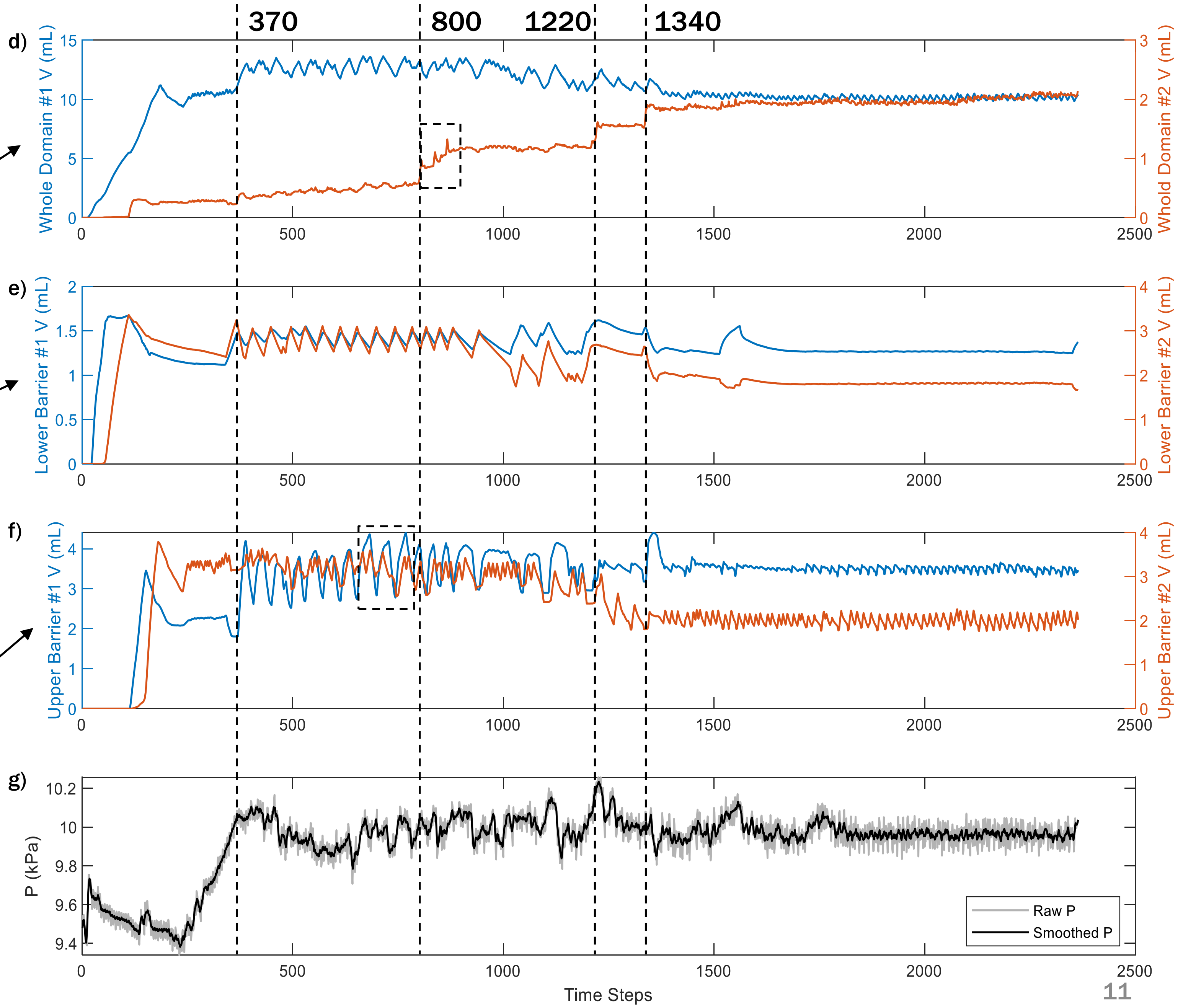



0.2 mL/min



# Time series clustering analysis

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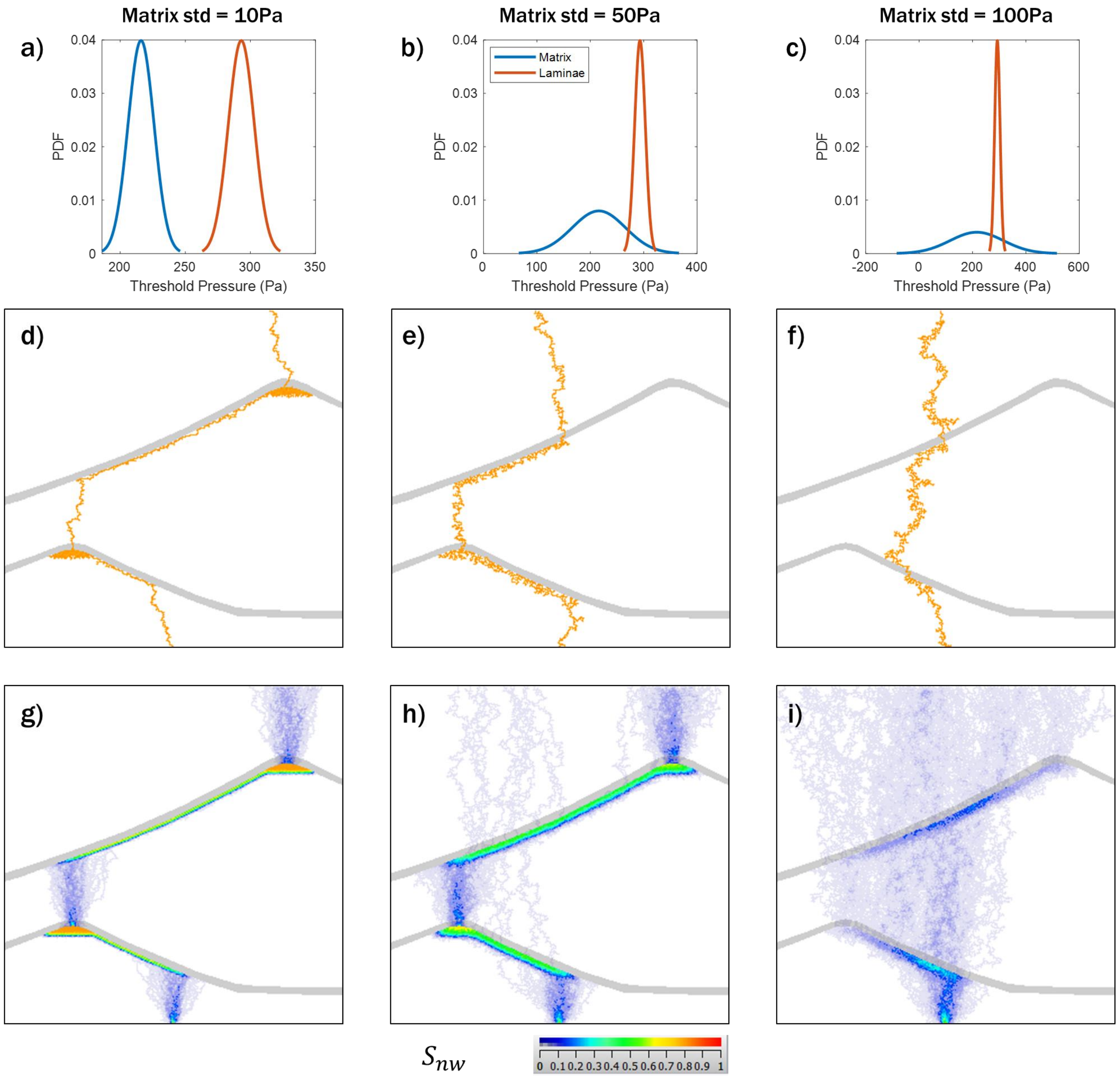
# Modeling the probability of early breaching with simulation

Single simulation run

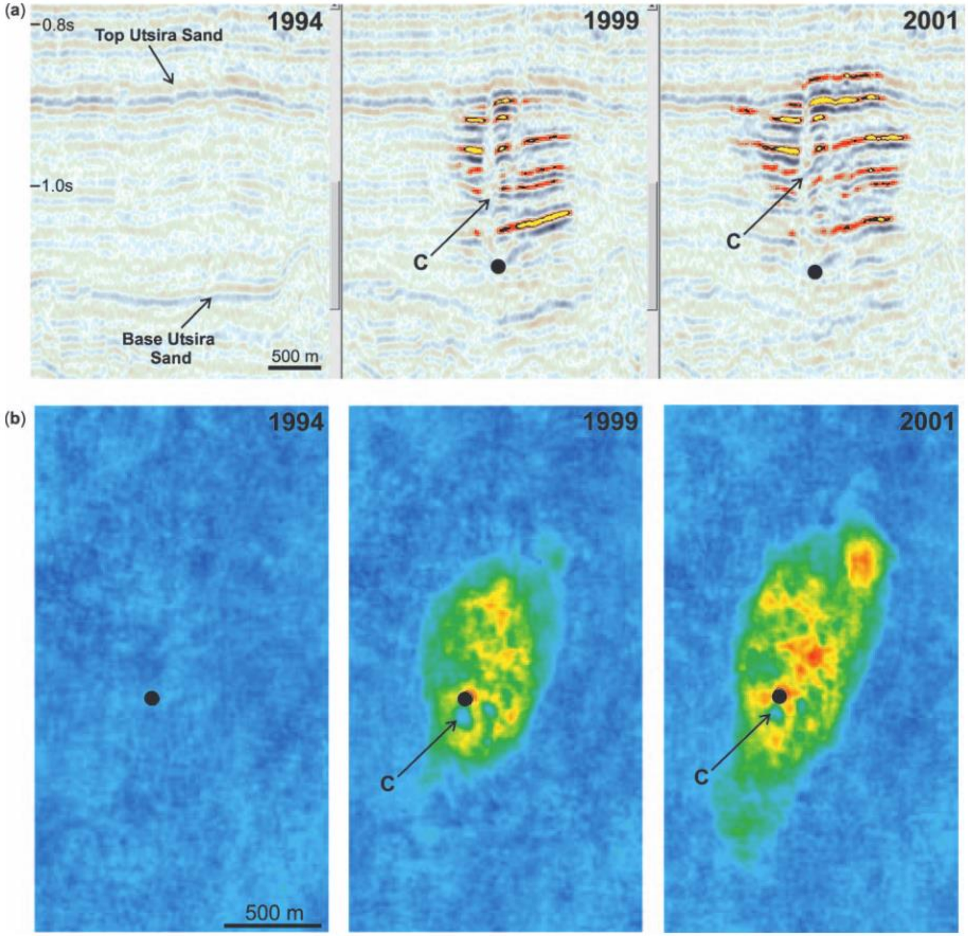
Multiple simulation runs combined



# In geologic $CO_2$ storage, time-lapse seismic survey is an important monitoring method

- To monitor the $CO_2$ plume saturation and migration extent
- Sandbox models provide an alternative to simulations for uncertainty quantification

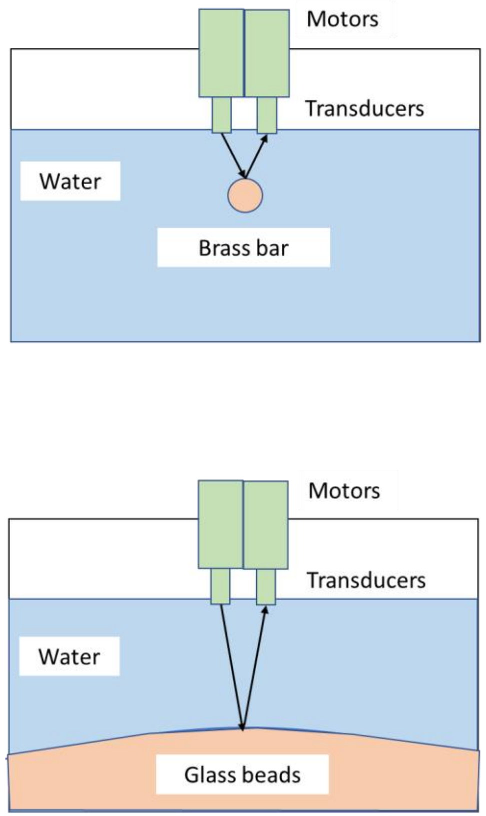
4D seismic quantification of a growing $CO_2$ plume at Sleipner, North Sea



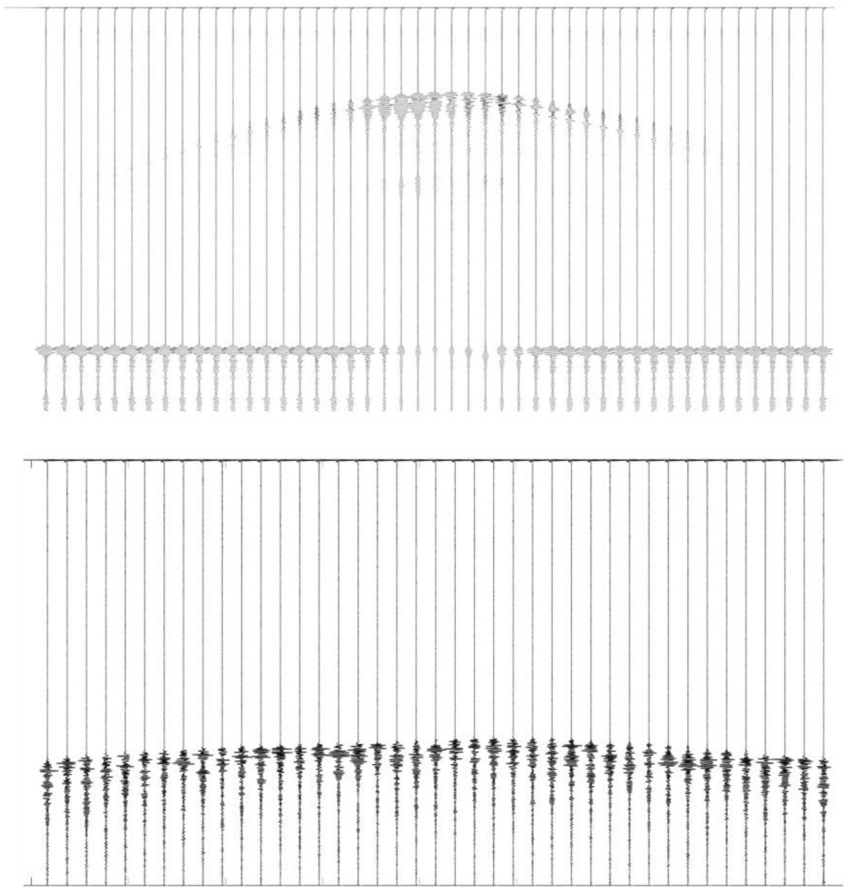

Chadwick et al., 2005

# Lab-scale ultrasonic sensing system

- Ultrasonic imaging
  - Same principle as seismic reflection
- Offshore $CO_2$ plume monitoring
  - Transducer frequency is 1MHz. At a typical scale for sandbox of 10,000:1, this represents a field source with a center frequency of 100 Hz. (Sherlock et al., 1997)

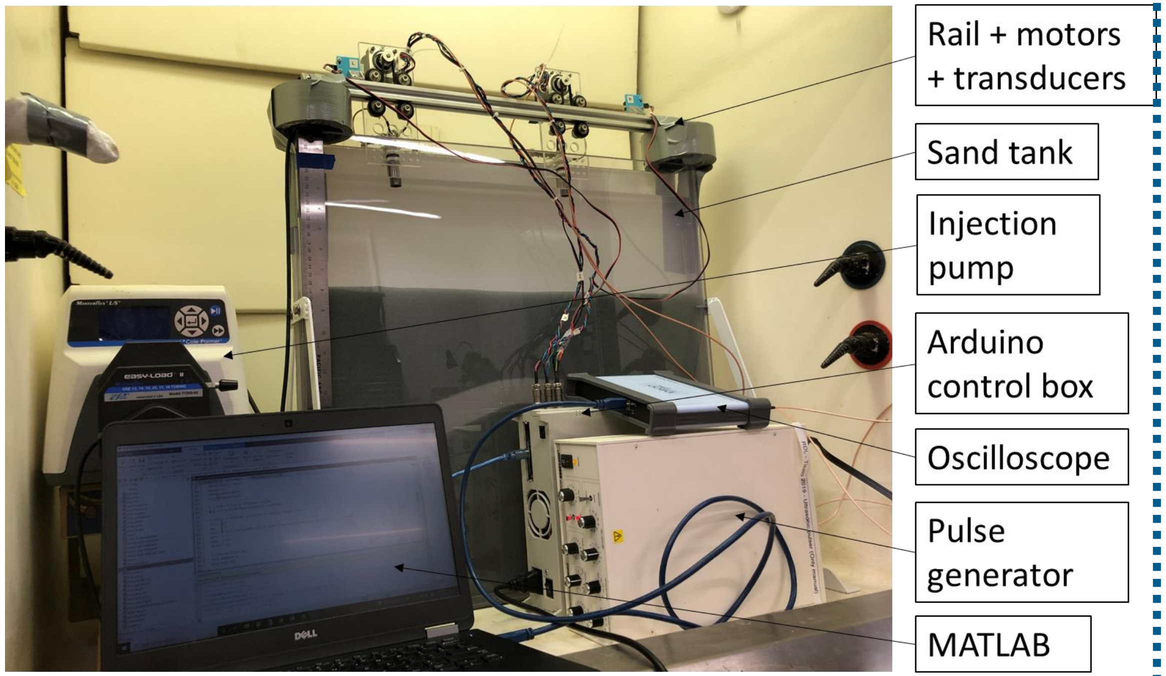


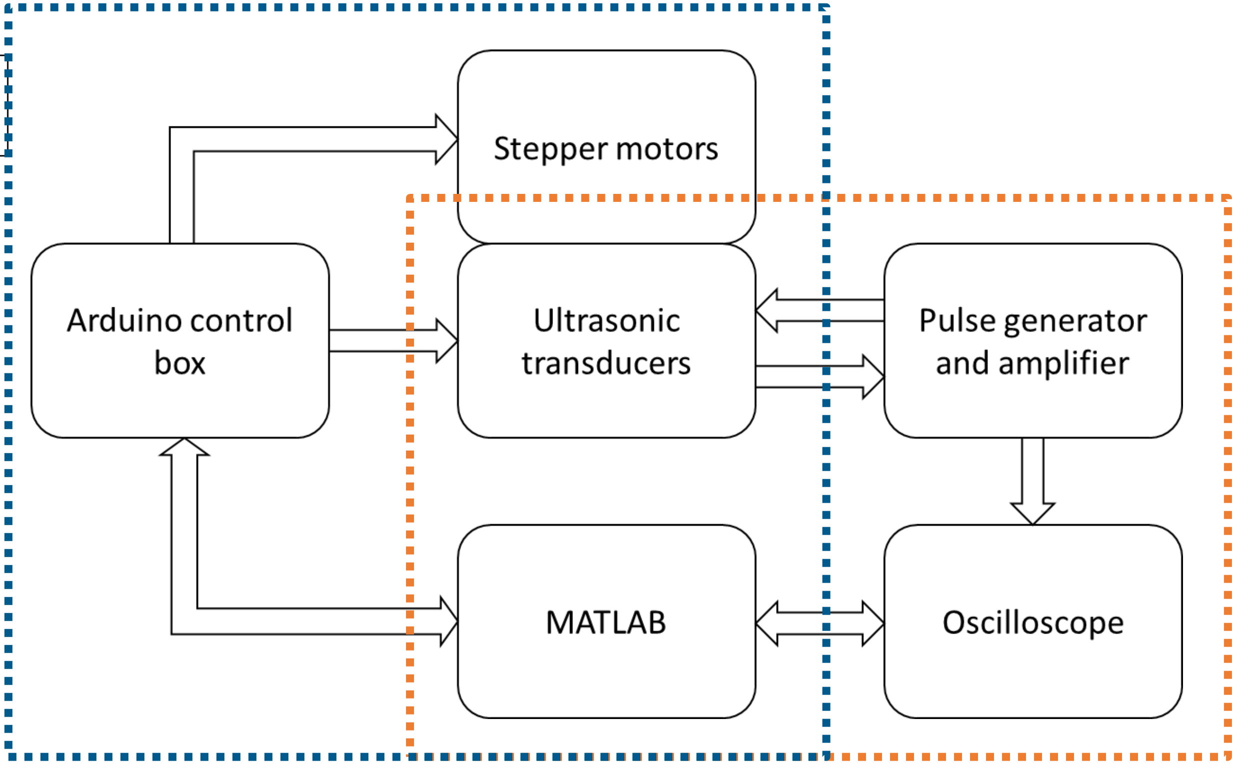

Zero offset panels



# Lab-scale ultrasonic sensing system setup

- Main components:
  - Ultrasonic signal generation and receiving system
  - Motors and their control system

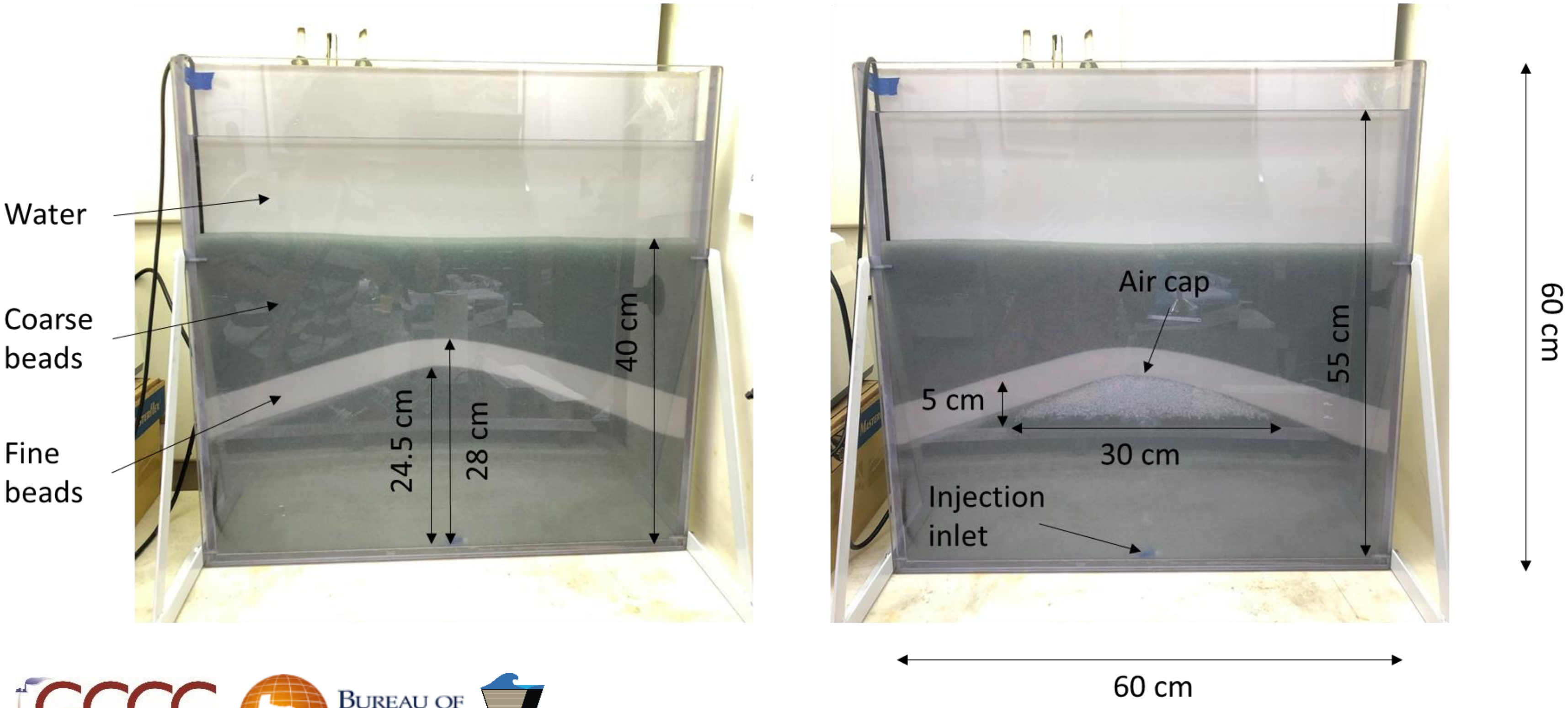


# Experimental procedure

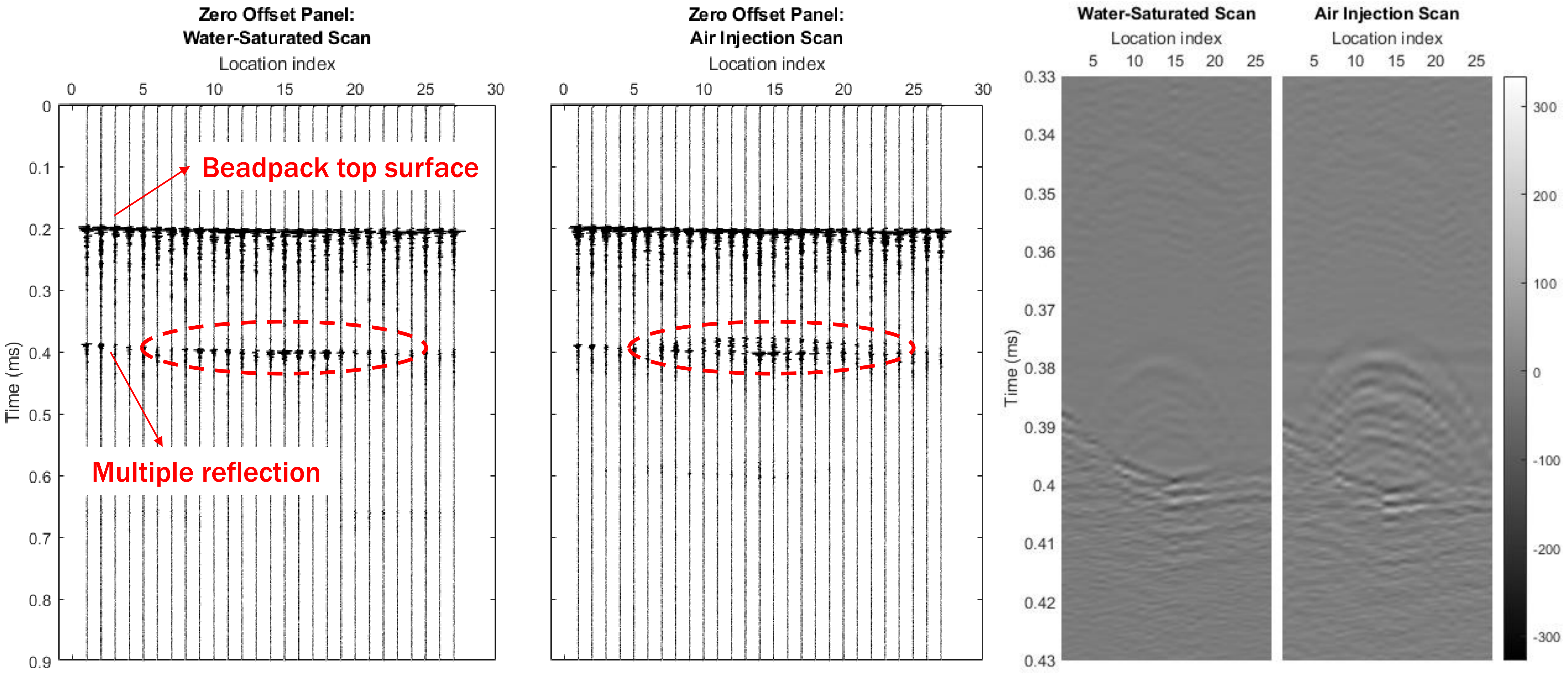
**Before air injection: water-saturated beadpack**

**After air injection: an air cap is now present**




- Wet packing
- Fine-bead anticline structure
- Water and air
- Two scans: before and after air injection

# Compare the images before and after air injection



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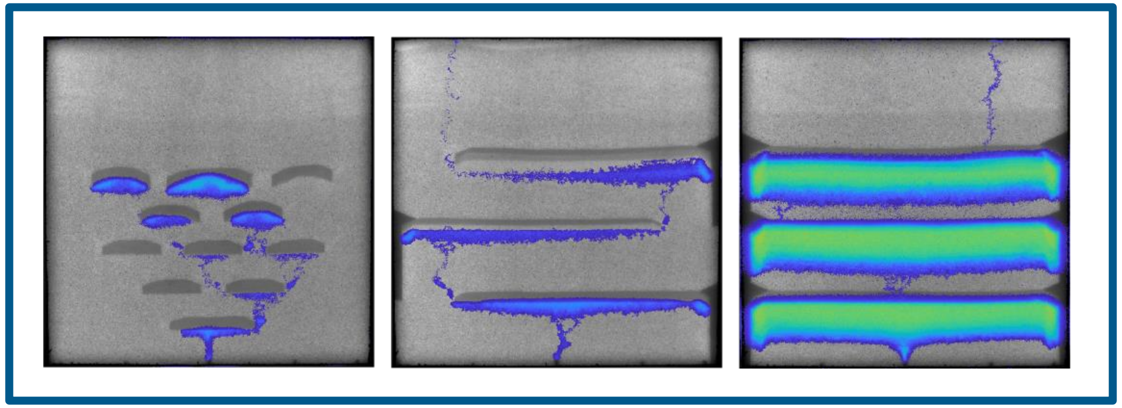
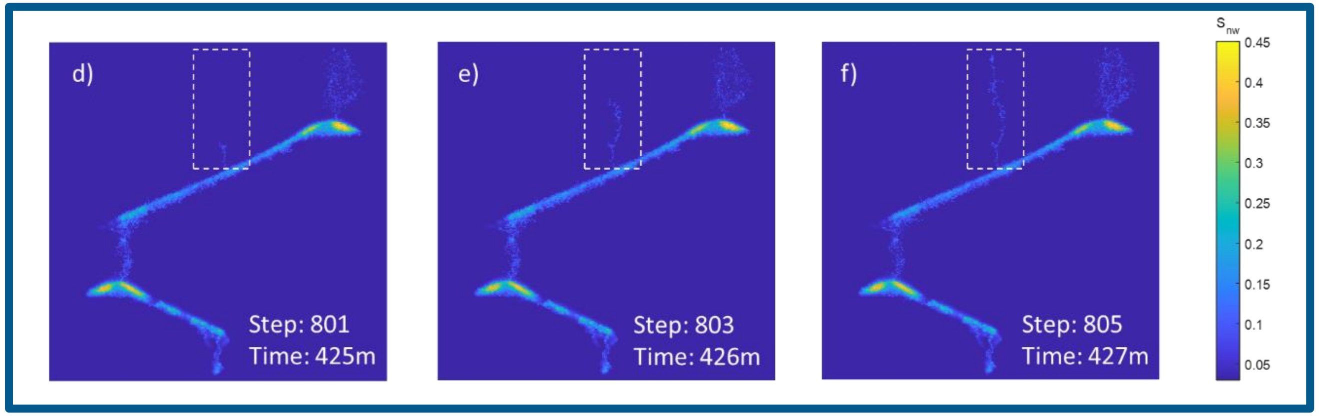
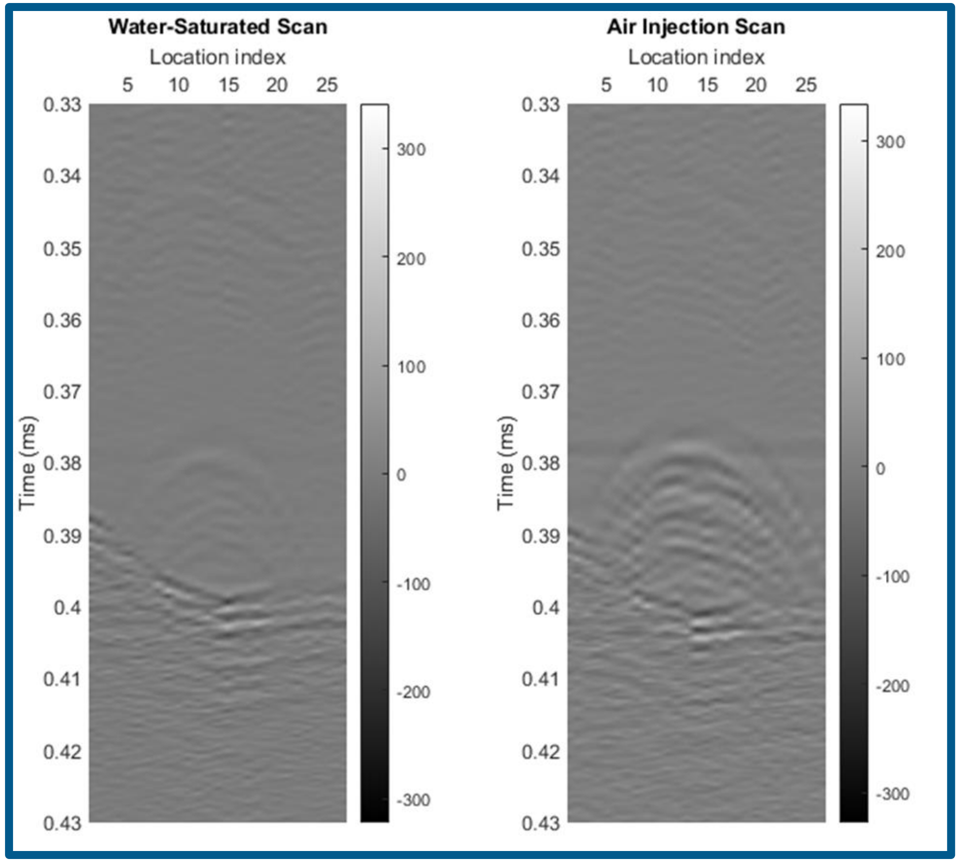
## Barrier Systems: Barrier area and frequency matter



## Flow Pulsation: Can lead to early breakthrough of capillary barriers




## Ultrasonic Sensing: The presence of a gas cap is detectable

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