Stanford University
Global Climate & Energy Project

Core- and pore-scale experimental study of relative permeability properties of CO_2 and brine in reservoir rocks

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- OVERVIEW -

- Long term motivations
- Experimental Setup - Procedure
- Core flooding experiments - Results
- Conclusions

- LONG TERM MOTIVATIONS -

Perform sub-core scale experiments and simulations to:

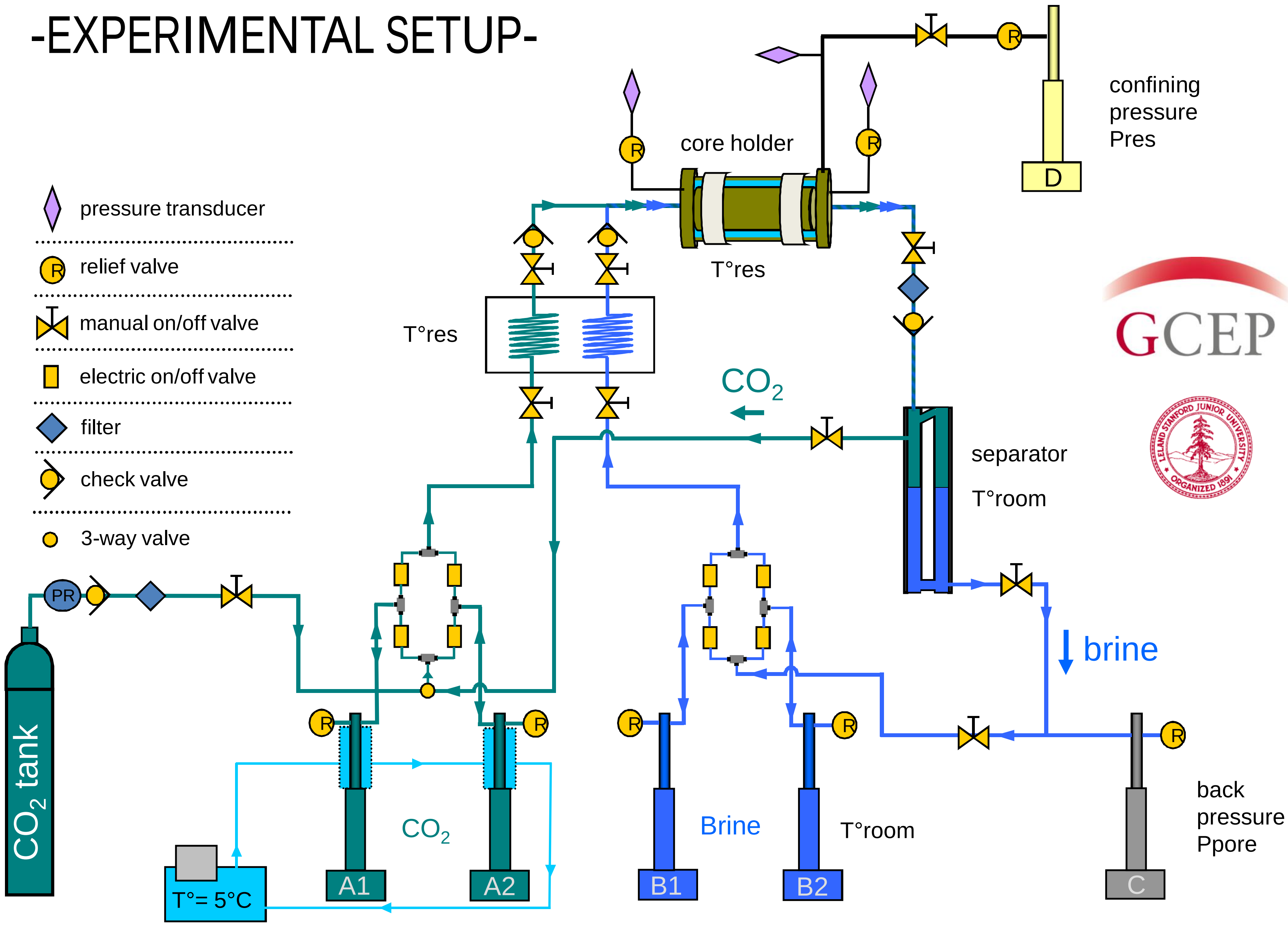
- get an improved understanding of the pore and core-scale physics

- predict the spatial and temporal distribution of CO_2 saturation and trapping

Today:

- 2-phase flow experiments on reservoir rocks (drainage)
- effect of injection rate on relative permeability to brine and CO_2
- influence of rock heterogeneities and gravity on CO_2 saturation

-EXPERIMENTAL SETUP-



- PROCEDURE -

Steady state relative permeability experiments at a given *total* volumetric flow rate:

- core initially saturated with brine
- CO_2 and brine are injected at a given fractional flow until steady state is reached

f_{CO2}= vol. flow rate of CO_2 / (vol. flow rate of brine + vol. flow rate of CO_2)

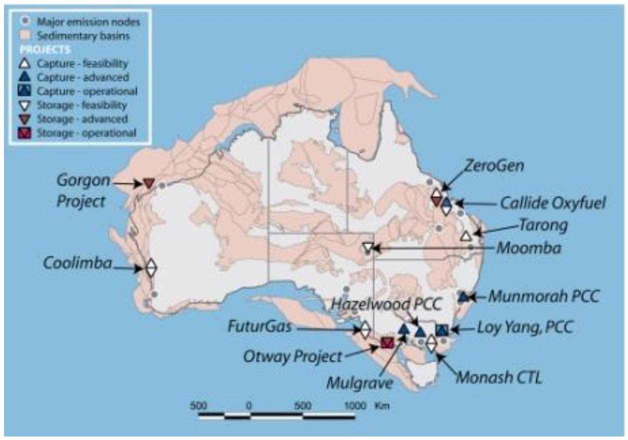
$f_{brine} = 1 - f_{CO2}$

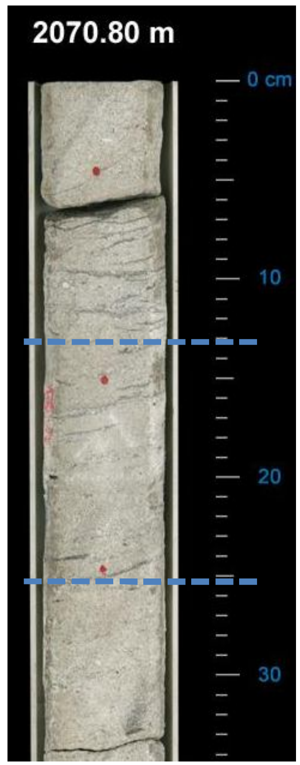
- at steady state, the pressure drop across the core is recorded and CO_2 saturation is determined

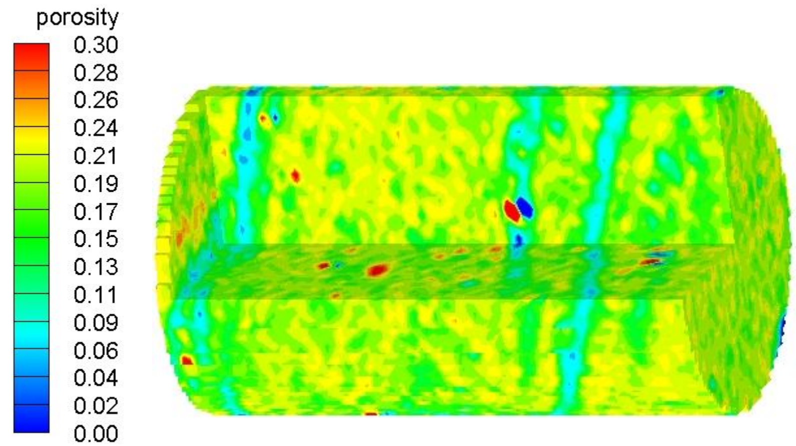
- f_{CO2} is increased

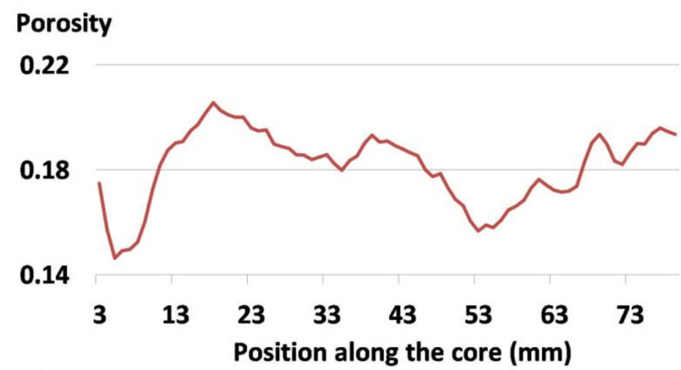
- EXPERIMENTS – #1 -

CO2CRC COOPERATIVE RESEARCH CENTRE FOR GREENHOUSE GAS TECHNOLOGIES





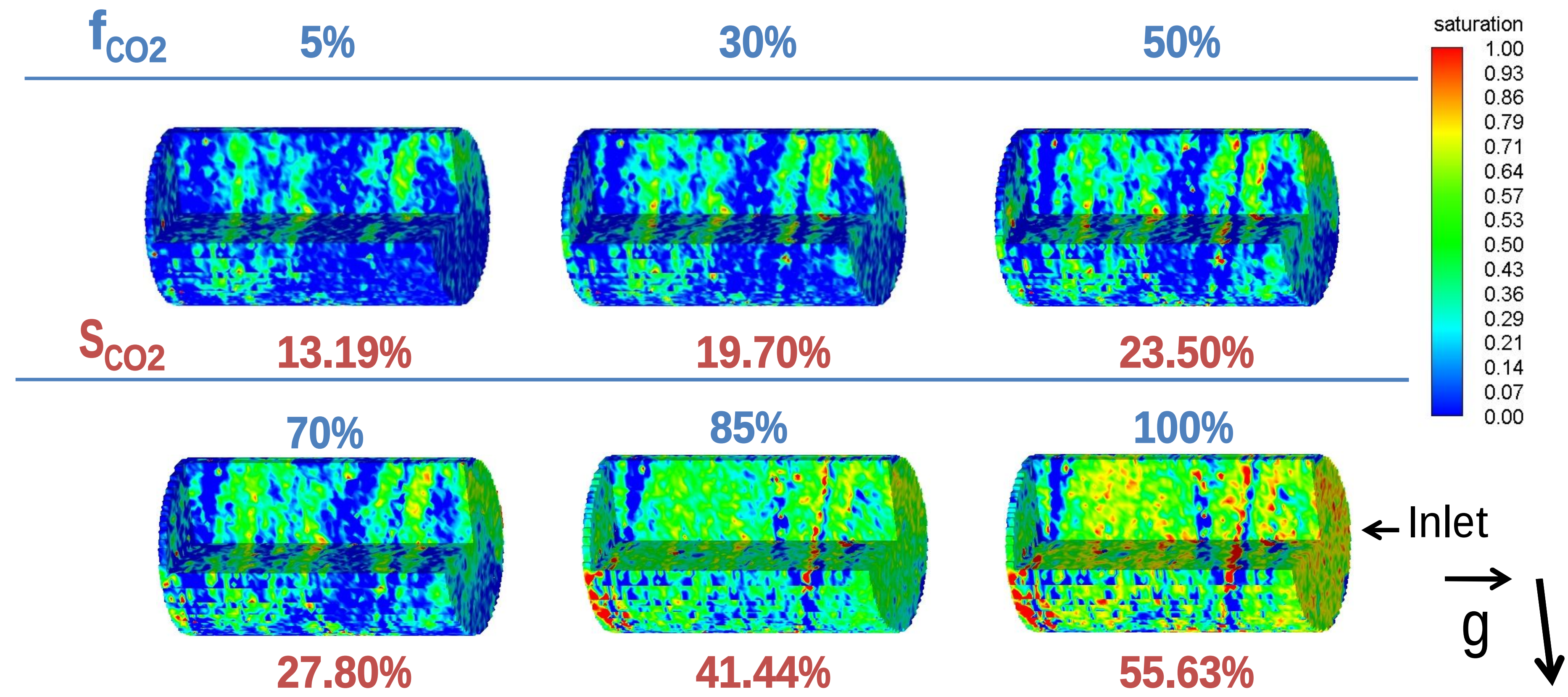




Otway Project
Well CRC-1
Otway basin, Australia

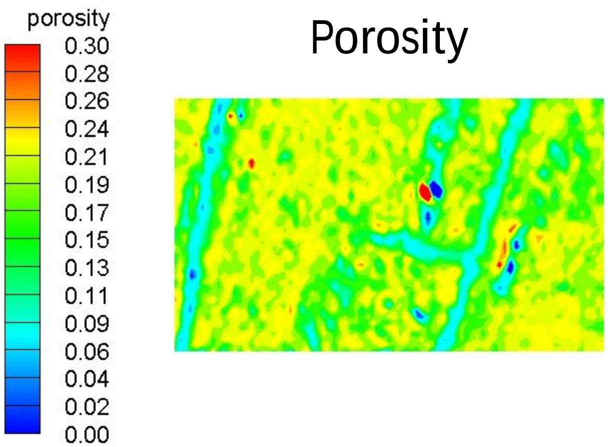
Sample:
5.08 cm diameter
8.5 cm long
k = 50mD

Saturation maps at steady state for different fractional flows of CO_2

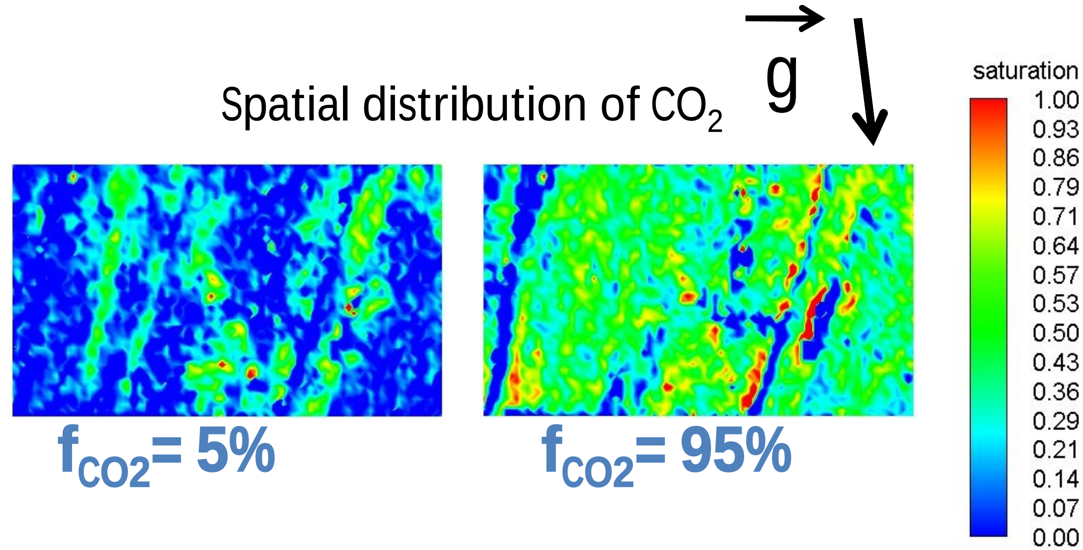


T = 63 °C
P_{pore} =1800 psi / 12.4 Mpa
brine composition: 6g/L NaCl+ 0.5 g/L $CaCl_2$
Drainage at 2 mL/min

Porosity



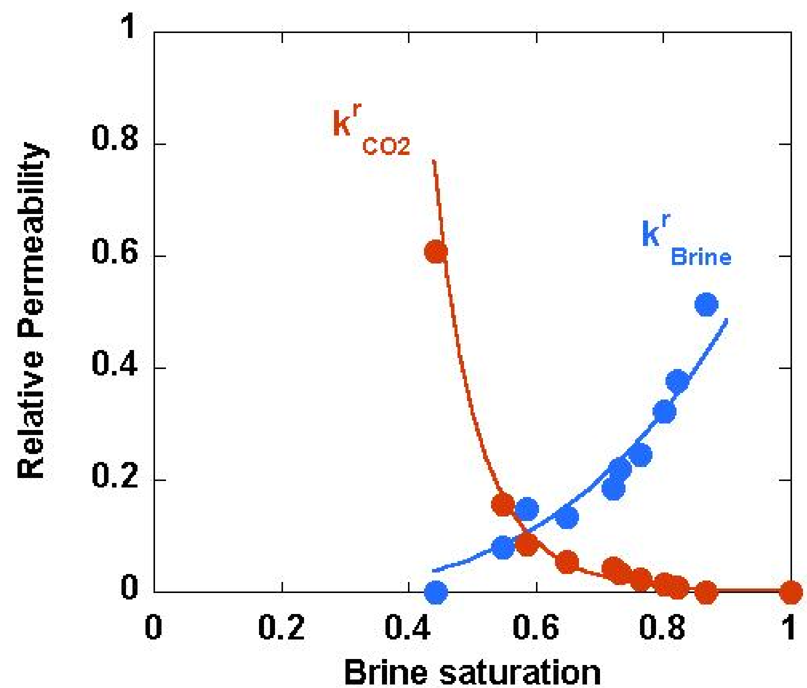
Spatial distribution of CO_2



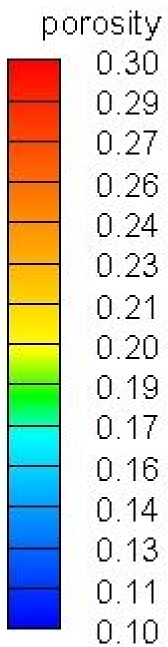
-> Strong correlation porosity / CO_2 saturation

-> High residual brine saturation

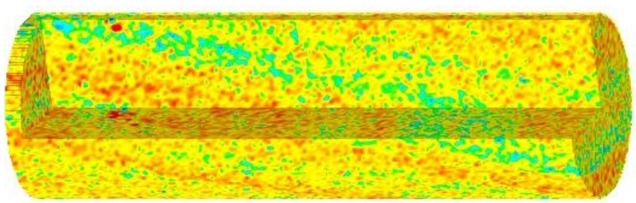
-> No visible gravity override



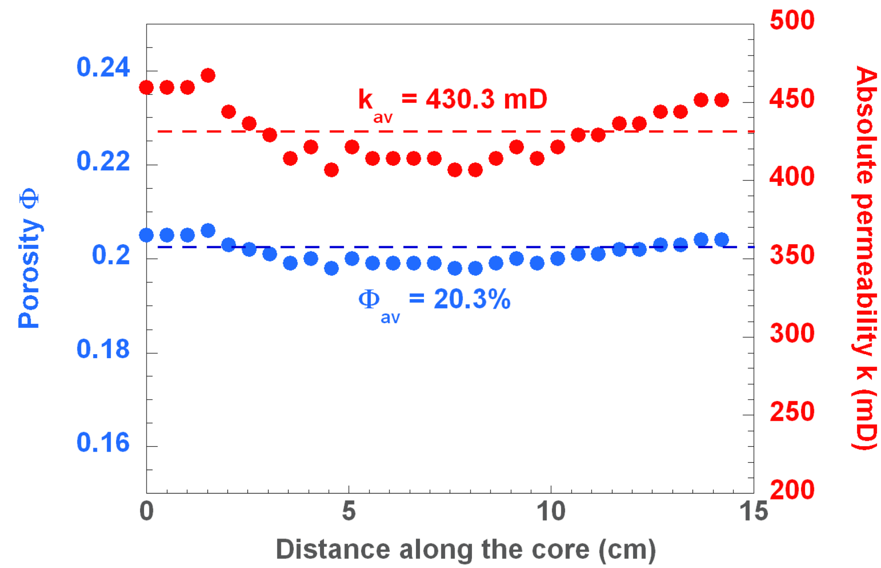
- EXPERIMENTS – #2 -



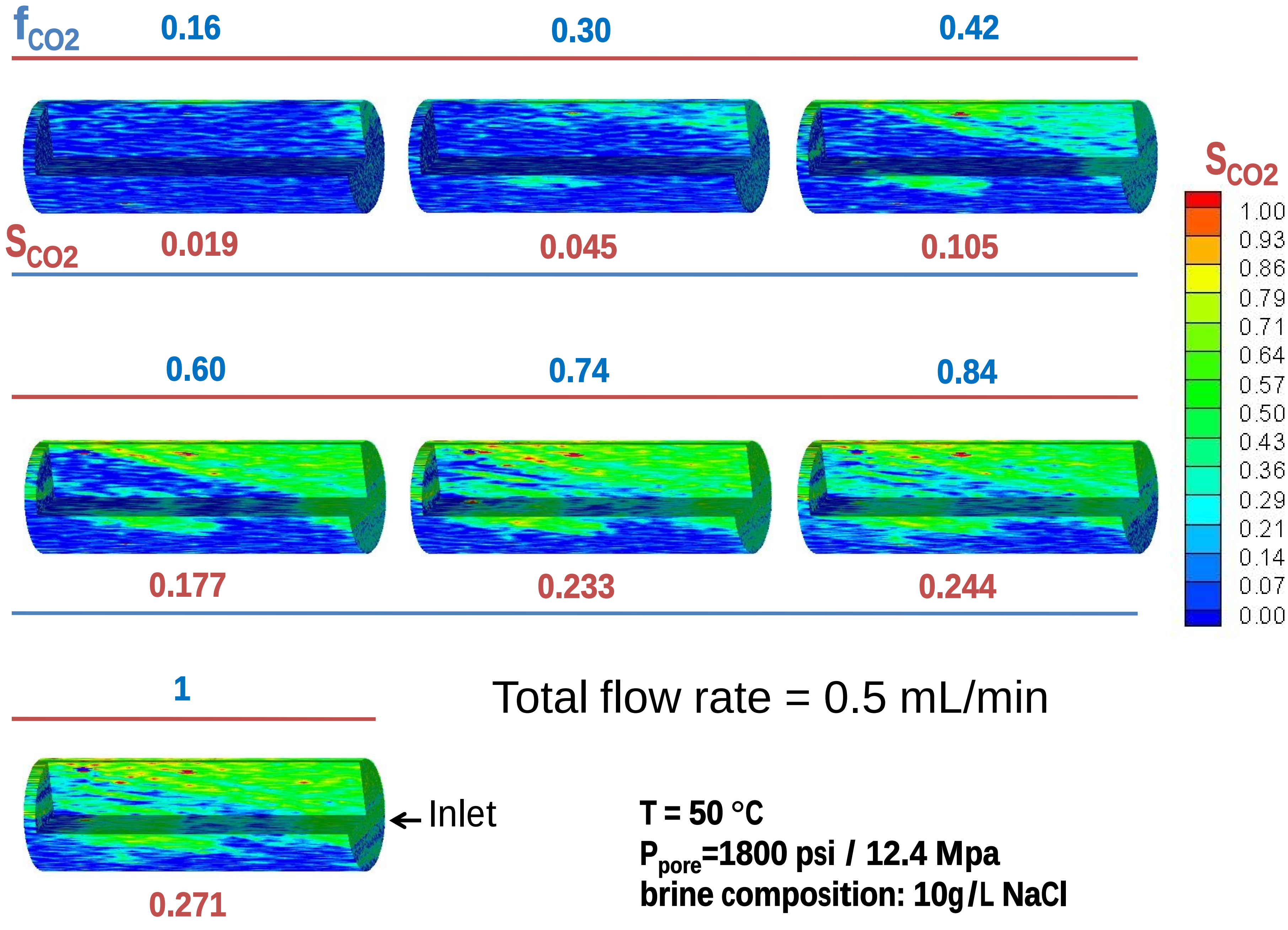
Berea Sandstone

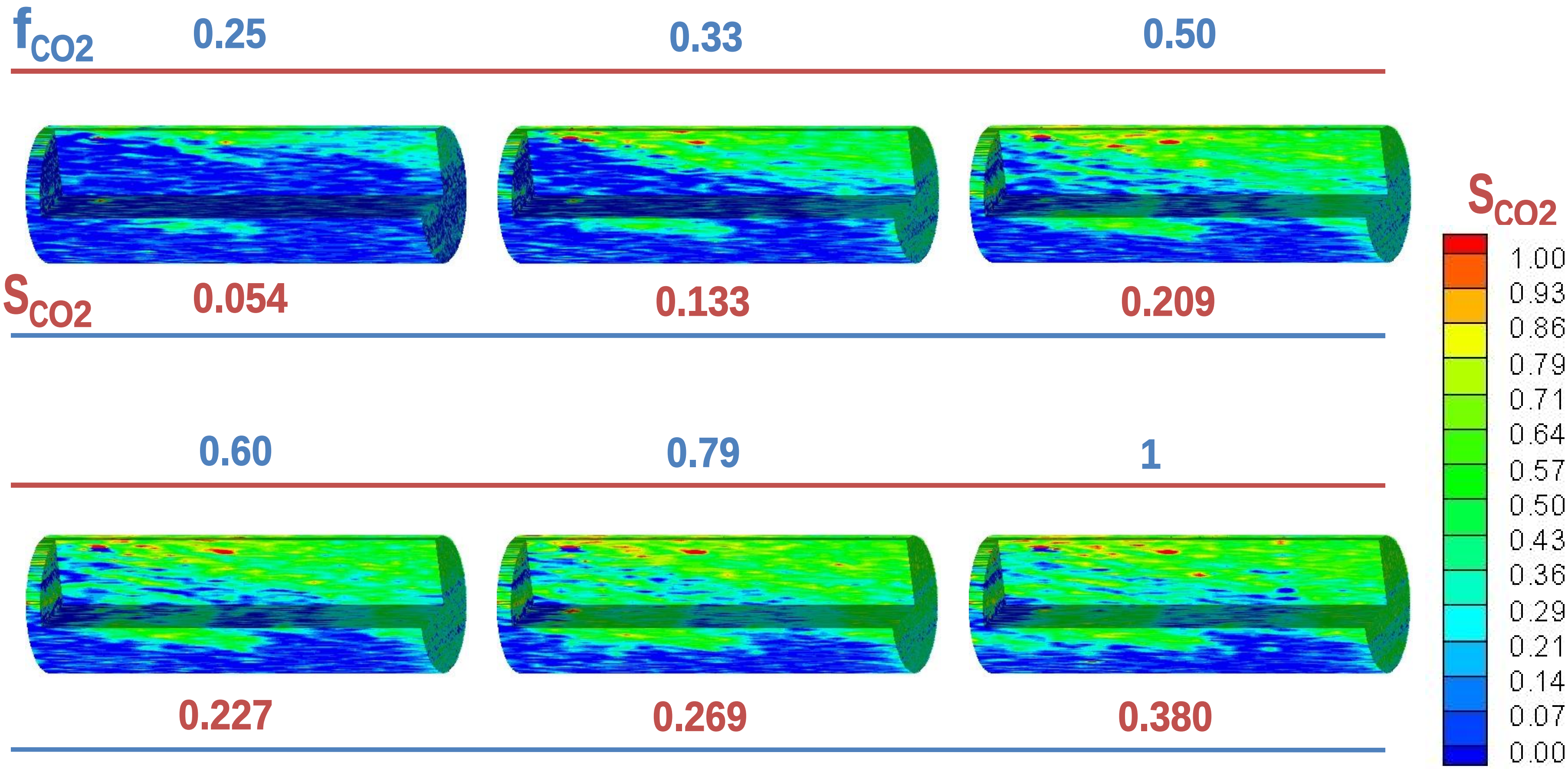


<u>Sample:</u>
5.08 cm diameter
15.24 cm long
k = 430mD

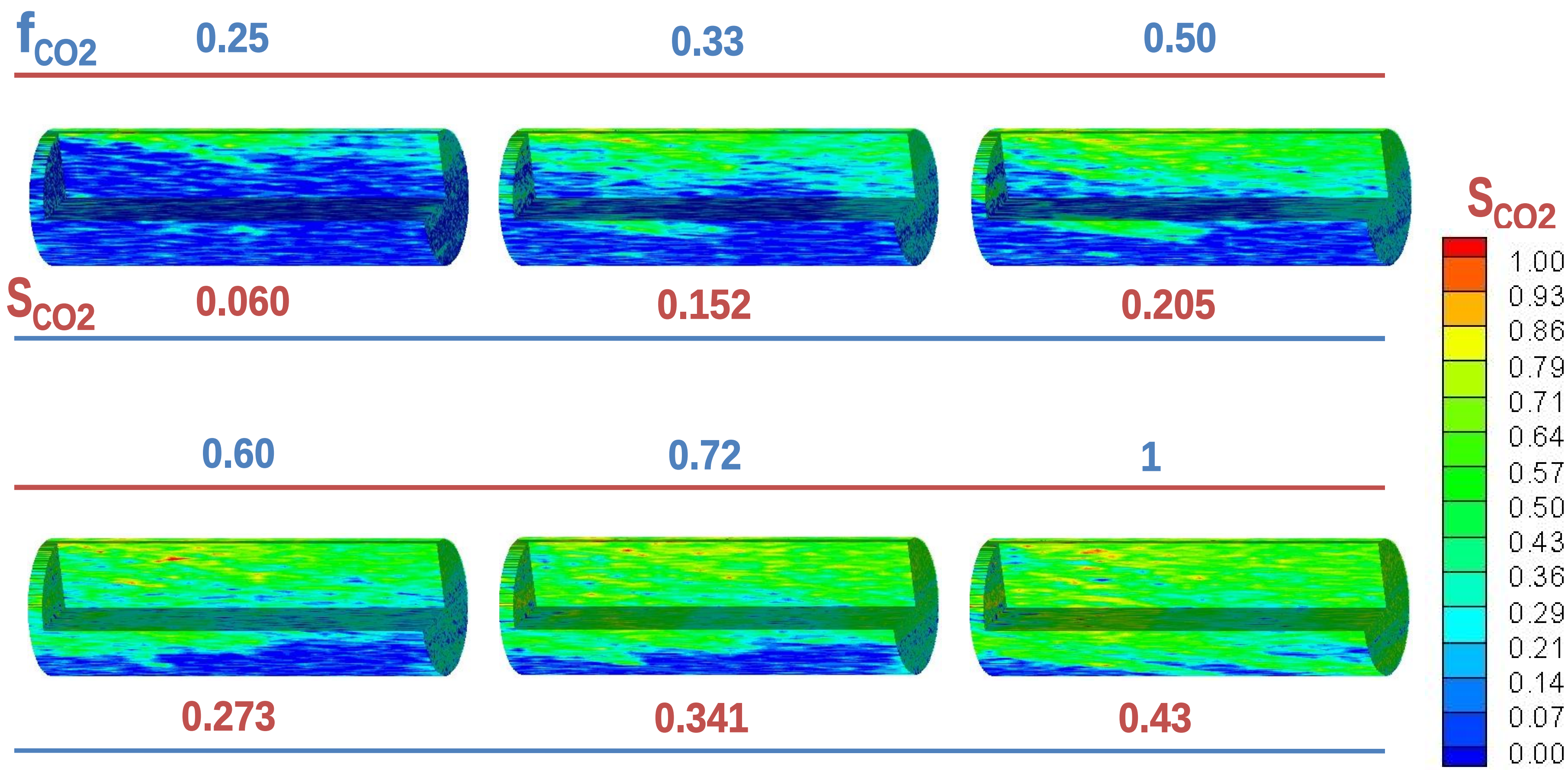


- non homogeneous core
- low porosity layers oriented in the diagonal of the sample


f_{CO2}
0.16
0.30
0.42
S_{CO2}
0.019
0.045
0.105
0.60
0.74
0.84
0.177
0.233
0.244
1
0.271
Inlet
S_{CO2}
1.00
0.93
0.86
0.79
0.71
0.64
0.57
0.50
0.43
0.36
0.29
0.21
0.14
0.07
0.00
Total flow rate = 0.5 mL/min
T = 50 °C
P_{pore}=1800 psi / 12.4 Mpa
brine composition: 10g/L NaCl



Total flow rate = 1.2 mL/min



Total flow rate = 2.6 mL/min

-> saturation dependant on flow rate

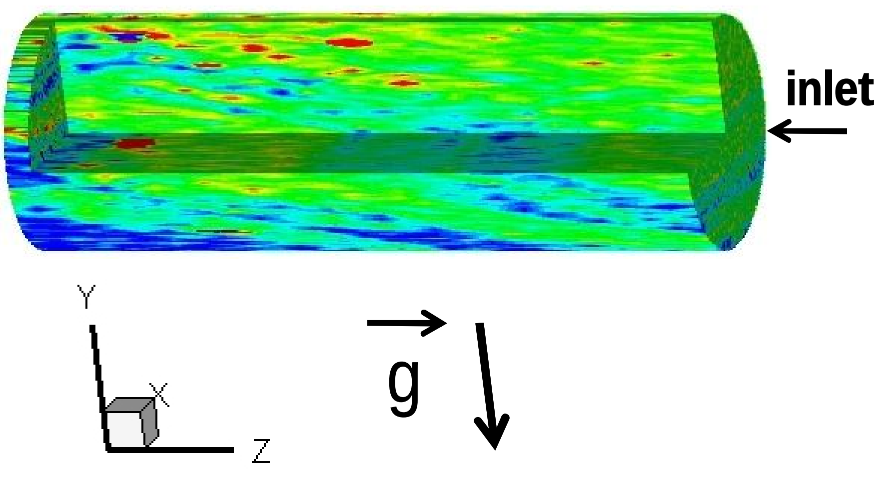
-> bottom of the core not invaded with CO2

- Role of gravity?-

- Core initially saturated with brine
- Injection of 100% CO_2 in two different configurations

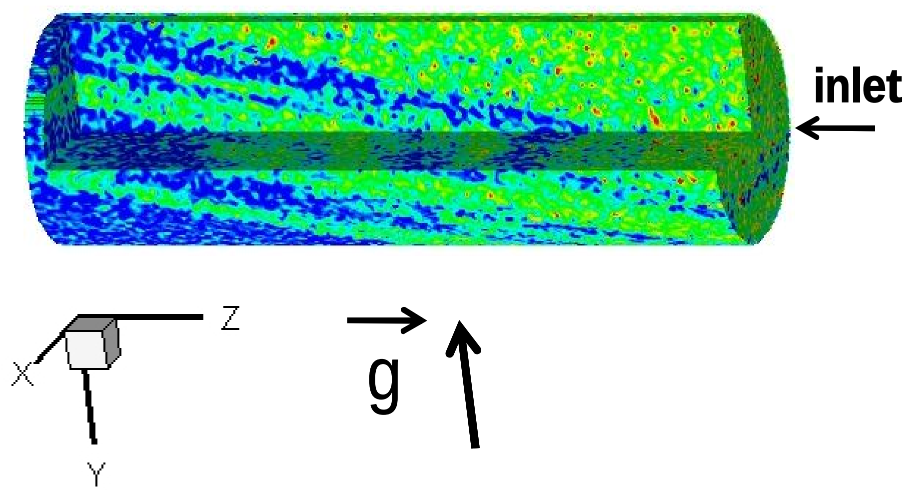
Configuration 1

Total flow rate = 3.39 mL/min
Av. CO_2 Saturation = 0.39



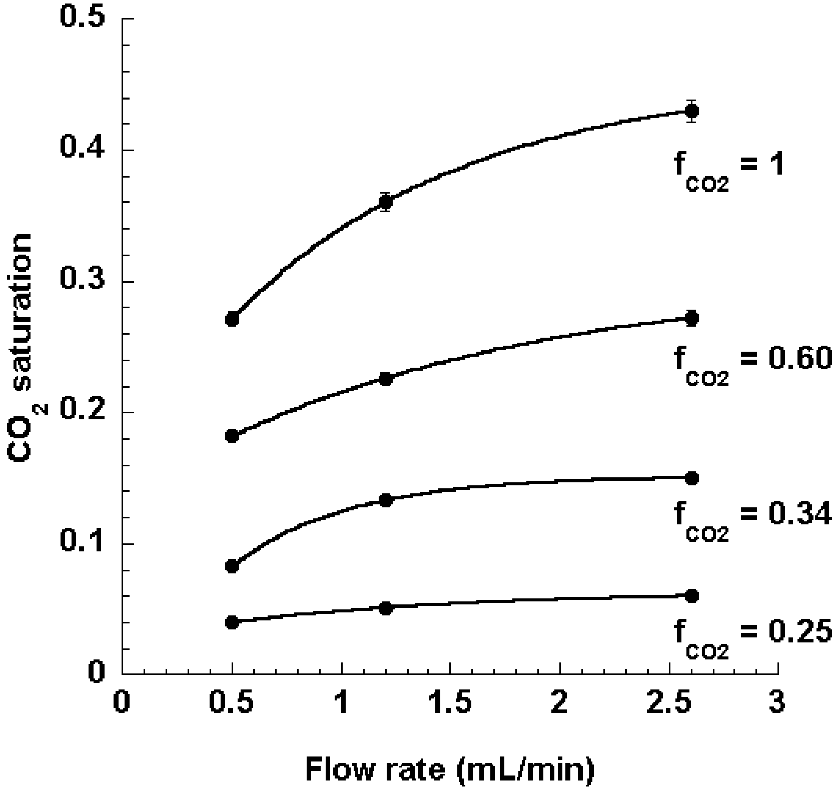
Configuration 2: **core flipped 180° around the main axis**

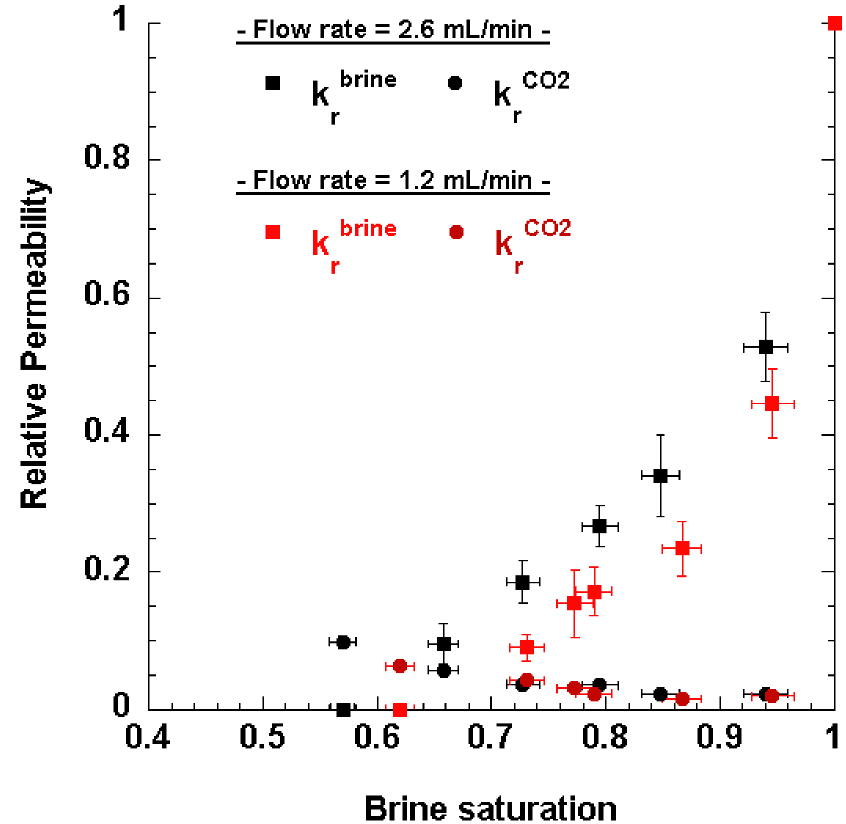
Total flow rate = 3.58 mL/min
Av. CO_2 Saturation = 0.33



-> No visible gravity effect

- Flow rate effect-

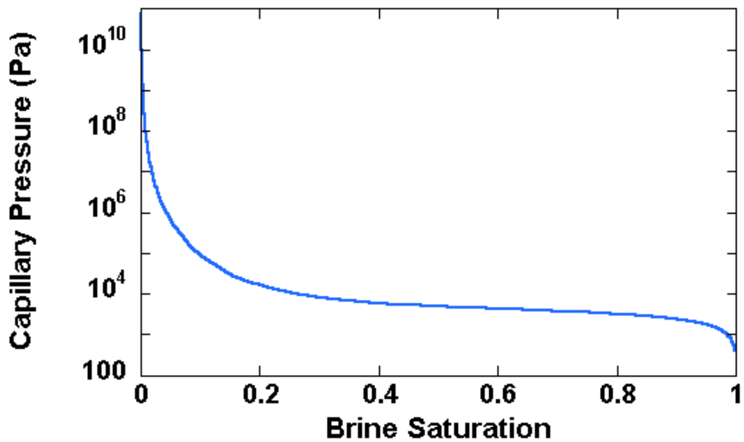


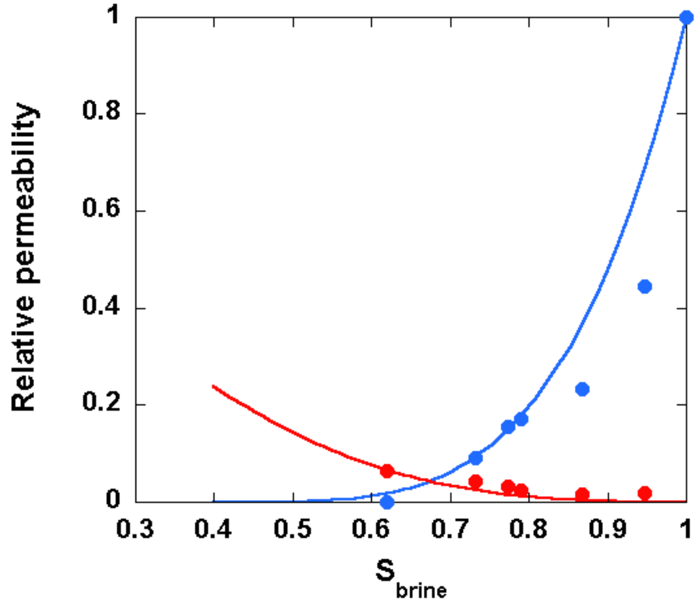


-> Saturation and relative permeability are function of flow rate

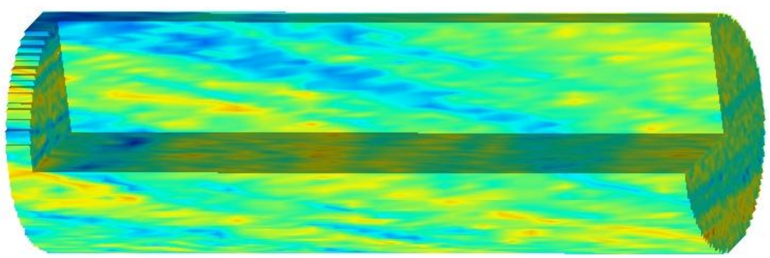
-> The higher the flow rate | the higher the saturation
| the higher the relative permeability

- Comparison with simulations -

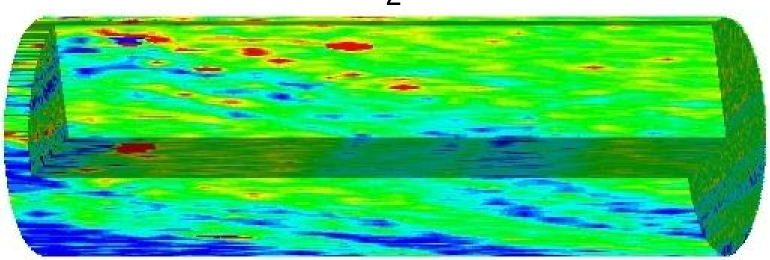


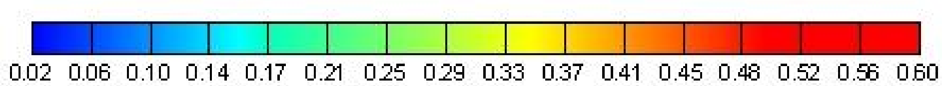


Simulation using TOUGH2 MP
50% CO_2, 1.2 mL/min



Experiment
100% CO_2, 2mL/min

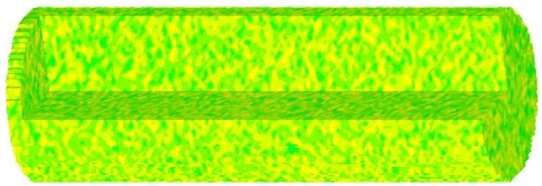


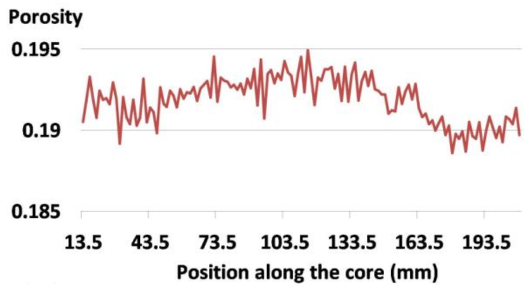


-> Good qualitative match between experiment and simulation

- EXPERIMENTS – #3 -

Homogeneous Berea Sandstone

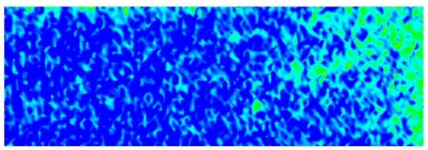


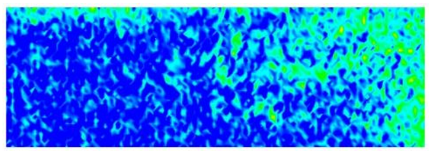


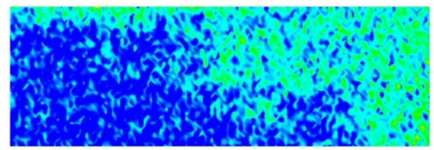
<u>Core Sample:</u>
5.08 cm dia.
20.2 cm long
k = 150 mD

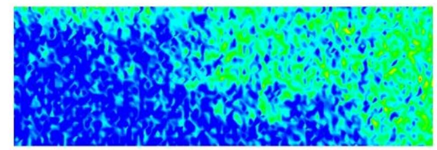
<u>Conditions:</u>
T = 63°C
P_{pore}=12.4 Mpa
1 mL/min

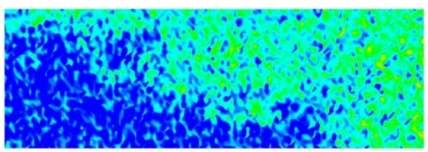
f_{CO2} / S_{CO2} (↓ Top, ← Inlet)

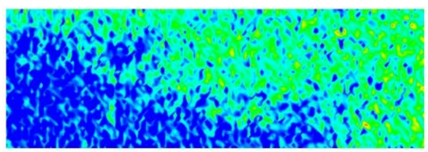
5%

7.19%

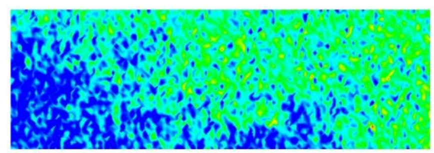
15%

11.82%

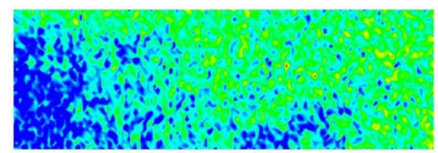
25%

15.75%

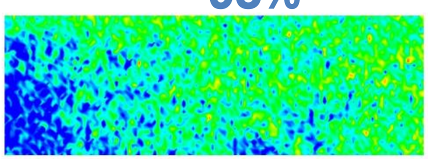
35%

17.88%

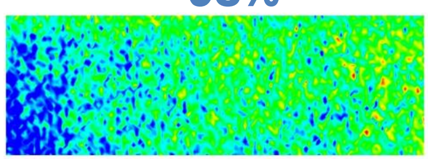
50%

21.31%

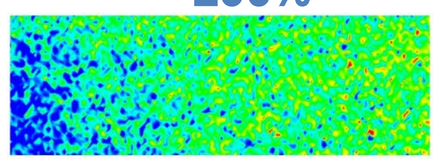
65%

24.02%

80%

28.19%

90%

31.46%

95%

34.05%

98%

36.54%

100%

38.19%

<u>-> gravity override</u>

- CONCLUSIONS-

Core flooding drainage experiments have been carried out at steady state on different core samples.

High injection rates and / or strong heterogeneities ⟶ capillary effect > gravity effect
Low injection flow rate in an homogeneous core ⟶ gravity override

Core saturation and CO_2 spatial distribution are flow rate dependant
⟶ relative permeability curves are flow rate dependant

TOUGH2 simulations can qualitatively reproduce the lab experiments. Improvements in correlations between porosity, saturation and capillary pressure are needed to replicate the experiments.

- FUTURE WORK-

Describe more precisely the flow rate effect on different sample, different conditions, wider flow rate range.

Experimental investigation of imbibitions, relative permeability hysteresis and capillary trapping.

- ACKNOWLEDGMENTS-

- **GCEP** (Global Climate and Energy Project at Stanford University)
- Michael Krause, Chia-Wei Kuo, Ljuba Miljkovic and Sally Benson, **ERE Department, Stanford University**
- **Organizing committee of GHGT9**