WELCOME TO RIGAKU VIRTUAL WORKSHOP

DEEP DIVE: DIGITAL ROCK ANALYSIS

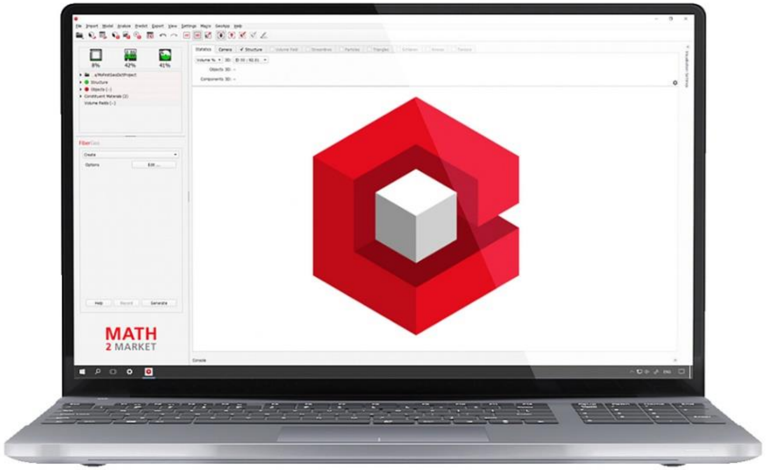
3. Digital Rock Simulations

Watch the recording

Presenter: **Aya Takase** | Director of X-ray Imaging

Co-presenter: **Angela Criswell** | Senior Scientist

Host: **Tom Concolino** | Analytical X-Ray Consultant



GeoDict
The Digital Material Laboratory

Dr. Arne Jacob | Math2Market

Application Engineer

You can ask questions during the presentation.
We might turn on your microphone for further discussions.

Recording will be available tomorrow.

Digital Rock Analysis – 3. Digital Rock Simulations

Virtual Workshop presented by Aya Takase

DIGITAL ROCK ANALYSIS SERIES

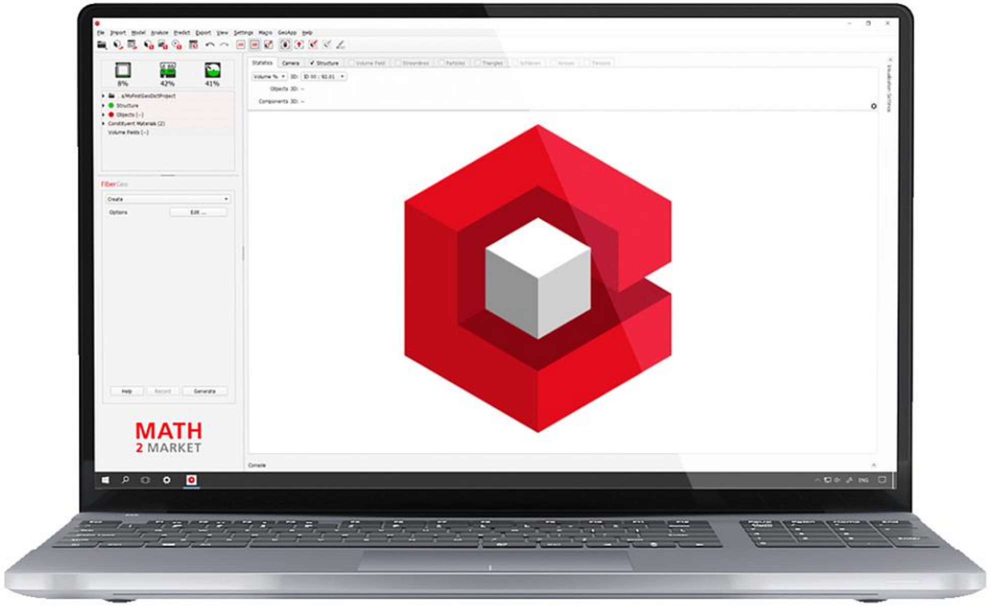
1. Data collection
2. Segmentation and property analyses
3. Digital rock simulations

THINGS WE'LL COVER

- How to calculate capillary pressure
- How to obtain relative permeabilities
- How to simulate drainage and imbibition processes

CT Lab HX by Rigaku

The versatile and compact micro-CT scanner

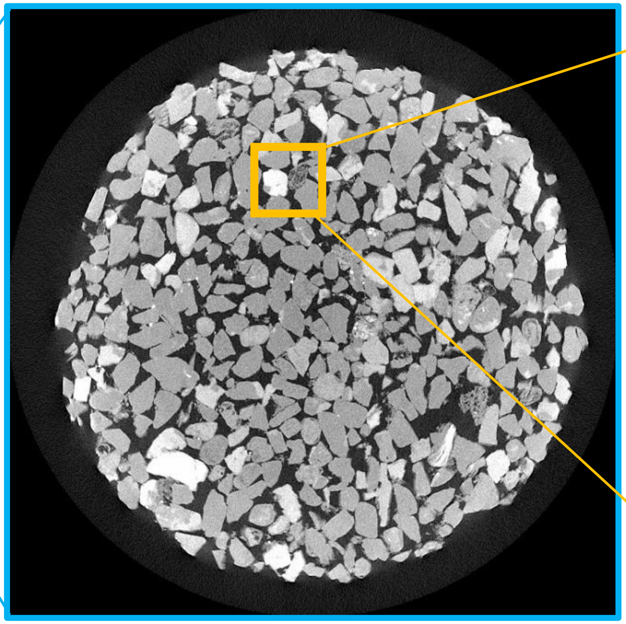


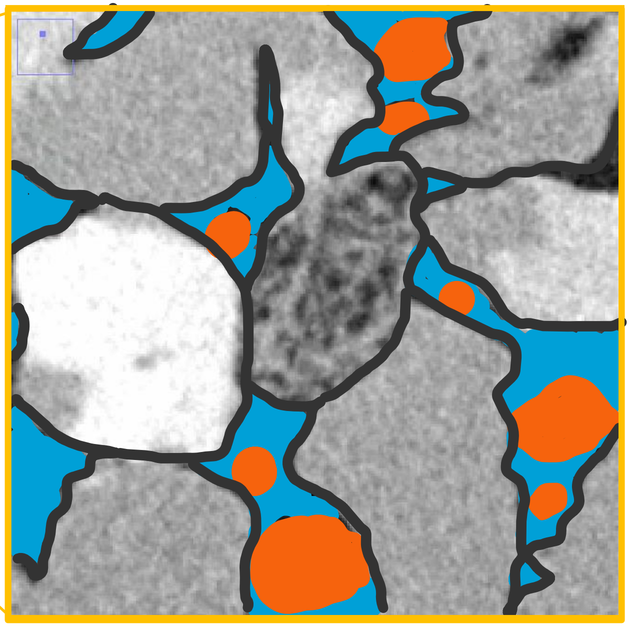
GeoDict by Math2Market

The Digital Material Laboratory

WHAT ARE DIGITAL ROCK SIMULATIONS FOR?

Sandstone

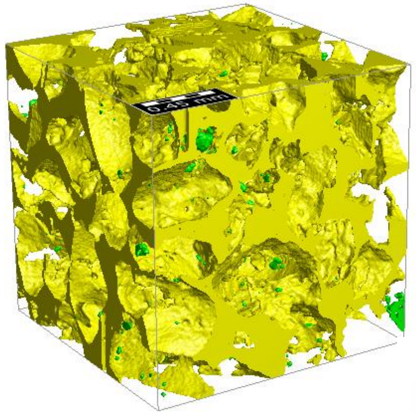


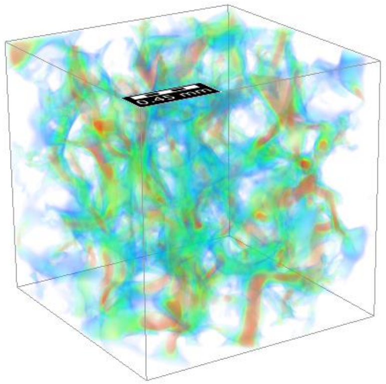


Water + Oil + Gas

Single-phase flow
(Routine Core Analysis)

Pore space

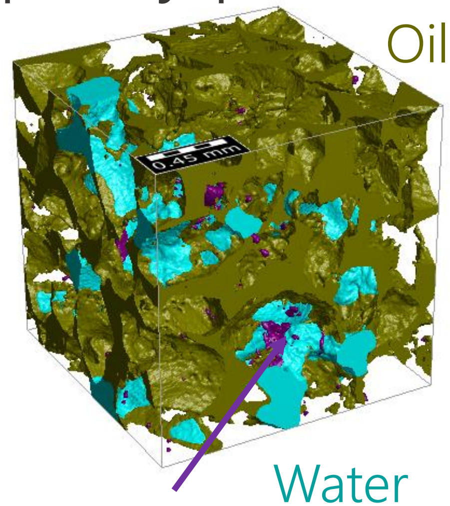


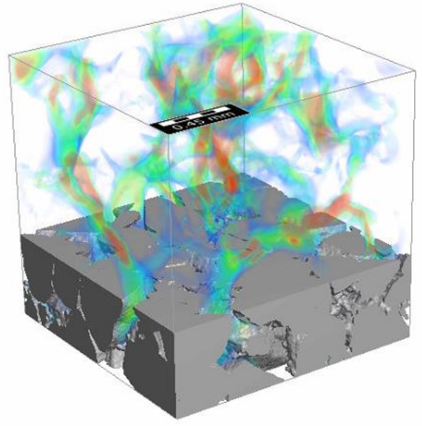


Absolute permeability

Two-phase flow
(Special Core Analysis)

Capillary pressure curve

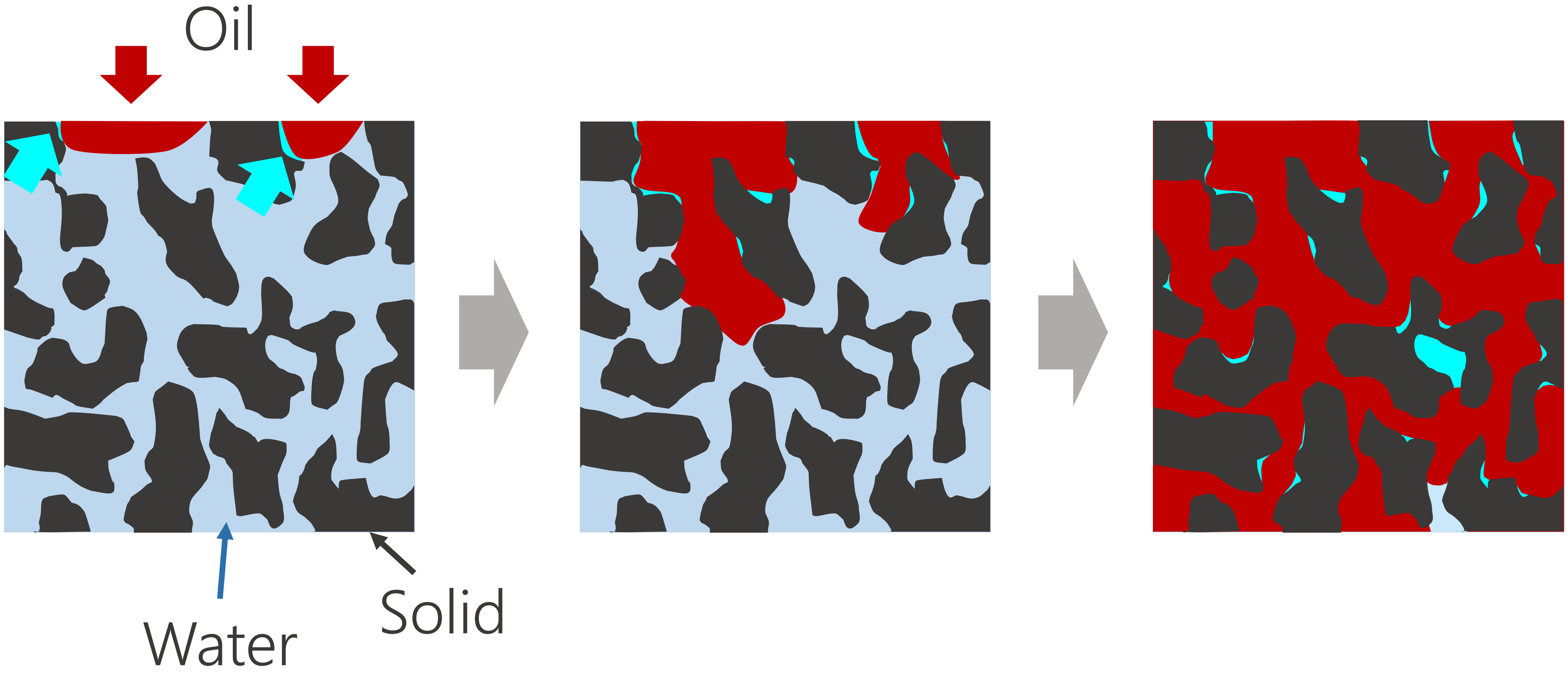




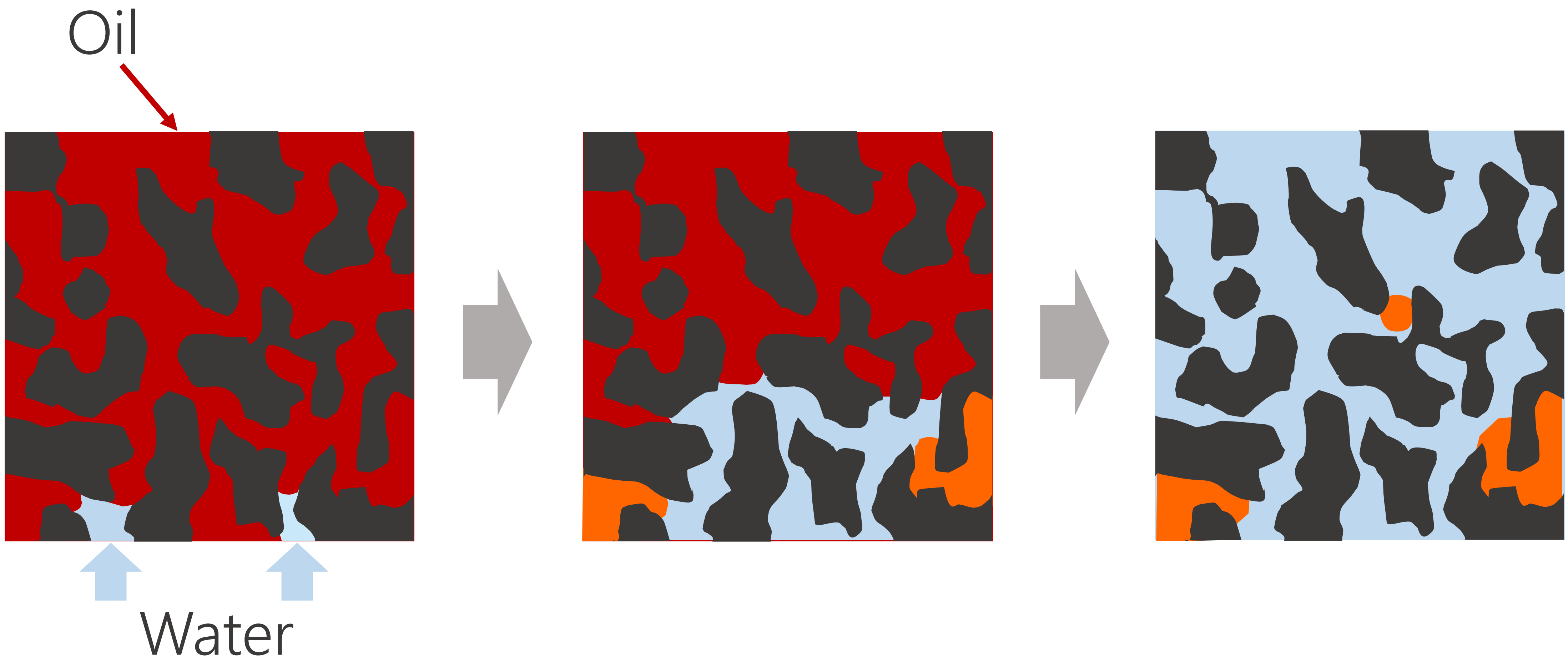
Relative permeability

WHAT DOES THIS PROCESS INVOLVE?

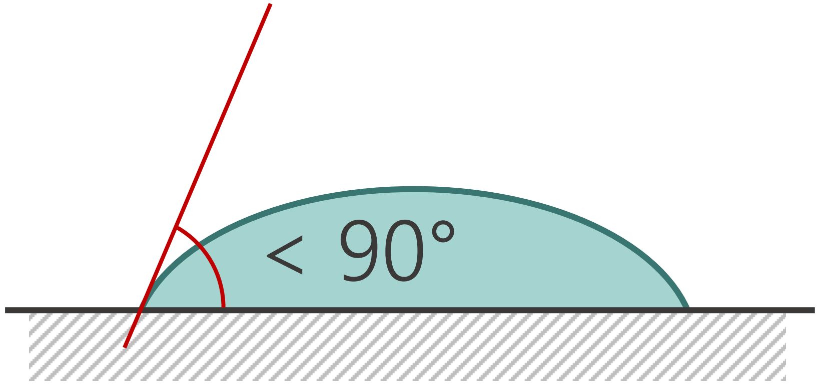
Drainage process: Non-wetting fluid replaces wetting fluid



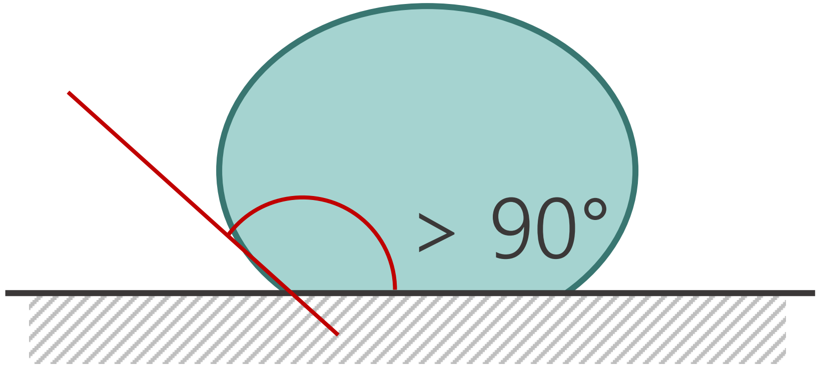
Imbibition process: Wetting fluid replaces non-wetting fluid



Wetting fluid

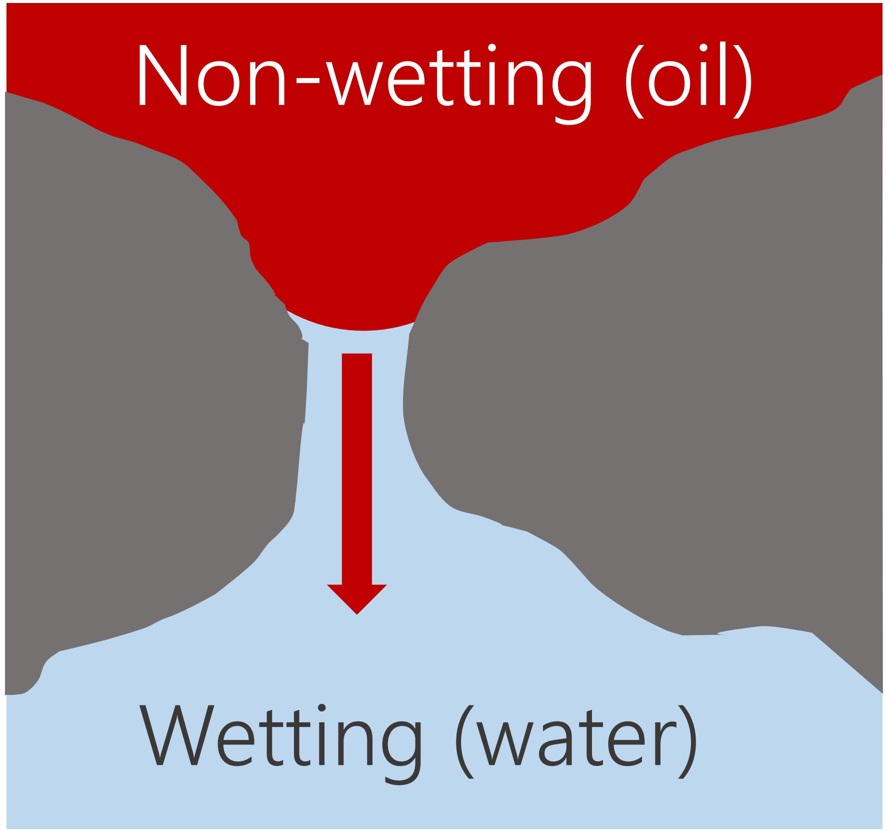


Non-wetting fluid



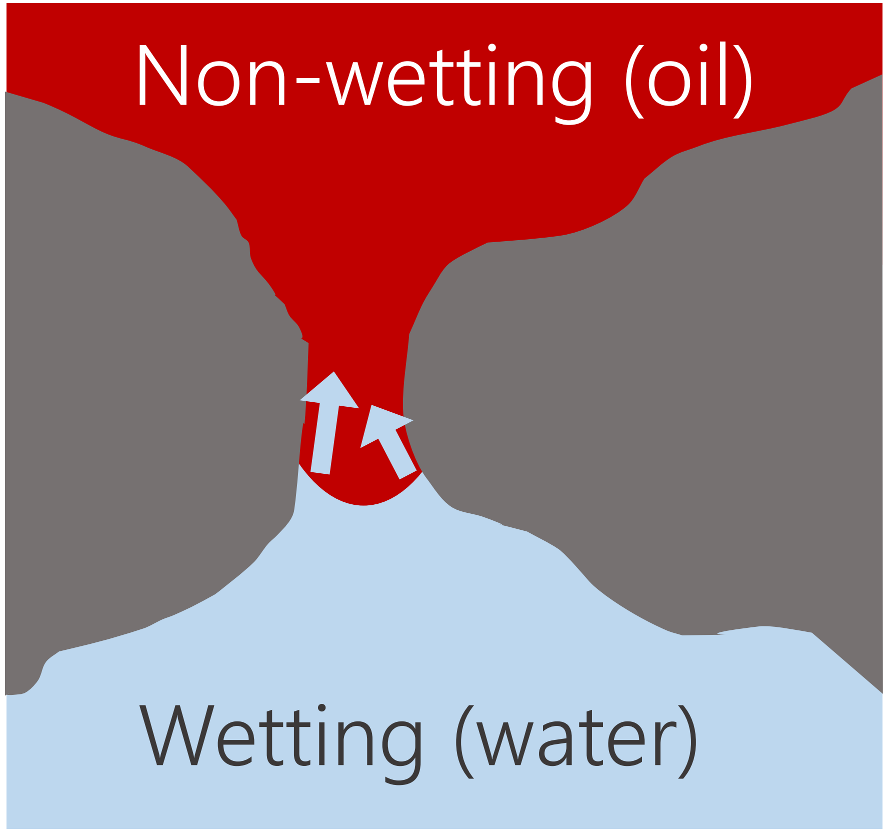
IS IMBIBITION SIMPLY AN INVERSE PROCESS OF DRAINAGE?

Drainage process: Non-wetting fluid is “pushed” in



Capillary pressure
≥ Pore’s threshold pressure

Imbibition process: Wetting fluid is “sucked” in

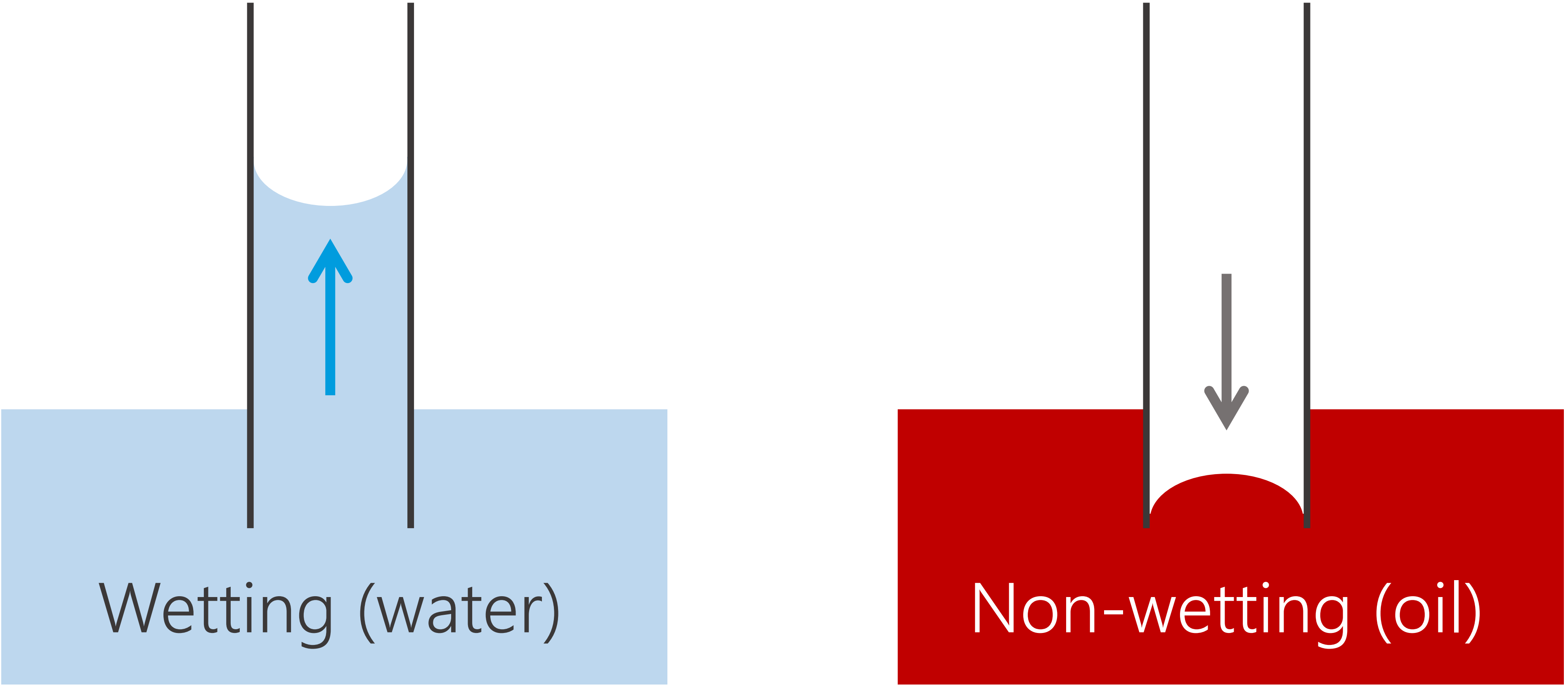


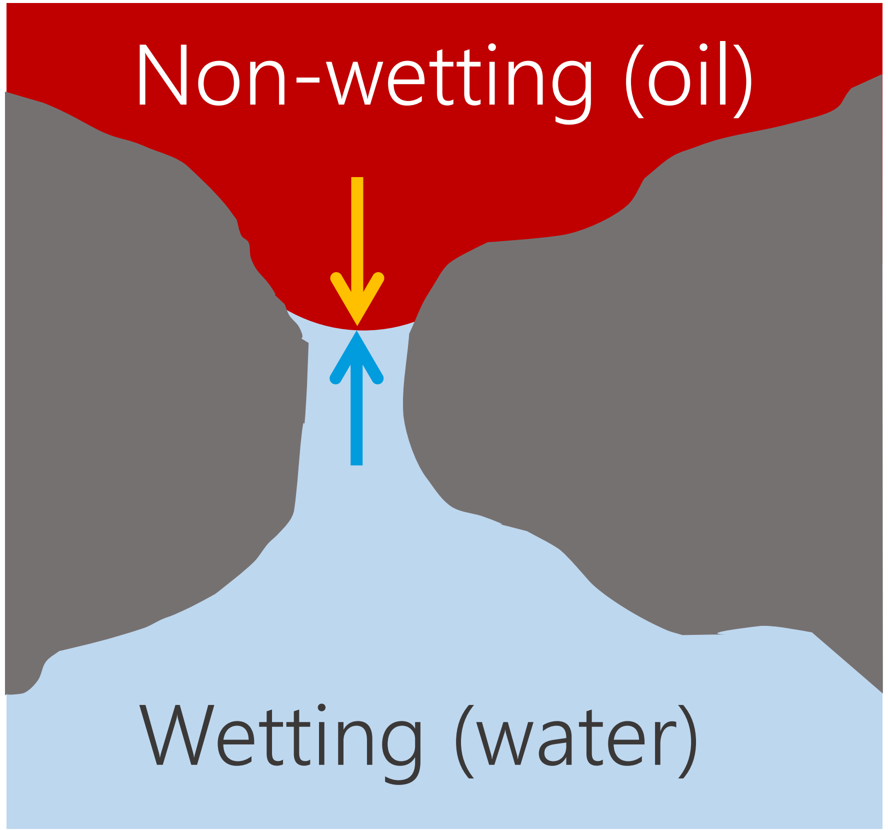
Wetting fluid enters the narrowest pores first

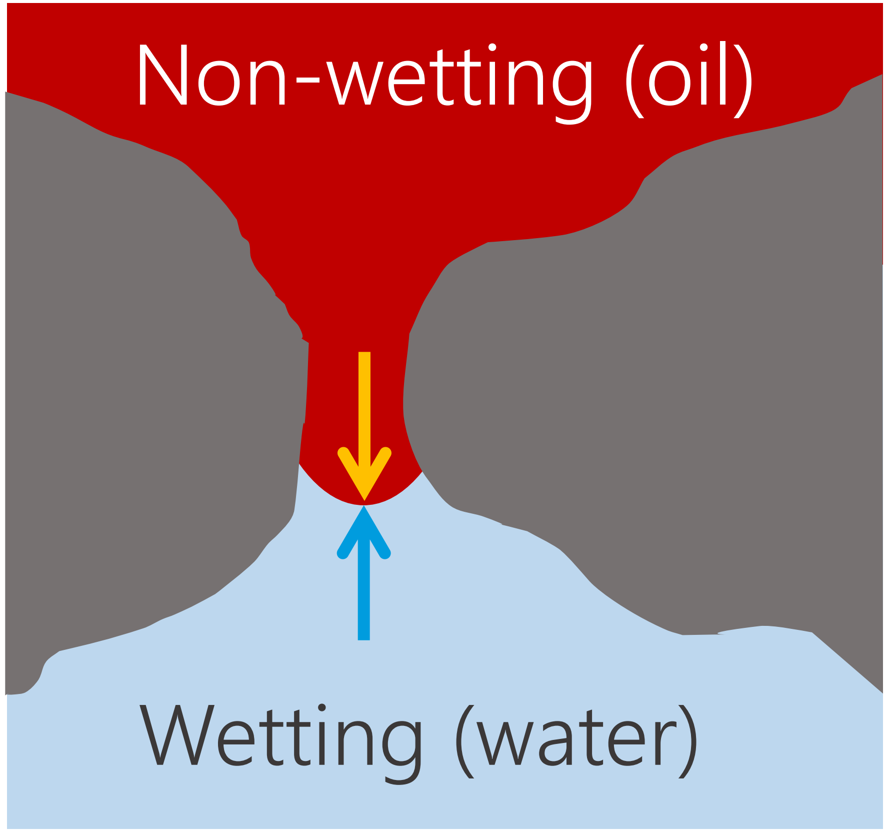
WHAT IS CAPILLARY PRESSURE?

Capillary pressure

The pressure between two immiscible fluids in a thin tube


Wetting (water)
Non-wetting (oil)


Non-wetting (oil)
Wetting (water)


Non-wetting (oil)
Wetting (water)

The Porous Diaphragm Method

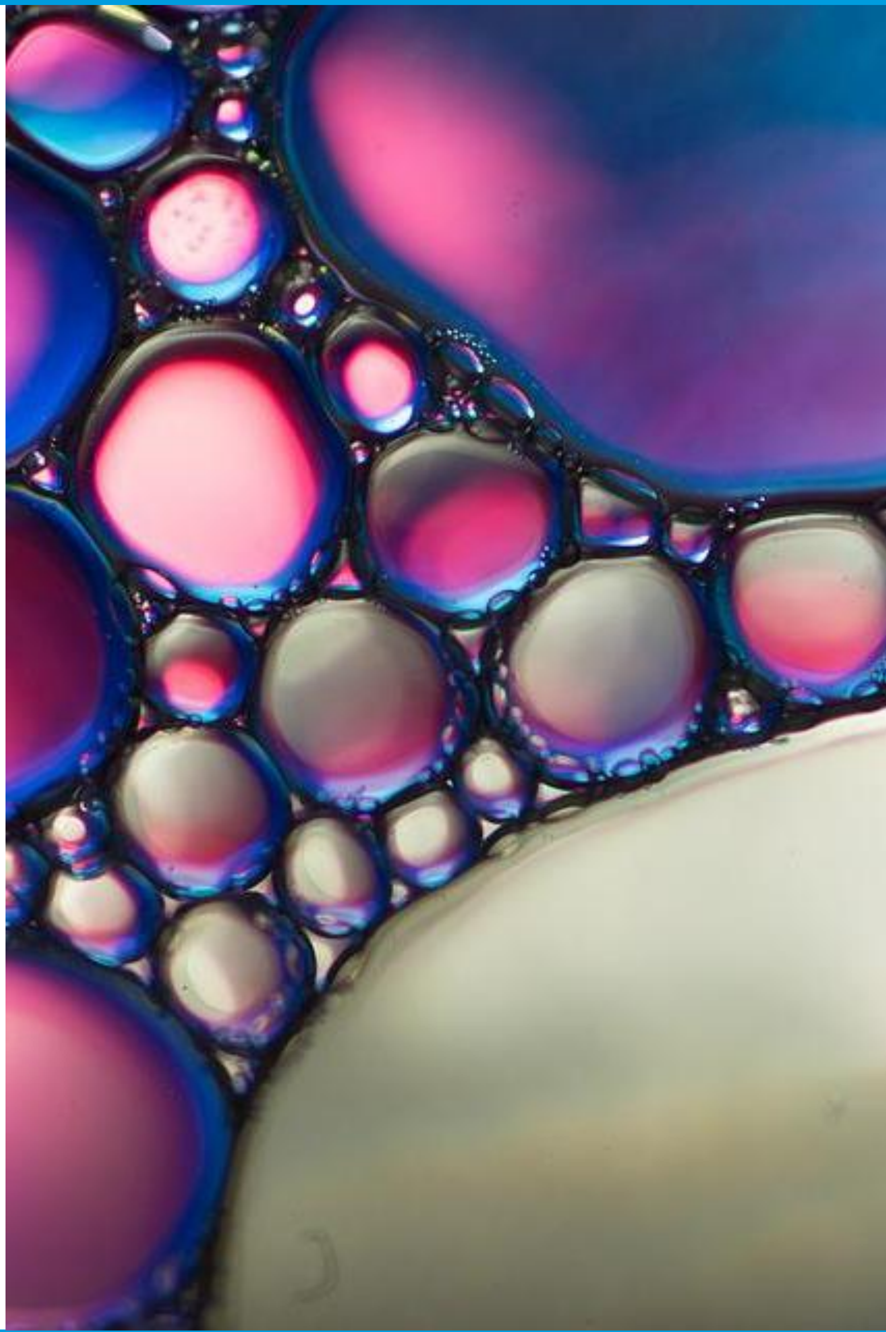
The Centrifugal Method

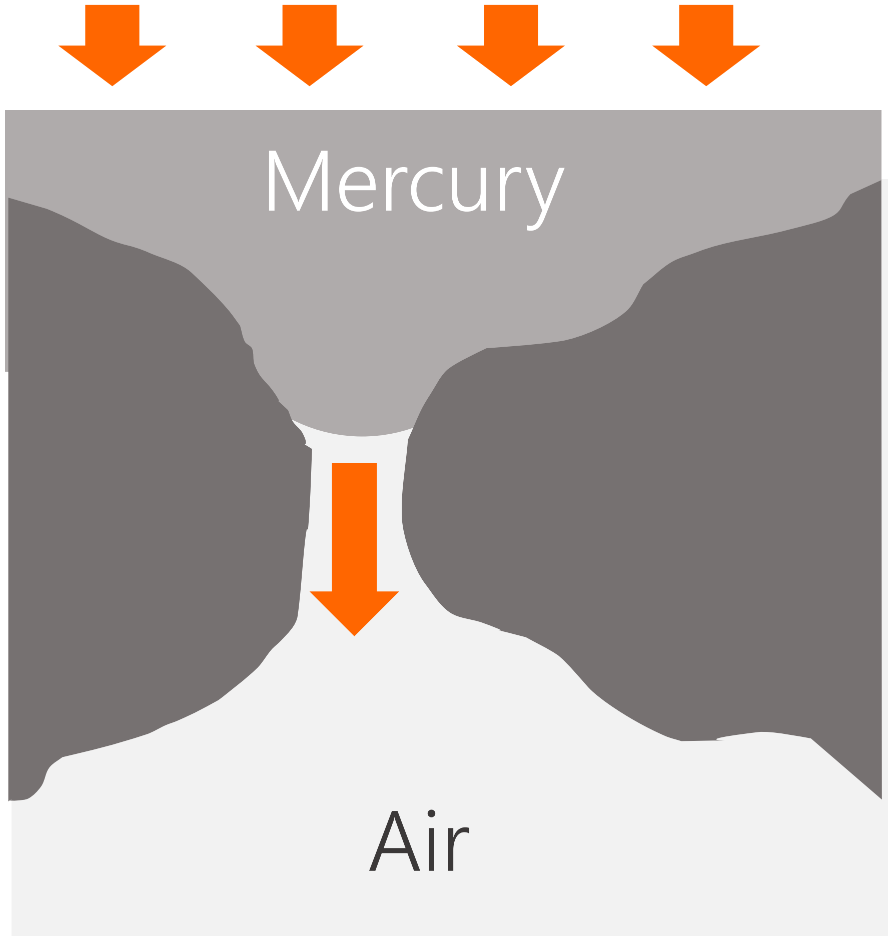
The Mercury Injection Method

Dynamic capillary pressure method

PERM Inc. Fundamentals of Fluid Flow in Porous Media

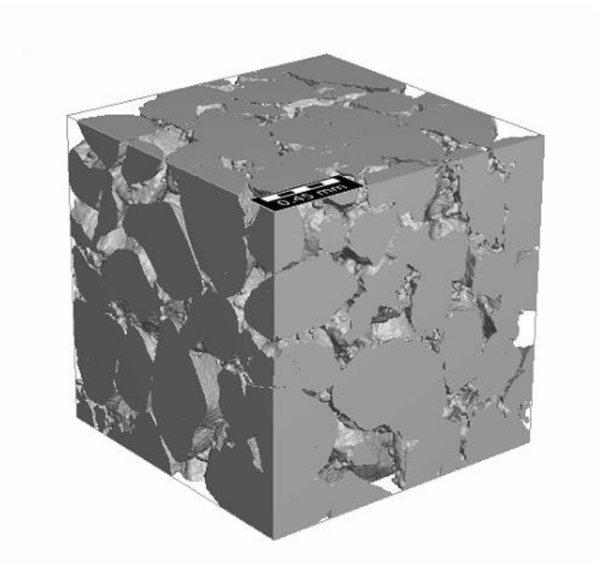
https://perminc.com

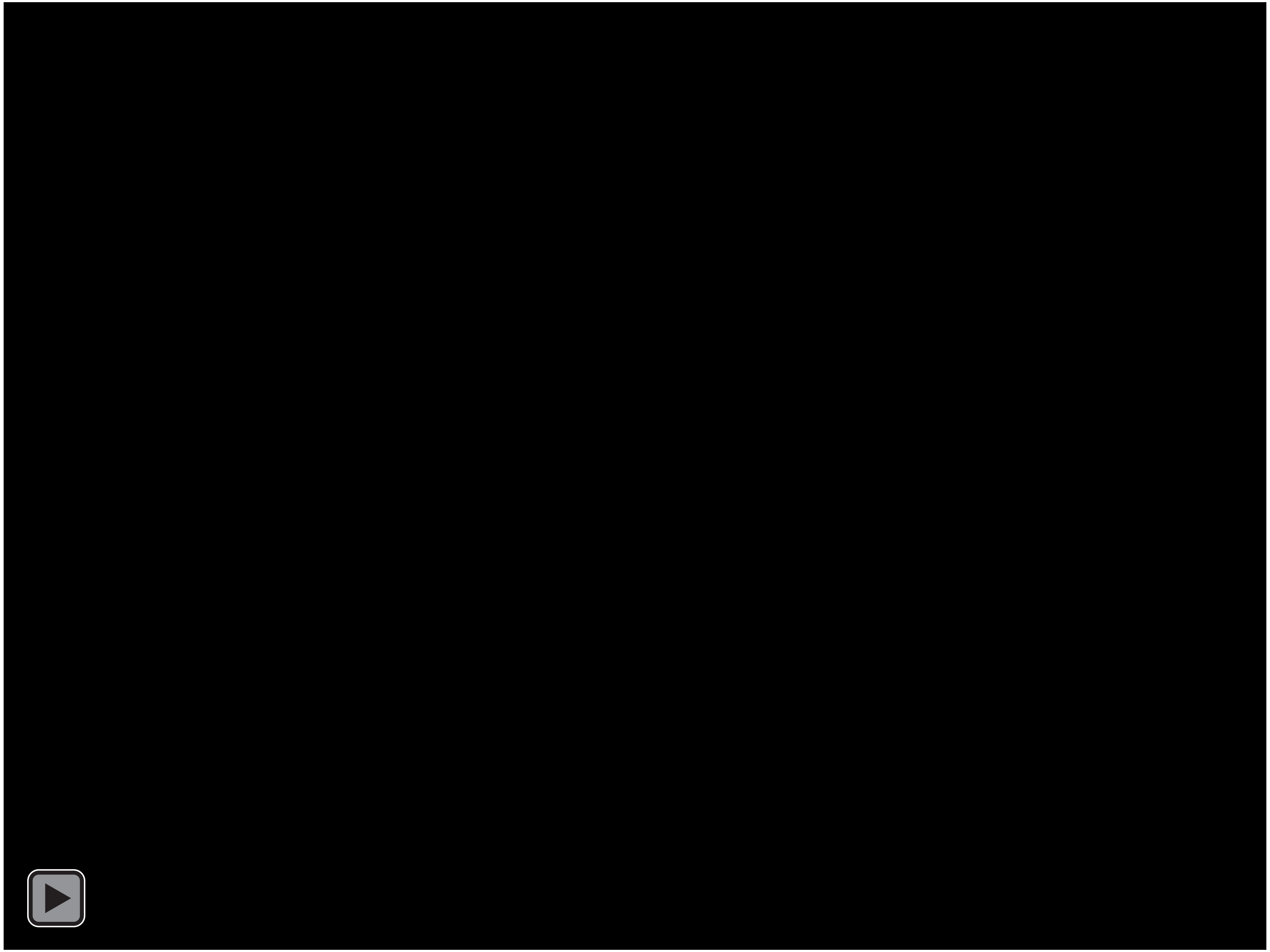




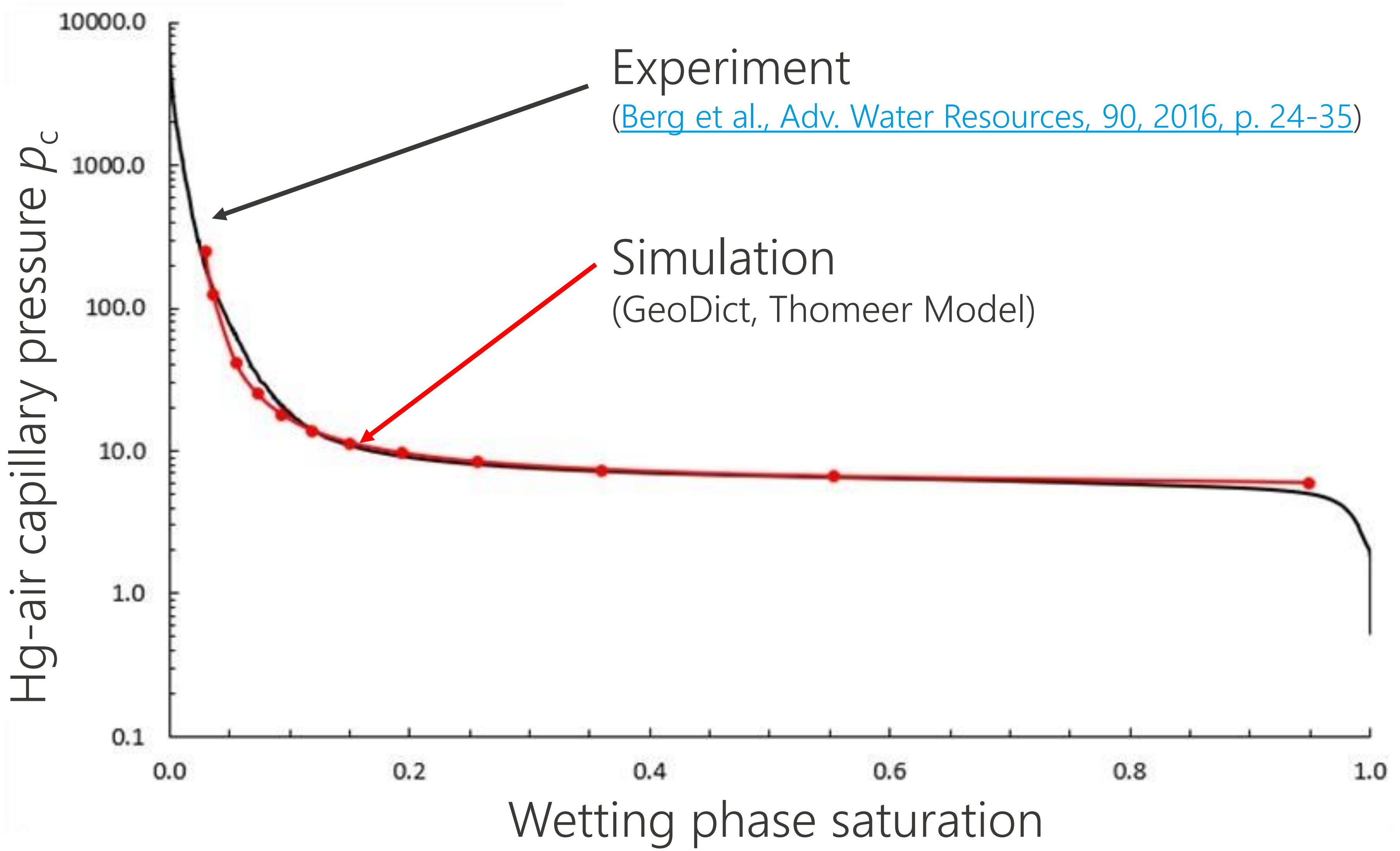
Measure the added pressure and Hg volume change

Or simulate the process


0.45 mm



HOW ACCURATE IS THE SIMULATION?



Experiment
(Berg et al., Adv. Water Resources, 90, 2016, p. 24-35)
Simulation
(GeoDict, Thomeer Model)
Hg-air capillary pressure p_c
10000.0
1000.0
100.0
10.0
1.0
0.1
0.0
0.2
0.4
0.6
0.8
1.0
Wetting phase saturation

CAN WE SIMULATE DRAINAGE AND IMBIBITION PROCESSES?

Quasi Static Pore Morphology Method

Young Laplace equation

Minimum radius of accessible pores

Surface tension

$$r = \frac{2\sigma}{p_c} \cos\alpha$$

Contact angle

Capillary pressure

Hilpert et al., Adv. Water Resources, 2001, 24, p. 243-255

Quasi Static Pore Morphology Method's drawback

The saturation jumps when a fluid passes the narrowest throat.

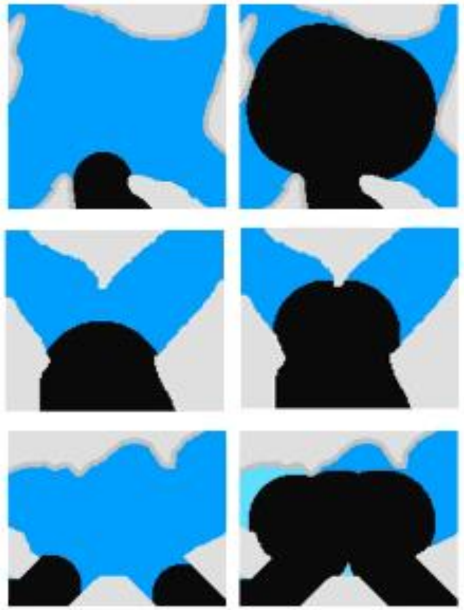
[GeoDict video: Advances in two-phase and single-phase flow simulations]

<u>Dynamic</u> Pore Morphology Method

- Non-monotonic capillary pressure
- Mixed wettability & forced imbibition
- Predicts critical events

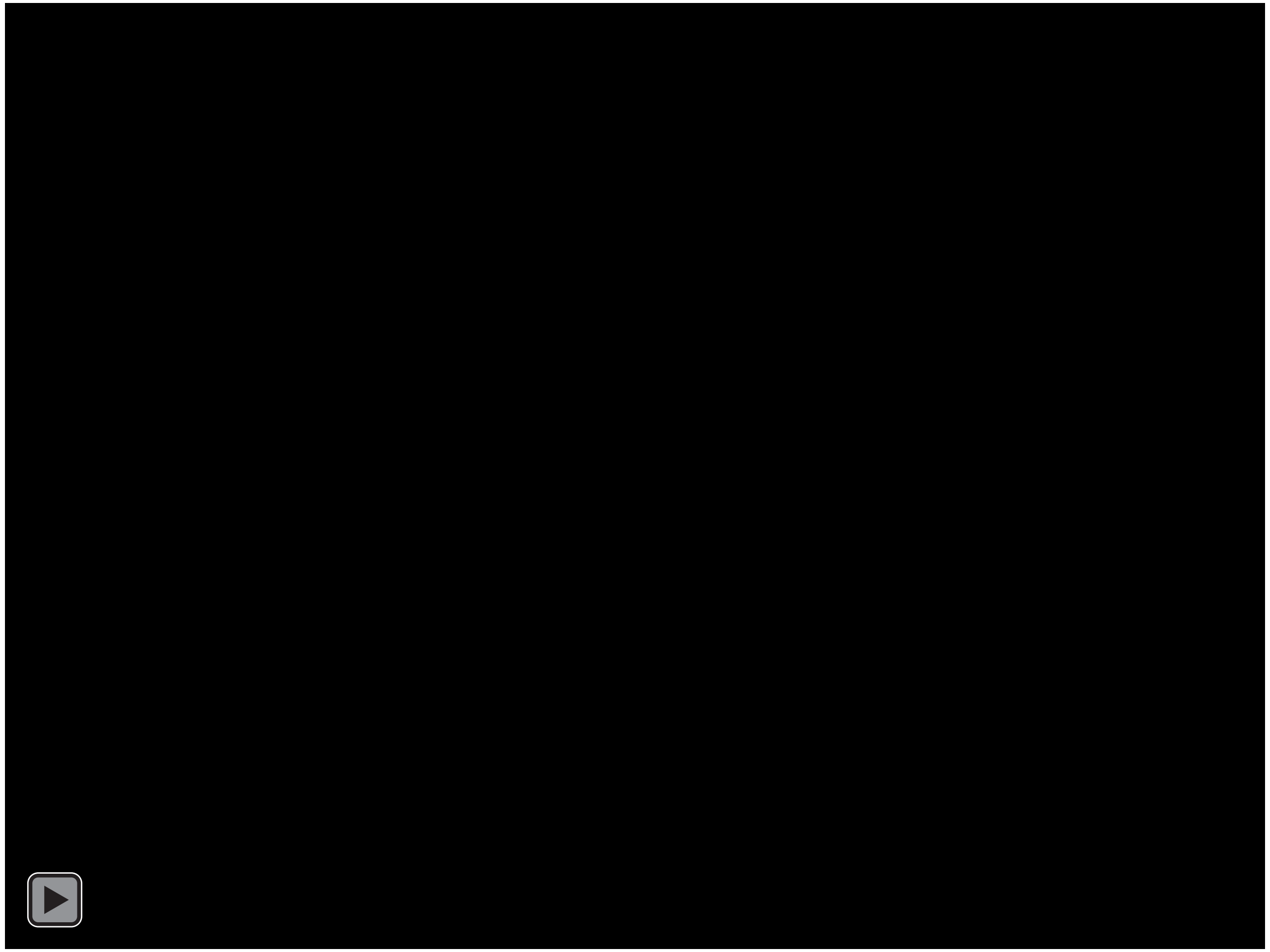
Jung et al., Phys. Rev. Fluids, 2016, 1, 074202

- Burst:
- Touch:
- Overlap:



GeoDict video: Advances in two-phase and single-phase flow simulations

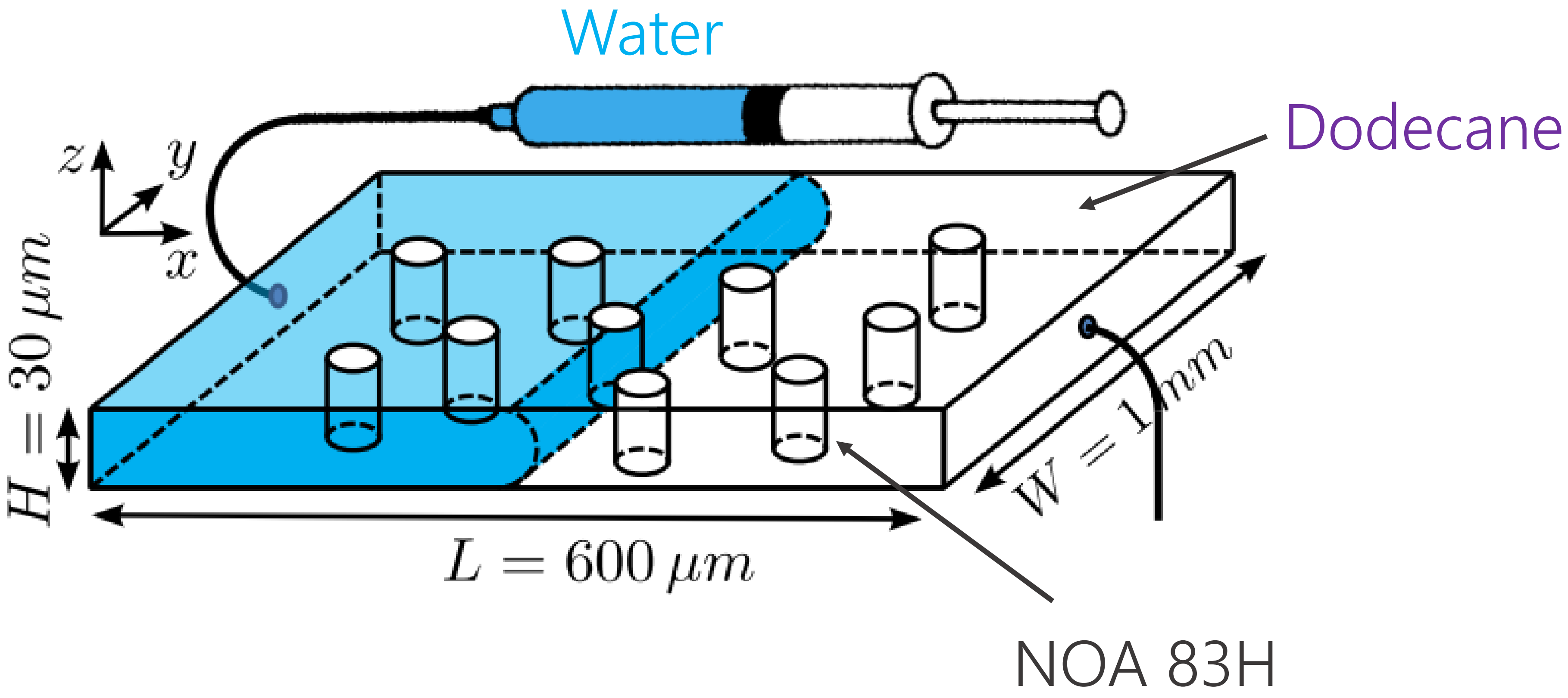
Dynamic Pore Morphology Method



[GeoDict video: Advances in two-phase and single-phase flow simulations]

HOW WELL DO SIMULATIONS MATCH EXPERIMENTS?

Hele-Shaw cell (Plexiglas casing)

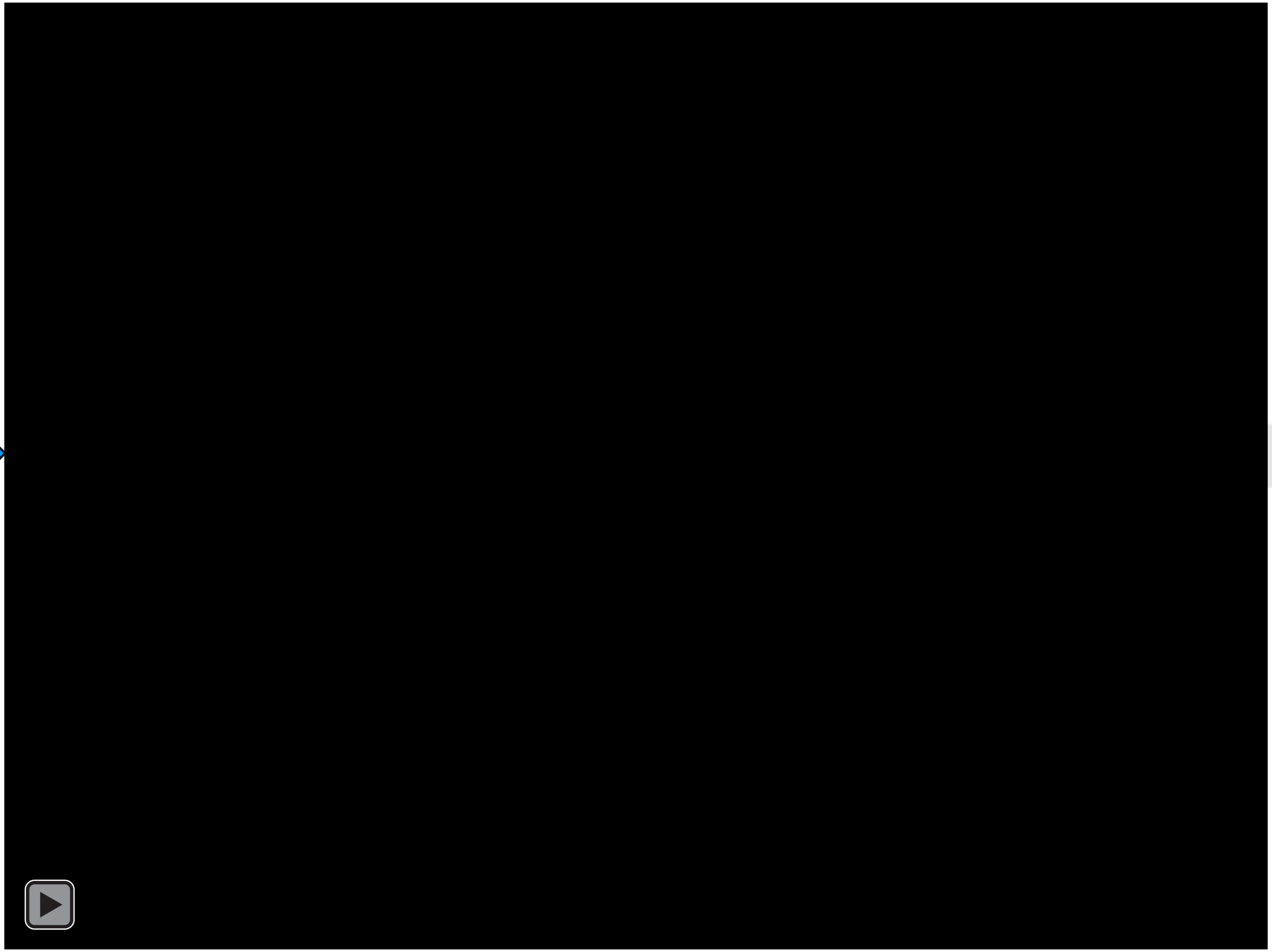


[Jung et al., Phys. Rev. Fluids, 2016, 1, 074202]

Contact angle → Air 46° (wetting) FC70 100° (neutral) Dodecane 125° (non-wetting)

Experiment

water



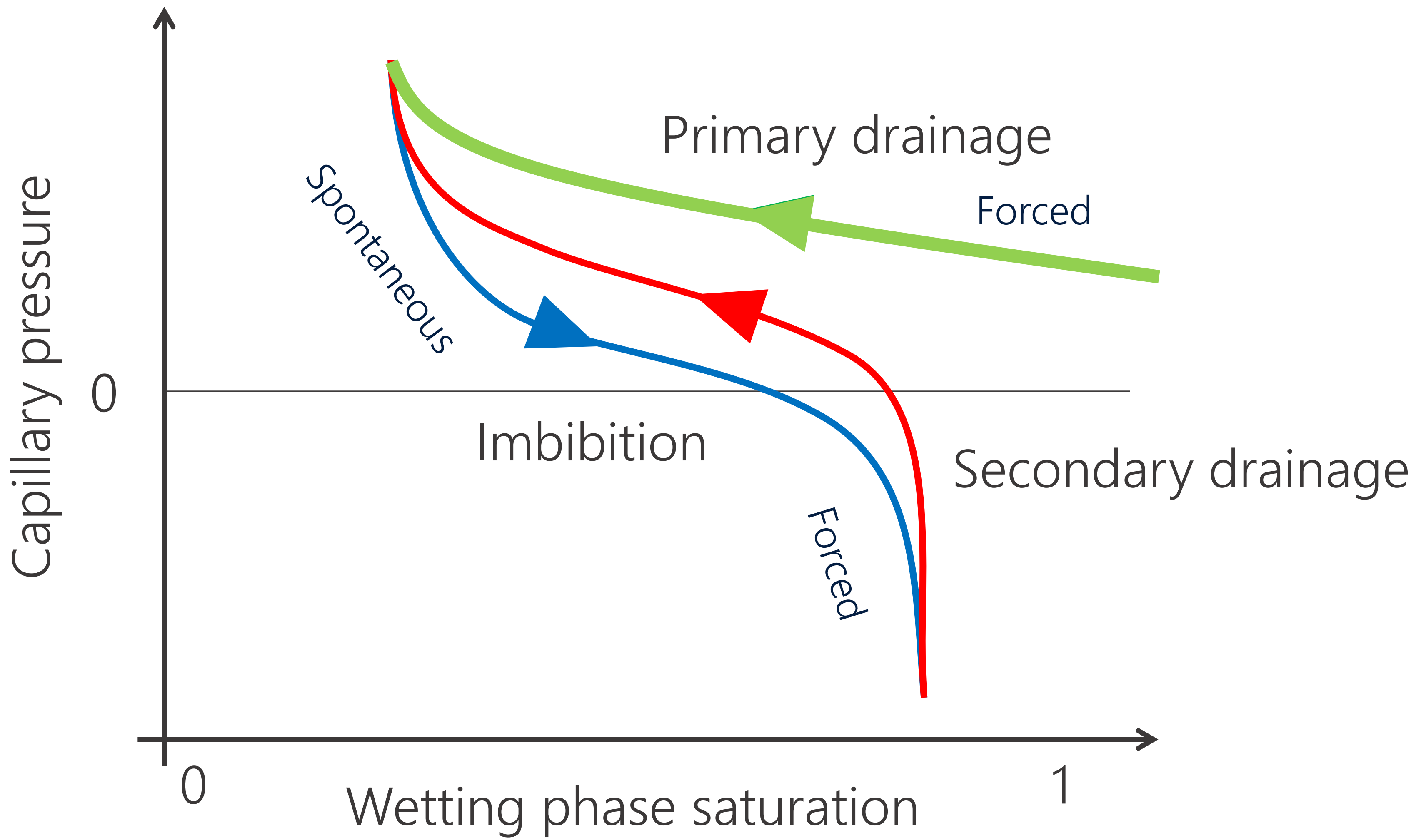
Simulation

Jung et al., Phys. Rev. Fluids, 2016, 1, 074202

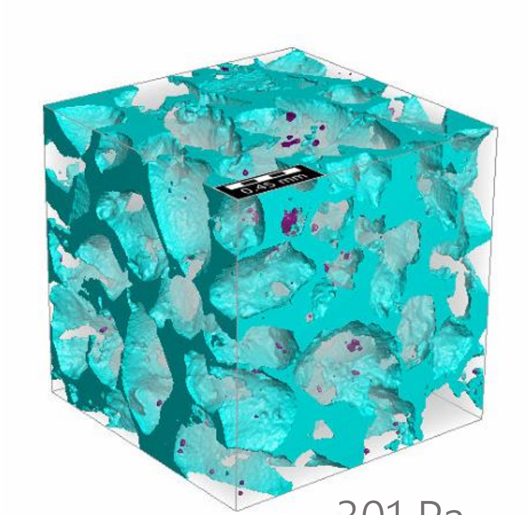
WHAT IS CAPILLARY PRESSURE CURVE?

Capillary pressure curve

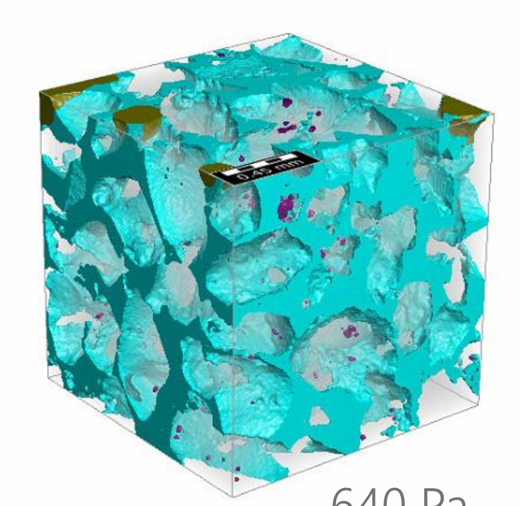
The relation between the capillary pressure and the fluid saturation



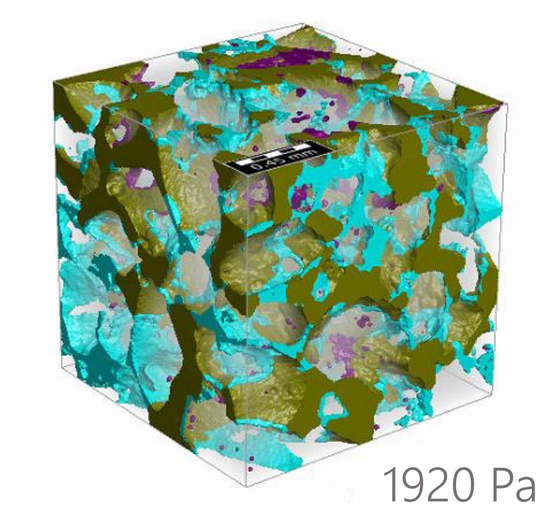
Capillary pressure
0
Primary drainage
Forced
Spontaneous
Imbibition
Secondary drainage
Forced
0
1
Wetting phase saturation



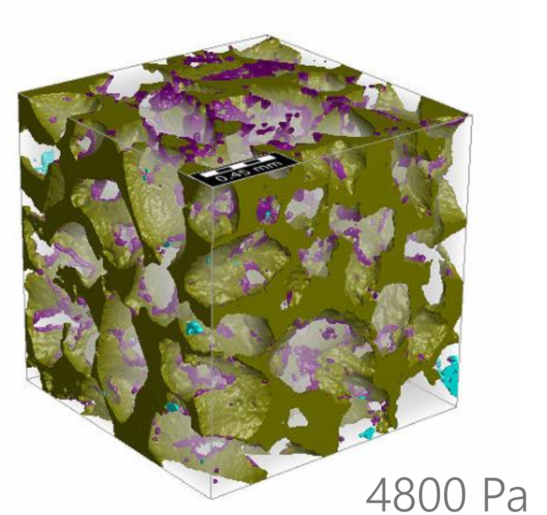
301 Pa



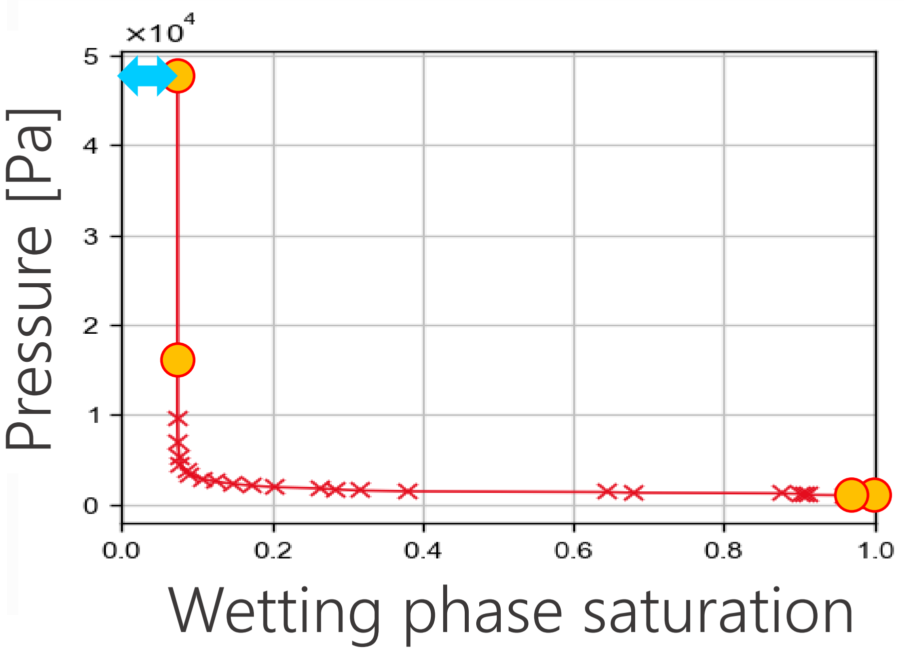
640 Pa

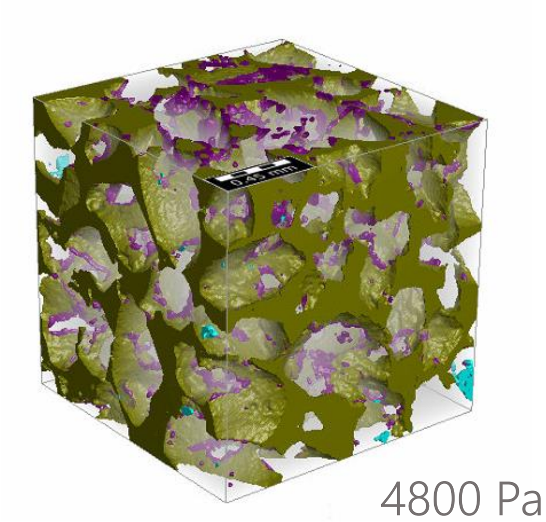


1920 Pa

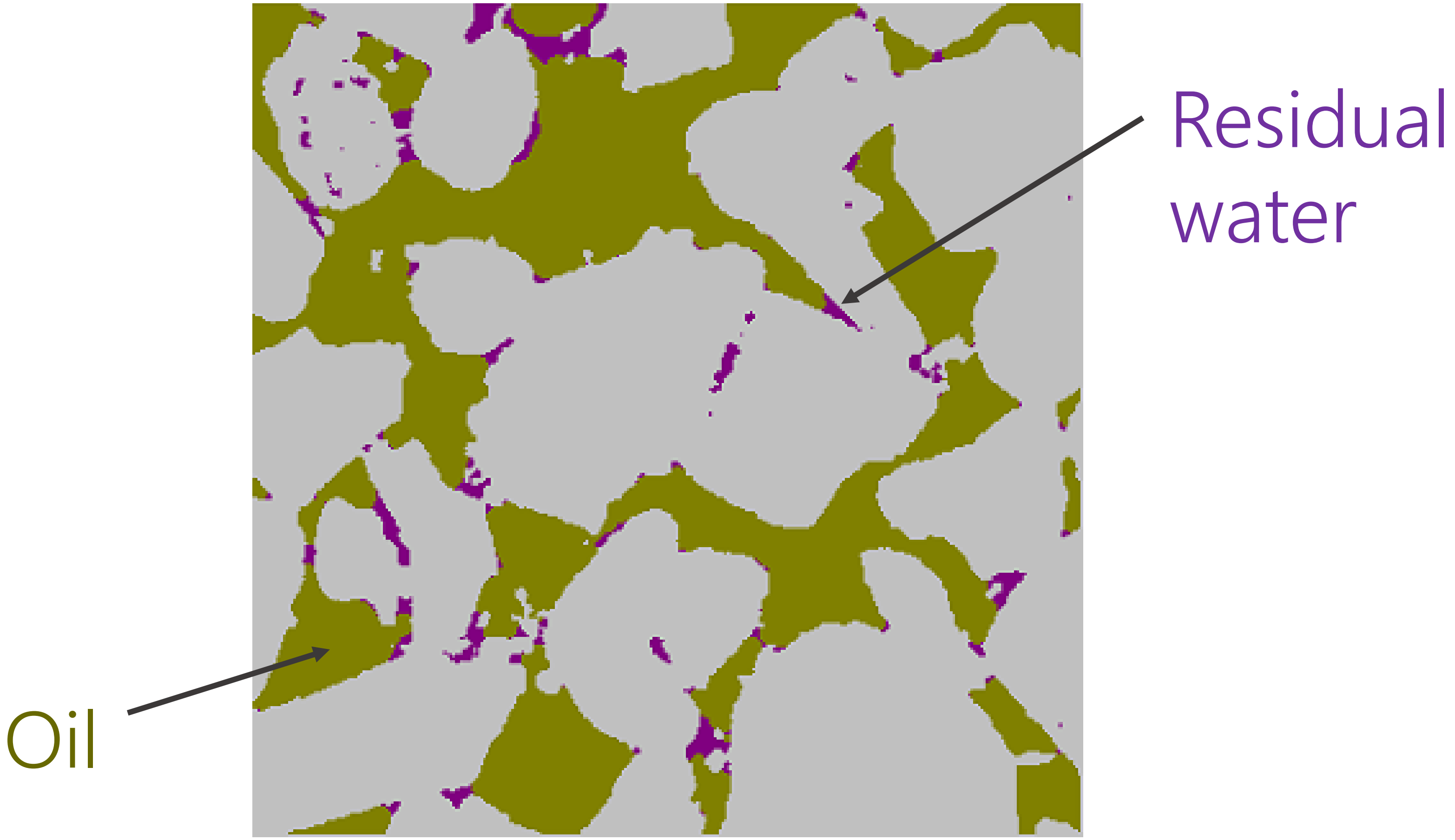


4800 Pa





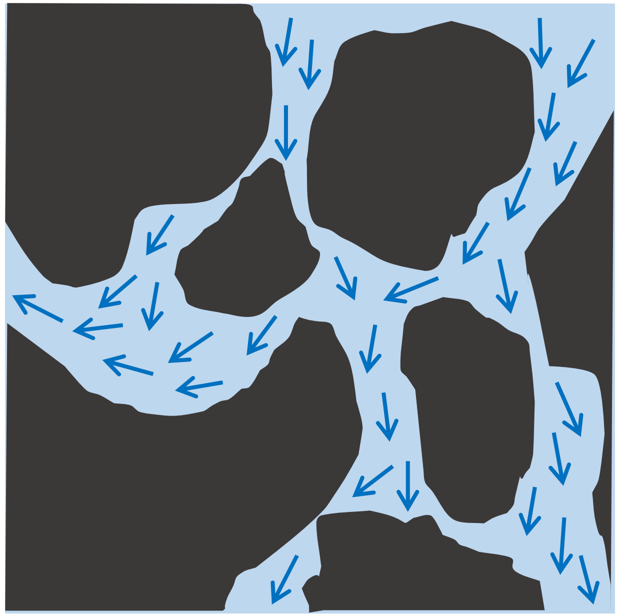
4800 Pa



CAN WE CALCULATE RELATIVE PERMEABILITY?

Absolute permeability K_1

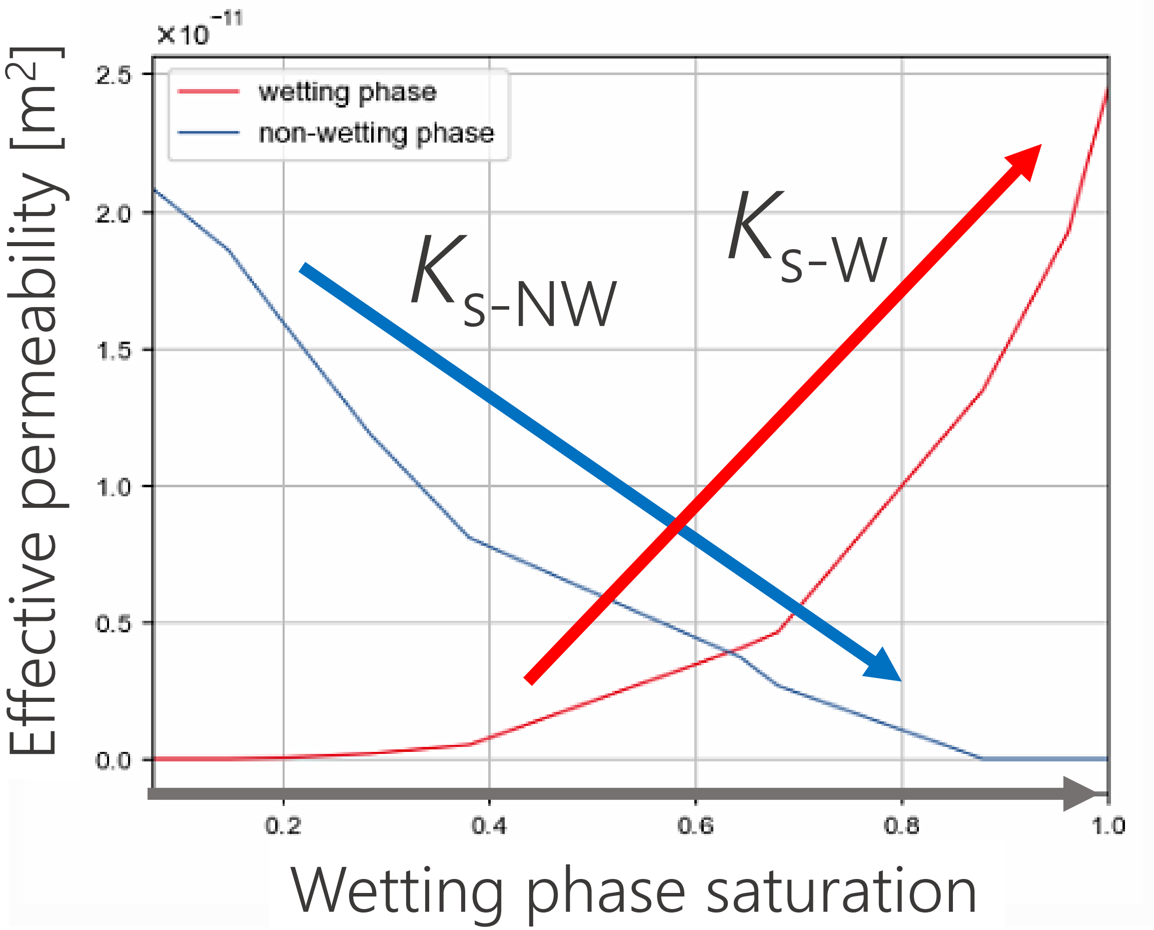
Relative permeability



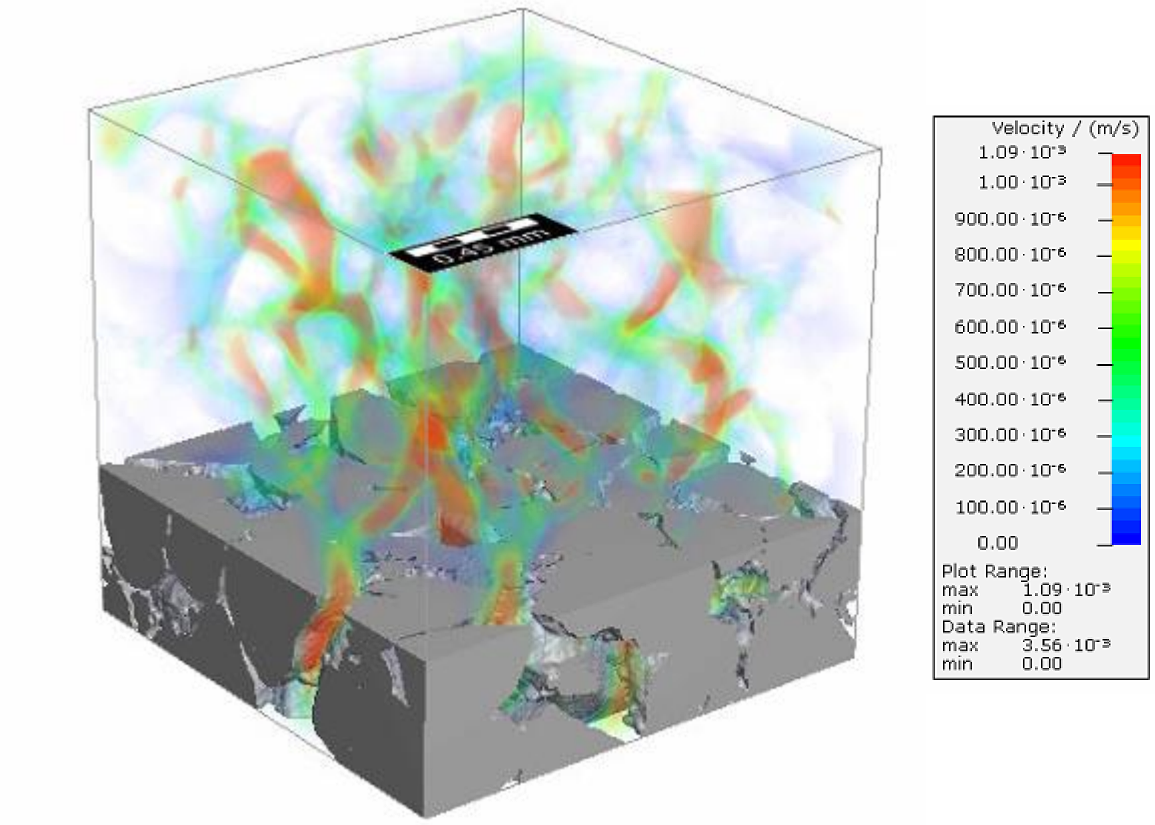
K_1 at saturation 100%

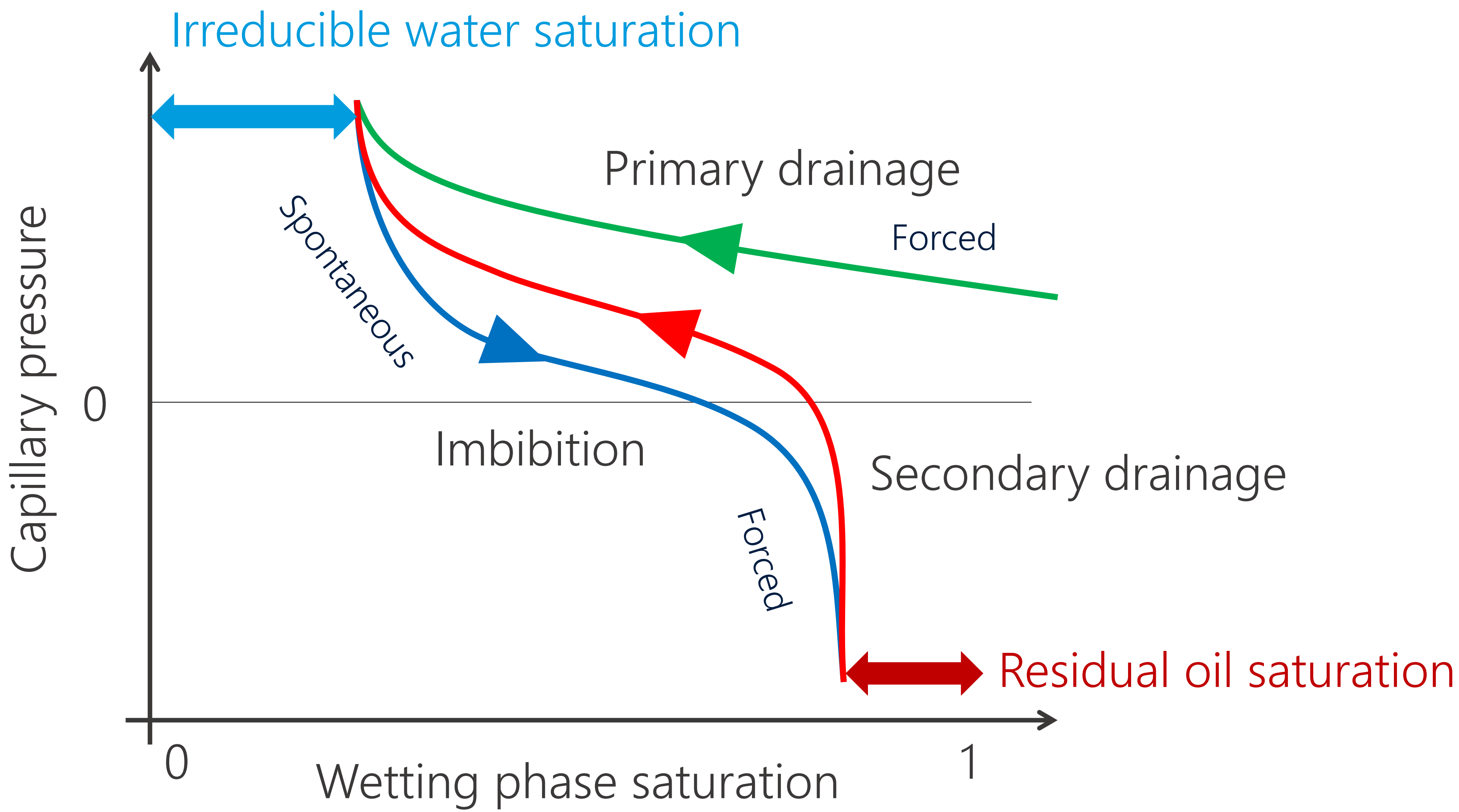
K_s/K_1 at saturation S%

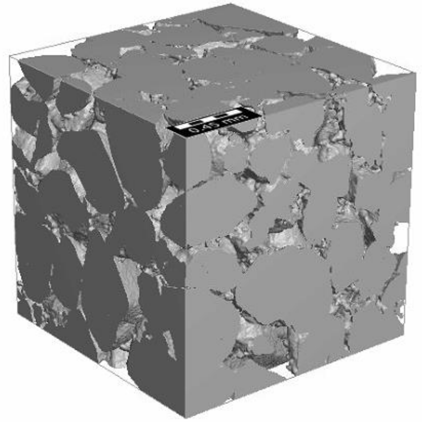
K_s: Saturation dependent permeability

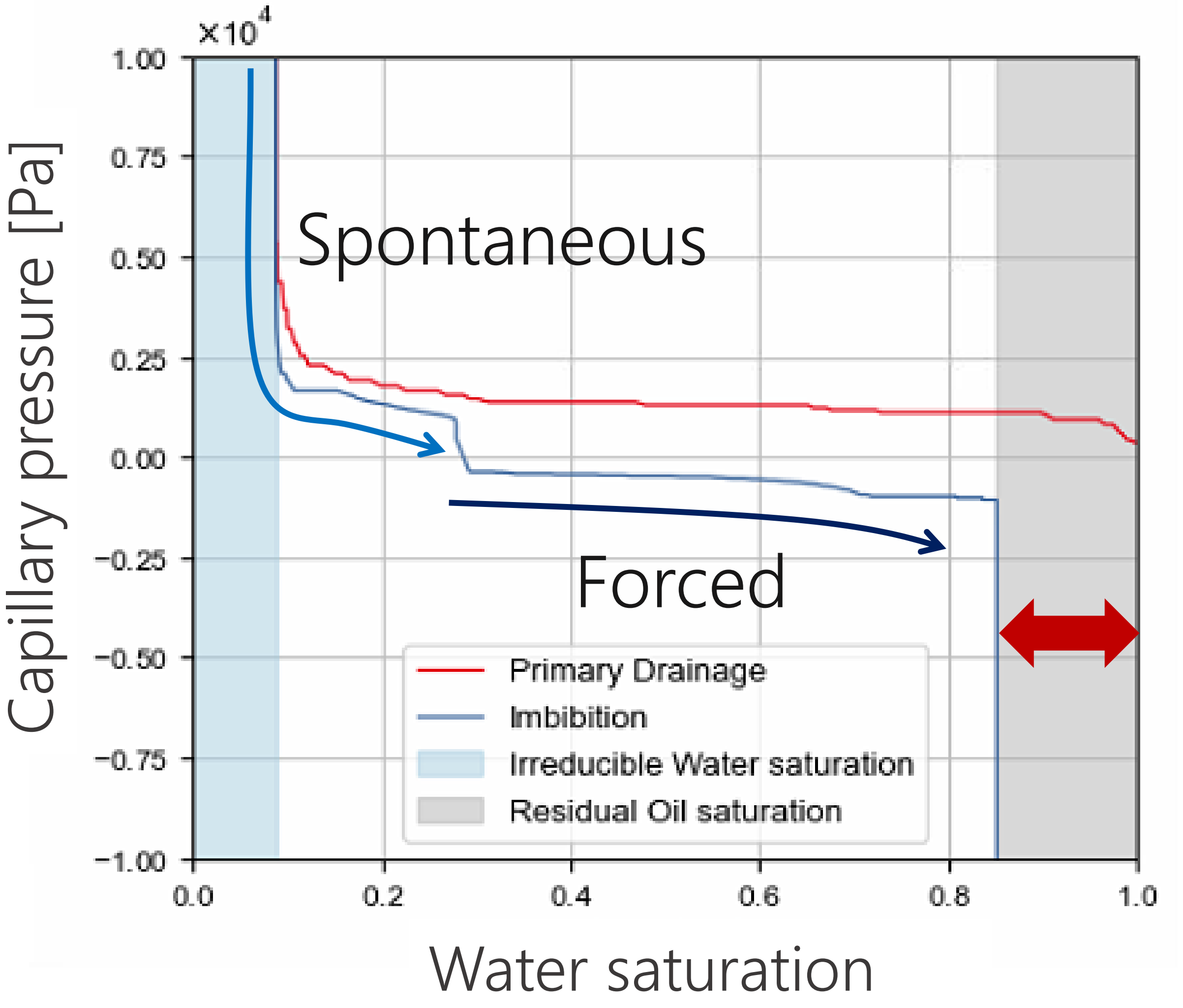


Velocity map




Irreducible water saturation
Primary drainage
Forced
Spontaneous
Capillary pressure
0
Imbibition
Secondary drainage
Forced
Residual oil saturation
0
Wetting phase saturation
1

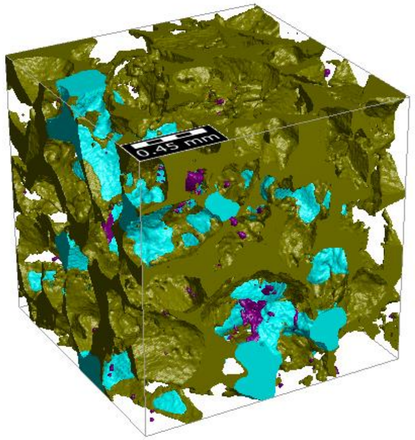


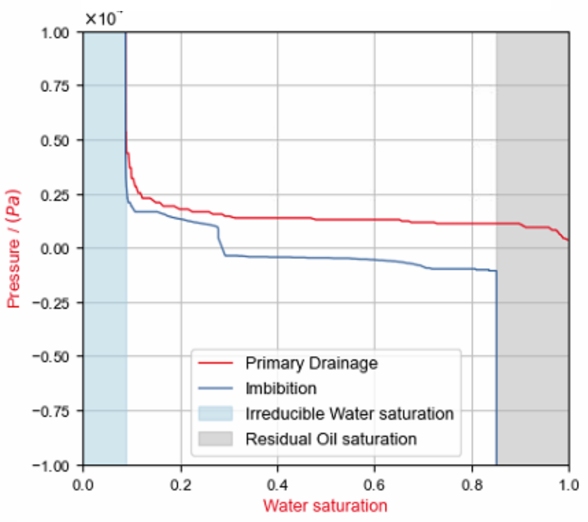


Residual oil saturation
= 0.149

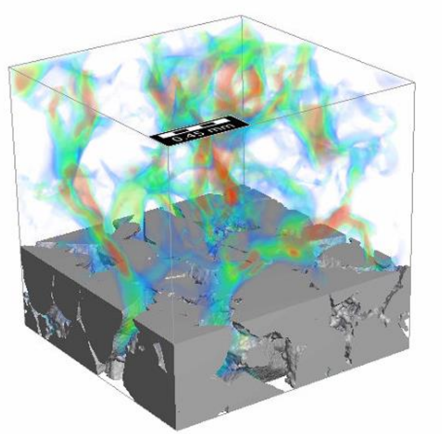
Two-phase flow (Special Core Analysis)

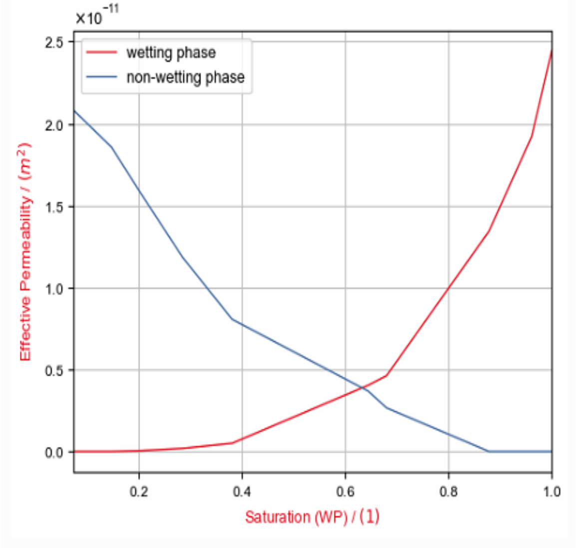
Capillary pressure curve





Relative permeability





THINGS COVERED

- How to calculate capillary pressure
- How to obtain relative permeabilities
- How to simulate drainage and imbibition processes

Q & A SESSION

We'll follow up with
your questions.

Recording will be
available tomorrow.

Register for
the next workshop.

Next: Filtration Analysis

1. Data collection

October 12th Wednesday

11:00 am PDT / 2:00 pm EDT

THANK YOU FOR JOINING US
SEE YOU NEXT TIME