WELCOME TO RIGAKU VIRTUAL WORKSHOP

DEEP DIVE: DIGITAL ROCK ANALYSIS

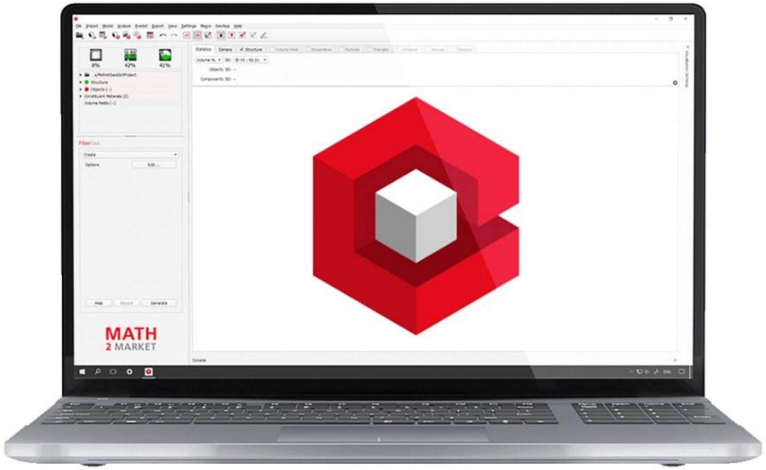
2. Segmentation and Property Analyses

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 – 2. Segmentation & Property Analyses

Virtual Workshop presented by Aya Takase

DIGITAL ROCK ANALYSIS SERIES

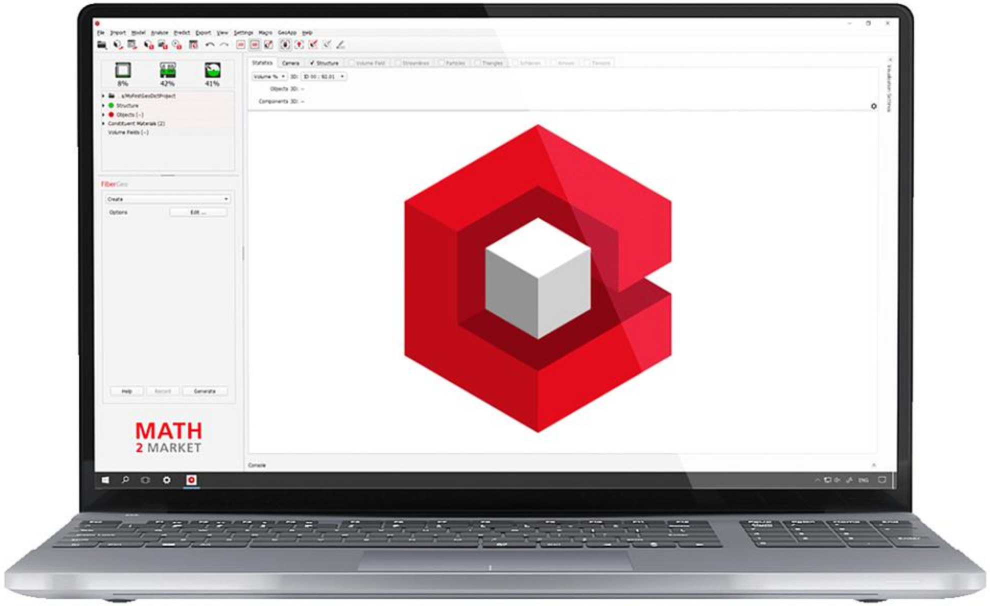
1. Data collection
2. Segmentation and property analyses
3. Digital rock simulations

THINGS WE'LL COVER

- How to segment CT images
- How to analyze basic properties such as porosity, percolation path, grain size, absolute permeability etc.

CT Lab HX by Rigaku

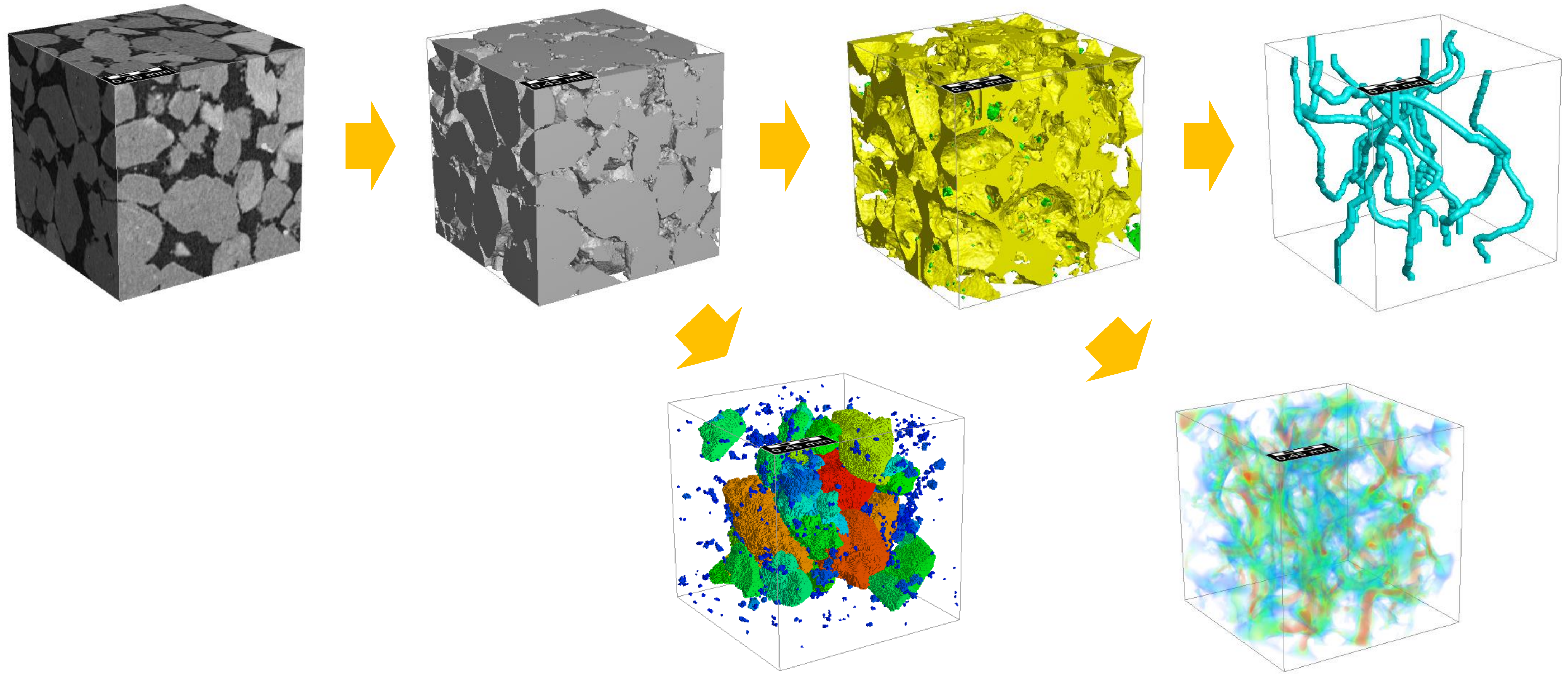
The versatile and compact micro-CT scanner



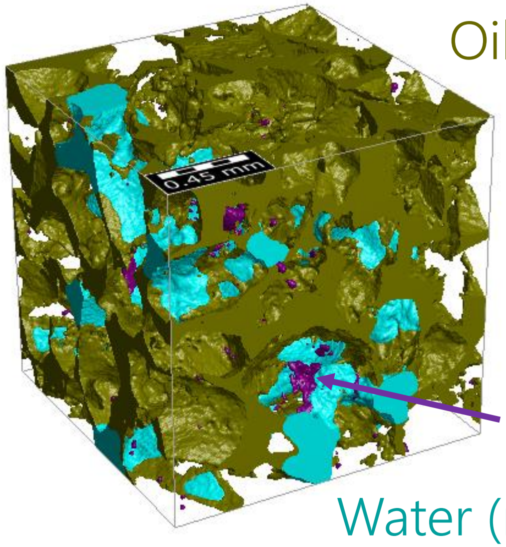
GeoDict by Math2Market

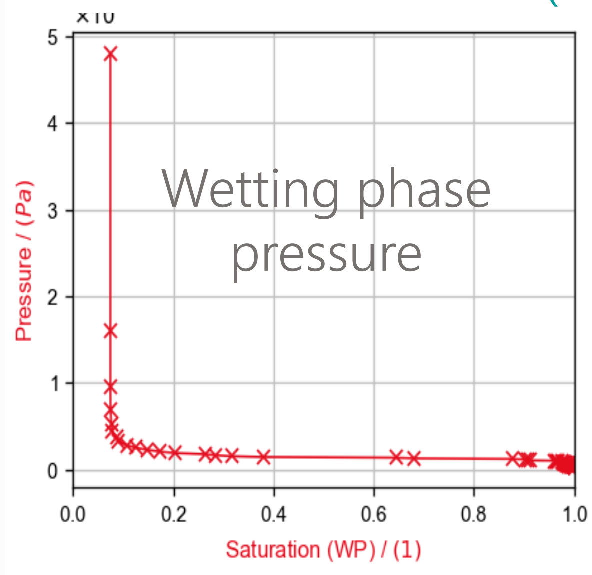
The Digital Material Laboratory

WHAT DOES DIGITAL ROCK ANALYSIS INVOLVE?

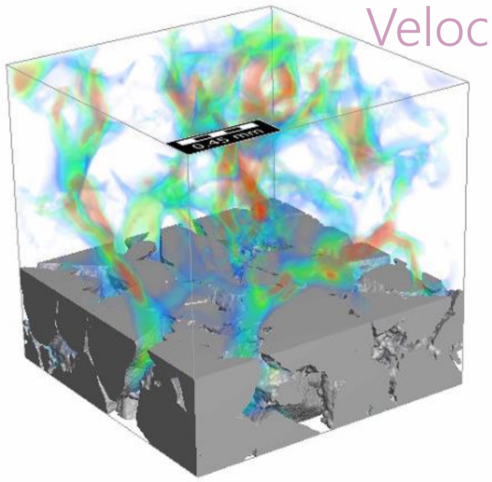

CT scan
Segmentation
Pore space
Percolation path
Grain size
Absolute permeability

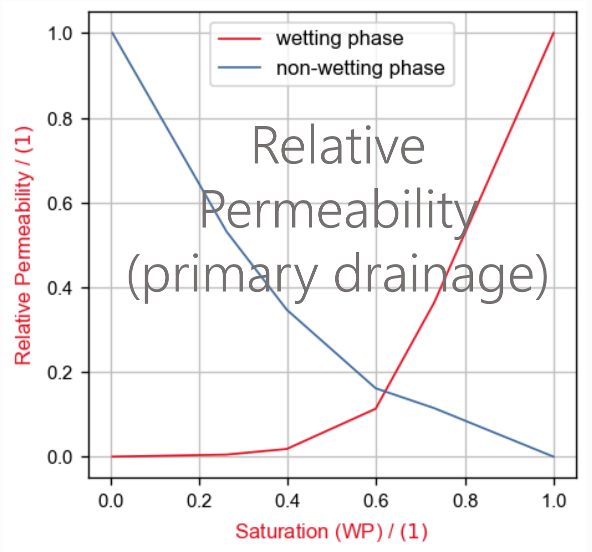
Capillary pressure curve



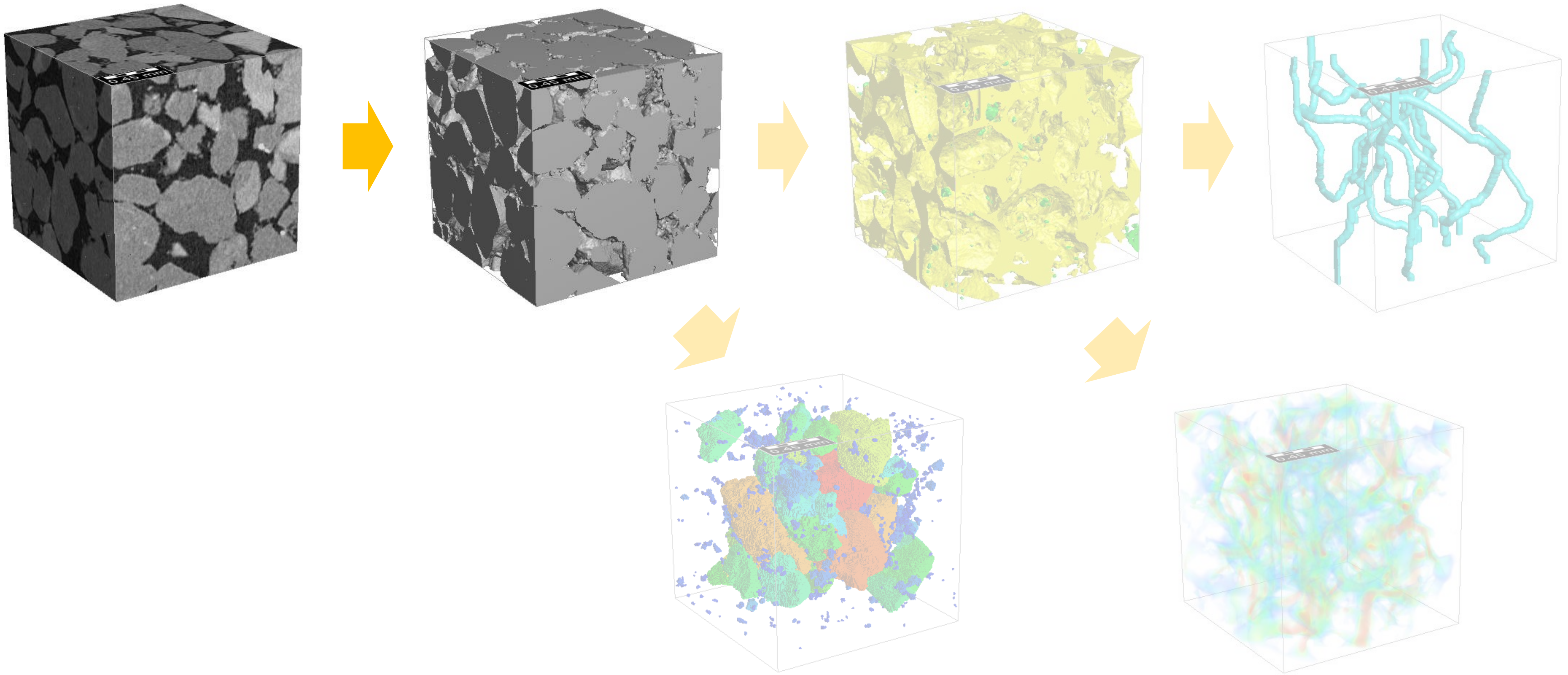


Relative permeability



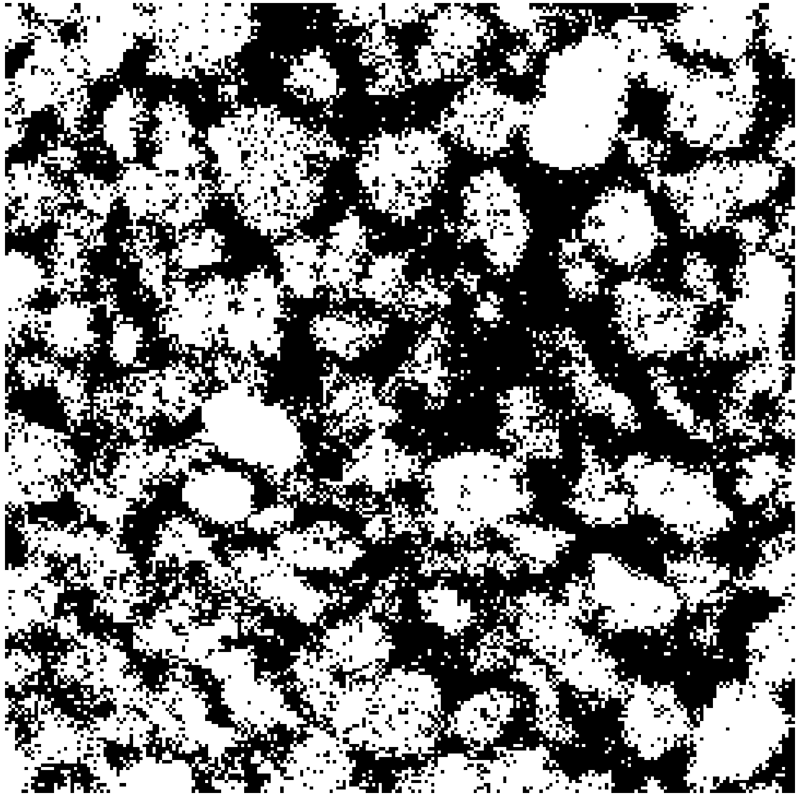


CT scan | Segmentation | Pore space | Percolation path

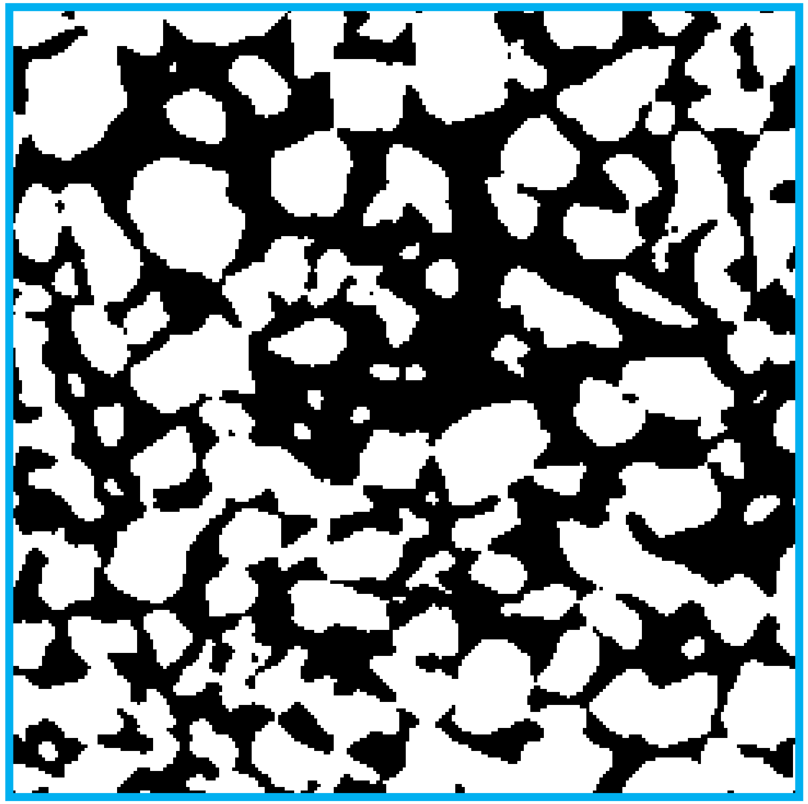


Grain size | Absolute permeability

HOW DO WE CHOOSE A SEGMENTATION METHOD?

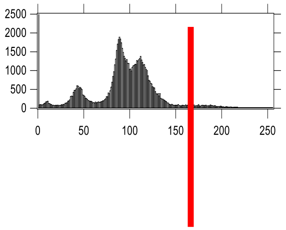


Bad

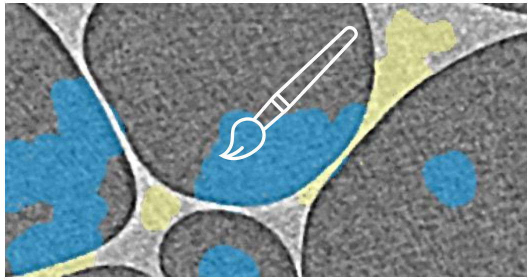


Good

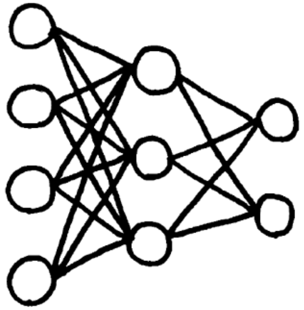
Simple → Complex



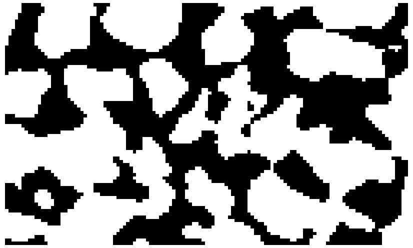
Thresholding



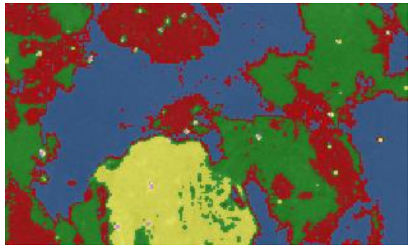
Machine learning



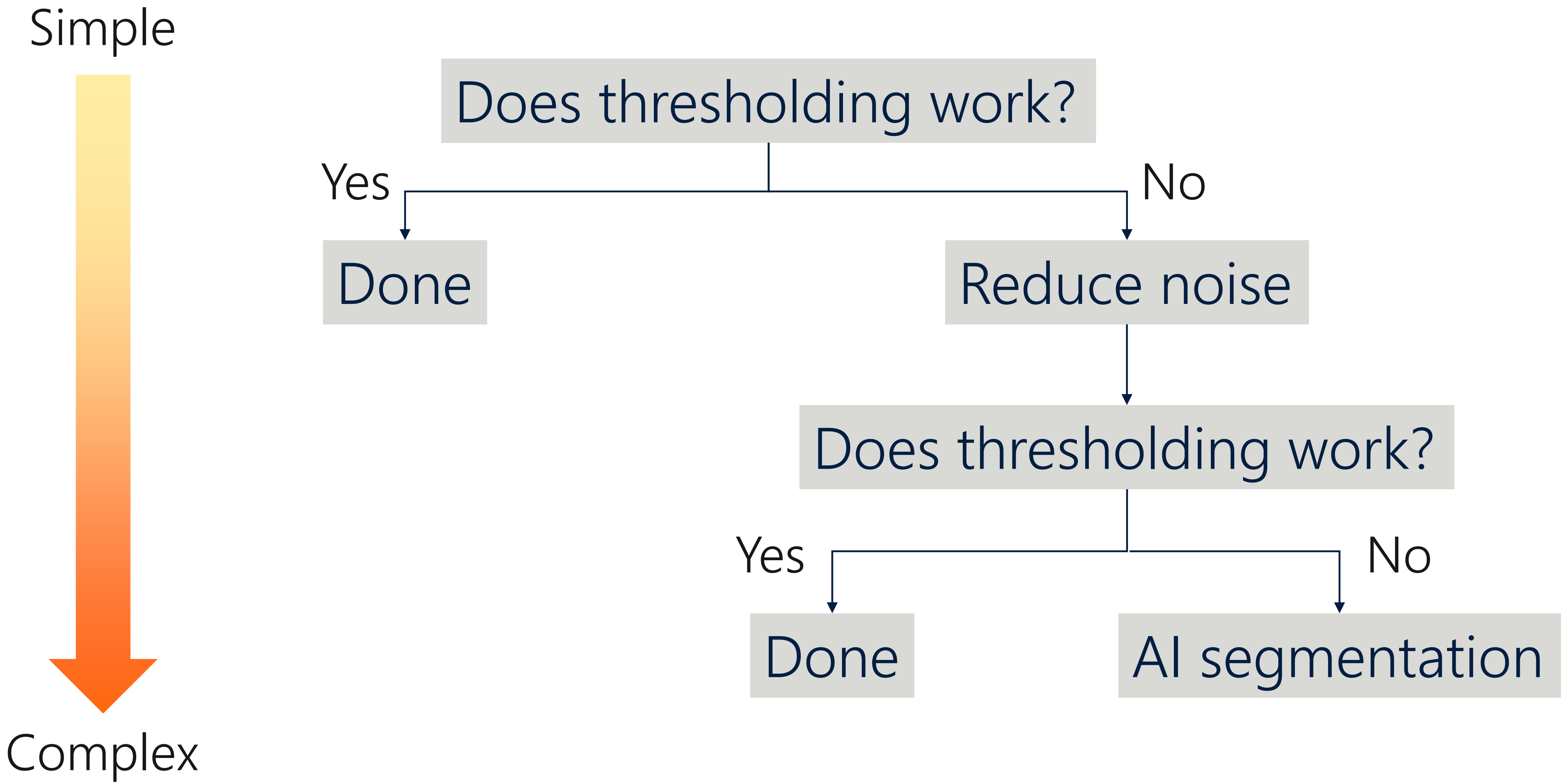
Deep learning



Binary

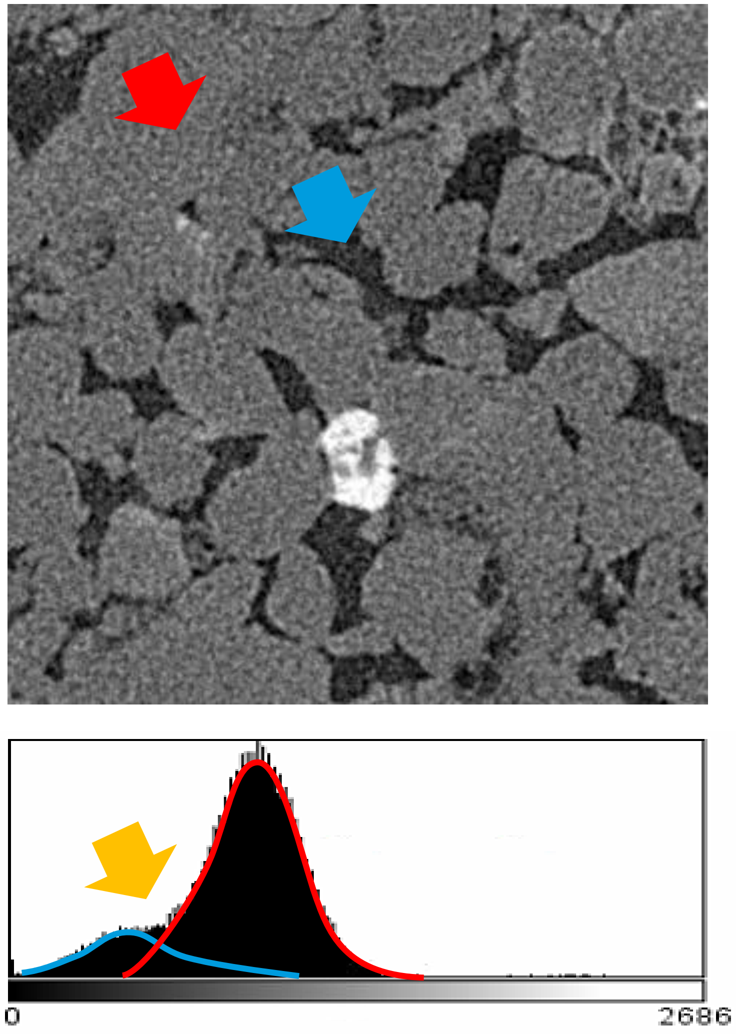


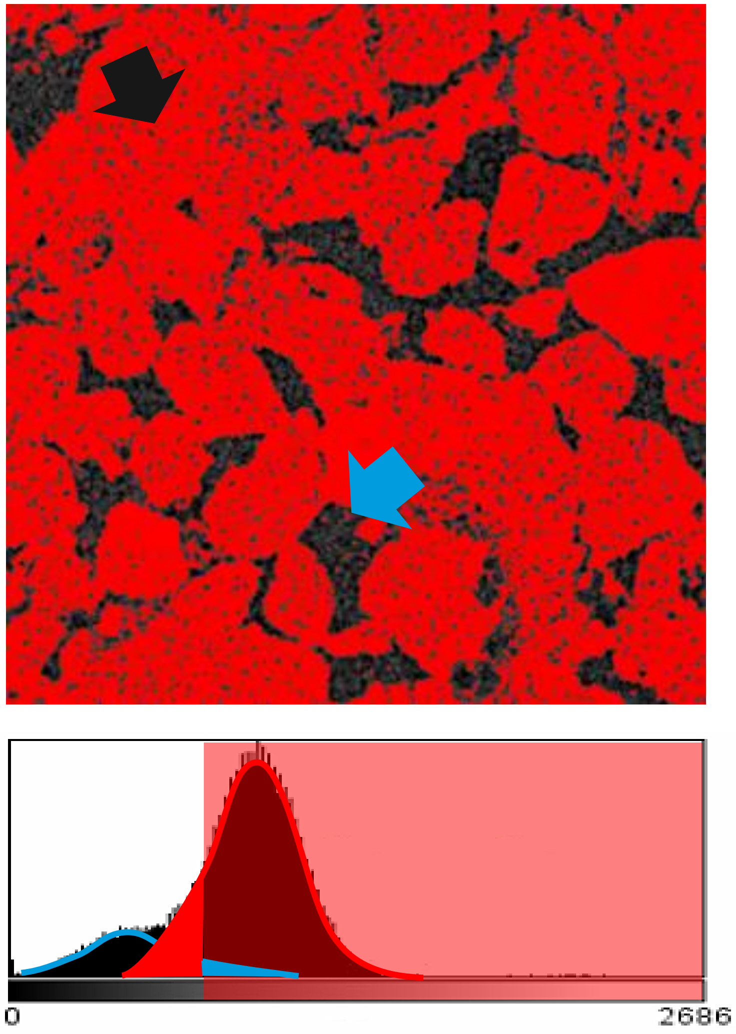
Multi-phase

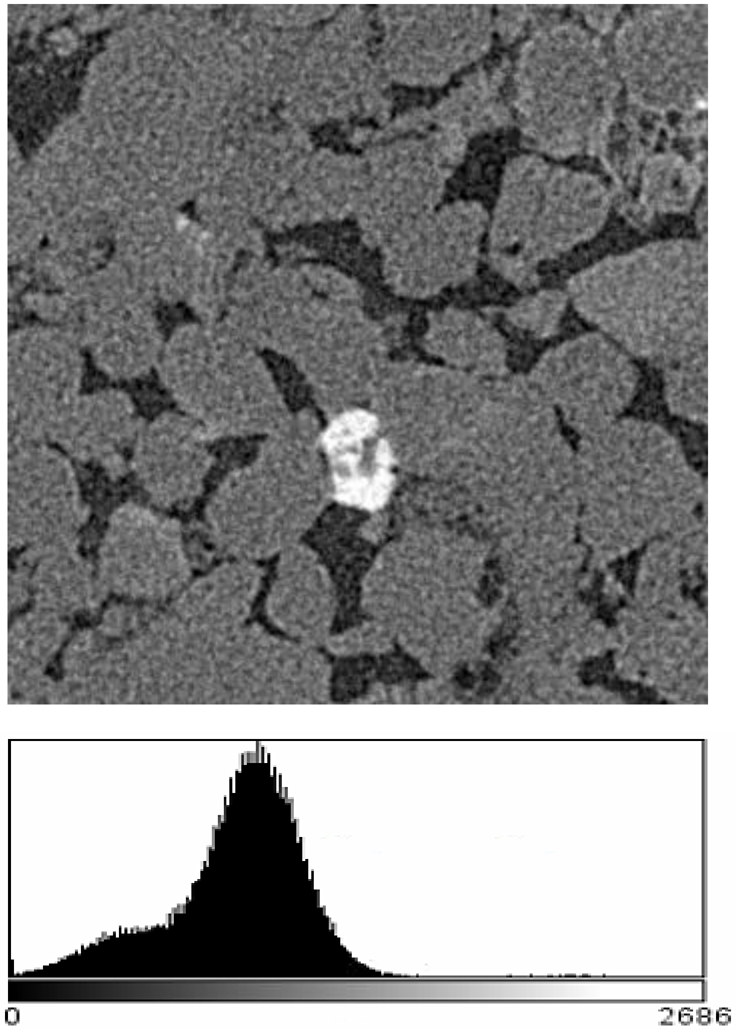

Simple
Complex
Does thresholding work?
Yes
No
Done
Reduce noise
Does thresholding work?
Yes
No
Done
AI segmentation

WHAT MAKES SEGMENTATION DIFFICULT?

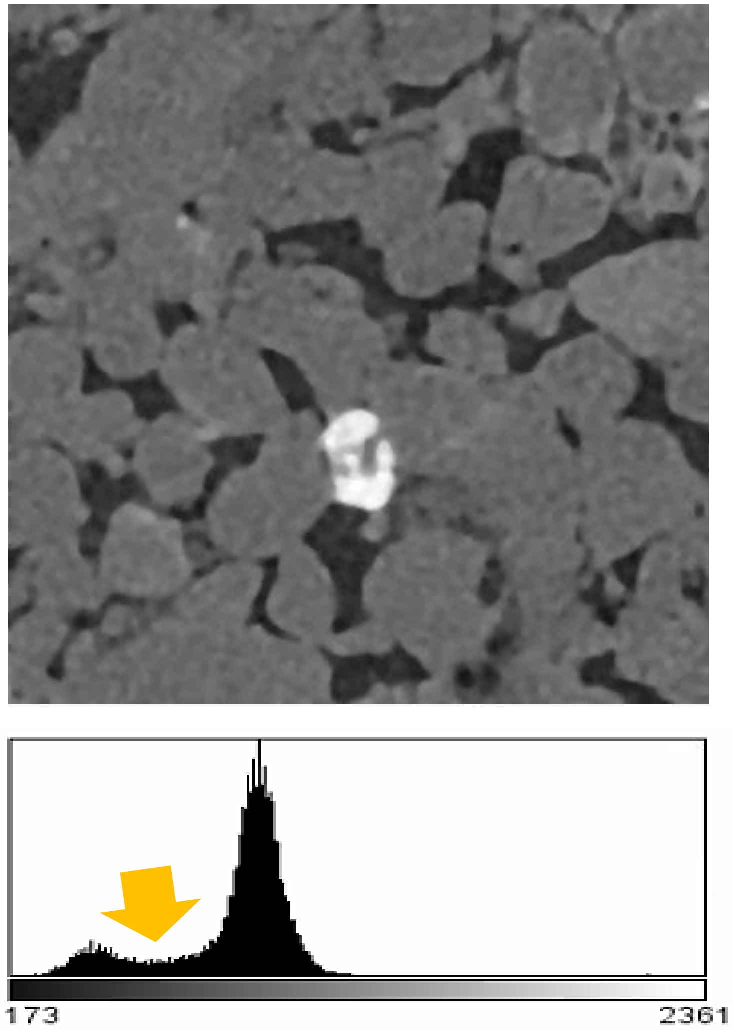
Otsu binarization



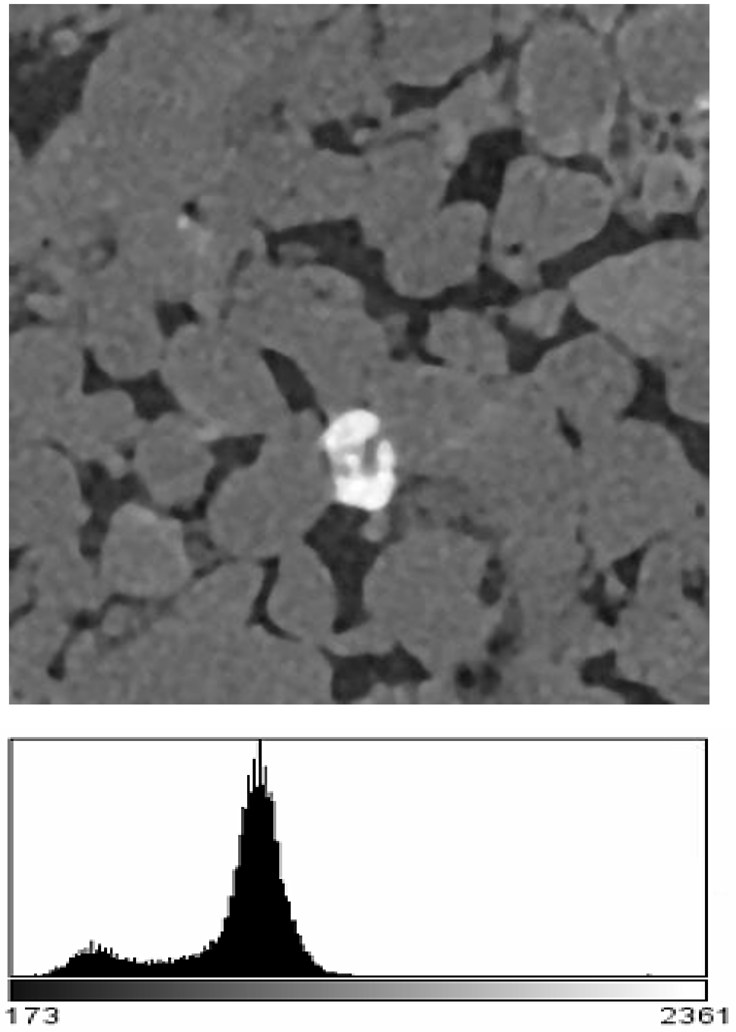




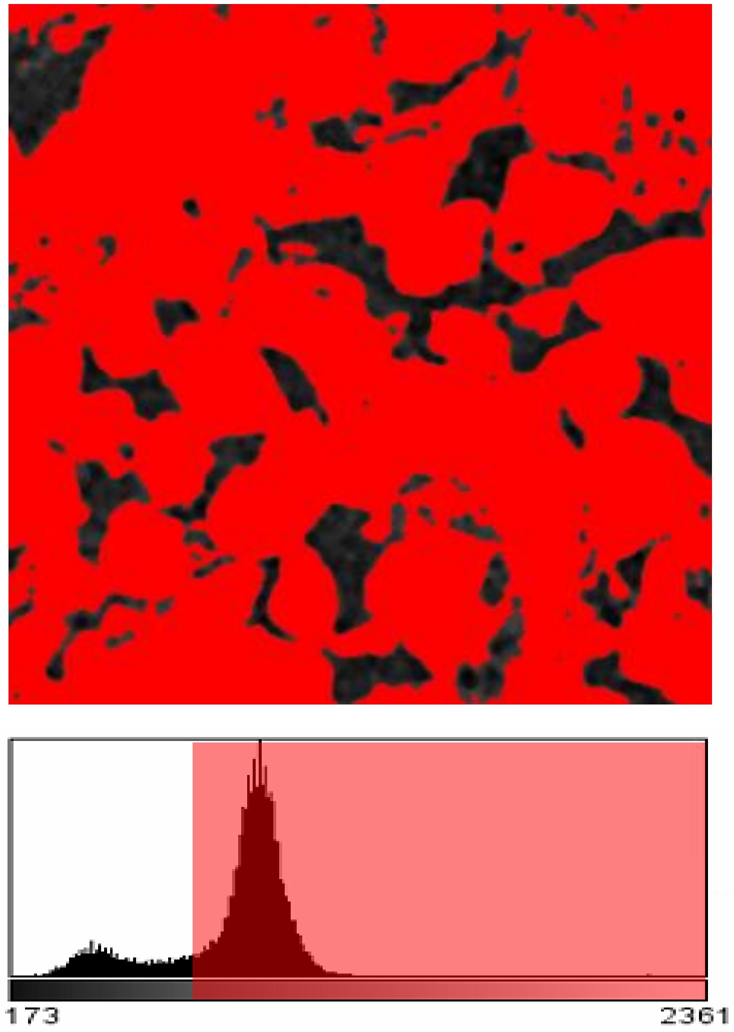
Median filter



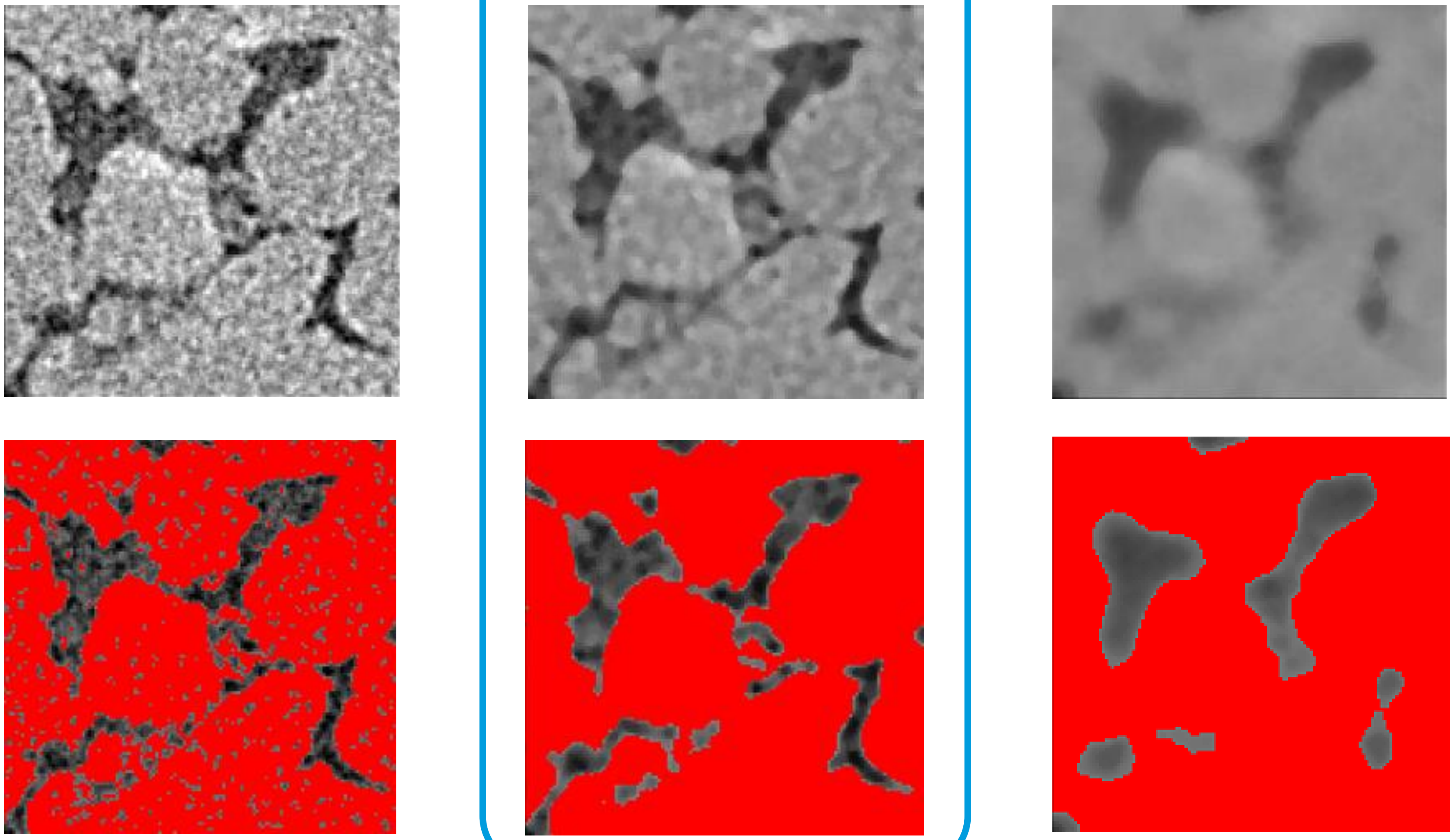
Median filter



Otsu binarization

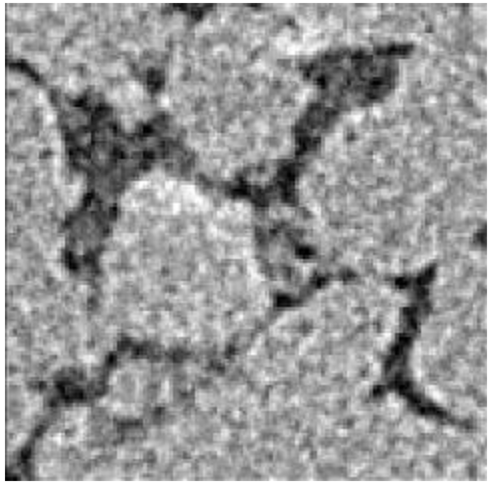


	Original	Median K=2	Median K=8
Gray scale			
Otsu binarization			

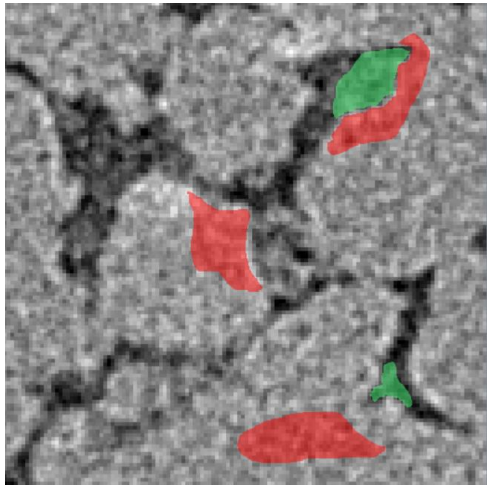


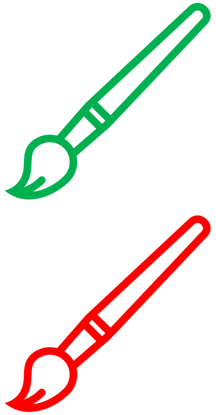
Original

Gray scale

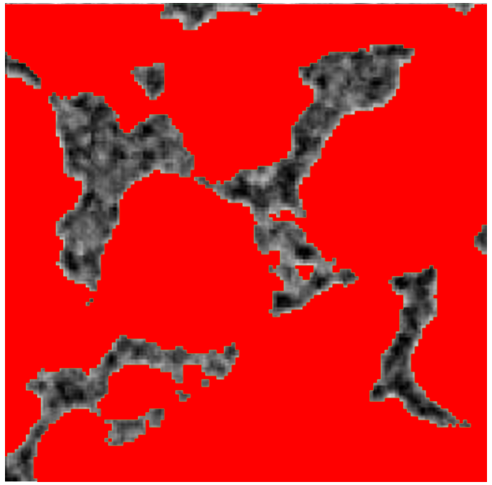


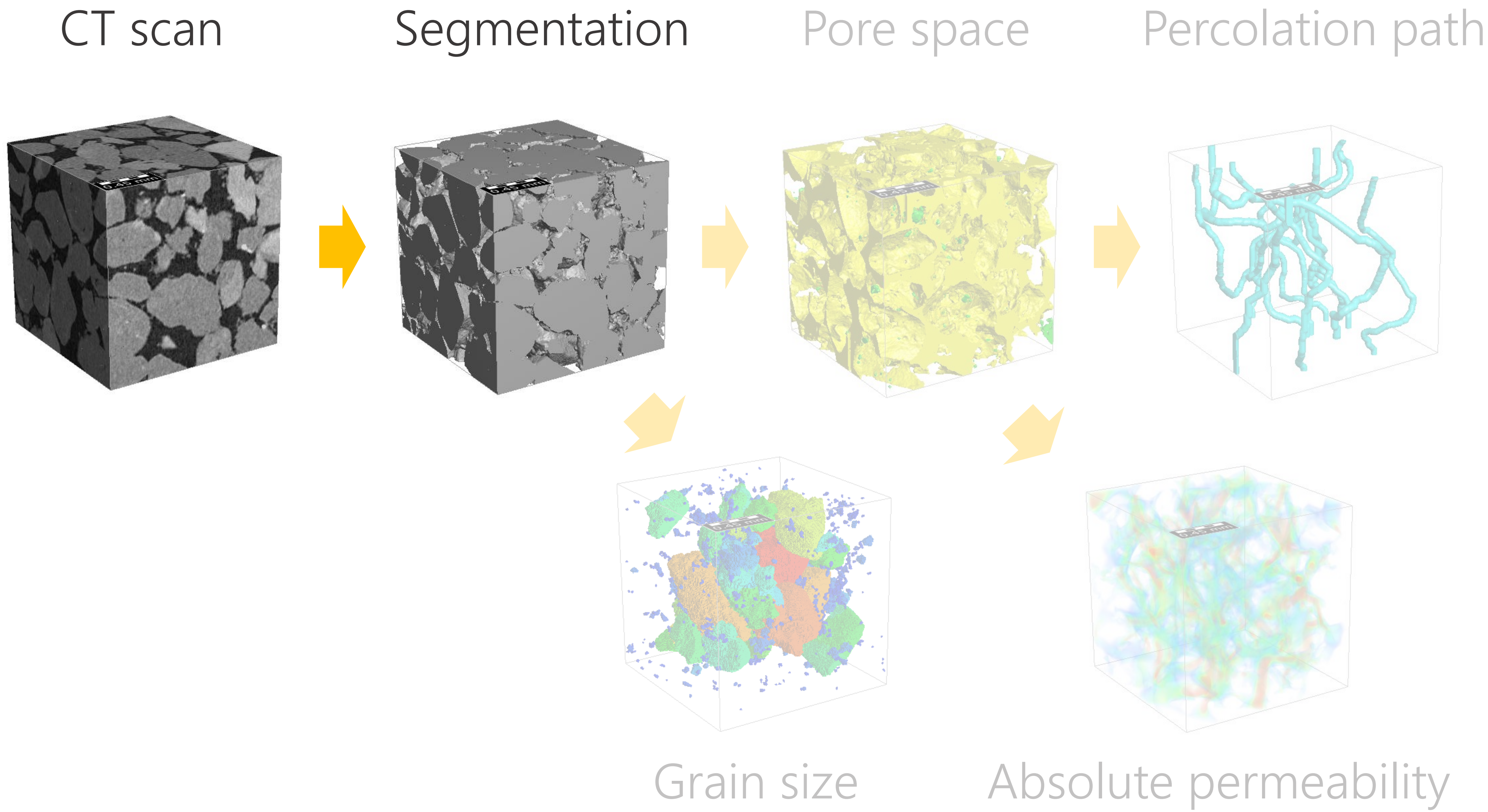
Training data





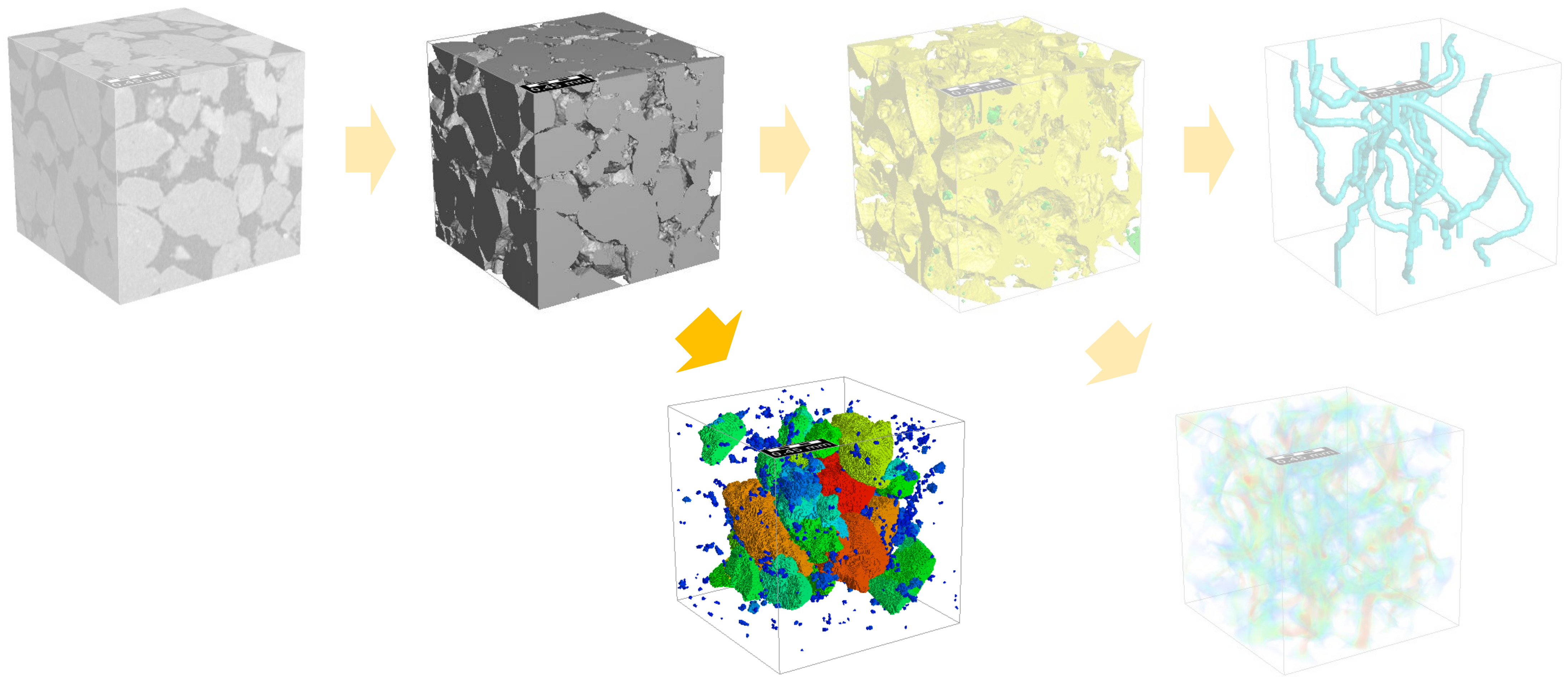
Machine learning



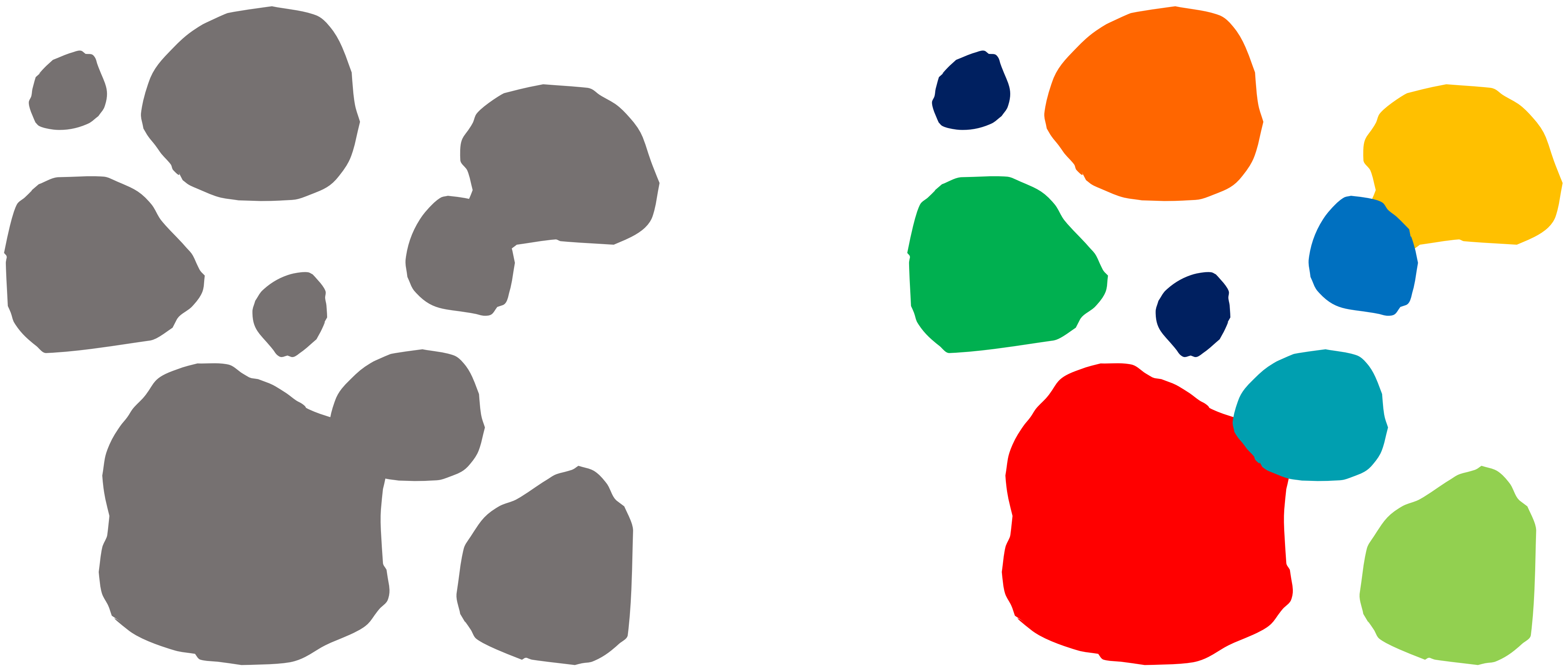


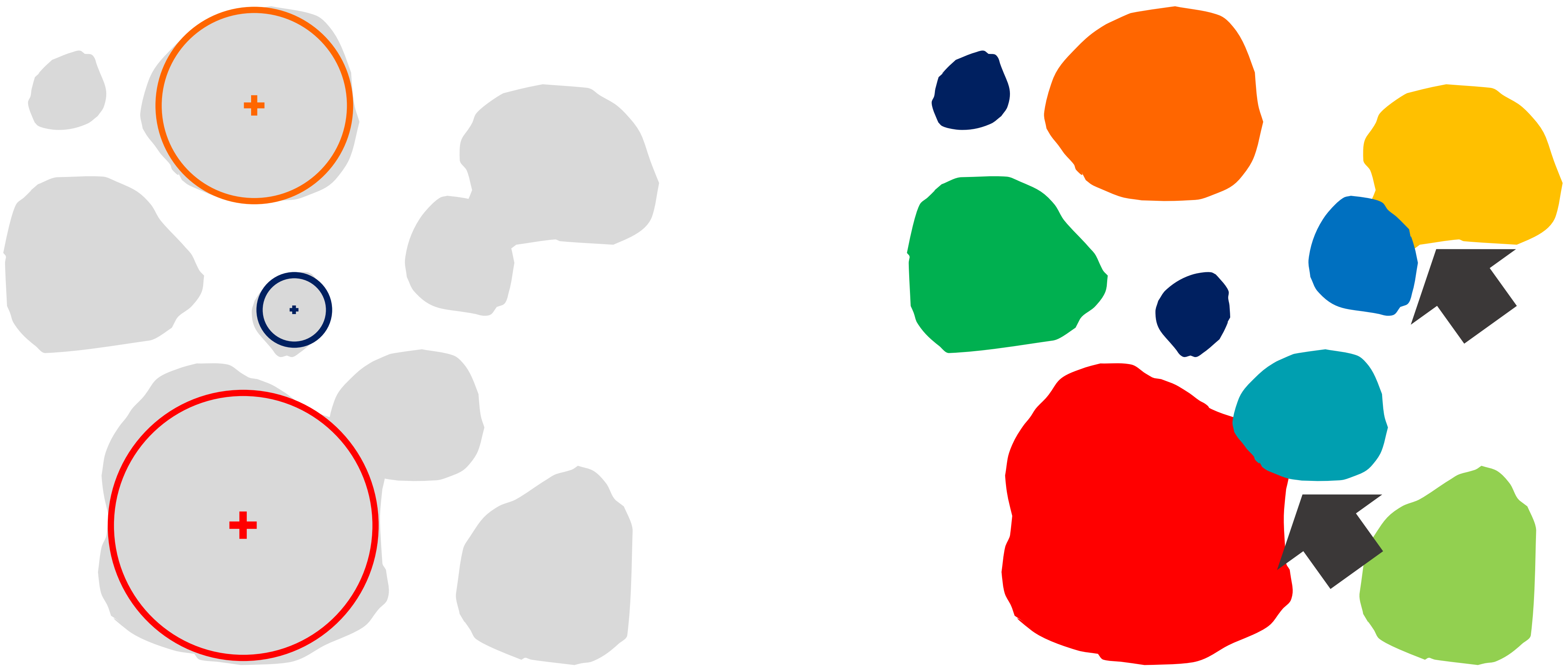
CT scan
Segmentation
Pore space
Percolation path
Grain size
Absolute permeability

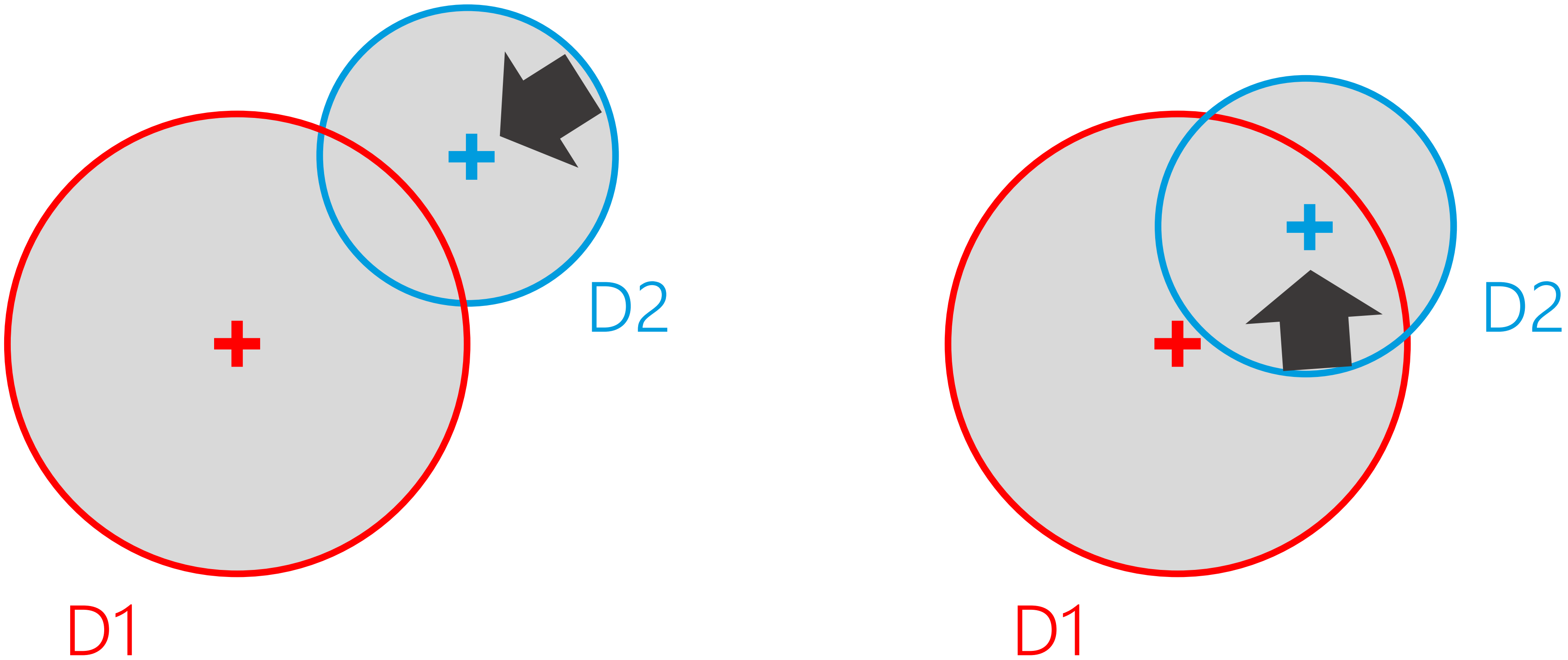
CT scan | Segmentation | Pore space | Percolation path

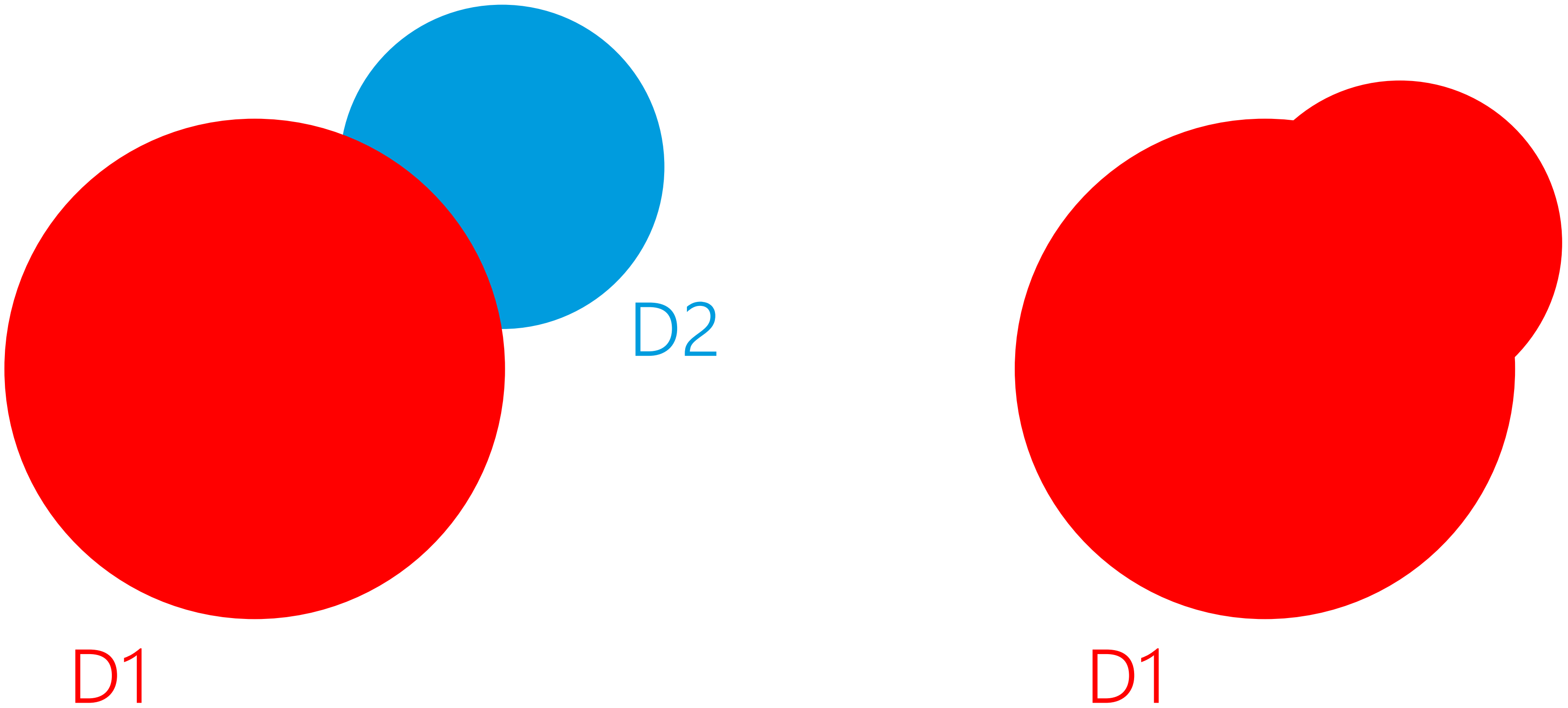


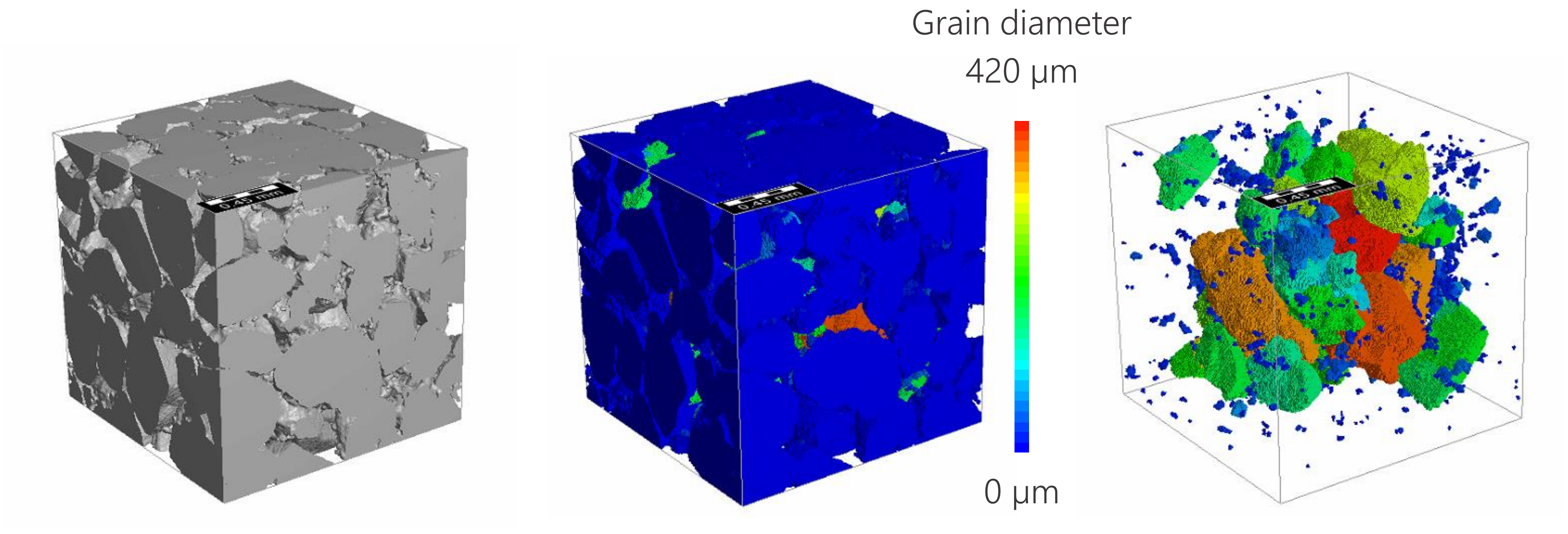
Grain size | Absolute permeability



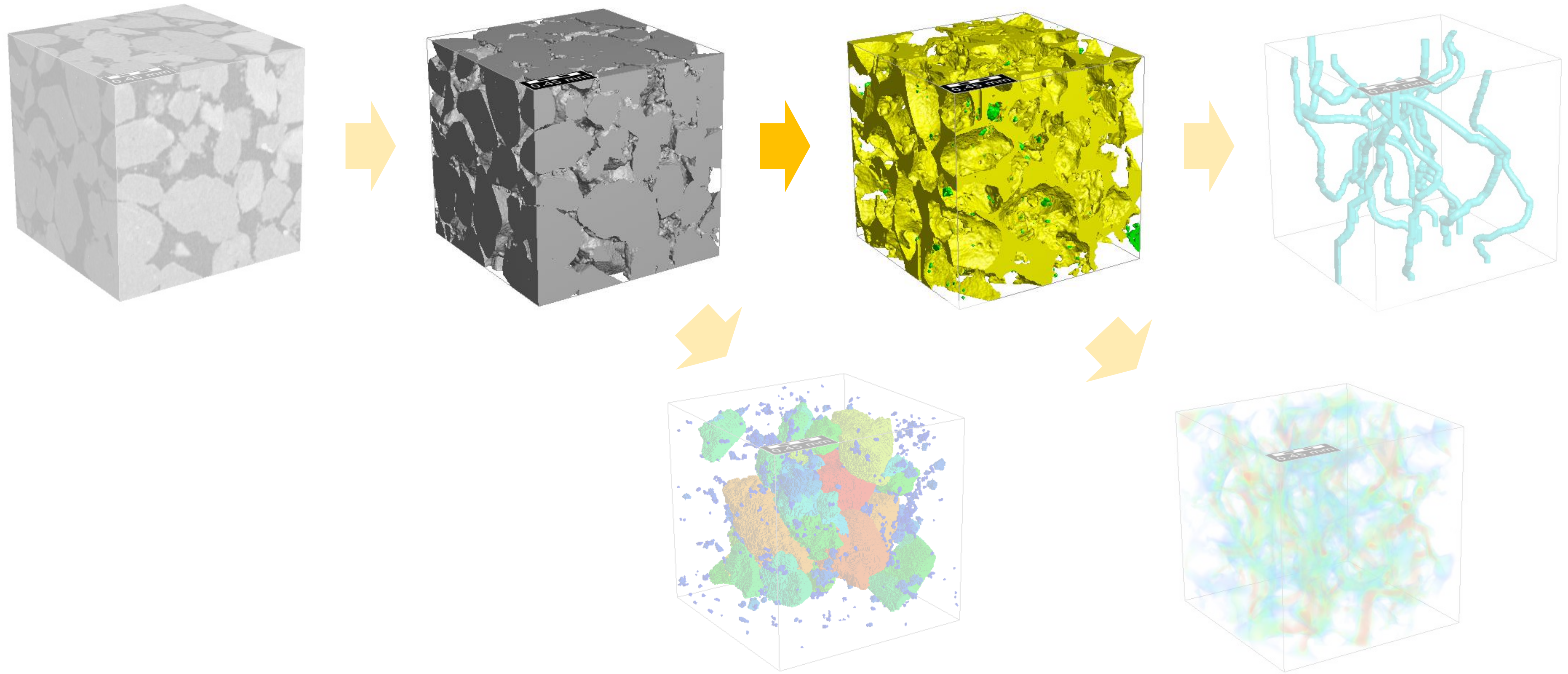



D2
D1
D2
D1

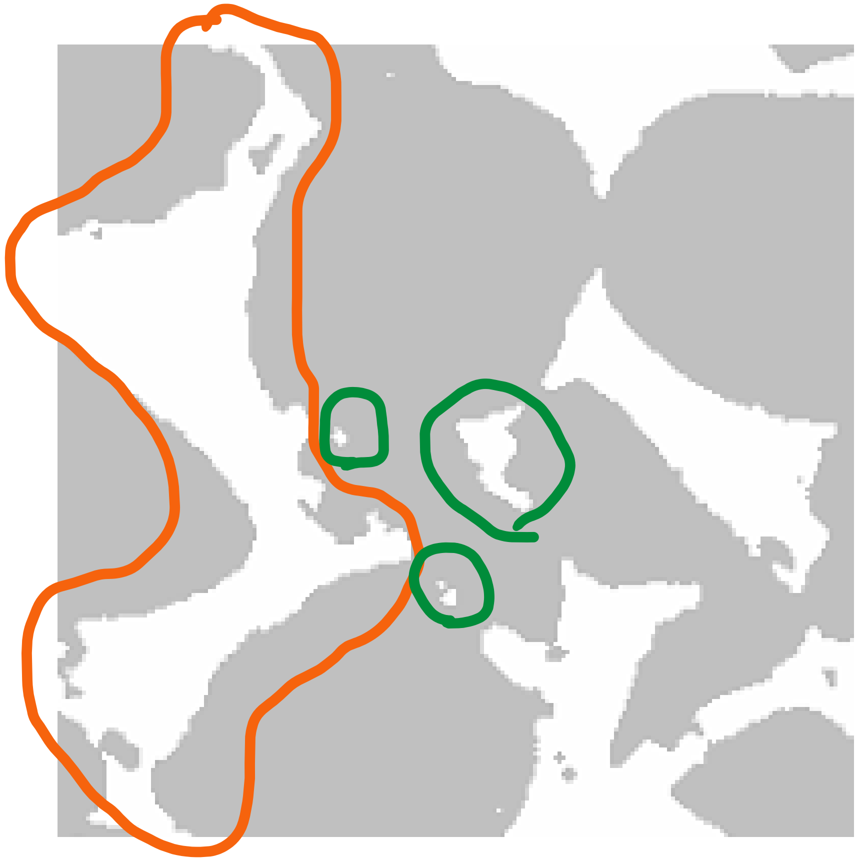

D2
D1
D1


Grain diameter
420 µm
0 µm

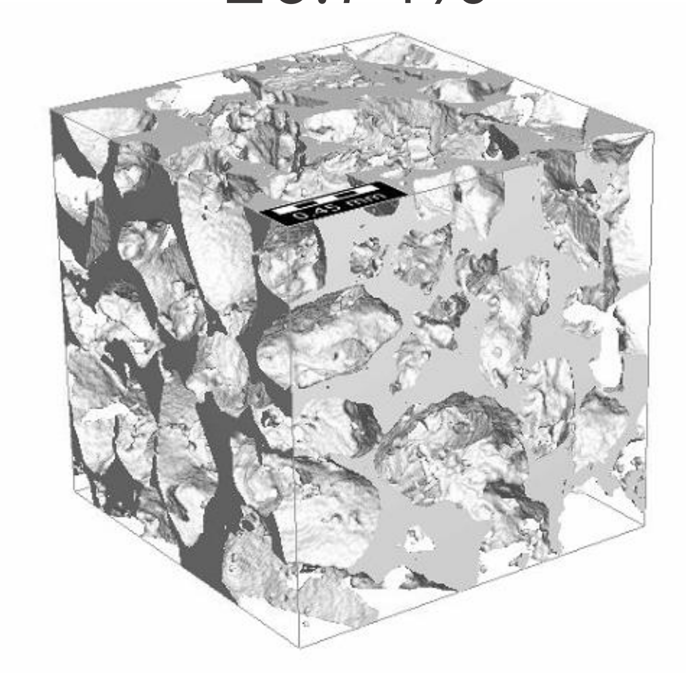
CT scan Segmentation Pore space Percolation path



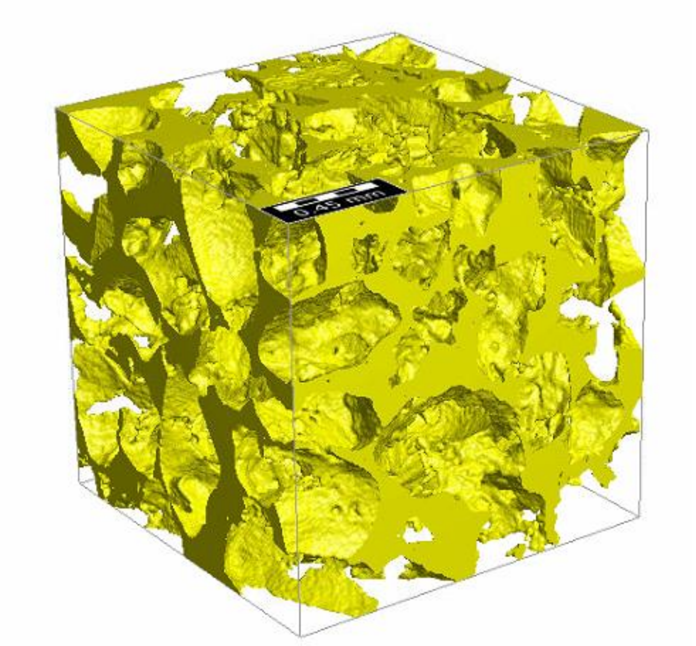
Grain size Absolute permeability



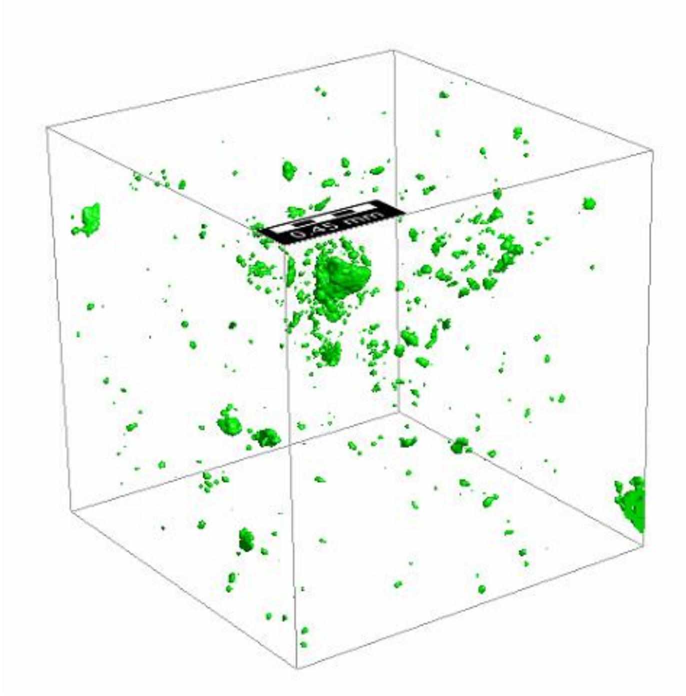
Overall porosity
26.74%



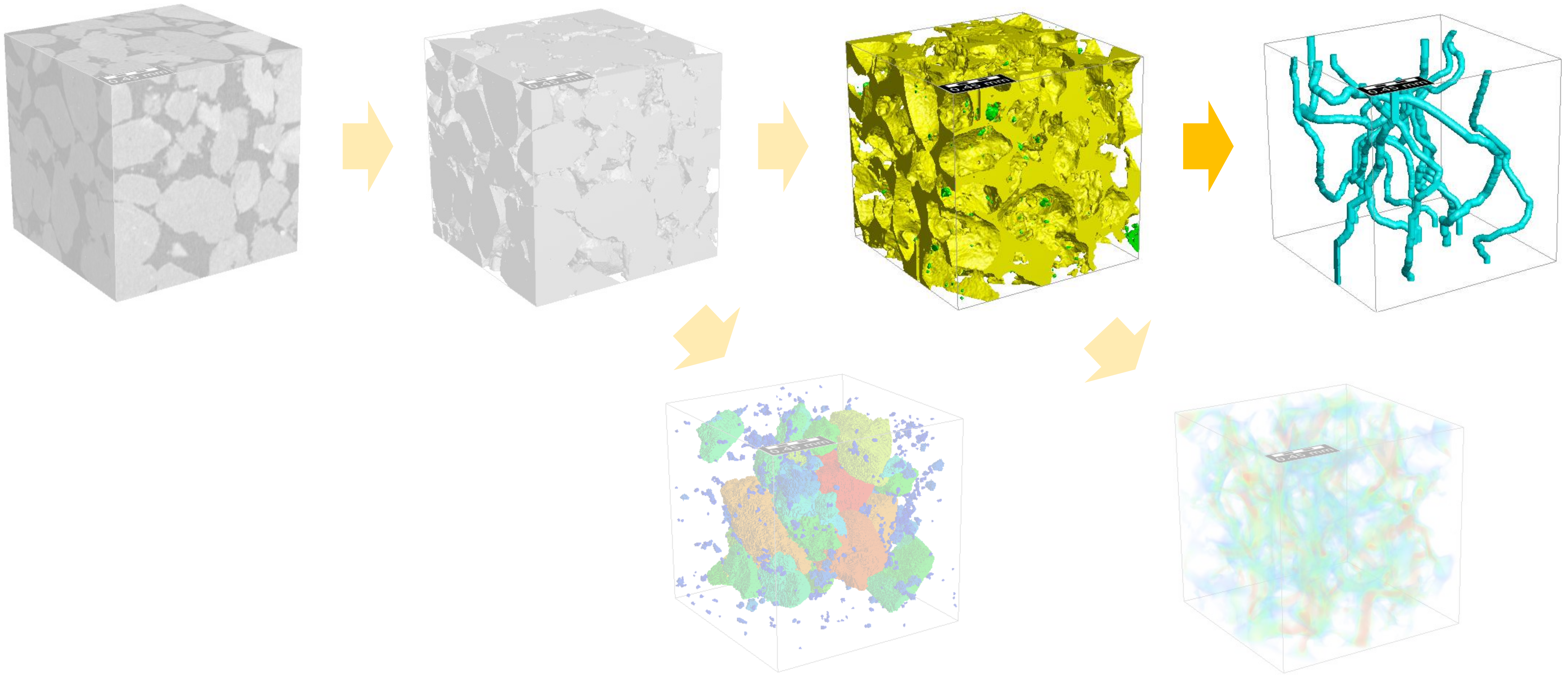
Open porosity
26.62%



Closed porosity
0.12%



CT scan | Segmentation | Pore space | Percolation path

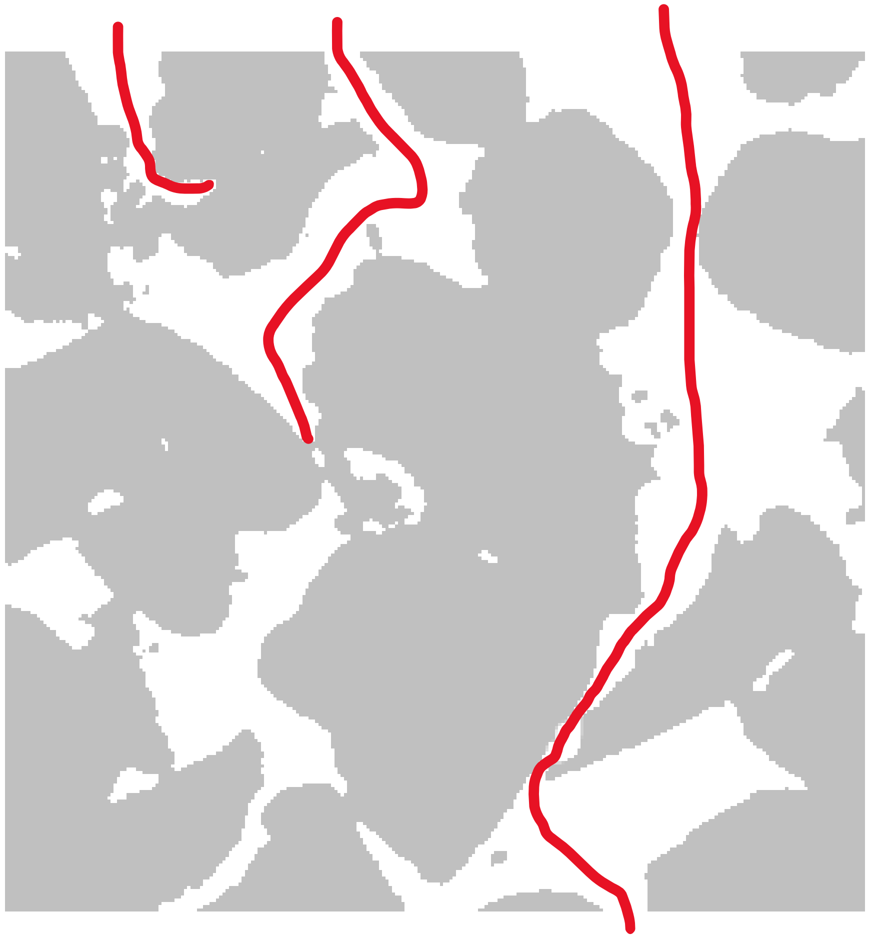


Grain size | Absolute permeability

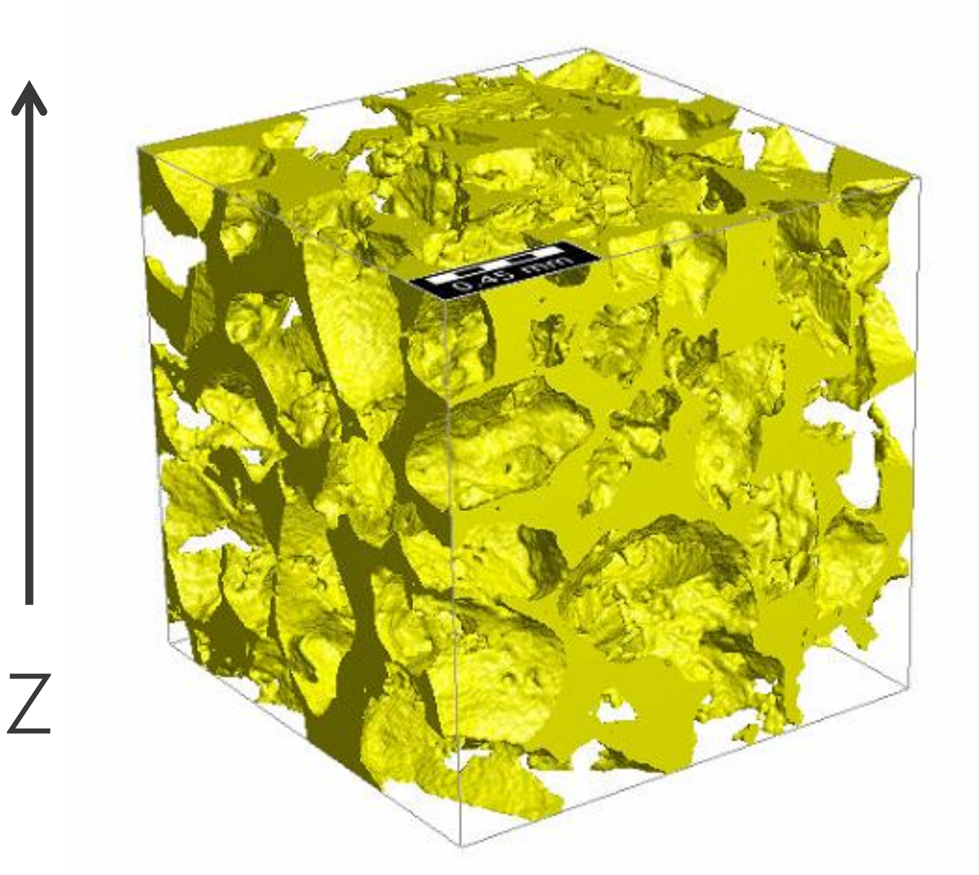
WHAT IS PERCOLATION?

Percolation

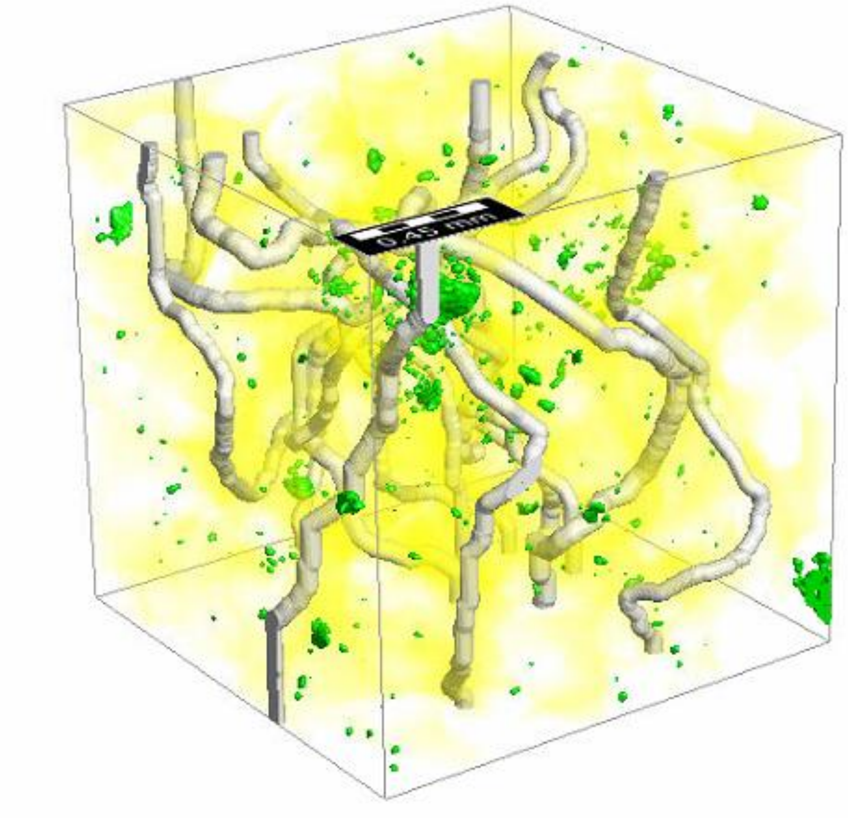
The slow movement of fluid through the pores in soil or permeable rock.

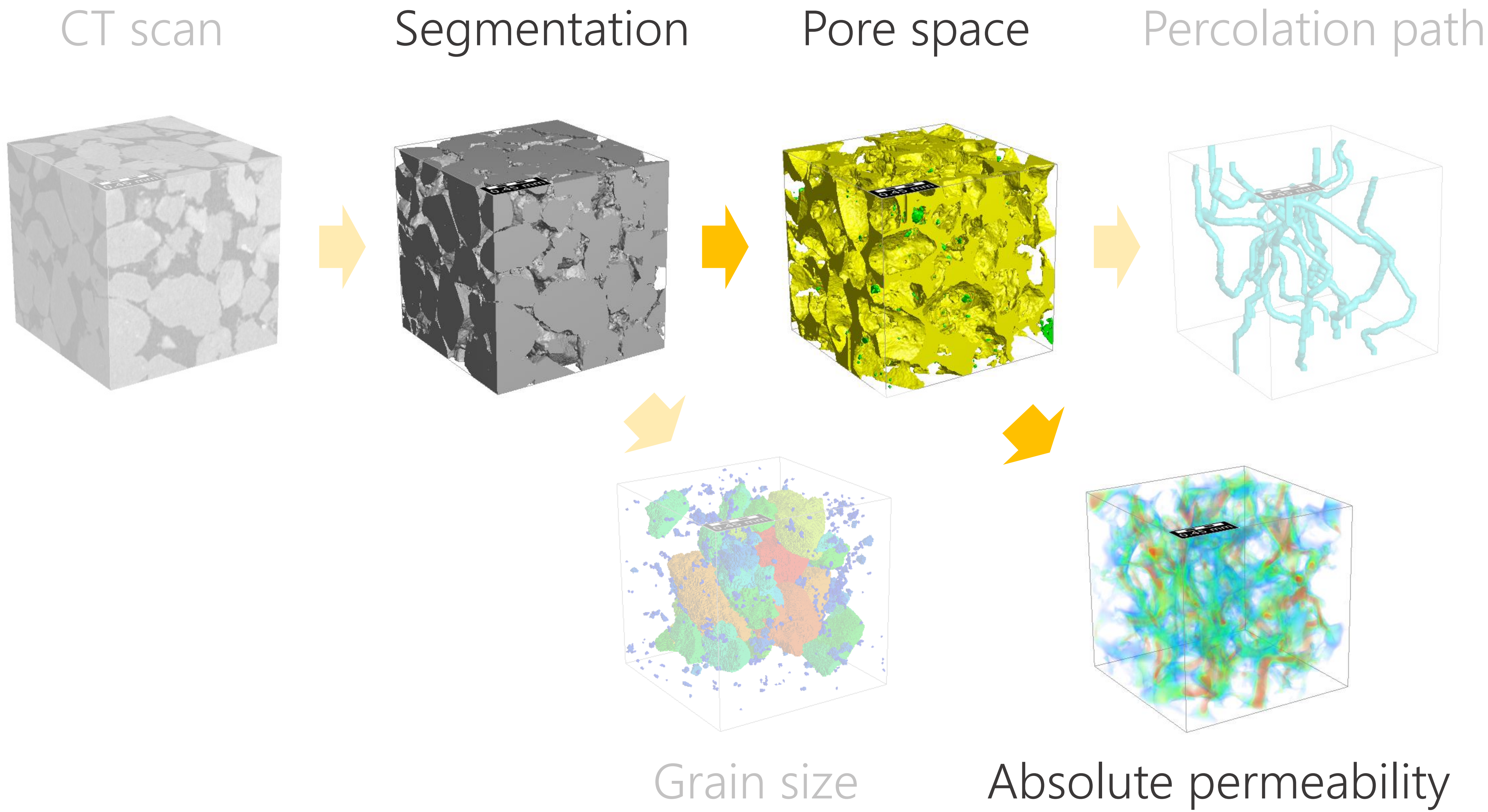


Open pores



10 percolation paths in Z direction




CT scan
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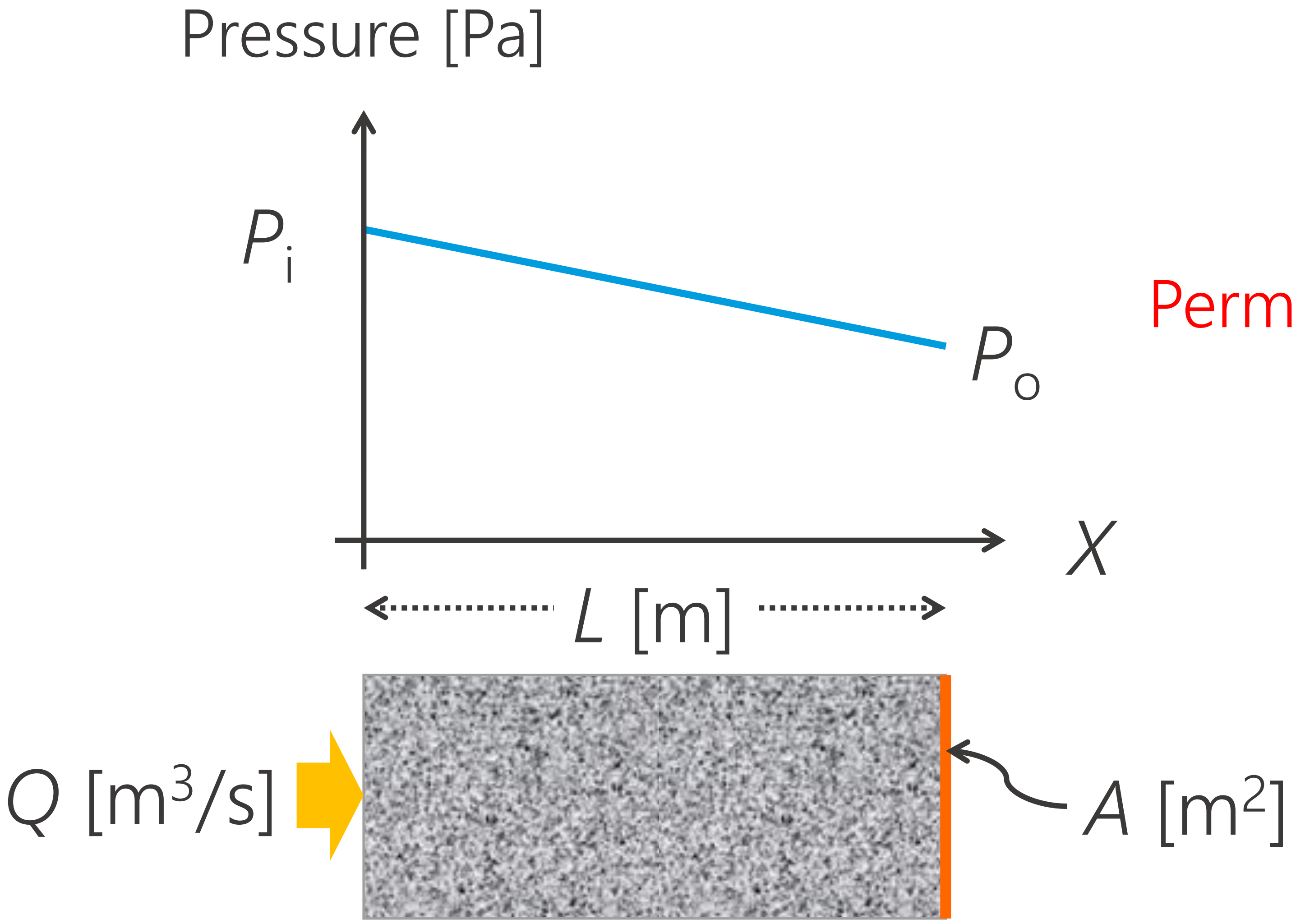
WHAT IS PERMEABILITY?



Volumetric flow rate
(Darcy's law)

Permeability [m²]

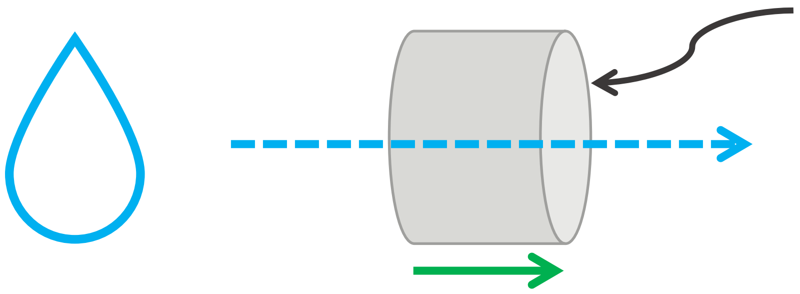
$$Q = \frac{kA(P_i - P_o)}{\mu L}$$

Viscosity of the fluid [Pa·s]

Permeability k [m^2] → k [D]

$$1 \text{ Darcy} = 0.987 \times 10^{-12} \text{ m}^2 \approx 10^{-12} \text{ m}^2$$

Area 1 cm^2



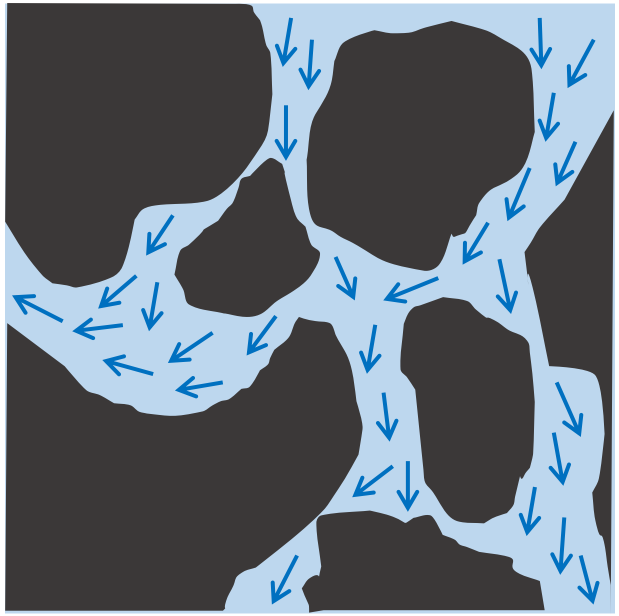
Water 1 cm^3

Viscosity = 1 centiPoise

Pressure drop 1 atm/cm

WHAT'S DIFFERENT BETWEEN ABSOLUTE & RELATIVE PERMEABILITIES?

Absolute permeability K_1



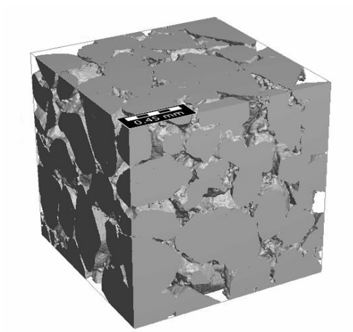
K_1 at saturation 100%

Relative permeability

K_s/K_1 at saturation S%

K_s: Saturation dependent permeability

HOW DO WE CALCULATE ABSOLUTE PERMEABILITY?



3D structure

Fluid with constant μ

Mass flow rate direction

Flow velocity $\vec{u}$ [m/s] (Darcy's law)

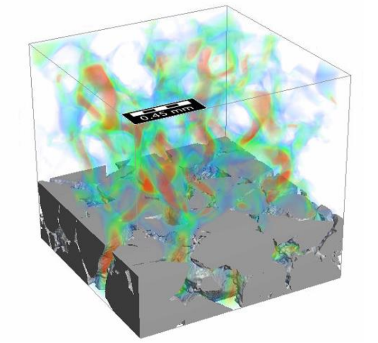
$$\vec{u} = \frac{K}{\mu}(\nabla p - \vec{f})$$

Permeability matrix K

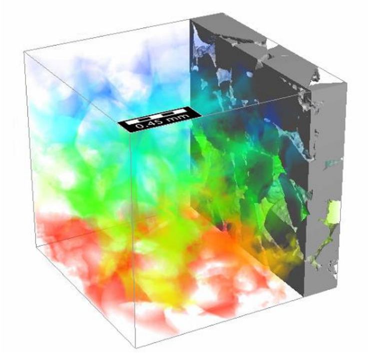
Viscosity μ

Pressure drop ∇p

Force density $\vec{f}$



Mean flow velocity at ∇p



Pressure drop at $\vec{u}$

Linden et al., Math2Market Report No. M2M-2018-01, October 2018

Darcy's law applies to very slow flows

$$-\mu\Delta\vec{u} + \nabla p = \vec{f}$$ **Stokes** conservation of momentum

When flow is fast

$$-\mu\Delta\vec{u} + (\rho\vec{u}\nabla)\vec{u} + \nabla p = \vec{f}$$ **Navier-Stokes**

Inertia

When flow is fast and porous medium exist

$$-\mu\Delta\vec{u} + (\rho\vec{u}\nabla)\vec{u} + \mu K^{-1}\vec{u} + \nabla p = \vec{f}$$

Effect of porous medium

Navier-Stokes-Brinkman

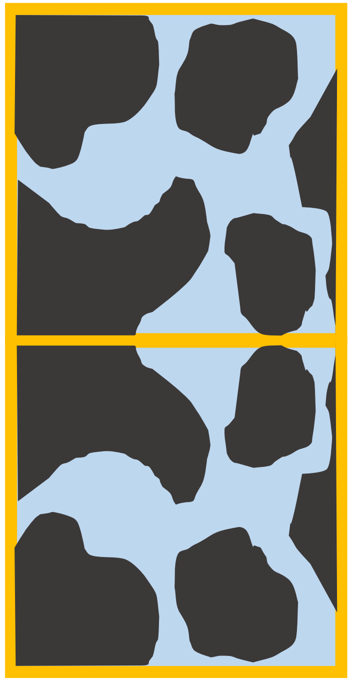
Flow velocity $\vec{u}$ [m/s], Pressure drop ∇p, Force density $\vec{f}$, Permeability K

Partial differential equation solvers

Solver	Highly porous	Less porous	RAM	Model
EJ (explicit jump)	Very fast	Slow	Low	Stokes
Simple FFT	Slow	Fast	High	All
LIR (left identity right)*	Very fast	Fast	Low	All

* Linden et al., Graph. Models, 2015, 82, p. 58-66

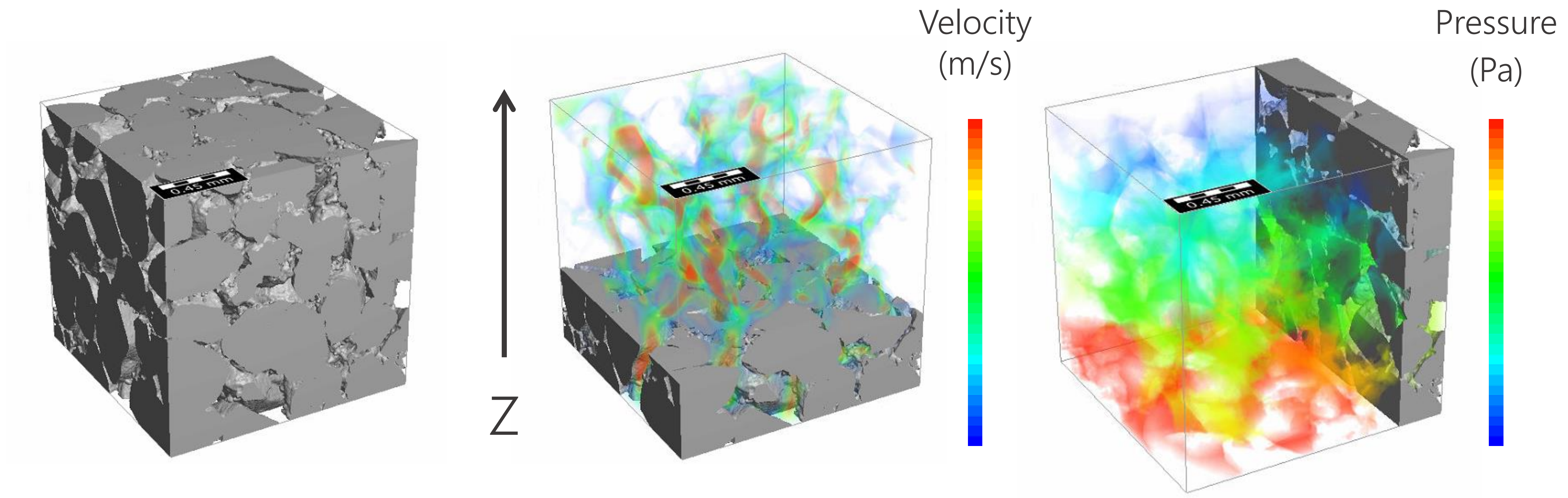
Boundary conditions



Symmetric

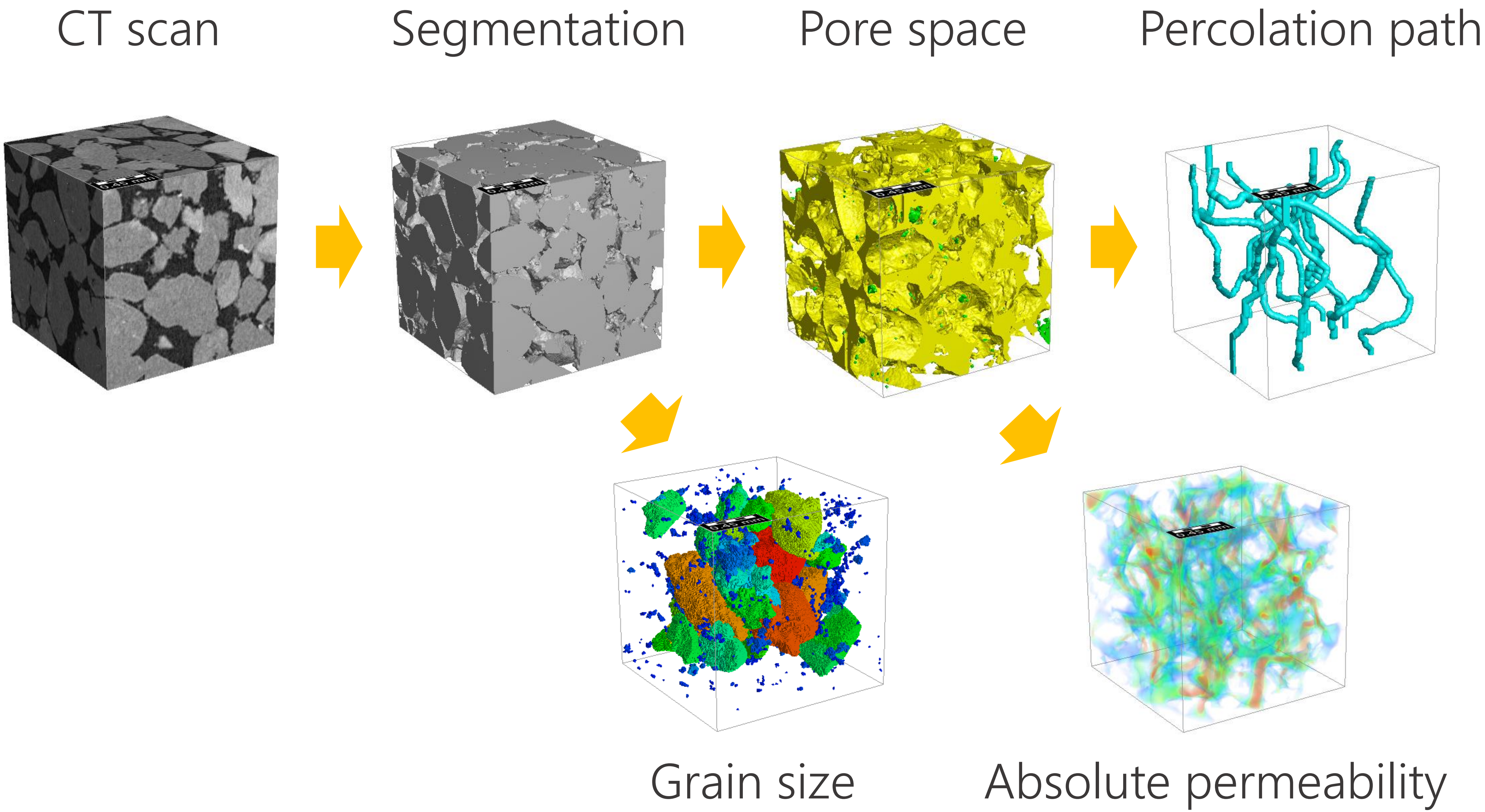
Periodic with inlet/outlet

Periodic



Permeability tensor [mD]

$\boldsymbol{K_{xx}}$	K_{xy}	K_{xz}
K_{yx}	$\boldsymbol{K_{yy}}$	K_{yz}
K_{zx}	K_{zy}	$\boldsymbol{K_{zz}}$


CT scan
Segmentation
Pore space
Percolation path
Grain size
Absolute permeability

THINGS COVERED

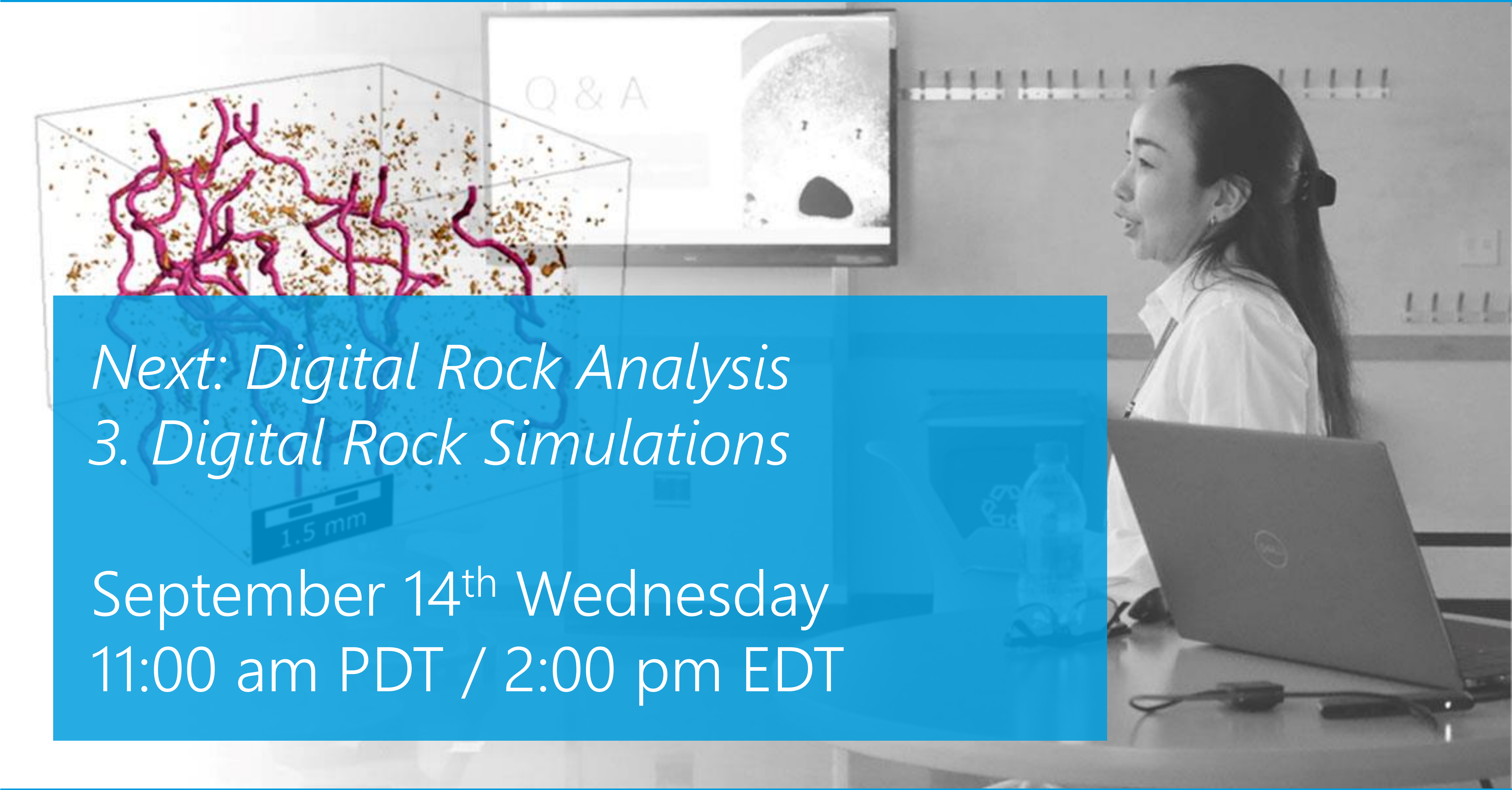
- How to segment CT images
- How to analyze basic properties such as porosity, percolation path, grain size, absolute permeability etc.

Q & A SESSION

We'll follow up with your questions.

Recording will be available tomorrow.

Register for the next workshop.



Next: Digital Rock Analysis
3. Digital Rock Simulations

September 14th Wednesday
11:00 am PDT / 2:00 pm EDT

THANK YOU FOR JOINING US
SEE YOU NEXT TIME

Tokyo, Japan