WELCOME TO RIGAKU VIRTUAL WORKSHOP

DEEP DIVE: DIGITAL ROCK ANALYSIS

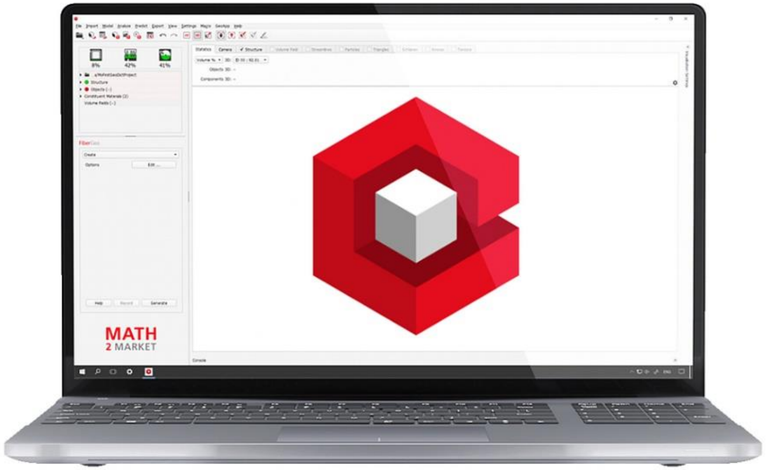
1. Data Collection

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

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 – 1. Data Collection

Virtual Workshop presented by Aya Takase

DIGITAL ROCK ANALYSIS SERIES

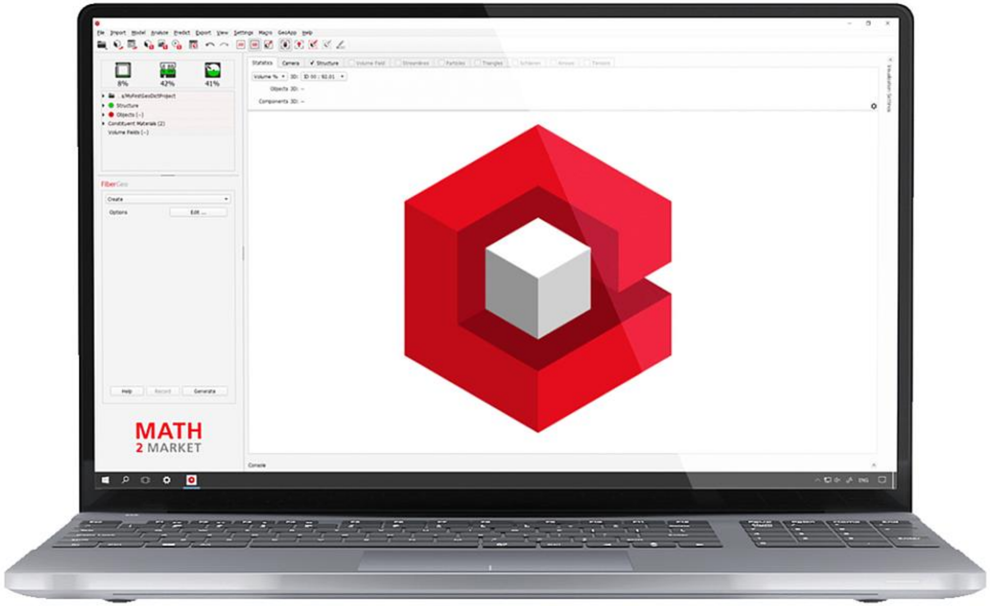
1. Data collection
2. Segmentation and property analyses
3. Digital rock simulations

THINGS WE'LL COVER

- How to assess the required resolution
- How to collect high-quality CT images
- How to evaluate the image quality

CT Lab HX by Rigaku

The versatile and compact micro-CT scanner



GeoDict by Math2Market

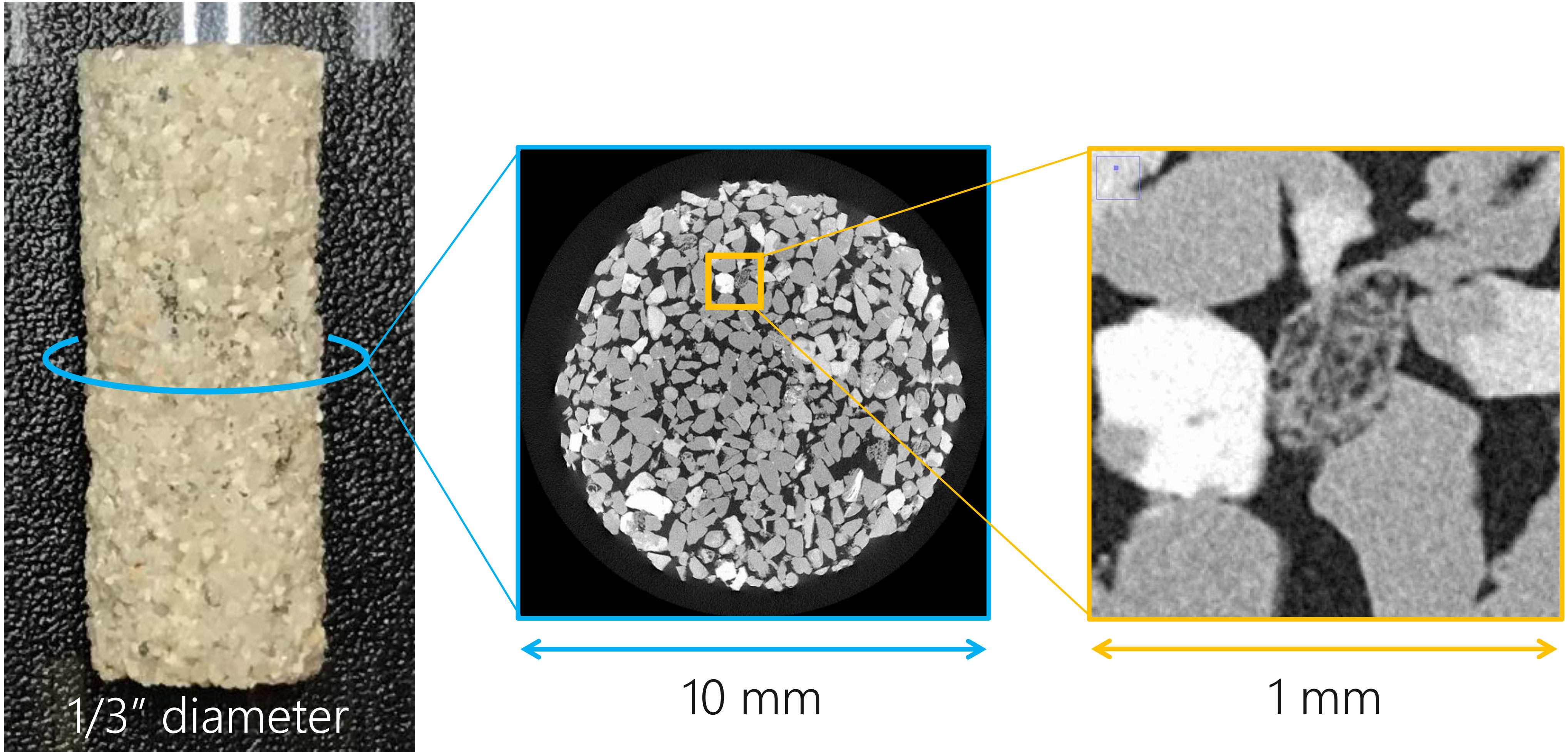
The Digital Material Laboratory

WHAT IS DIGITAL ROCK PHYSICS/ANALYSIS?

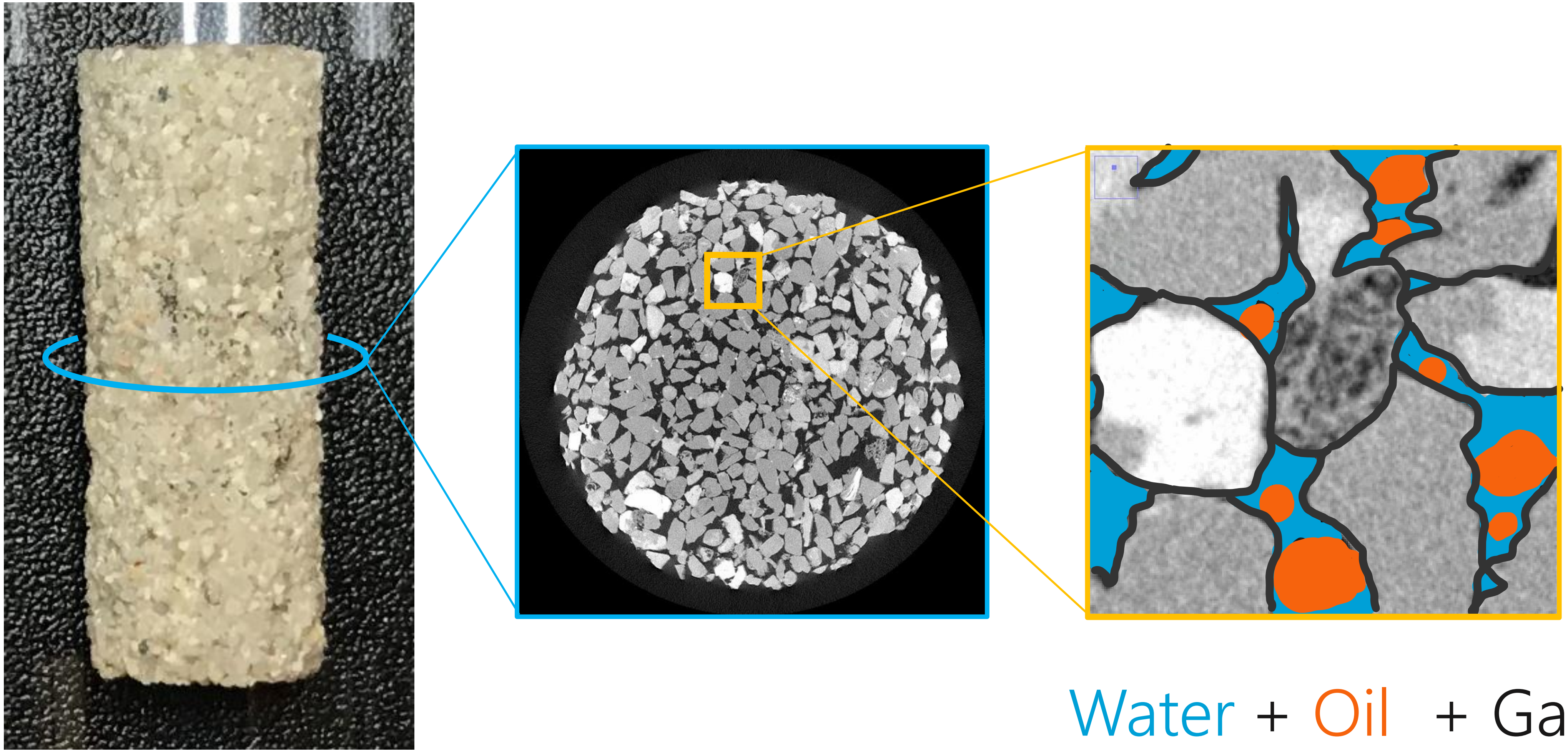
Digital rock physics

Analysis of flow properties of reservoir rocks using image-based computation

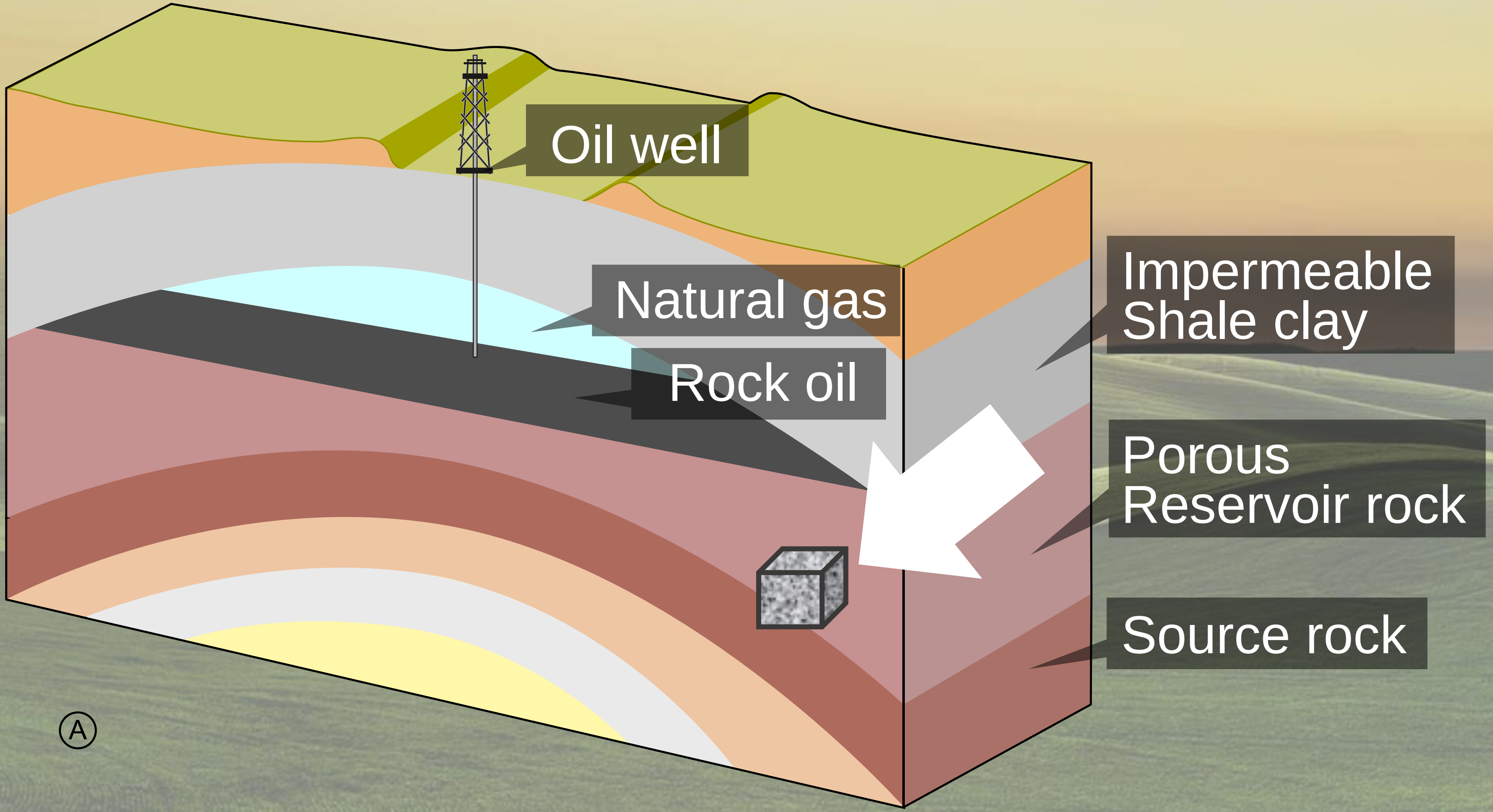
Sandstone



Sandstone



Water + Oil + Gas



By MagentaGreen- https://commons.wikimedia.org/wiki/File:Anticline_trap.svg

Porosity

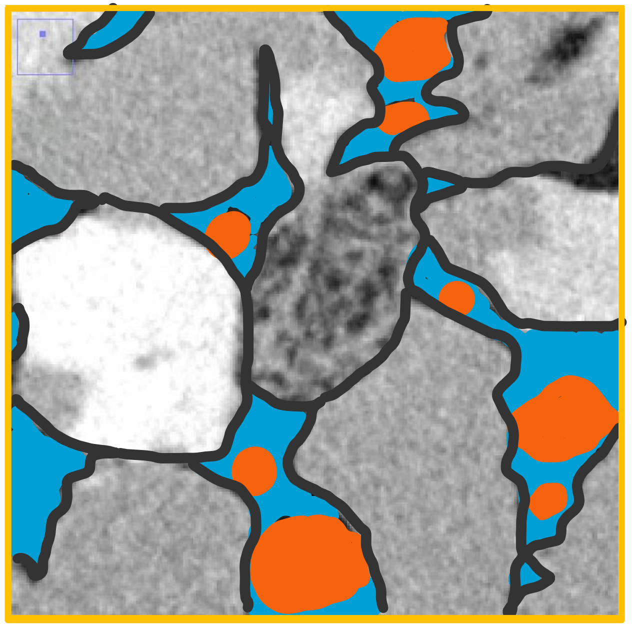
Ratio of open/connected pores

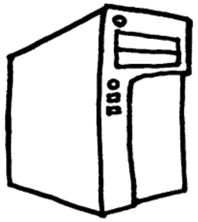
Absolute permeability

Relative permeability

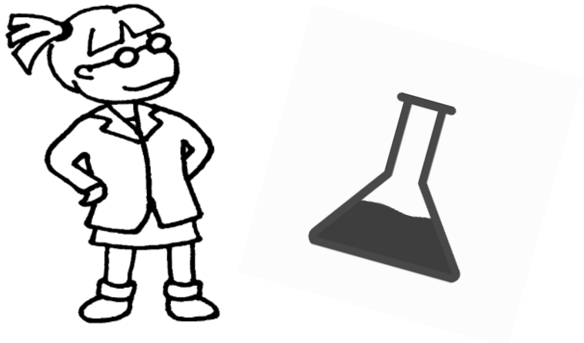
Mechanical properties

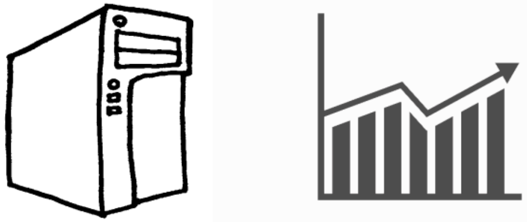
Forced imbibition characteristics



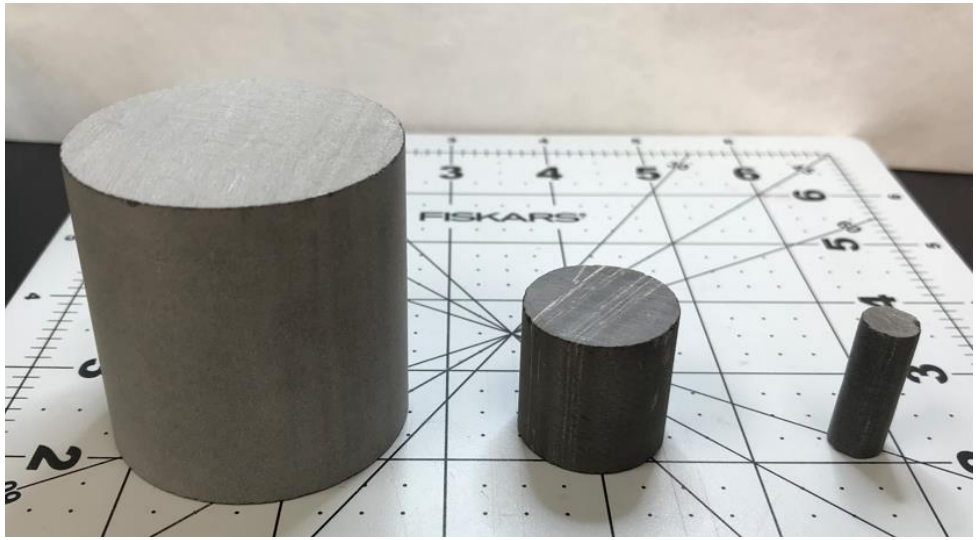
Experimental approach	Digital approach
Empirical	Theoretical
Slow (years)	Fast (weeks)
Expensive	Inexpensive
Needs to scale better	Needs to be validated

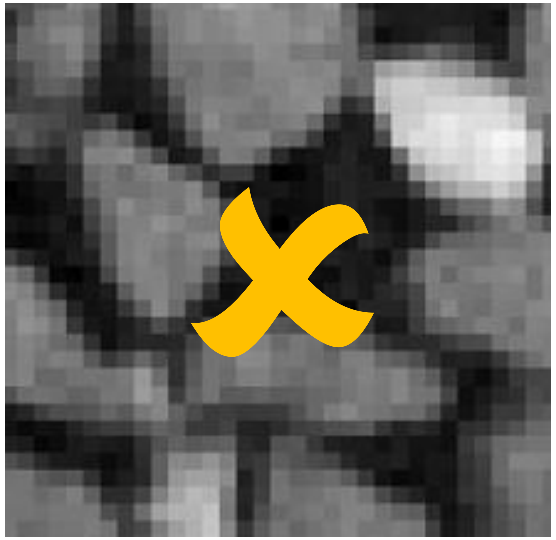


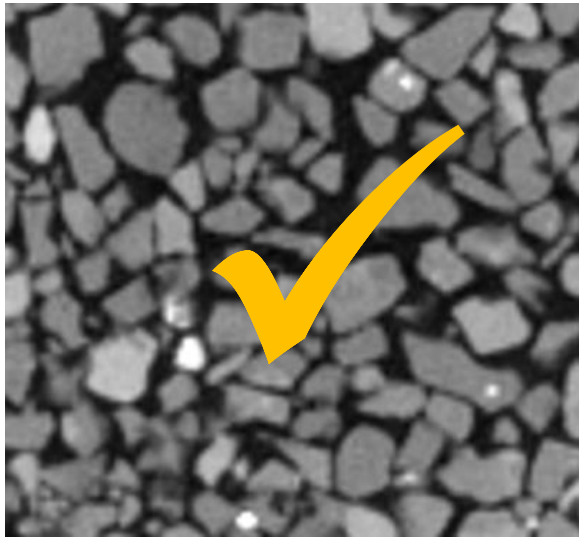


Experimental approach

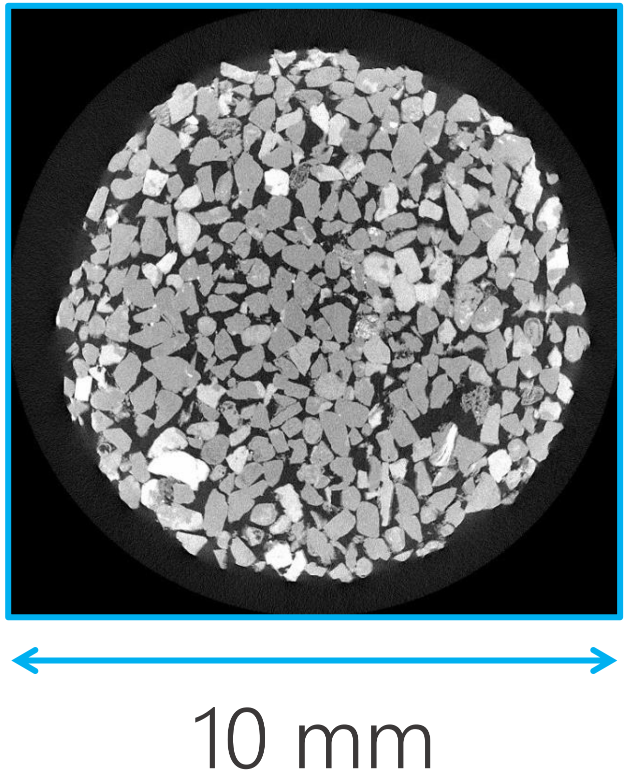
Digital approach

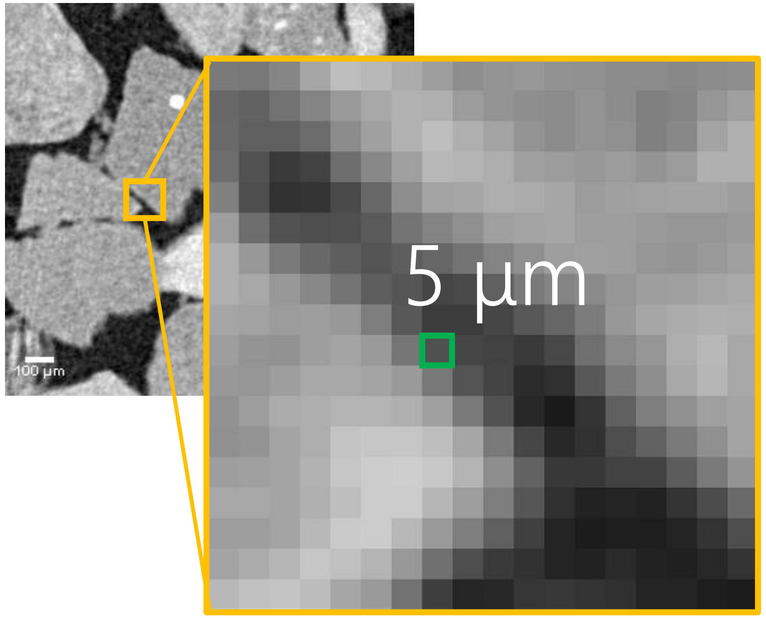


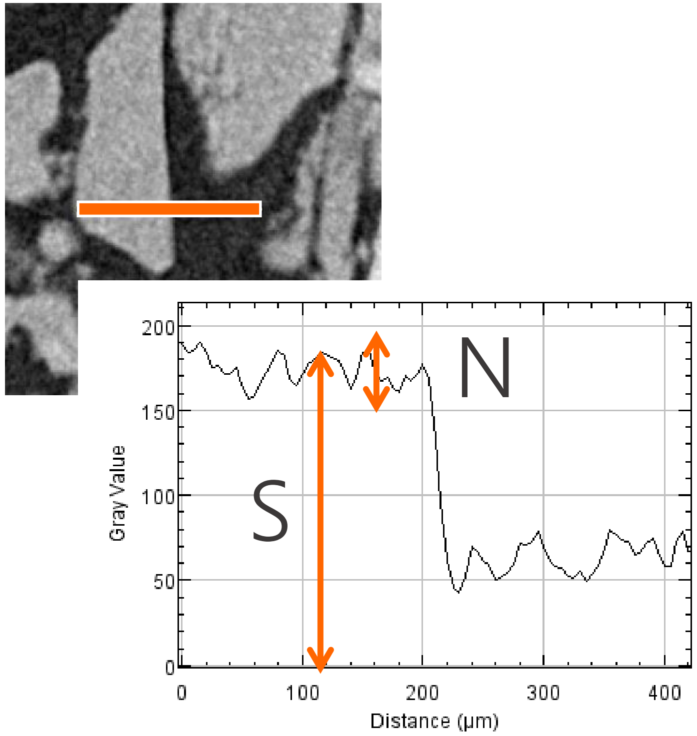




WHAT IMAGE PROPERTIES TO CONSIDER?







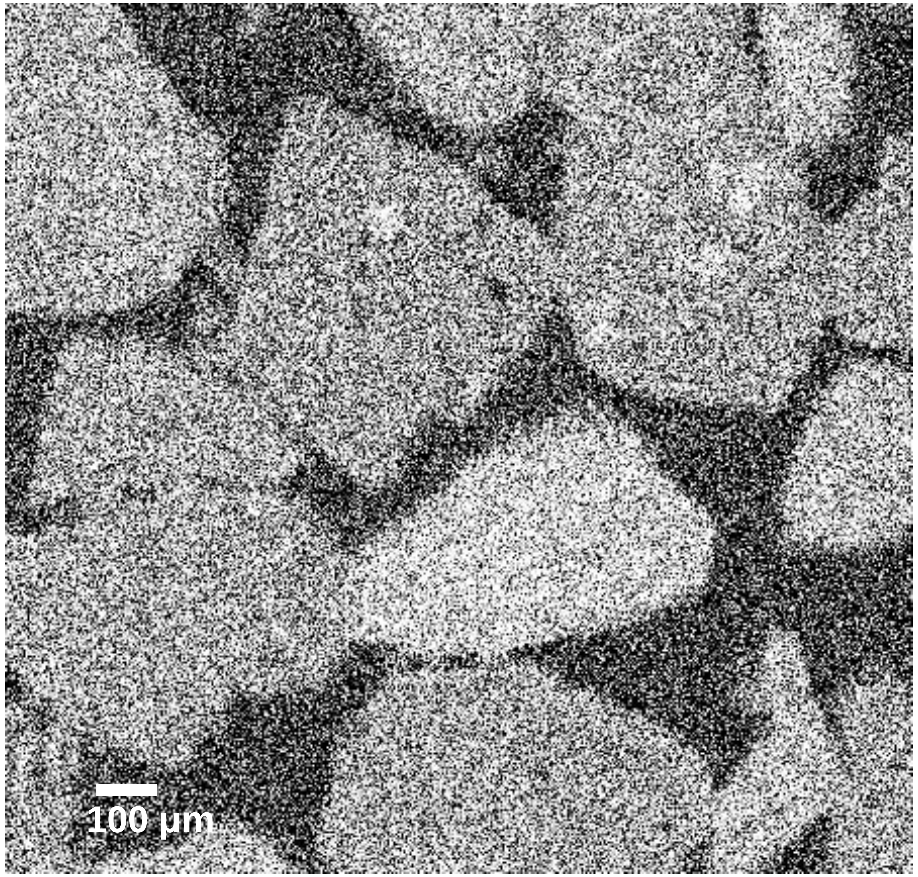
Field of view (FOV)

Voxel resolution

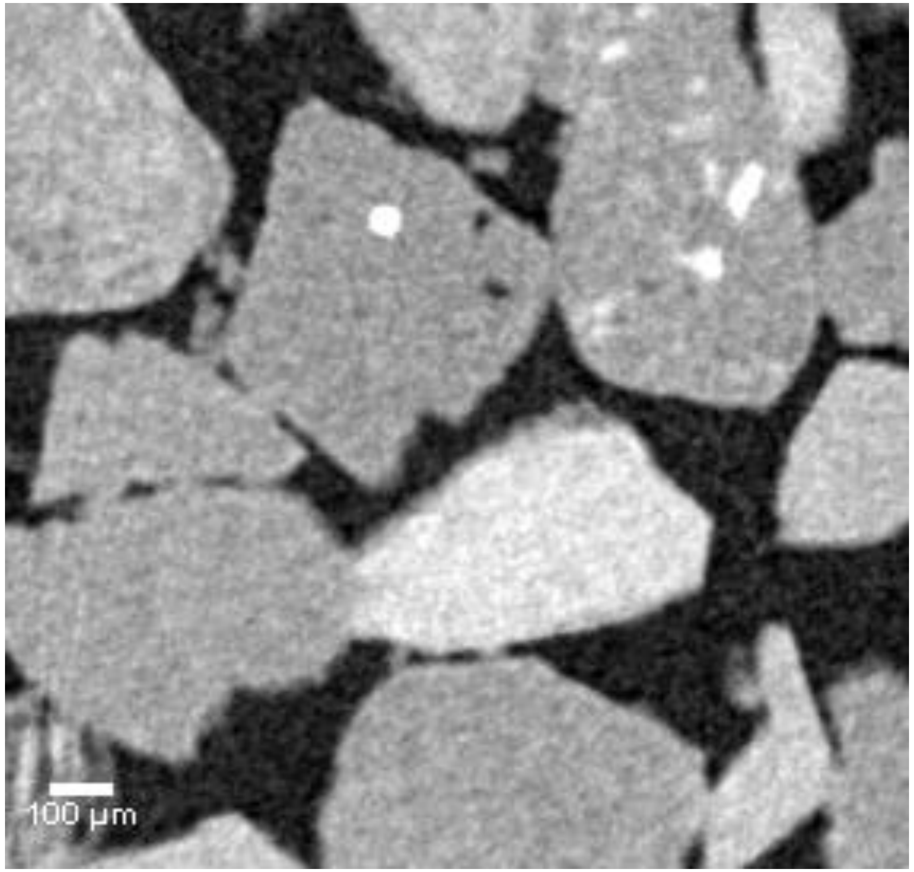
Signal-to-noise ratio

(scan time)

Signal-to-noise ratio

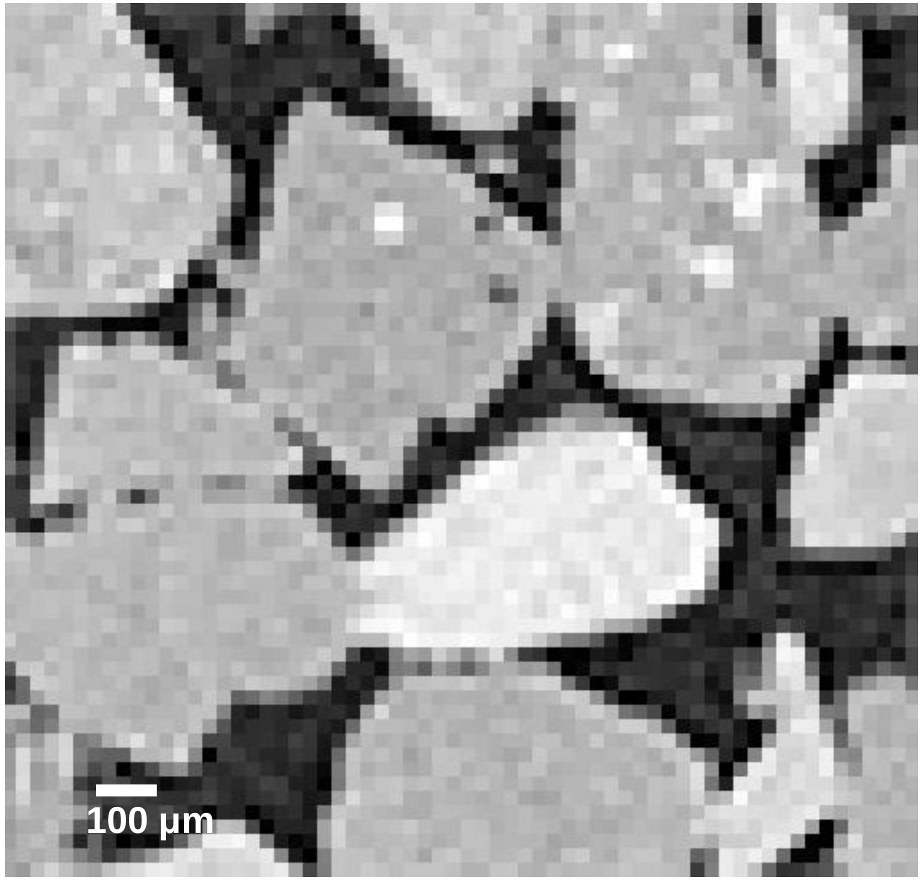


Not good enough

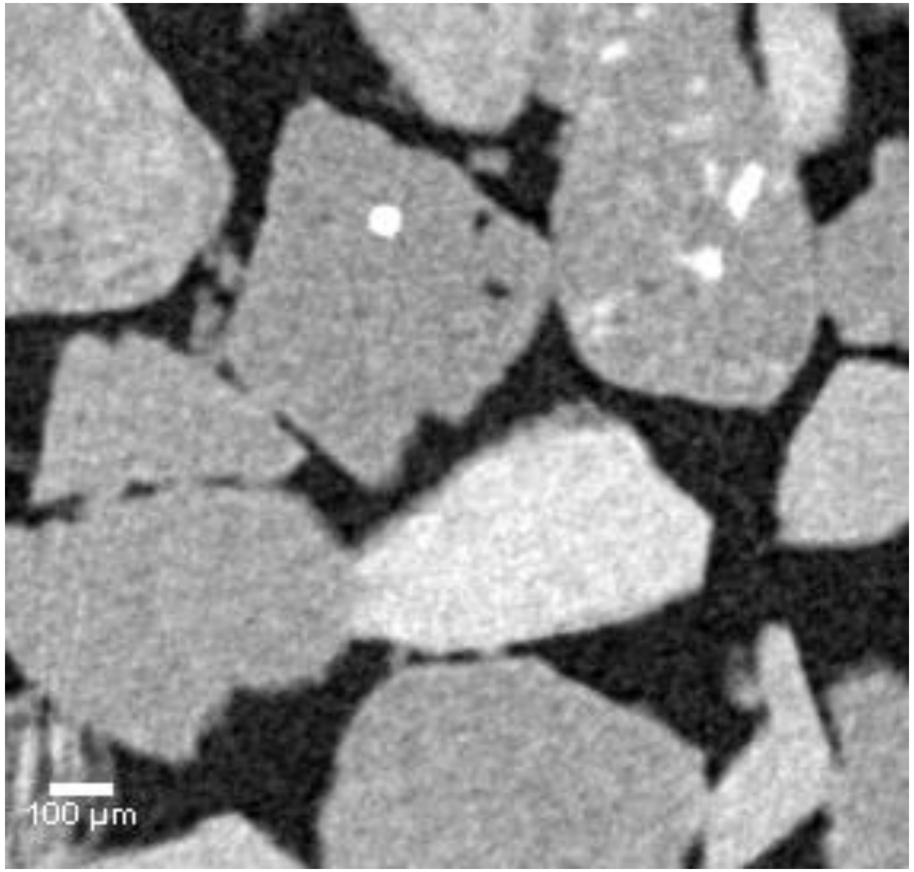


Good

Voxel resolution

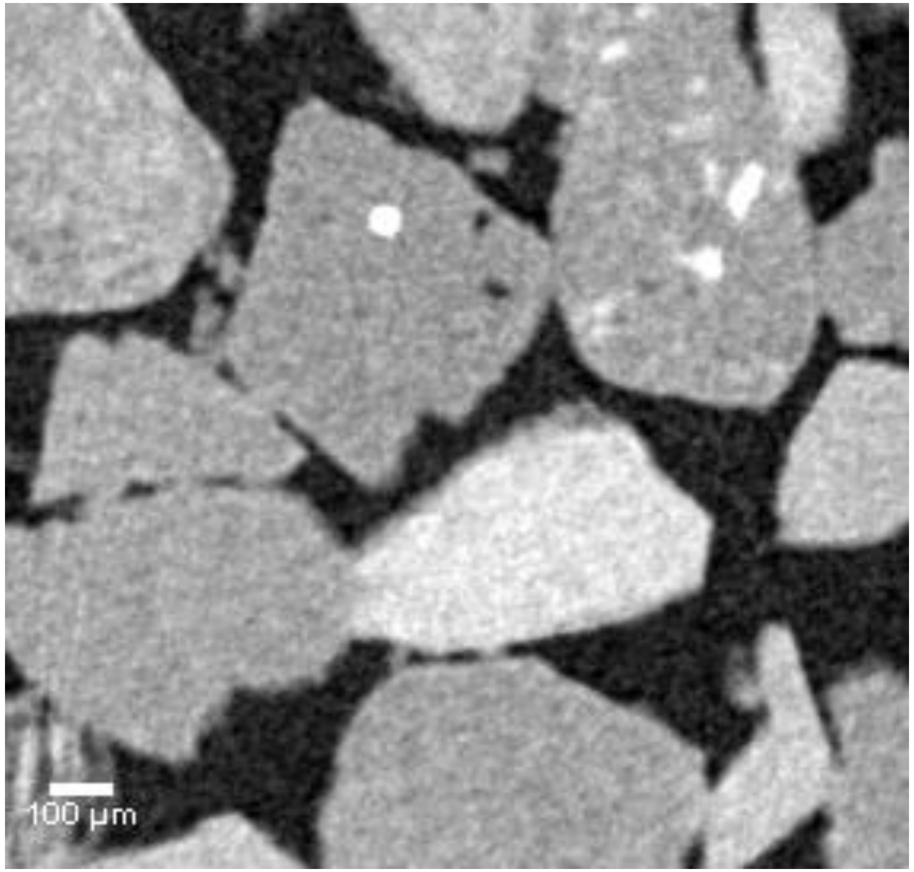


Not good enough

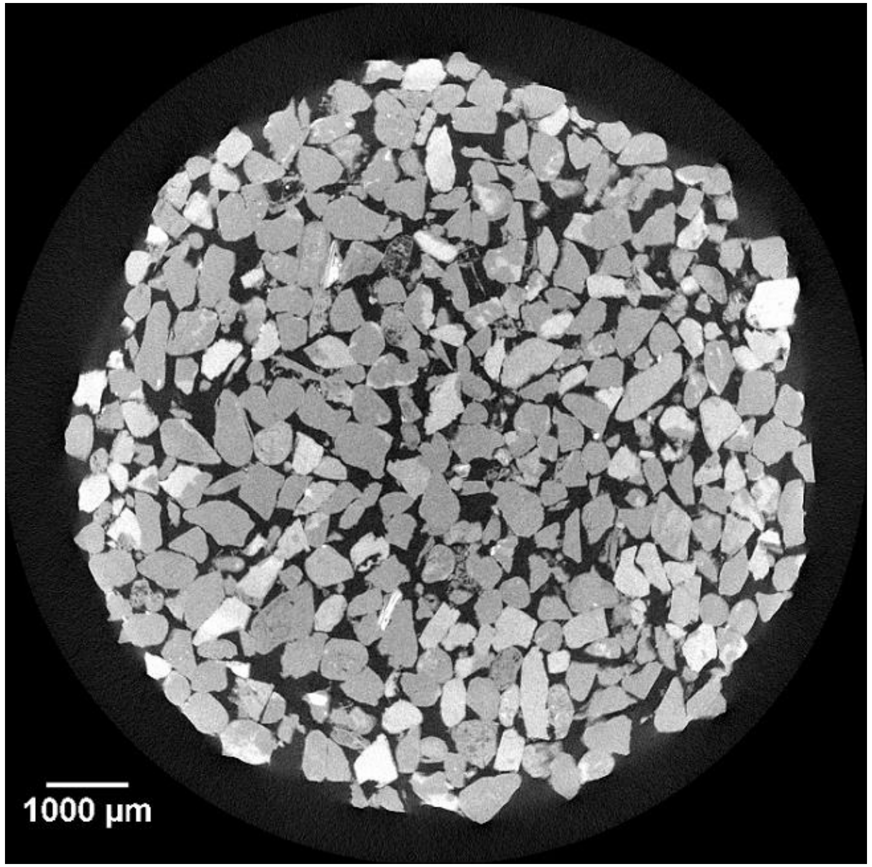


Good

Field of view (FOV)



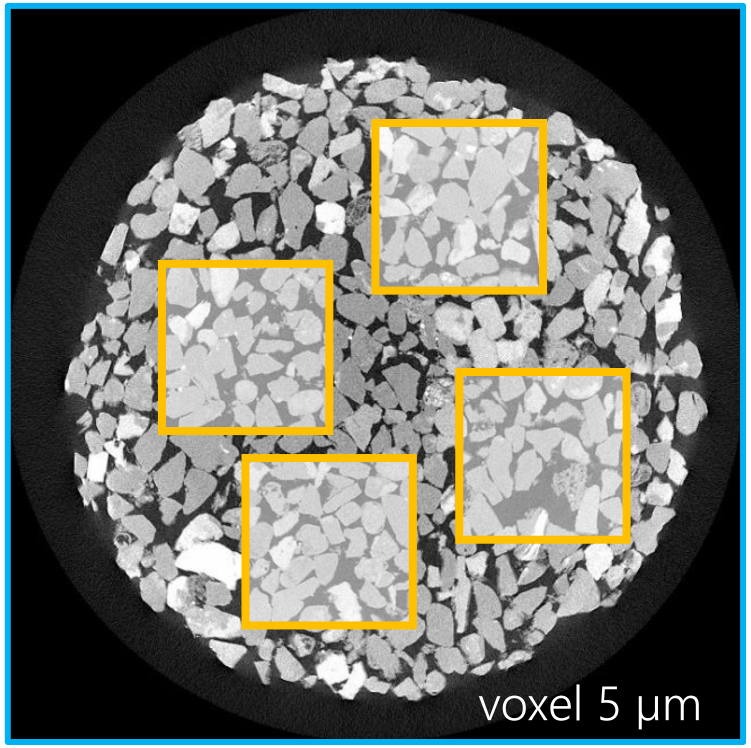
Not large enough



Large enough…File size?

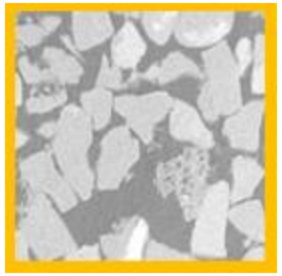
HOW DO WE SELECT ALL PARAMETERS?

Field of view (FOV) > Representative elemental volume (REV)



FOV 10 mm

$2K^3$, 16-bit, 16 GB

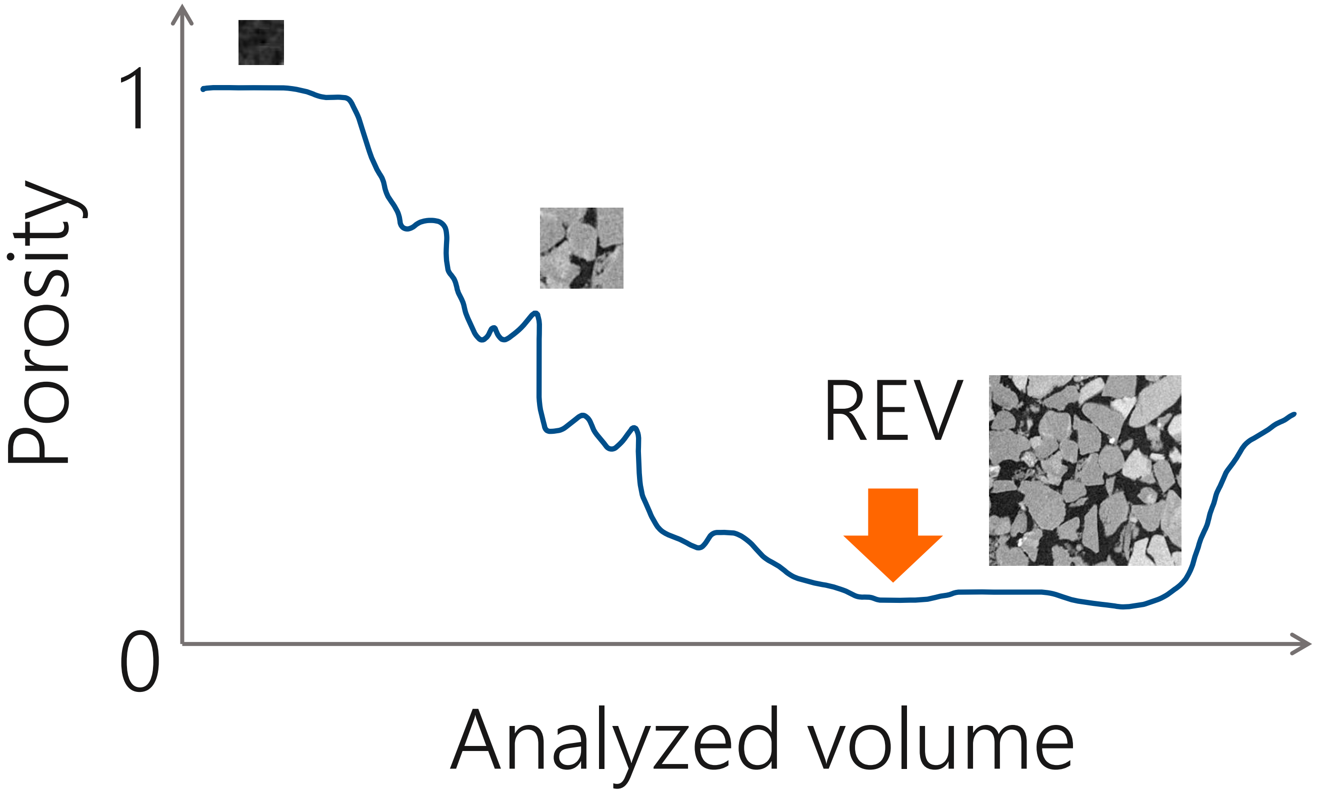


FOV 2.3 mm

450^3, 16-bit, 182 MB

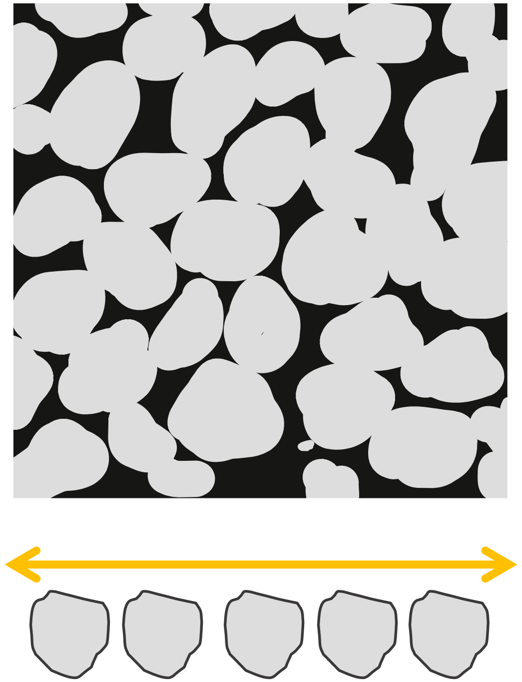
Representative elemental volume (REV)

Representative volume element (RVE)



Field of view (FOV) > REV ~ D_{eff} x 5 [*]

[*] Saxena et al., Adv. Water Resour., 2018, 116, p. 127-144

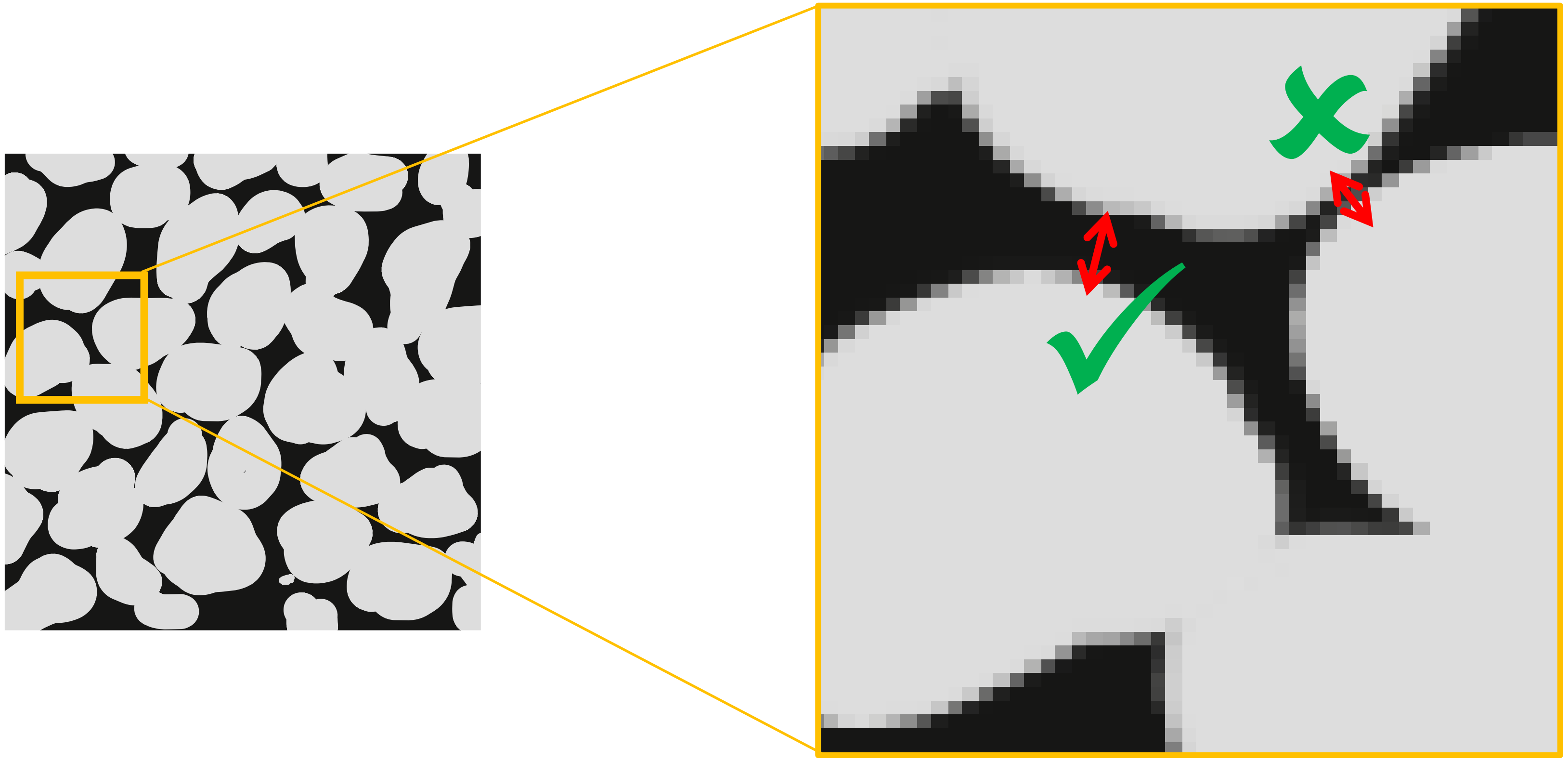


D_{eff}: The effective grain size

Definition: Rumpf et al., Chemie Ingenieur Technik, 1973, 43(6), p. 367-375

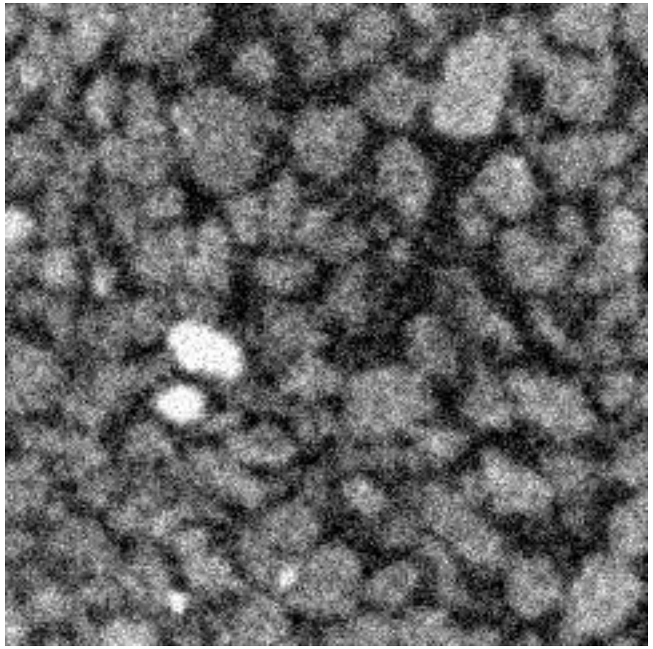
Empirical data: Glover et al., Geophysics, 2009, 74(1):E17

Voxel resolution < Dominant throat size / 10 [*]

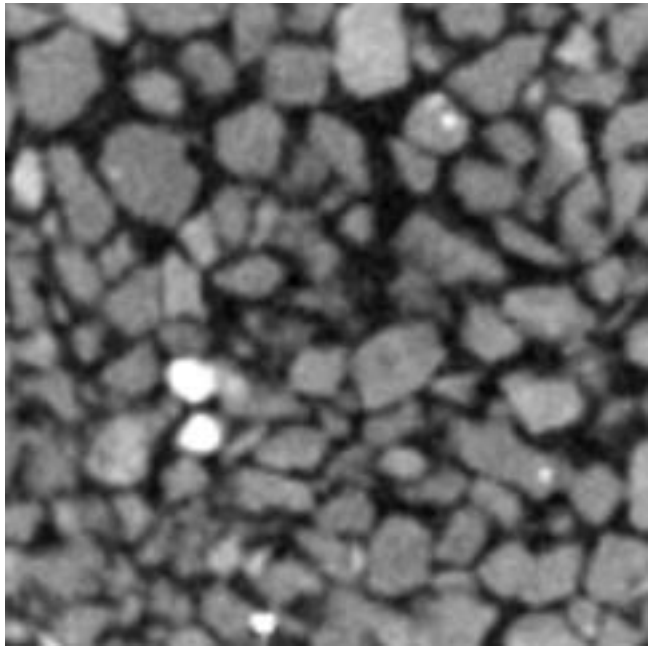


[*] Saxena et al., Adv. Water Resour., 116, 2018, p. 127-144

Signal to noise ratio (SNR) High enough to segment image

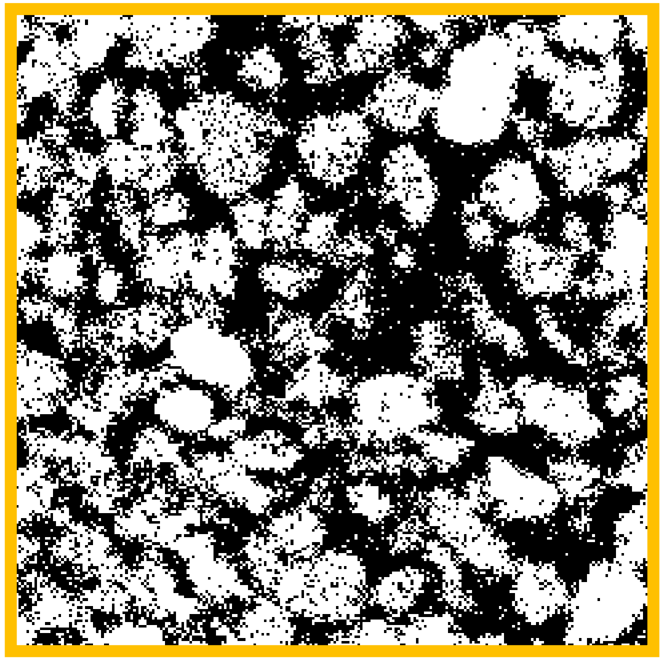


Low SNR

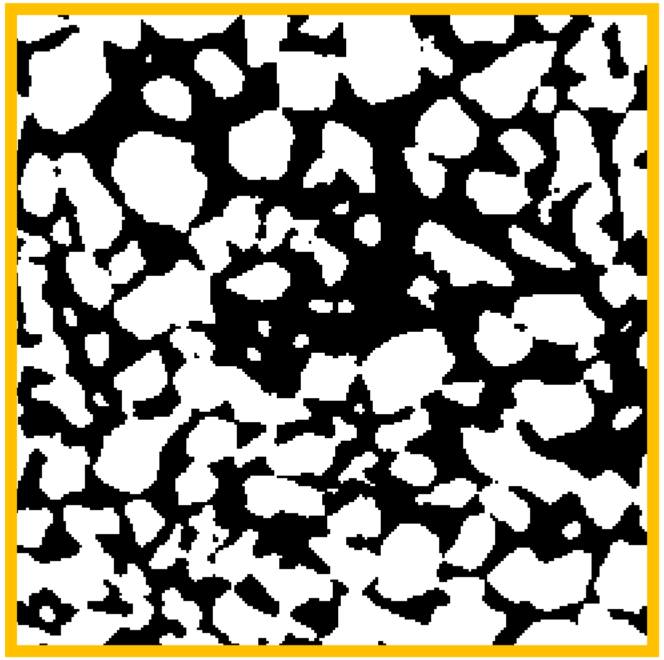


High SNR

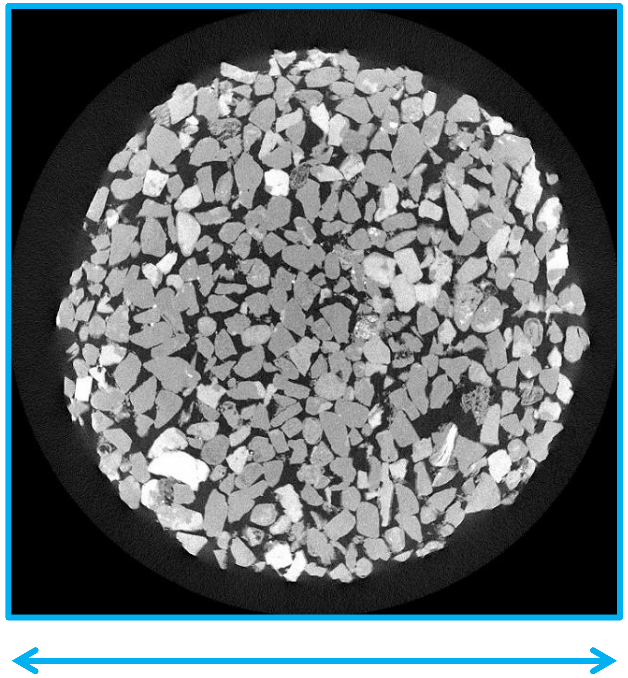
Signal to noise ratio (SNR) High enough to segment image



Low SNR

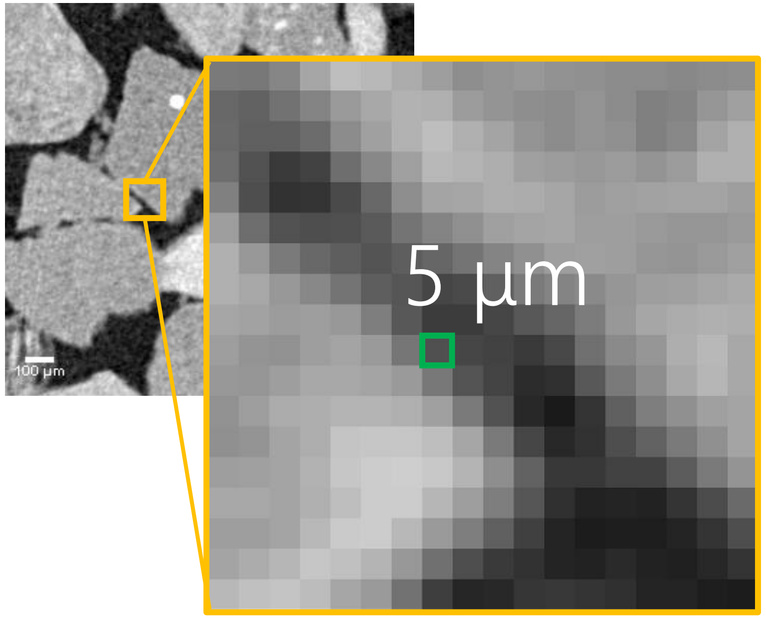


High SNR

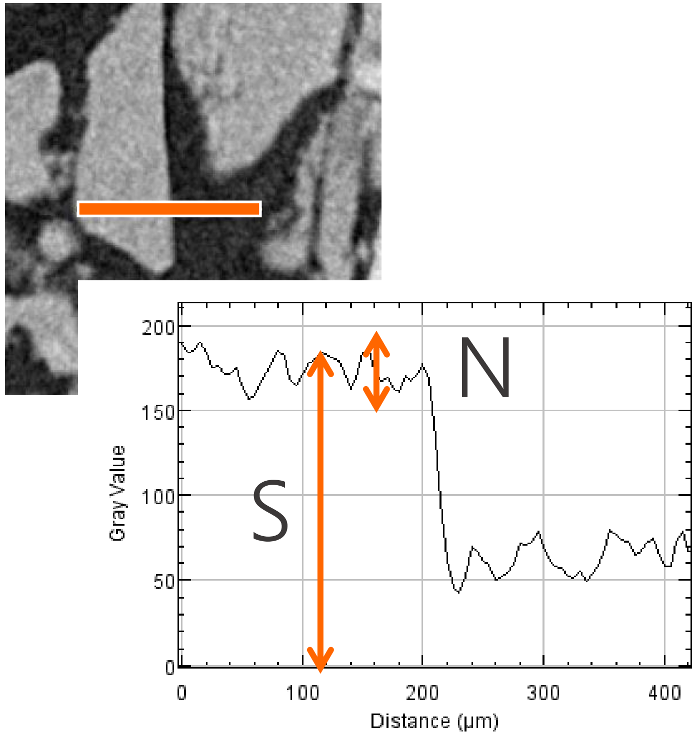


10 mm

Field of view (FOV)



Voxel resolution



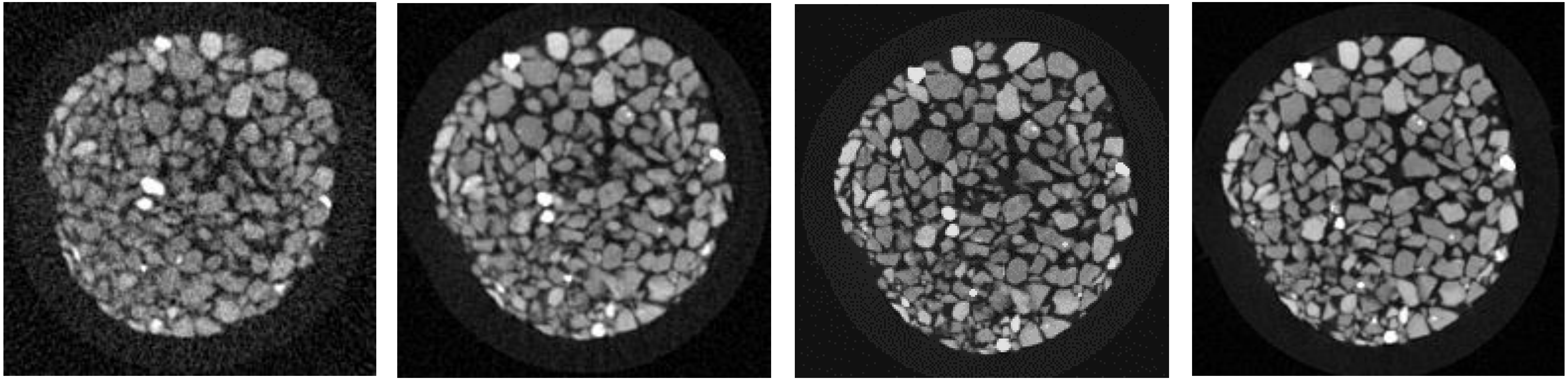
Signal-to-noise ratio

HOW DO WE INCREASE THE RESOLUTION & SNR?

Signal to noise ratio (SNR)

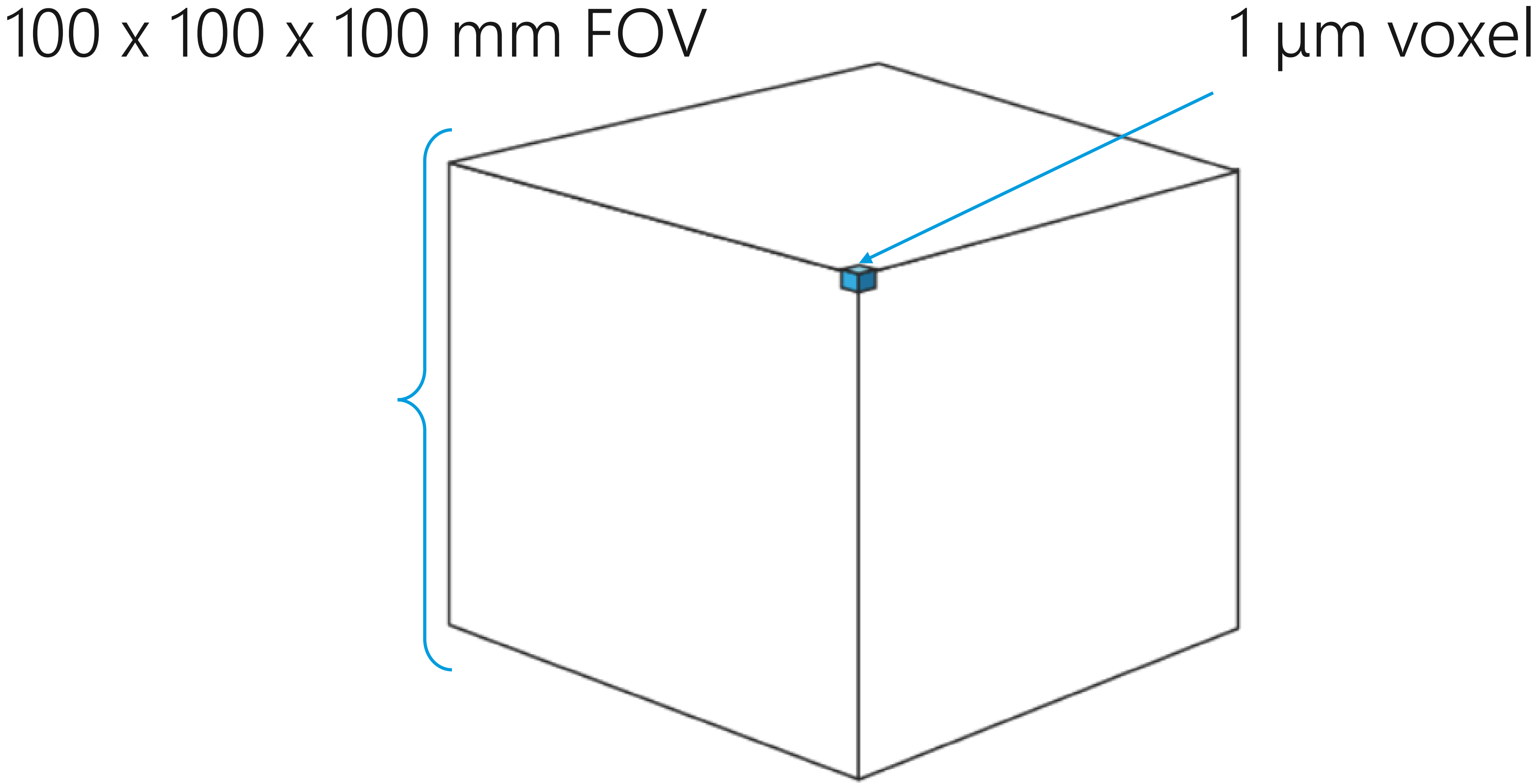
Voxel resolution

Scan time



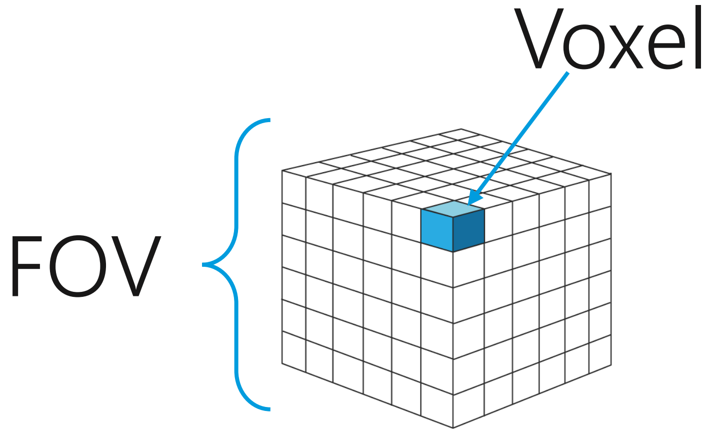
18 sec, 50 µm | 2 min, 50 µm | 17 min, 25.2 µm | 75 min, 9.4 µm

WHAT HAPPENS IF WE INCREASE THE FOV, TOO?

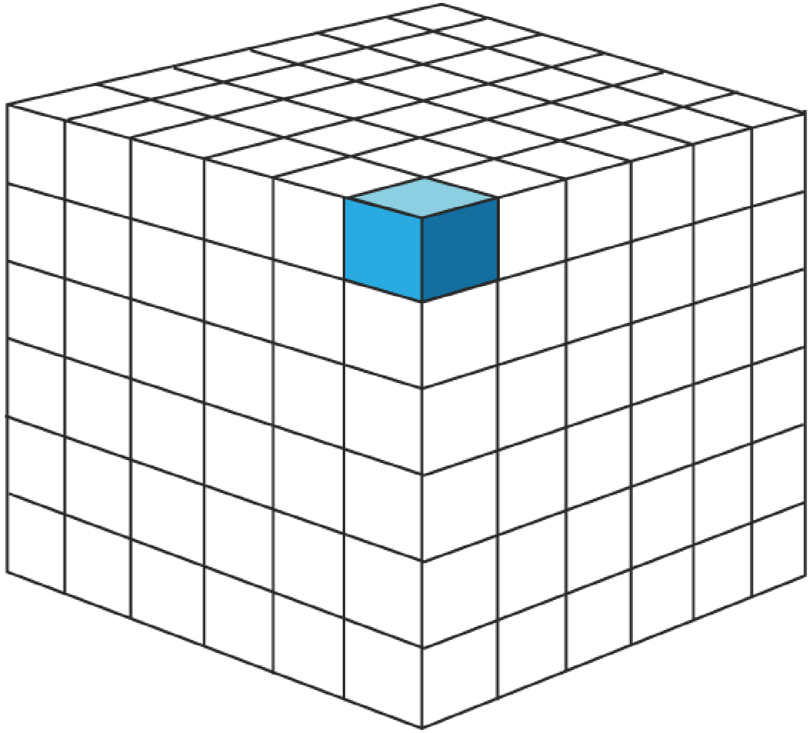


File size = 2 PB = 2000 TB

Voxel resolution = FOV / 3000 ~ FOV / 1000



Small FOV, small voxel



Large FOV, large voxel

WHAT DOES THIS ALL MEAN?

permeability (mDarcy)

porosity (fraction)

$$k = 3.8068G^{-1.3334}\left(\frac{\phi D}{2.13}\right)^2$$

pore throat diameter

G: ~ 0.2 for siliciclastic rocks

Thomeer, J. Pet. Technol., 1983, 35, p. 809-814

Saxena et al., Adv. Water Resour., 2017, 109, p. 211-235

permeability (mDarcy)

porosity (fraction)

$$k = 3.8068 G^{-1.3334} \left(\frac{\phi D}{2.13} \right)^2$$

pore throat diameter

Minimum *D* ~ voxel size x 10

permeability (mDarcy)

porosity (fraction)

Required voxel size

permeability (mDarcy)

porosity (fraction)

$$k = 3.8068 G^{-1.3334} \left(\frac{\phi D}{2.13} \right)^2$$

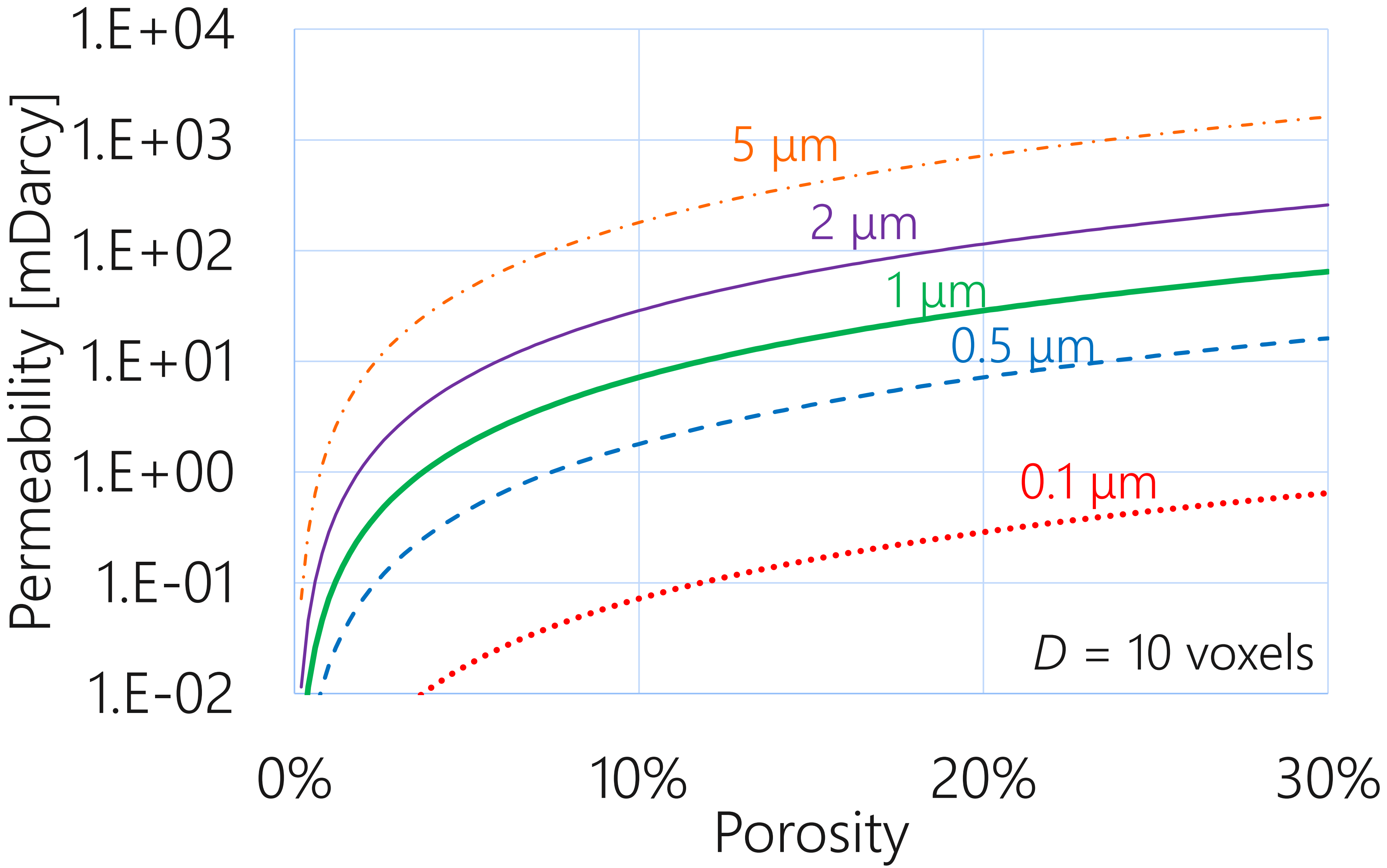
pore throat diameter

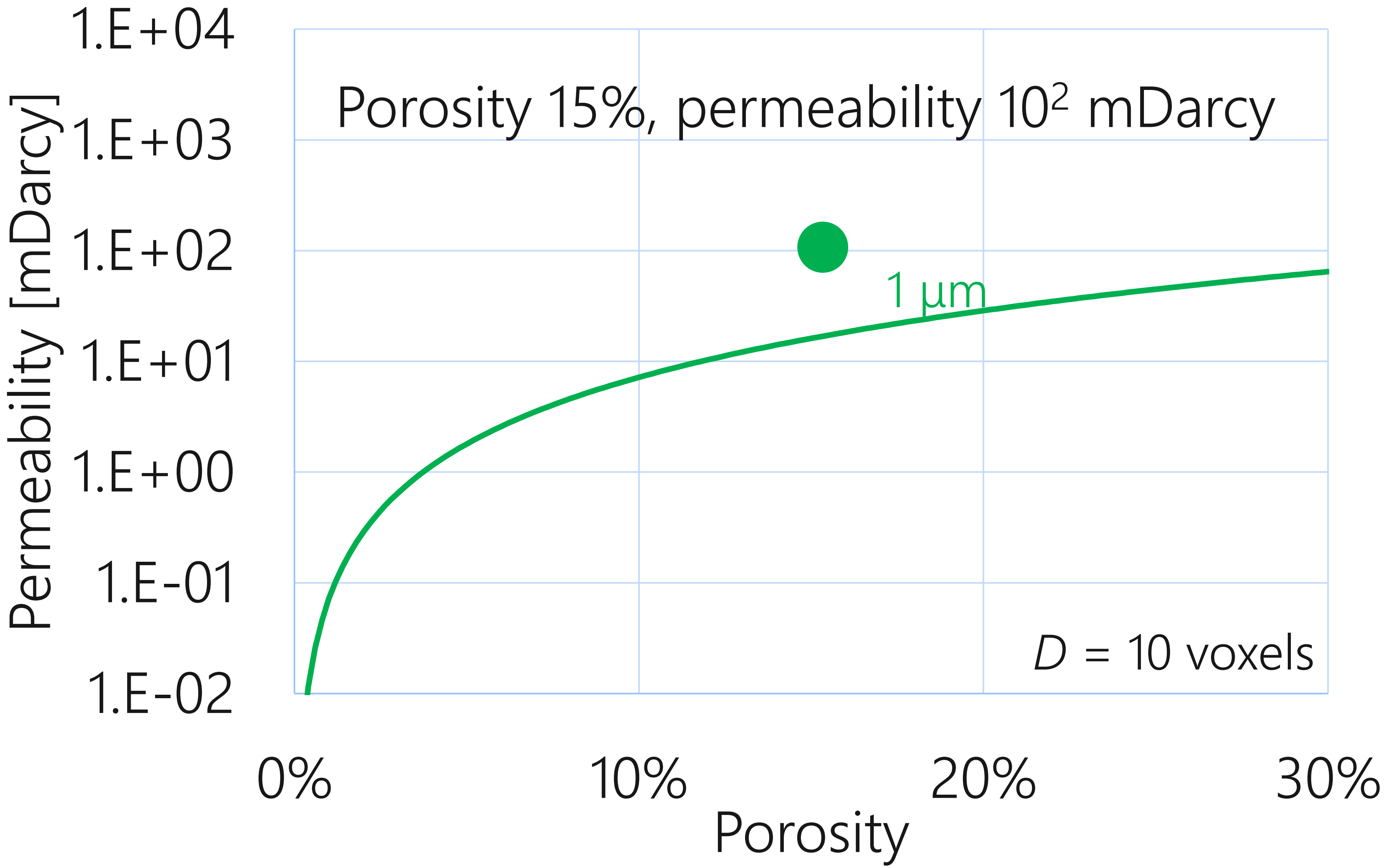
Minimum *D* ~ voxel size x 10

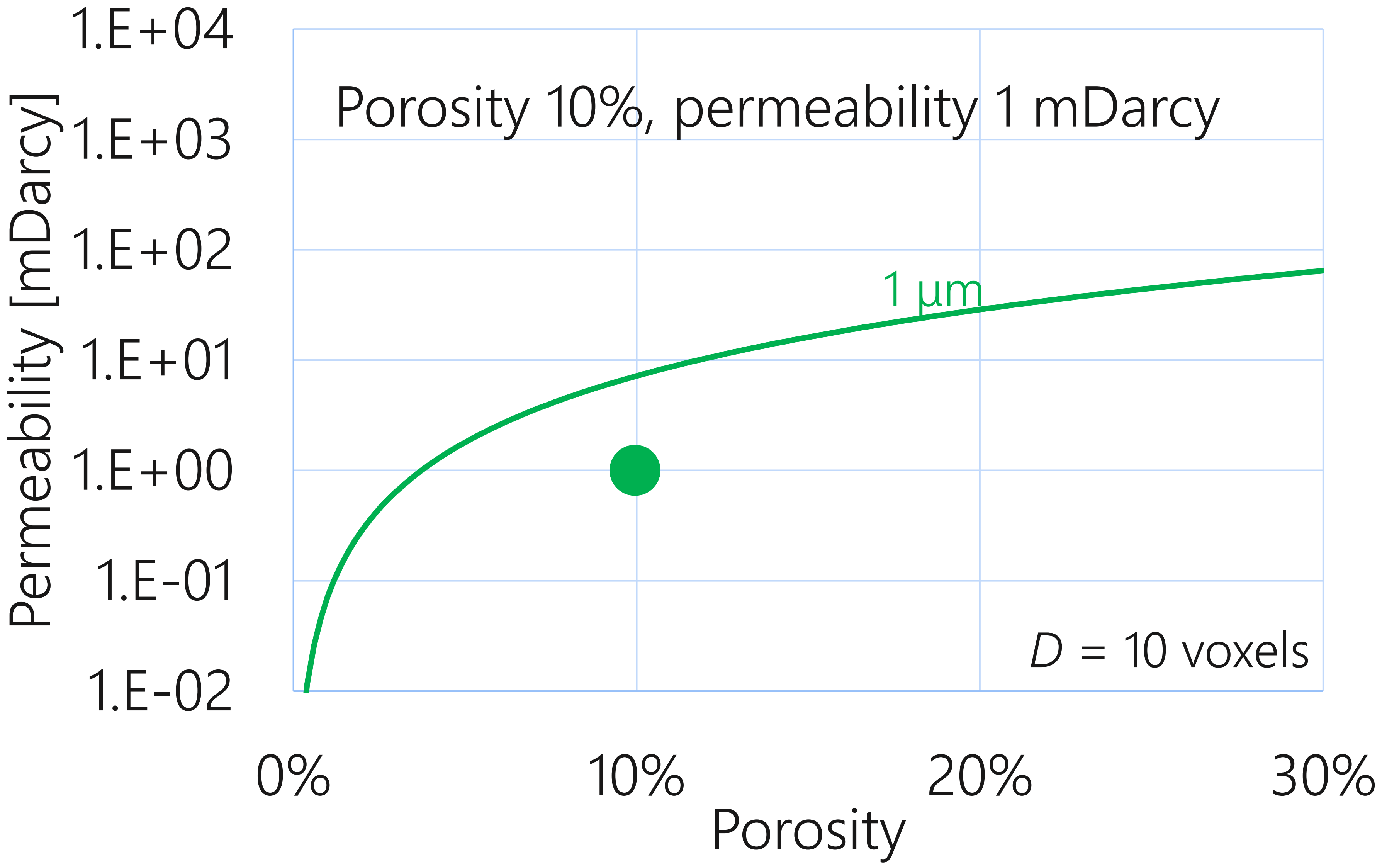
voxel size

porosity (fraction)

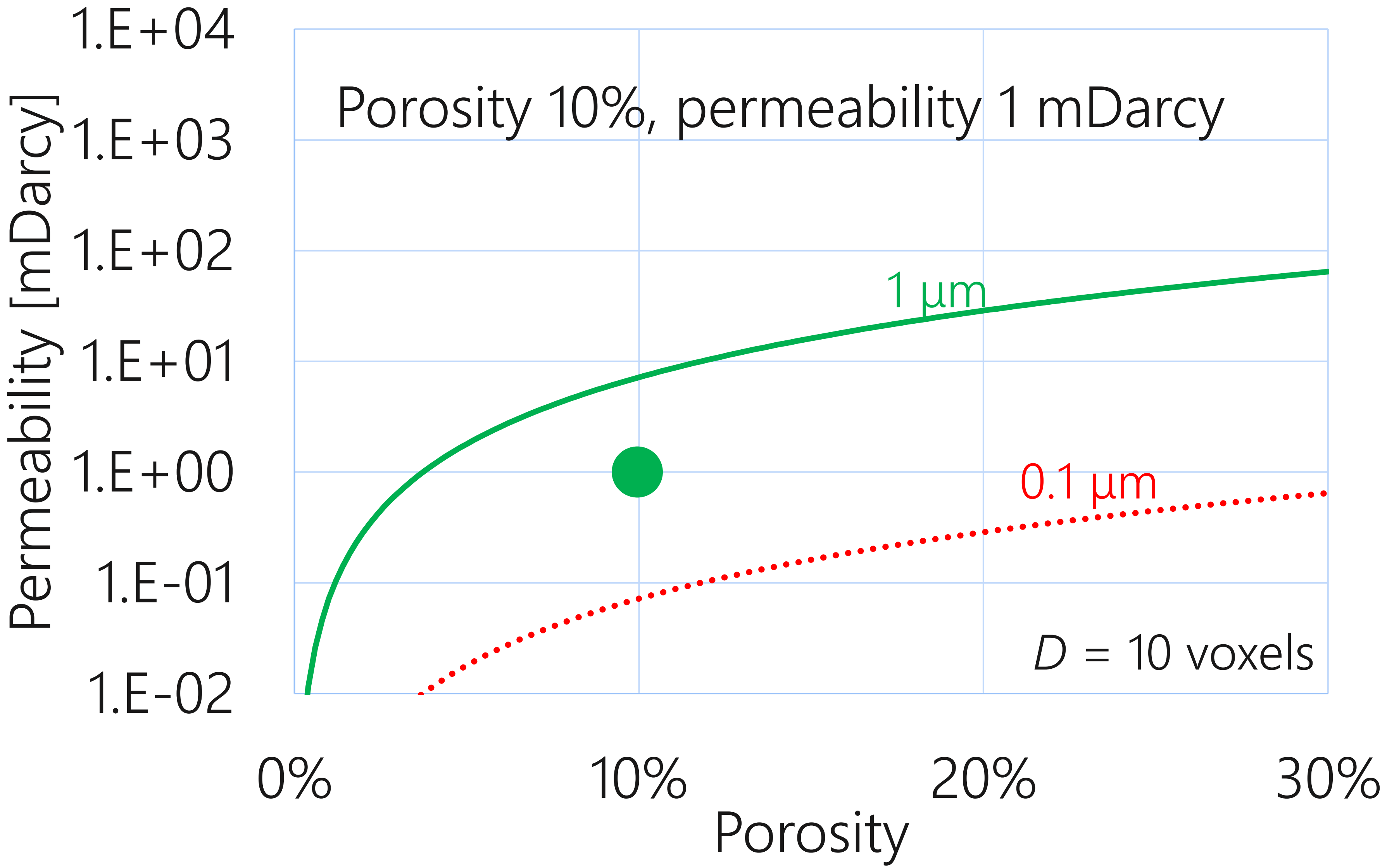
Minimum permeability


1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
1.E-02
Permeability [mDarcy]
5 µm
2 µm
1 µm
0.5 µm
0.1 µm
D = 10 voxels
0%
10%
20%
30%
Porosity


Porosity 15%, permeability 10² mDarcy
1 µm
D = 10 voxels
Permeability [mDarcy]
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
1.E-02
0%
10%
20%
30%
Porosity



Porosity 10%, permeability 1 mDarcy
Permeability [mDarcy]
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
1.E-02
1 µm
D = 10 voxels
0%
10%
20%
30%
Porosity

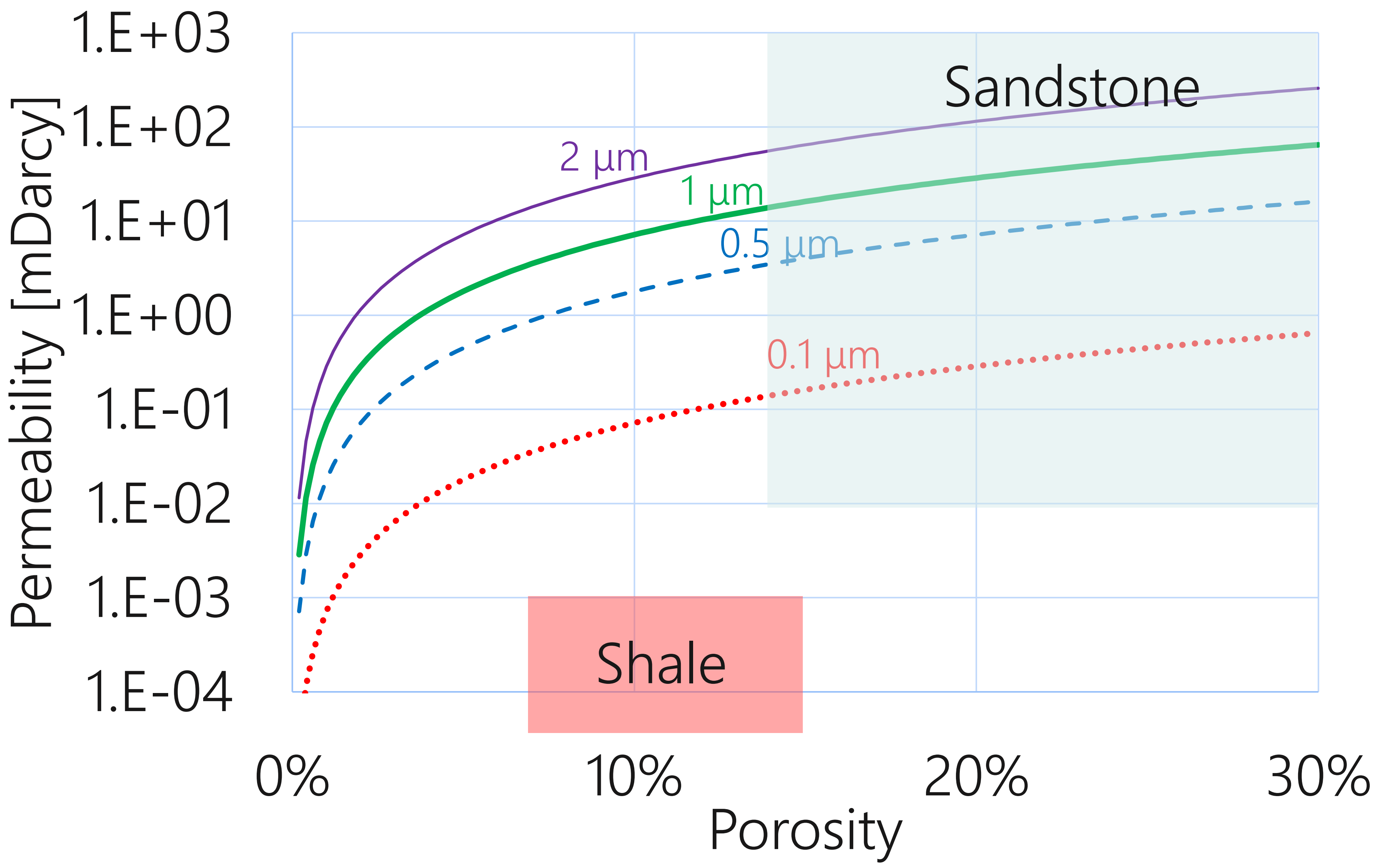


Porosity 10%, permeability 1 mDarcy
Permeability [mDarcy]
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
1.E-02
1 µm
0.1 µm
D = 10 voxels
0%
10%
20%
30%
Porosity

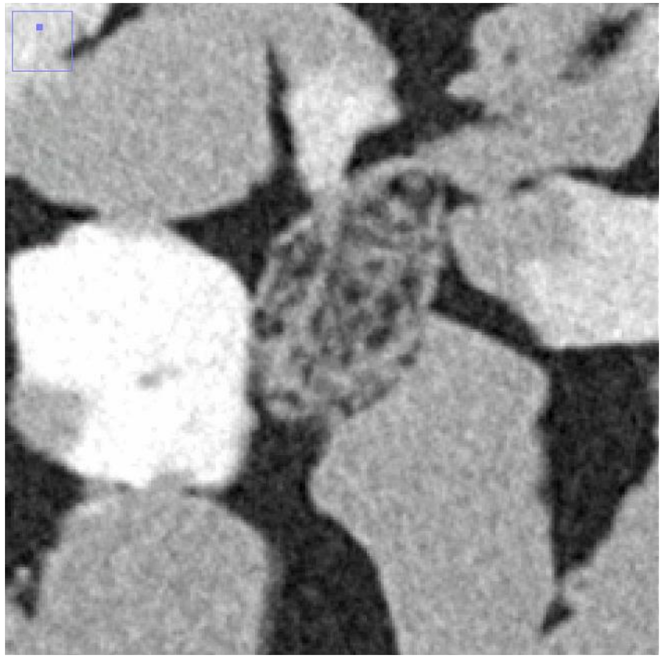
Rock type	Permeability (mD)*	Porosity**
Coarse gravel	10^6 - 10^7	
Sands, gravels	10^3 - 10^6	
Fine sand, silt	10^{-1} - 10^3	
Clay, shales	10^{-6} – 10^{-3}	8 – 15%
Limestones	10^3 - 10^5	
Sandstones	10^{-2} - 10^3	14 – 30%
Granite	10^{-5} – 10^{-1}	

* Introduction to Rock Properties by Prof. Robert Zimmerman at Imperial College London - Course Notes

** Wisconsin Geological and Natural History Survey

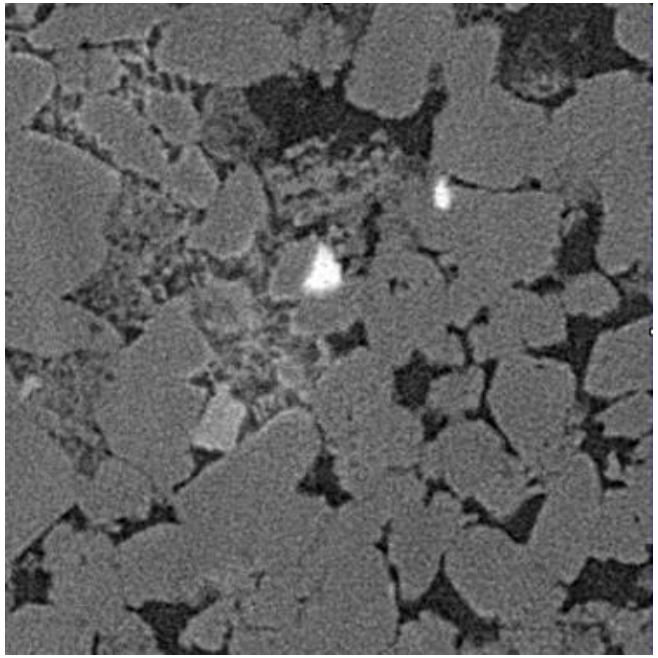


Permeability [mDarcy]
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
Sandstone
2 µm
1 µm
0.5 µm
0.1 µm
Shale
0%
10%
20%
30%
Porosity



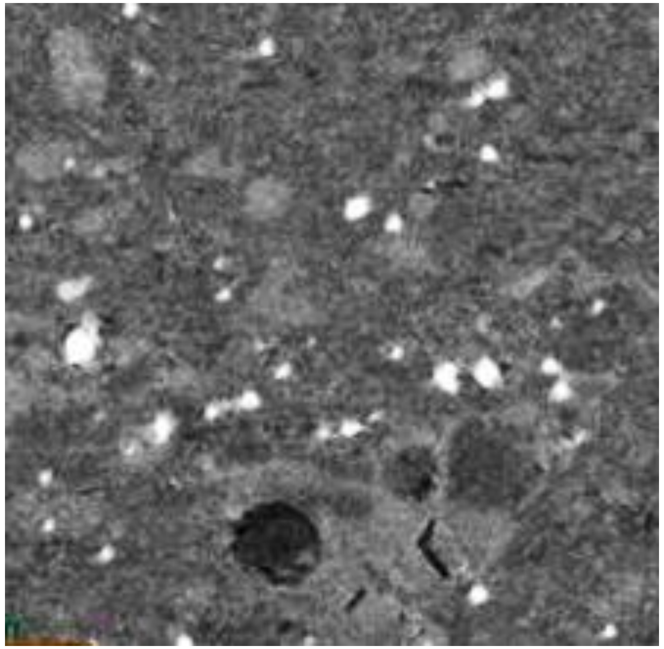
~ 1 mm

Sandstone Idaho Gray
FOV 10 mm, voxel 5 µm
2 hr 20 min scan



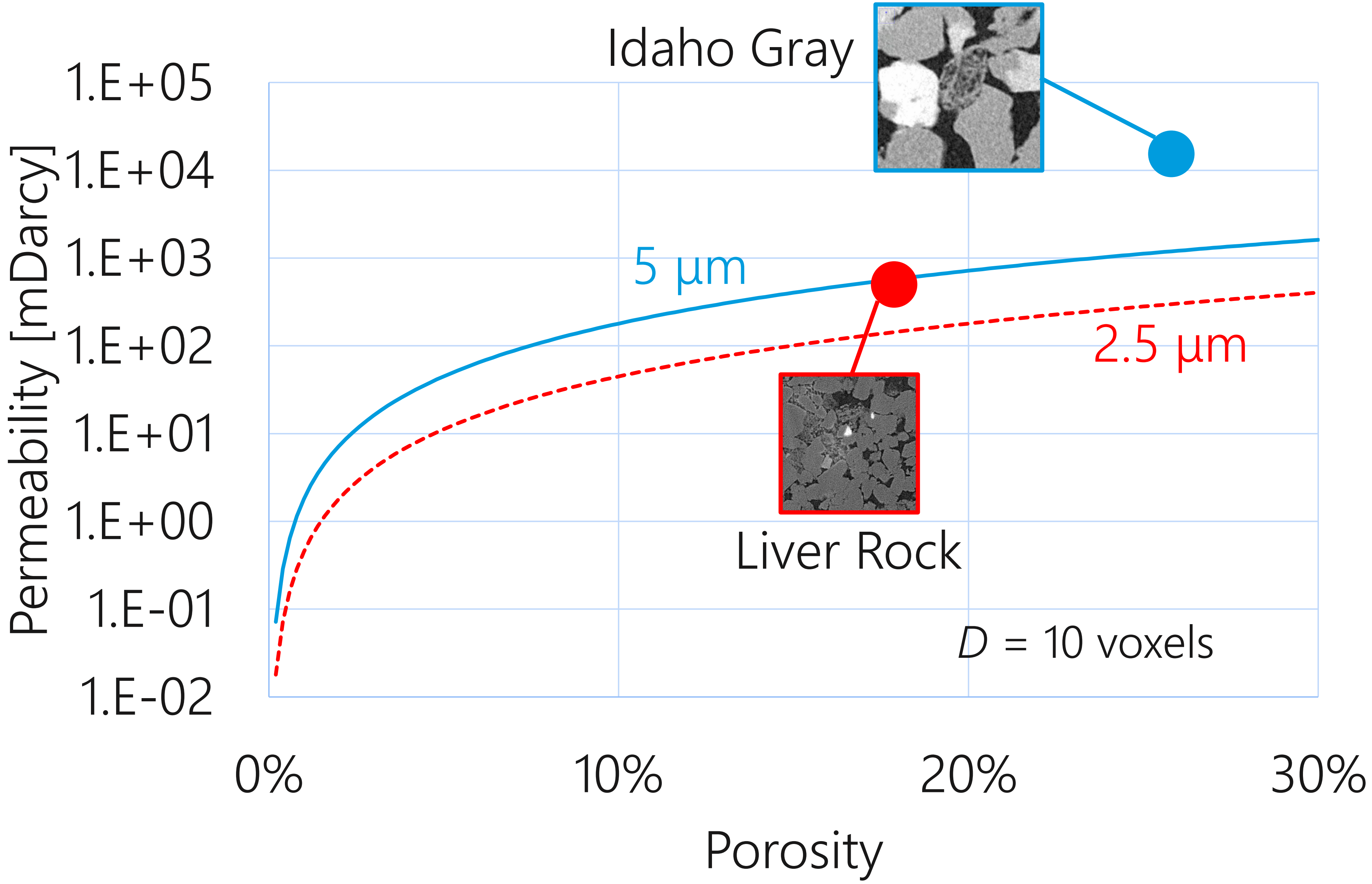
~ 1 mm

Sandstone Liver Rock
FOV 7 mm, voxel 2.5 µm
17 hr 30 min scan



~ 200 µm

Shale Eagle Ford
FOV 0.7 mm, voxel 0.31 µm
14 hr scan


Idaho Gray
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
1.E-02
Permeability [mDarcy]
5 µm
2.5 µm
Liver Rock
D = 10 voxels
0%
10%
20%
30%
Porosity

THINGS COVERED

- How to assess the required resolution
- How to collect high-quality CT images
- How to evaluate the image quality

USEFUL RESOURCES

- PetroWiki

  https://petrowiki.spe.org/Rock_type_influence_on_permeability

- Digital Rocks Portal

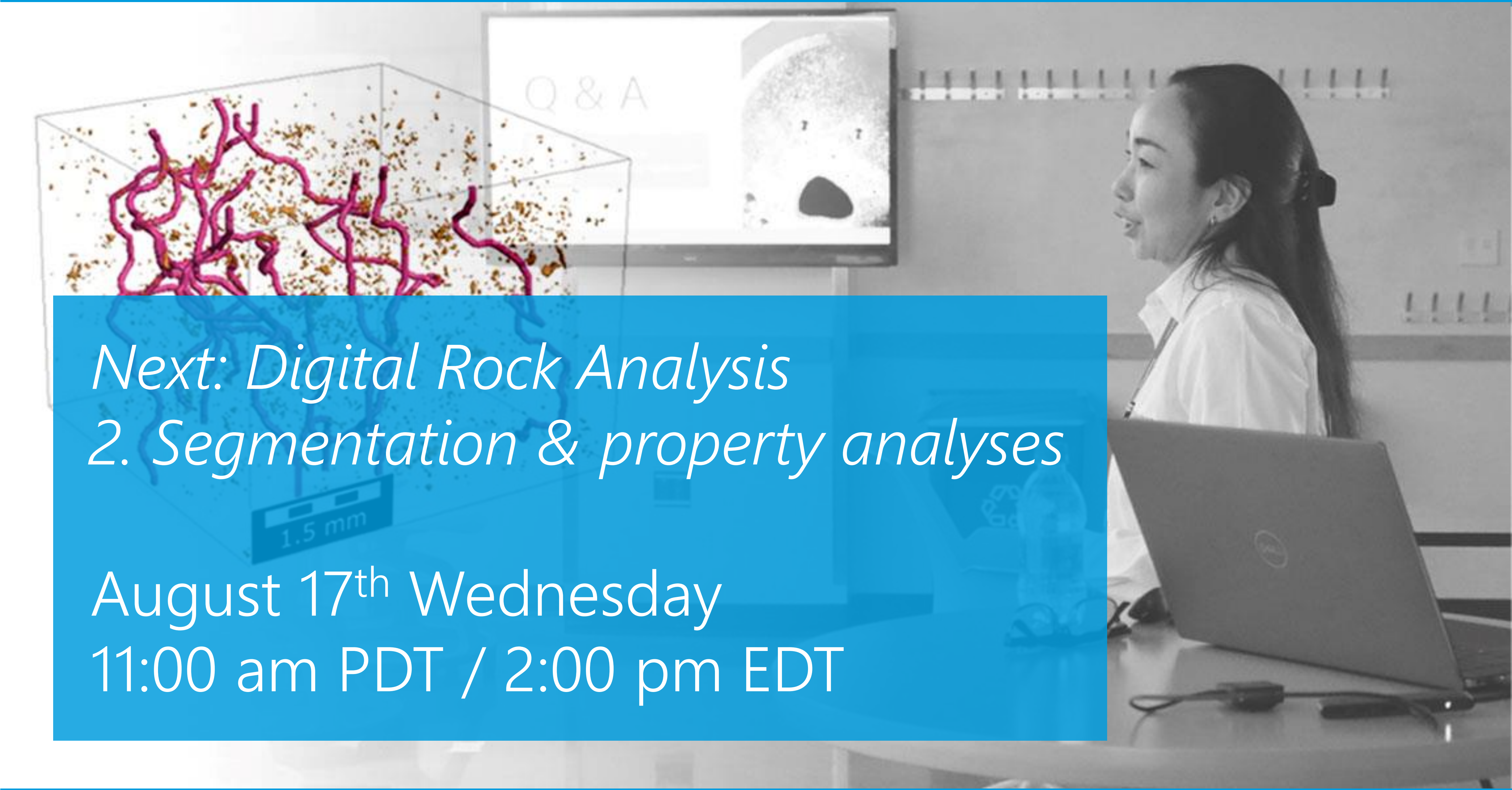
  https://www.digitalrocksportal.org/

Q & A SESSION

We'll follow up with your questions.

Recording will be available tomorrow.

Register for the next workshop.



Next: Digital Rock Analysis
2. Segmentation & property analyses

August 17th Wednesday
11:00 am PDT / 2:00 pm EDT

THANK YOU FOR JOINING US
SEE YOU NEXT TIME

USC - Los Angels, CA