WELCOME

RIGAKU WEBINAR SERIES

X-RAY COMPUTED TOMOGRAPHY FOR MATERIALS SCIENCE *GEOLOGY APPLICATIONS*

IS STARTING NOW.

Presenter: Aya Takase

Senior Scientist
Rigaku Americas Corporation

Host: Tom McNulty

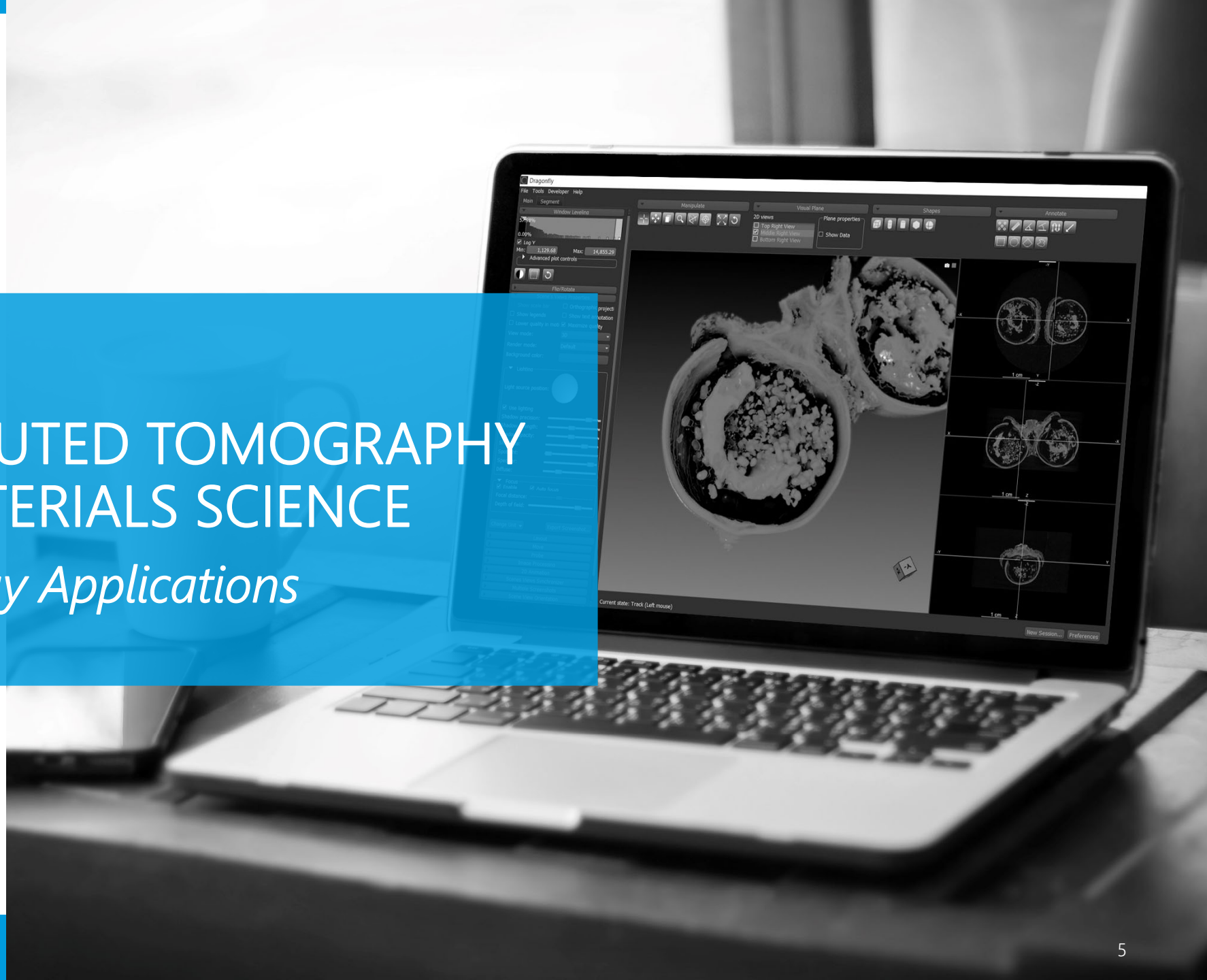
Senior Vice President
Rigaku Americas Corporation

You can send us questions during the presentation.
They will be addressed at the end of the presentation.

A recording of this webinar will be available.
You will receive an email with a link to it tomorrow.

X-RAY COMPUTED TOMOGRAPHY FOR MATERIALS SCIENCE

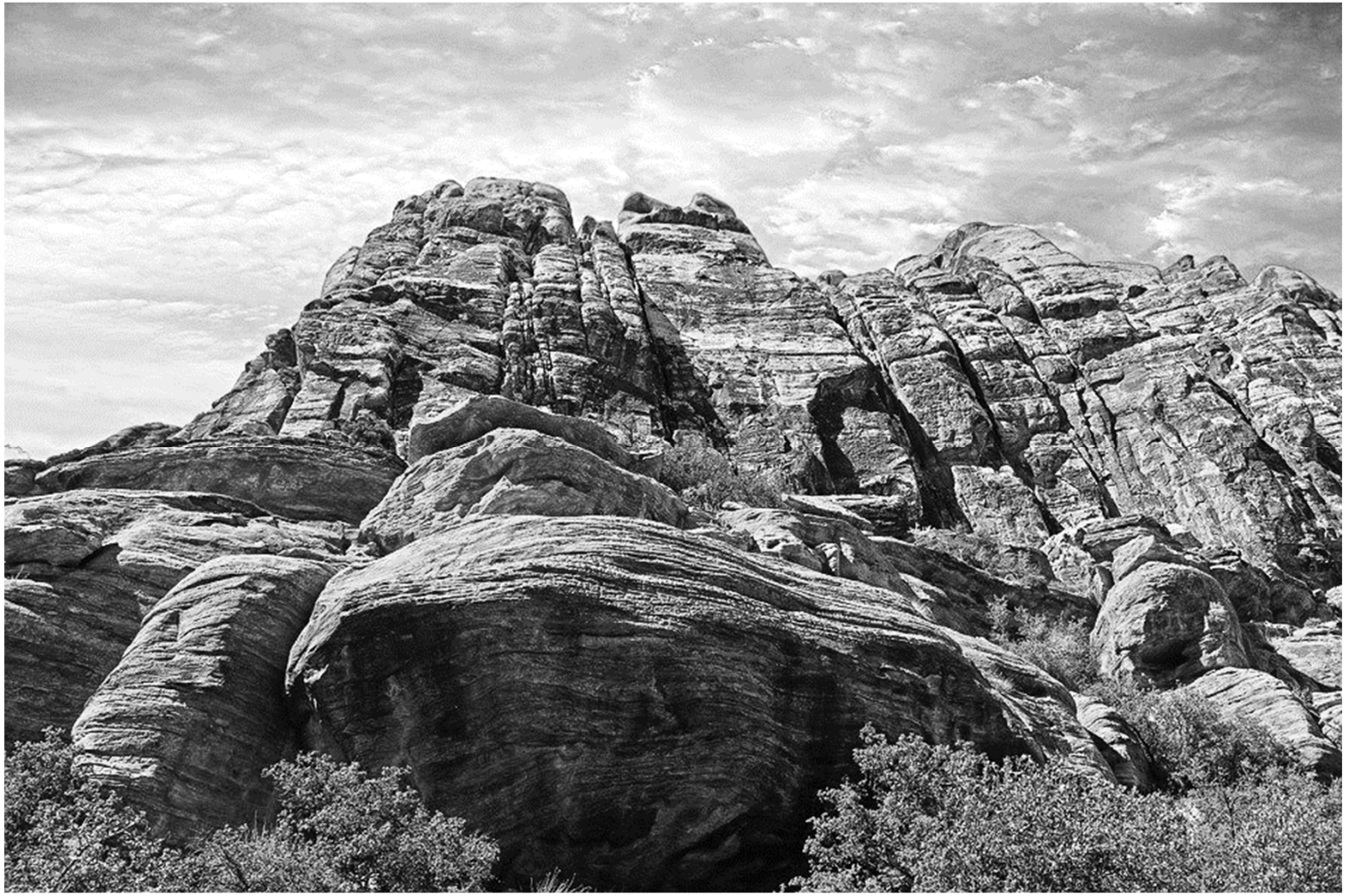
Geology Applications

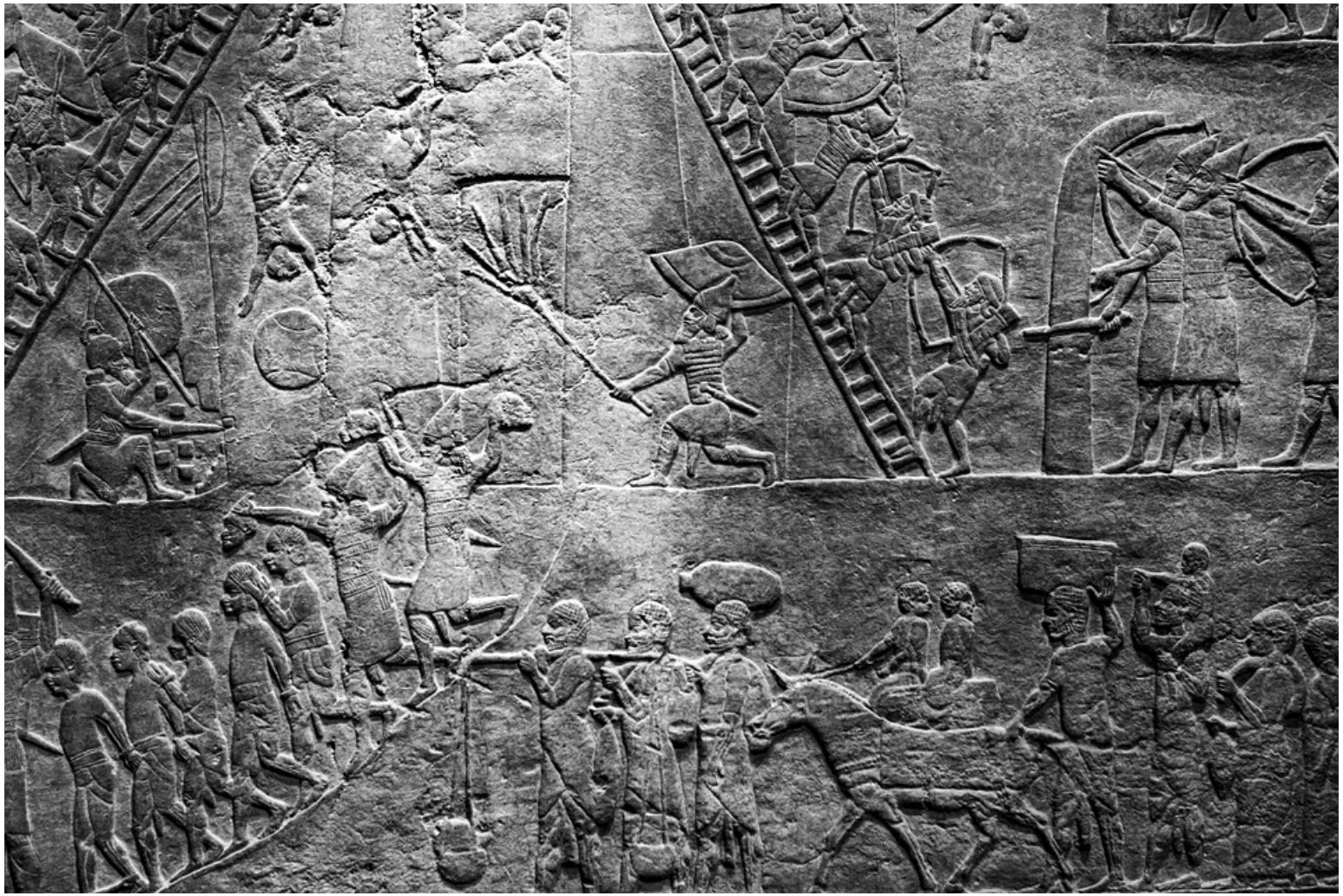


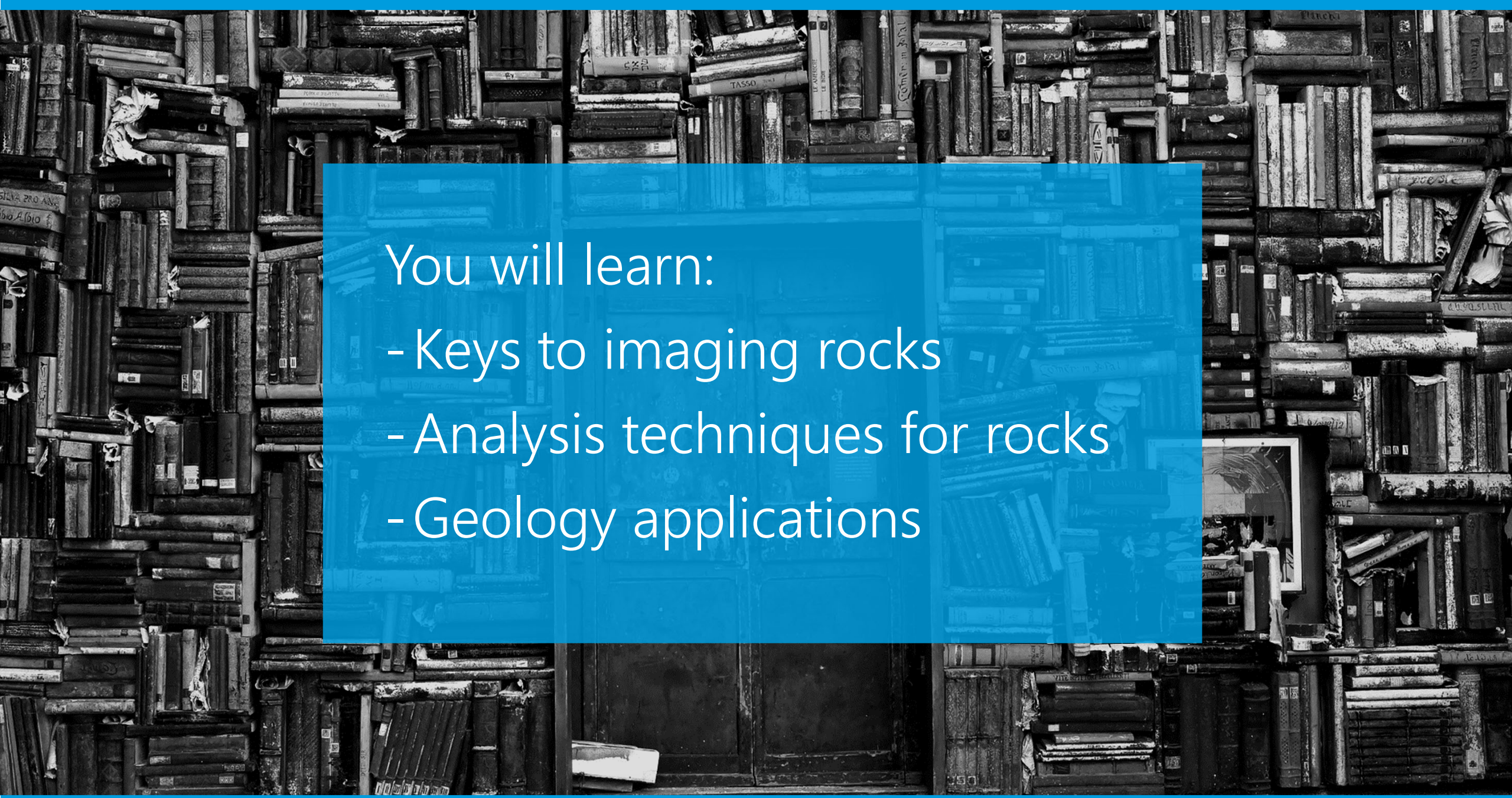
GEOLOGY

ge·ol·o·gy

a science that deals with the history of the earth and its life especially as recorded in rocks (Merriam-Webster)







You will learn:

- Keys to imaging rocks
- Analysis techniques for rocks
- Geology applications

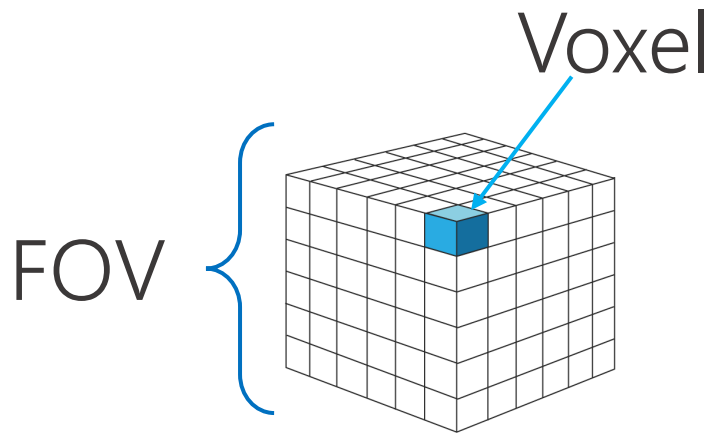
WHAT TO CONSIDER?

Resolution & FOV

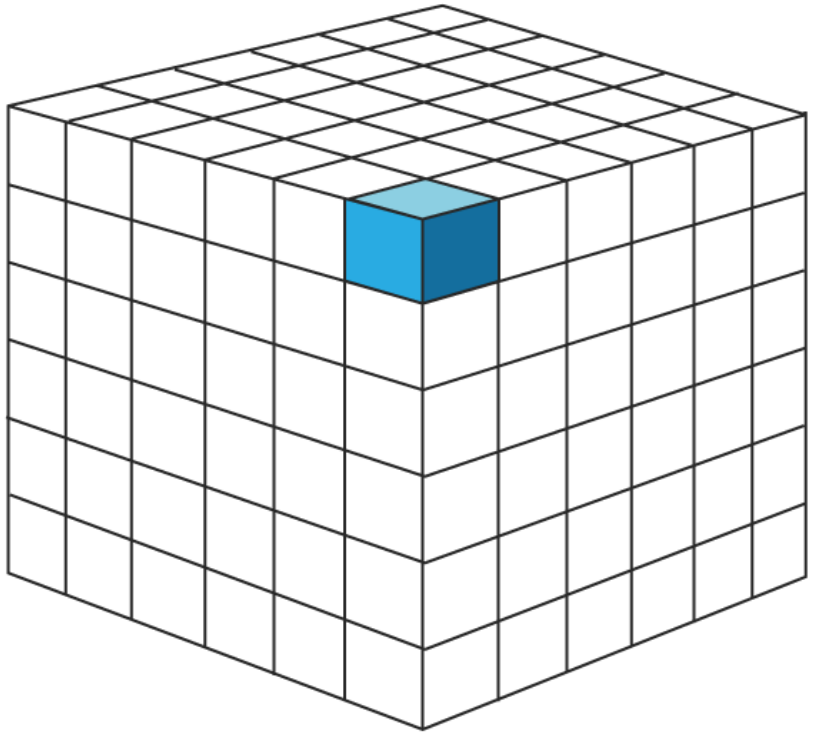
Contrast

Resolution & FOV

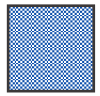
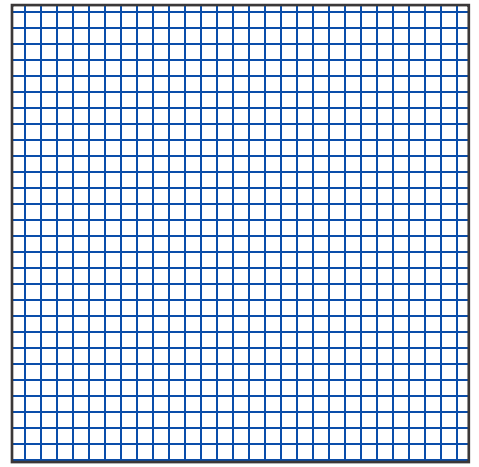
Contrast



Small FOV, small voxel



Large FOV, large voxel

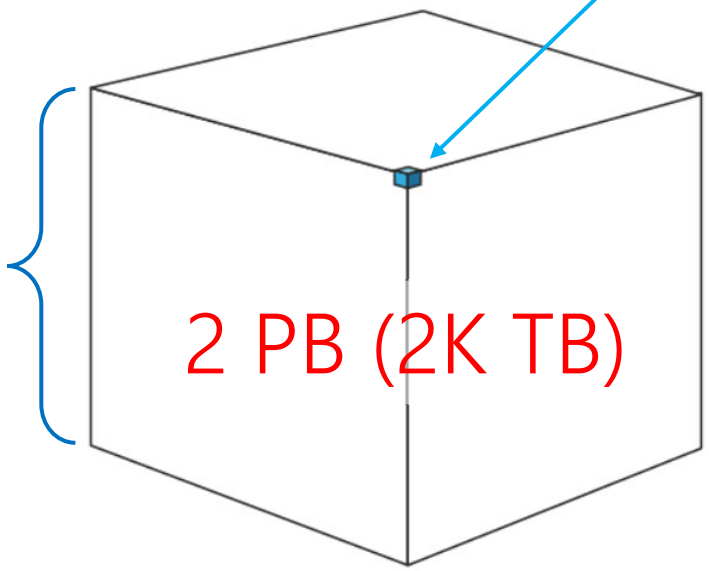
	High-resolution Small FOV	Low-resolution Large FOV
		
Pros	Details revealed	Large sampling size
Cons	Limited sampling size	Details lost

WHY NOT ALWAYS USE HIGH-RESOLUTION?

$$\text{Voxel size} = \frac{\text{FOV}}{3000} \sim \frac{\text{FOV}}{1000}$$

100 x 100 x 100 mm FOV

1 µm voxel

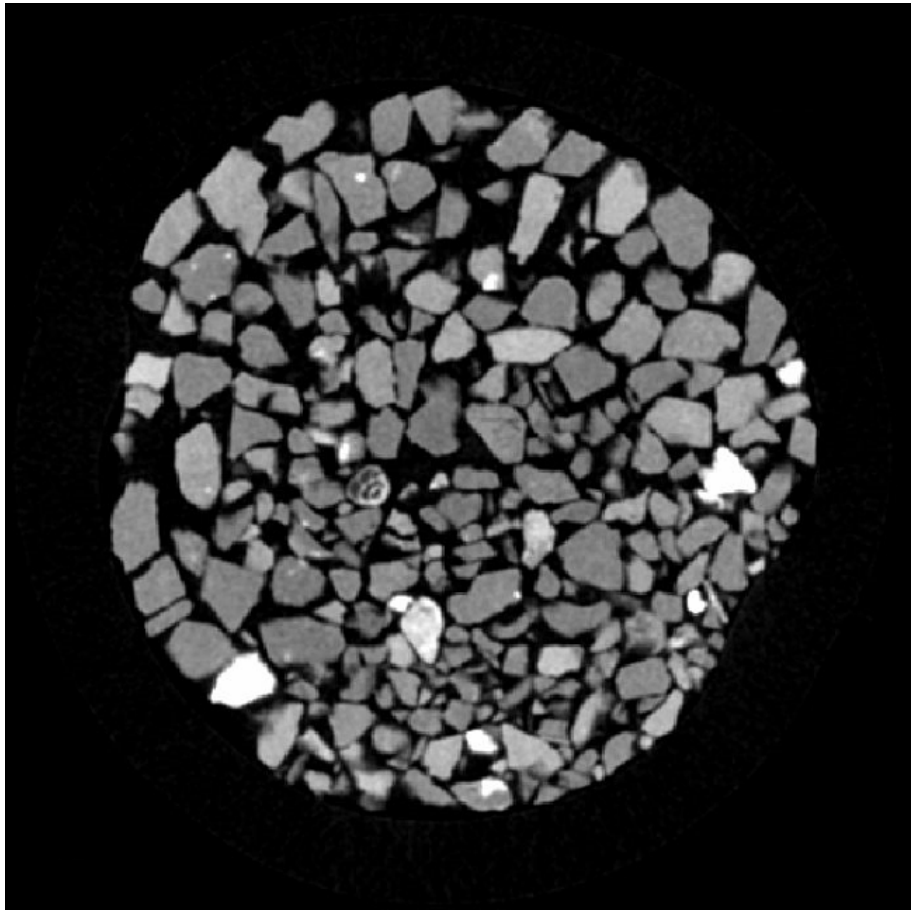


To keep the file size under control.

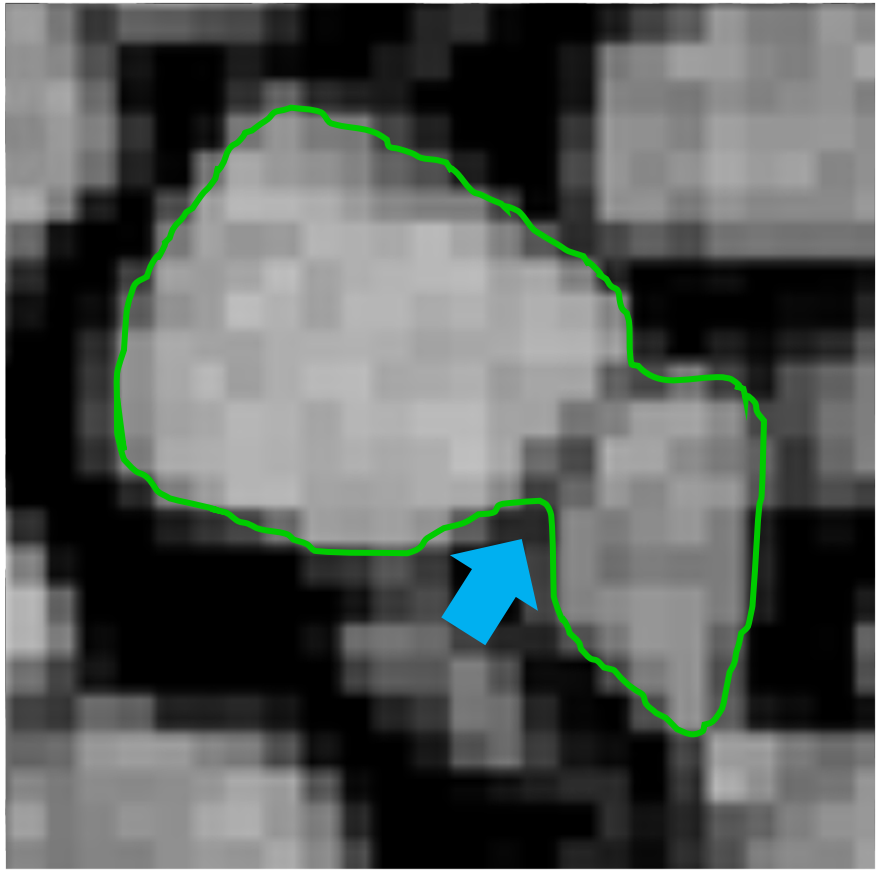
Run test scans and analysis.

WHAT HAPPENS IF RESOLUTION IS TOO LOW?

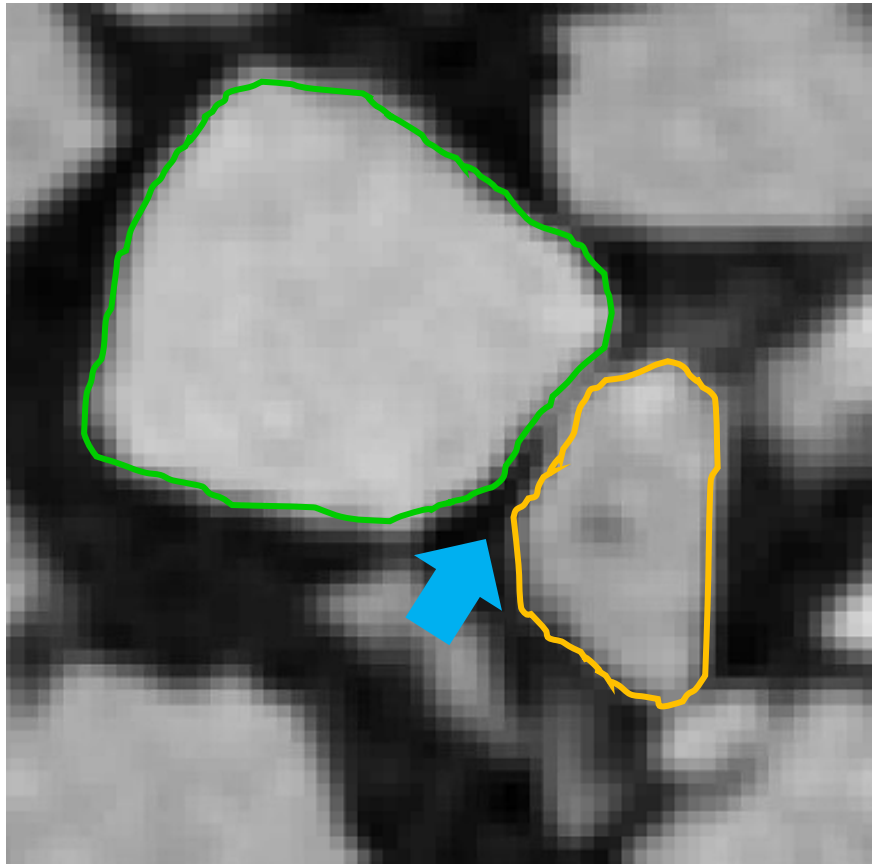
Packed sand



Packed sand

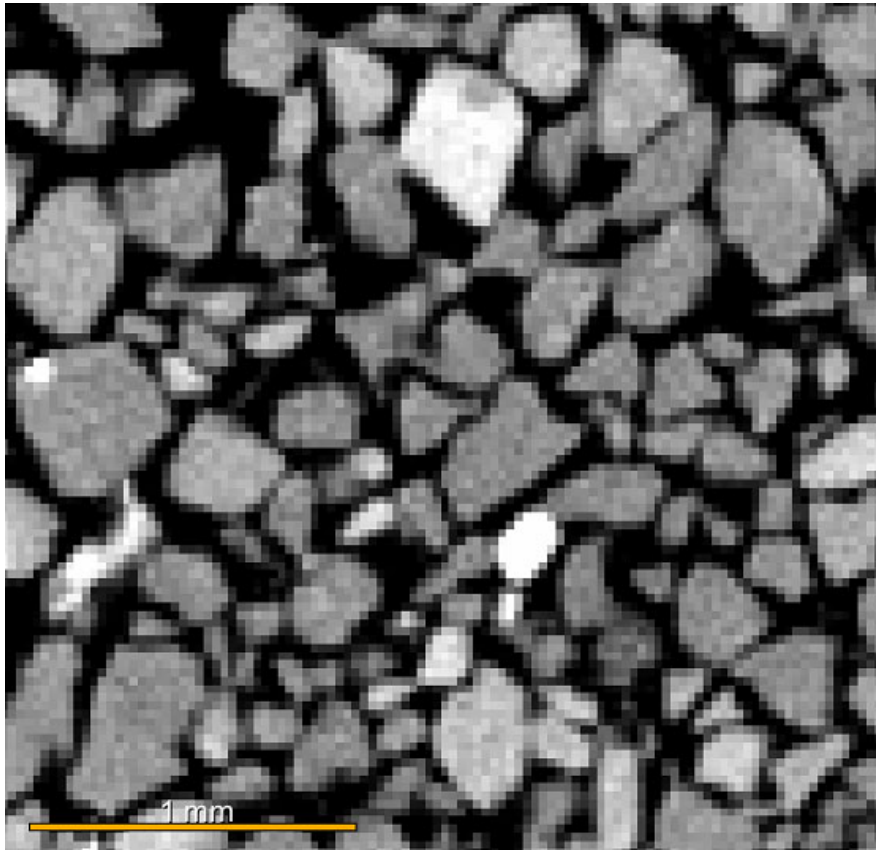


25.2 µm

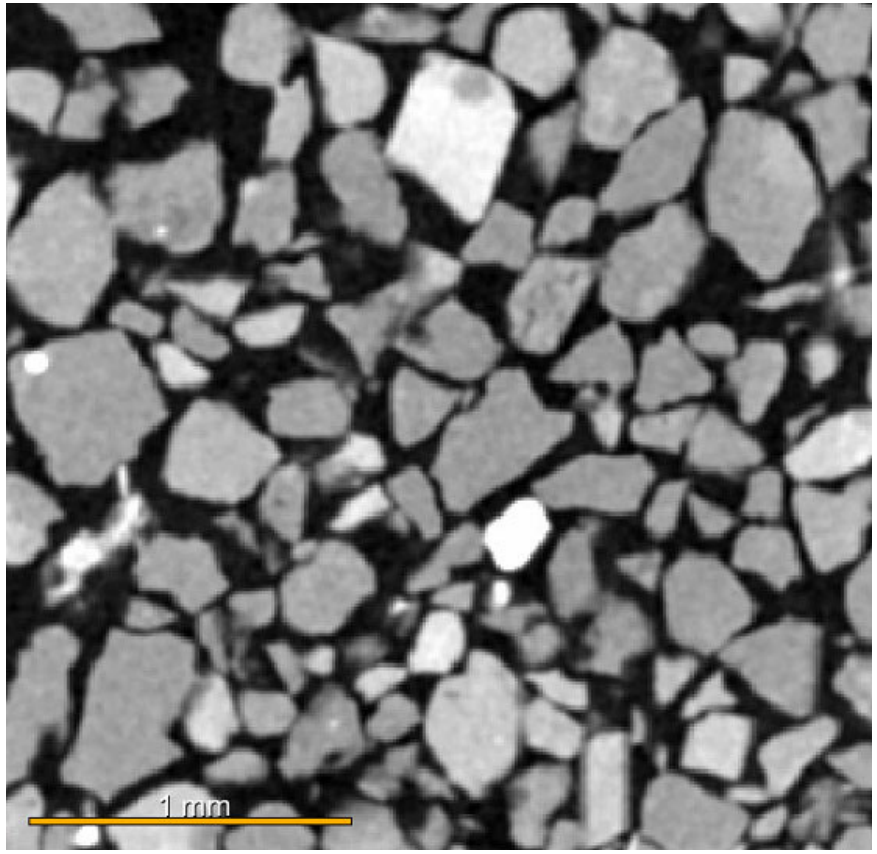


9.4 µm

Packed sand

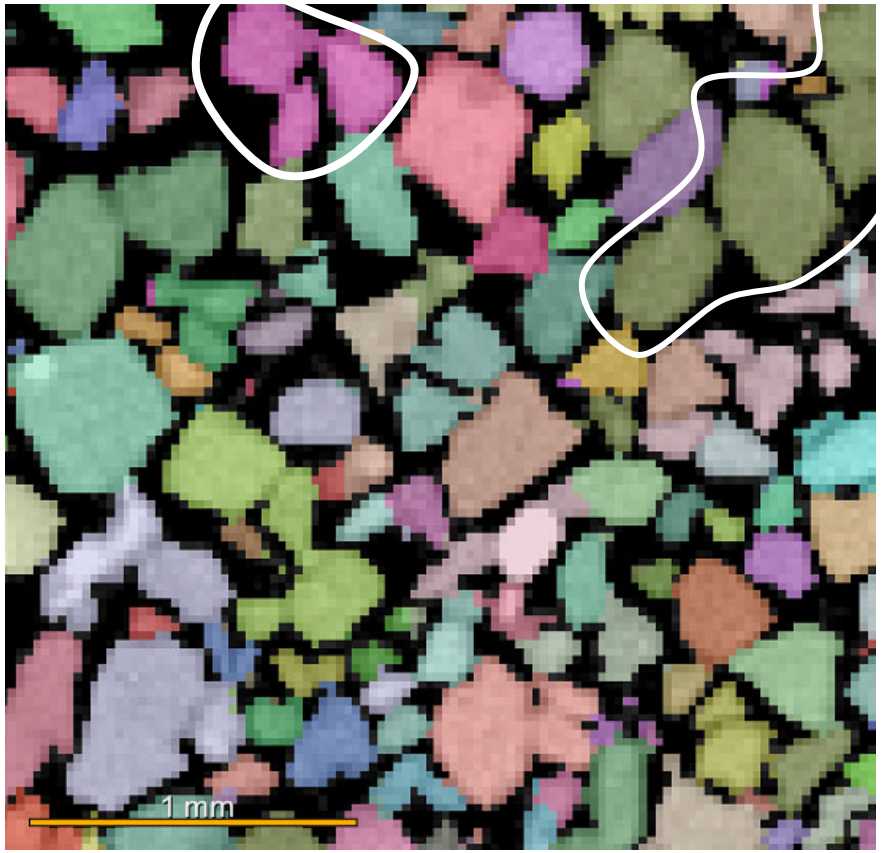


25.2 µm

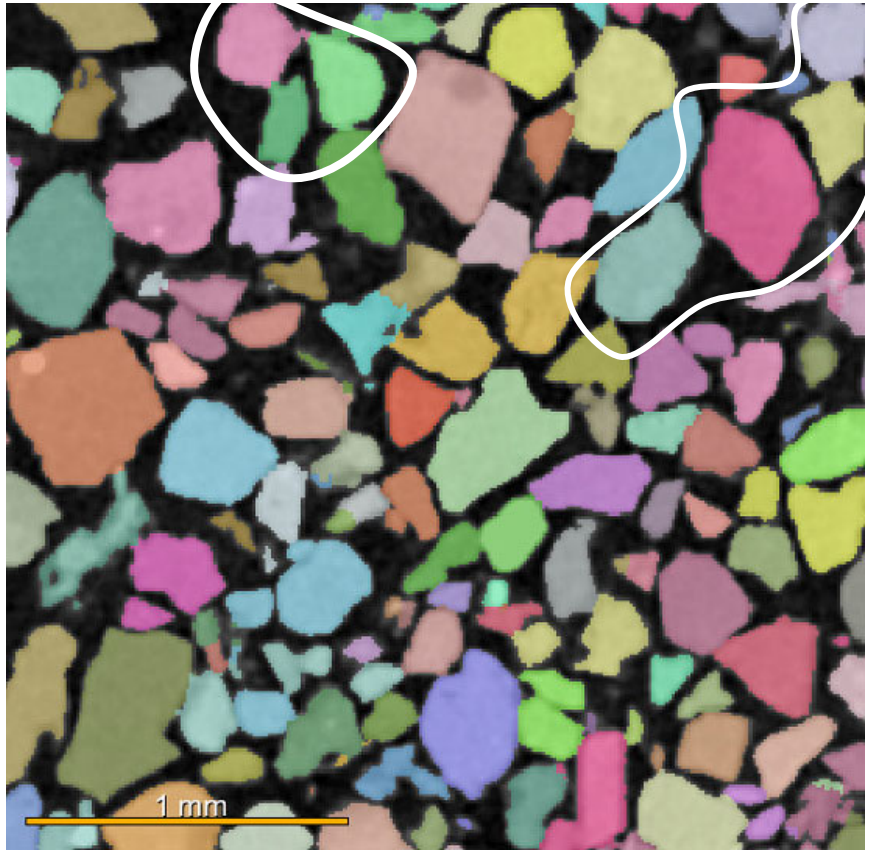


9.4 µm

Packed sand

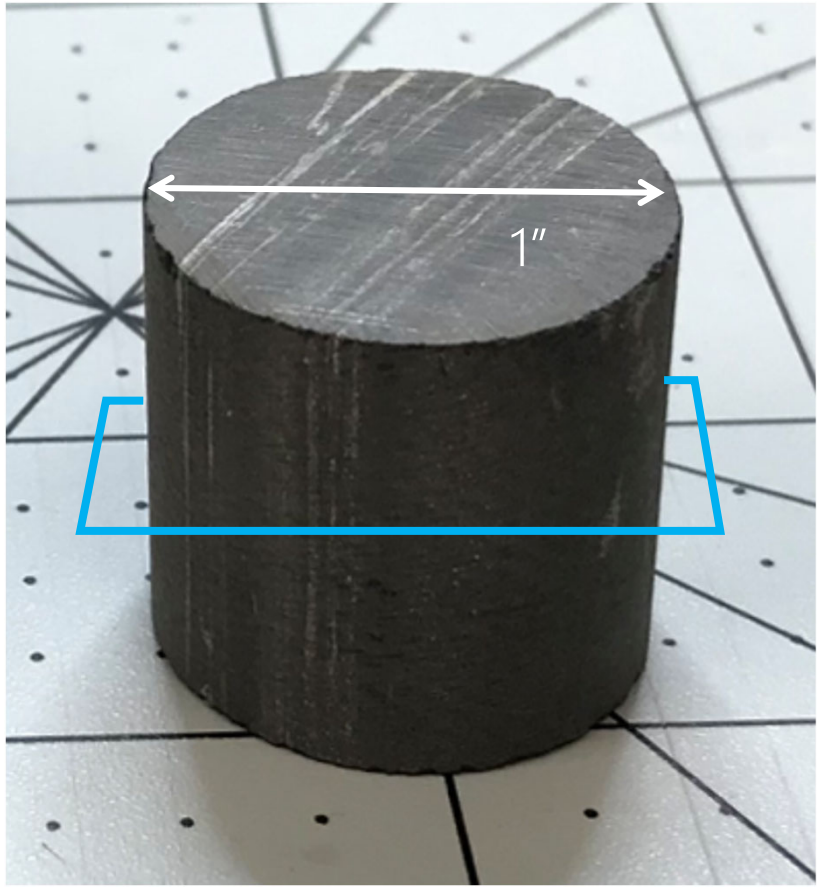


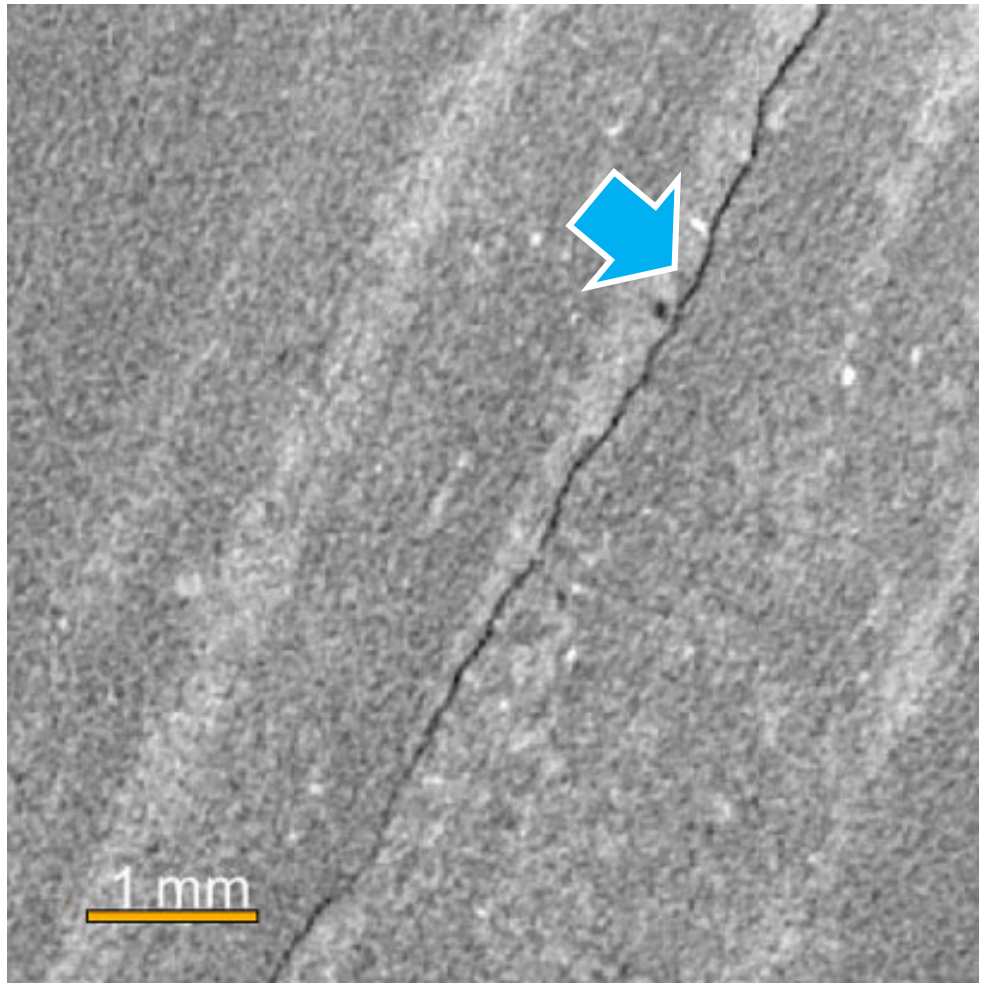
25.2 µm



9.4 µm

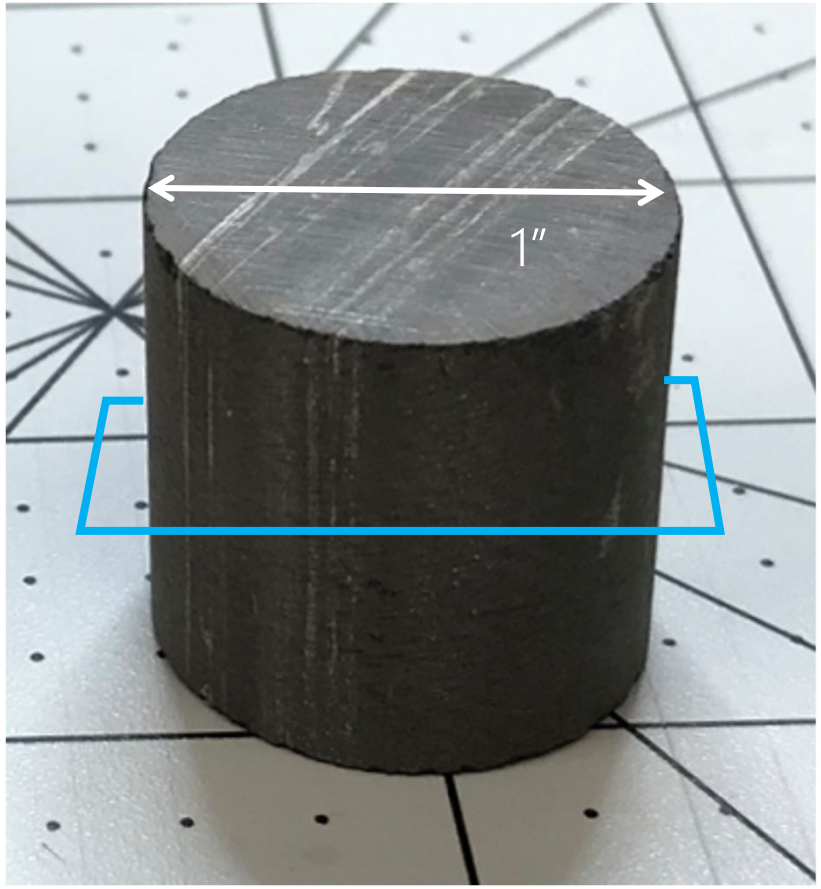
Shale

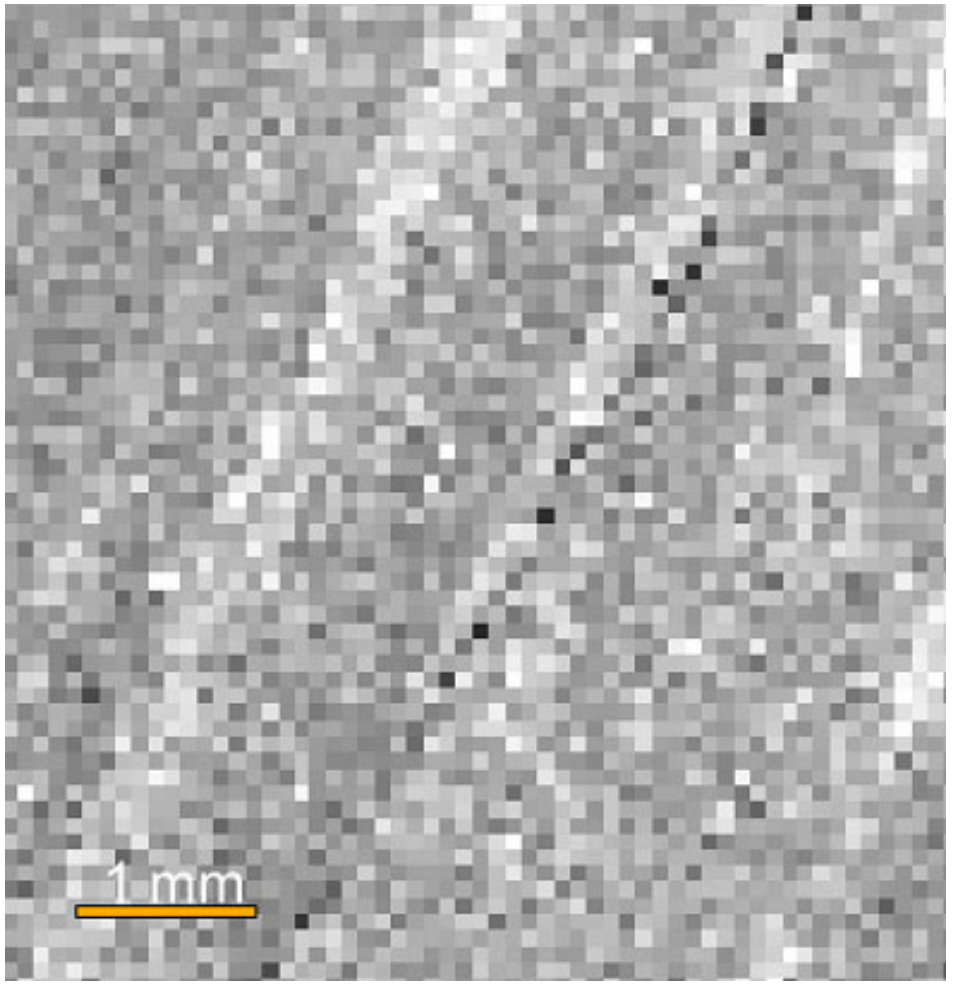




9.1 µm

Shale



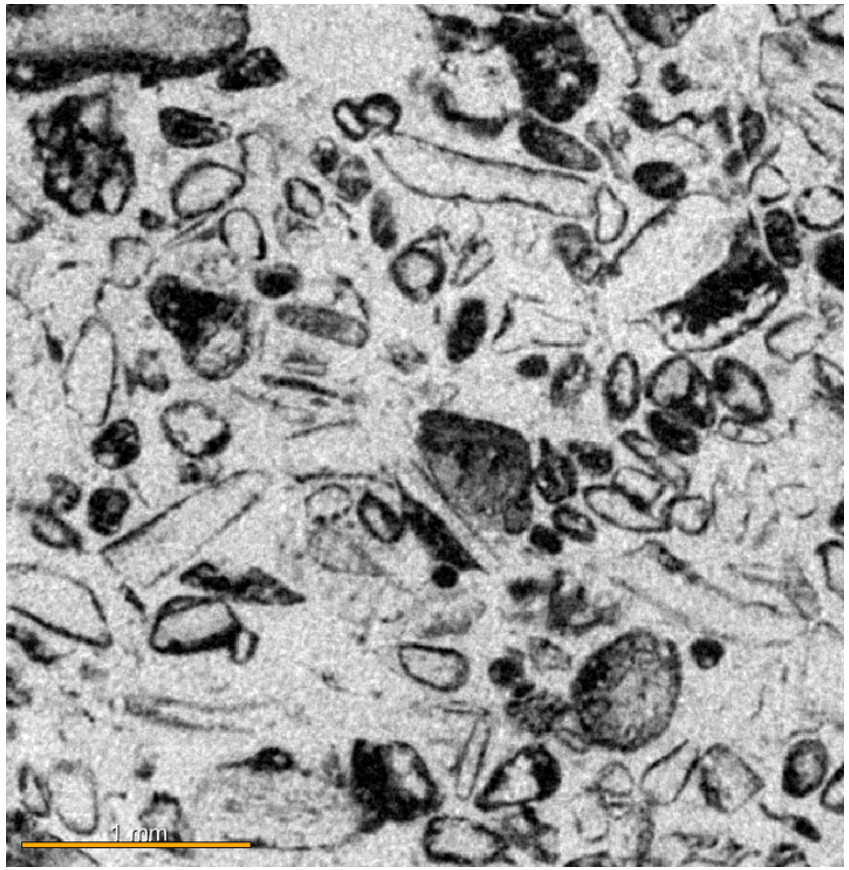


91 µm

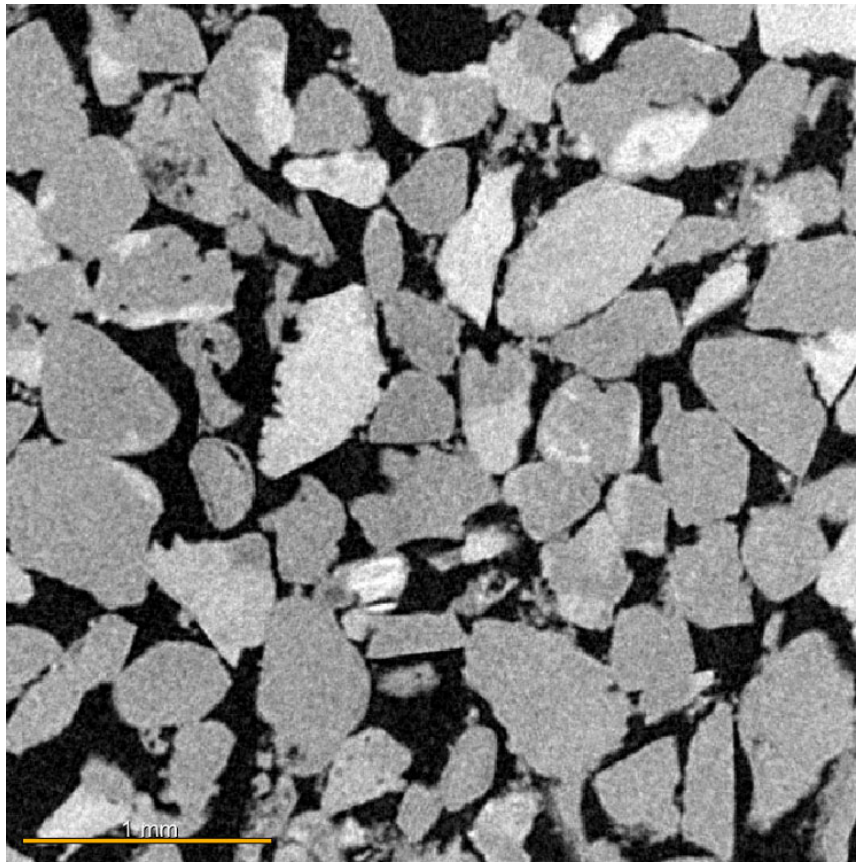
Resolution & FOV

Contrast

Carbonate



Sand stone

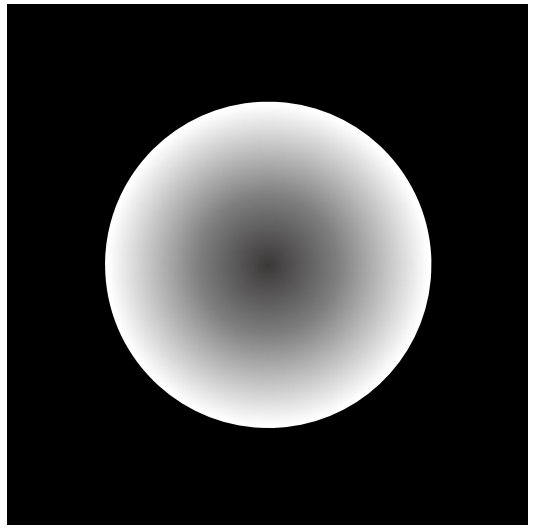


Mineral	Density [g/cm^3]
Quartz	2.65
Calcite	2.71
Corundum	4.02
Hematite	7.84

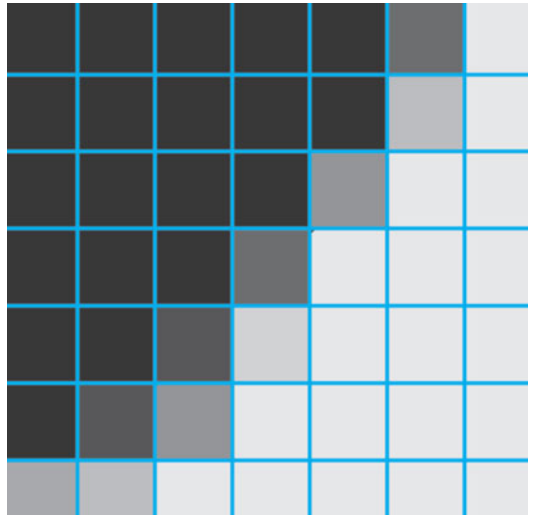
Density contrast is not a problem.

THEN WHAT CAN BE A PROBLEM?

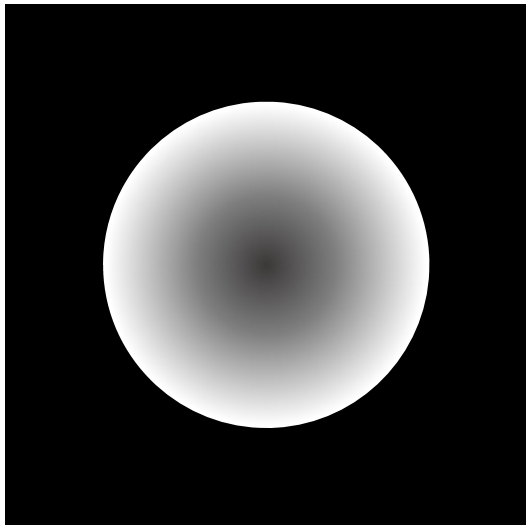
Beam hardening



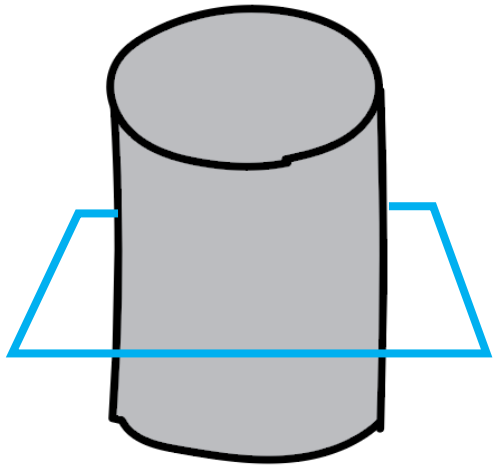
Partial volume effect



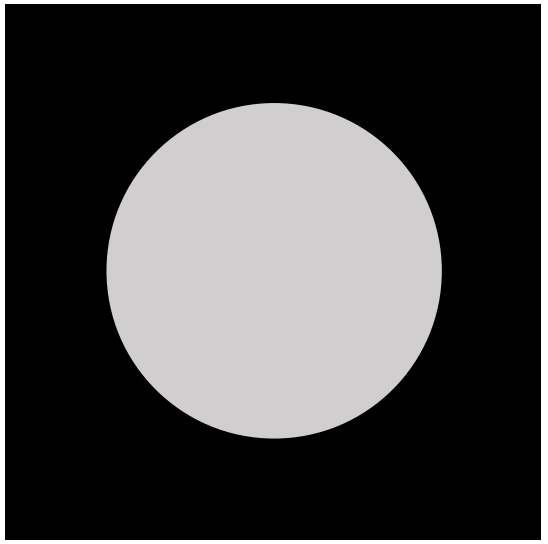
Beam hardening



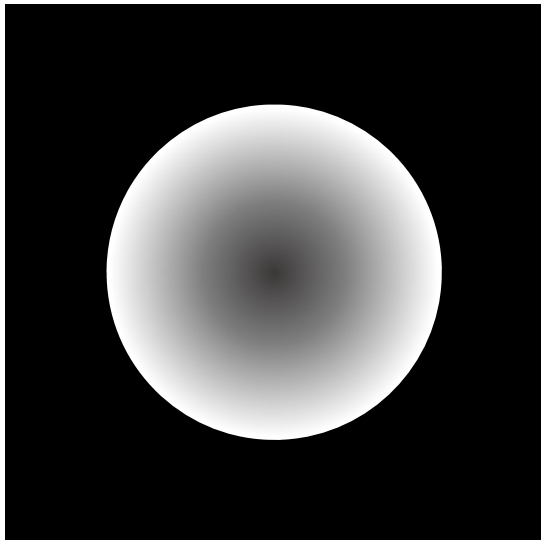
Partial volume effect

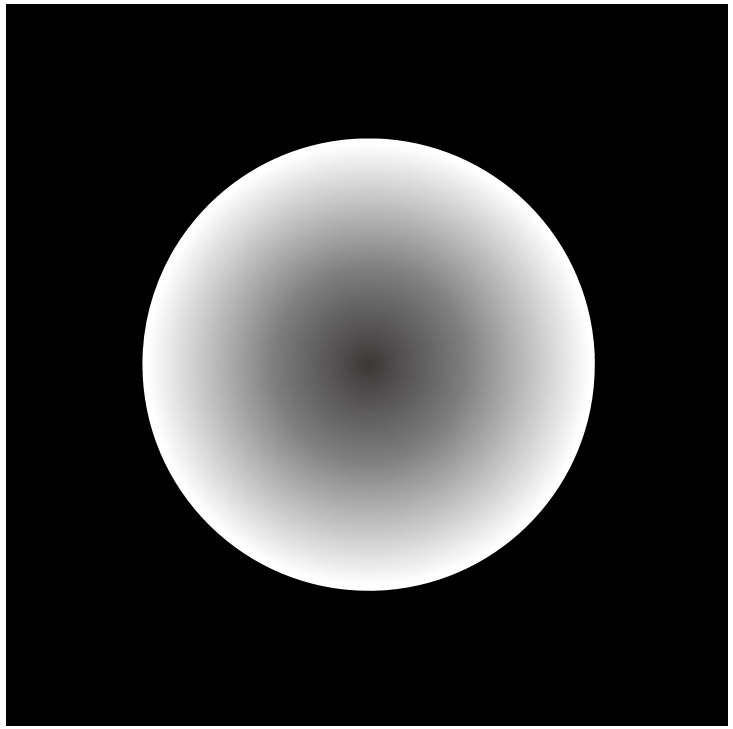


Monochromatic radiation

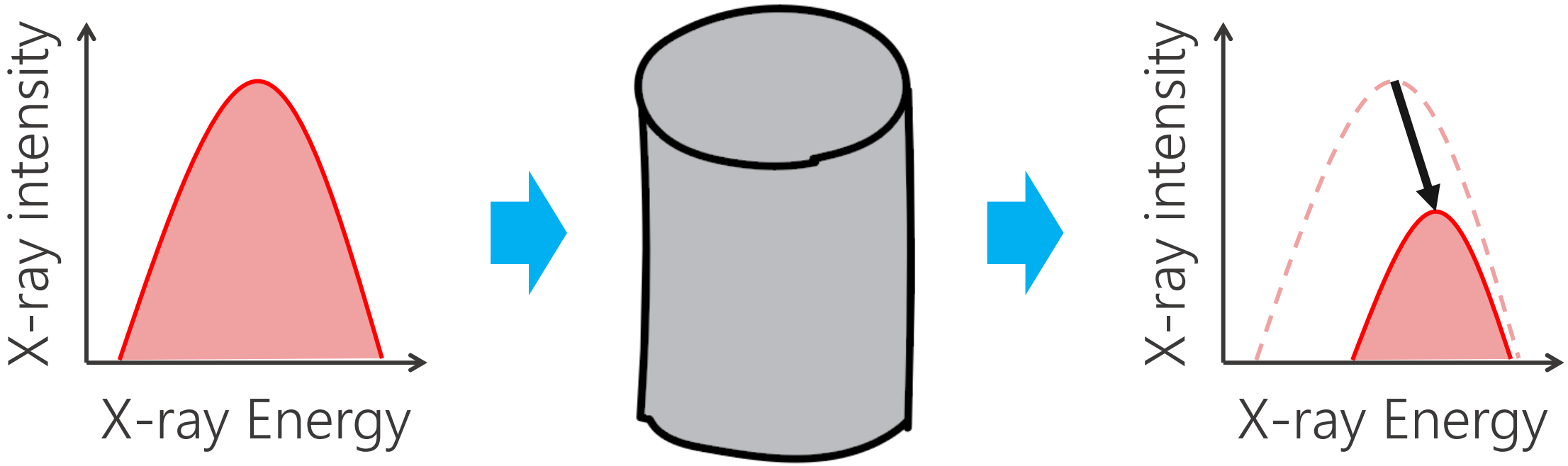


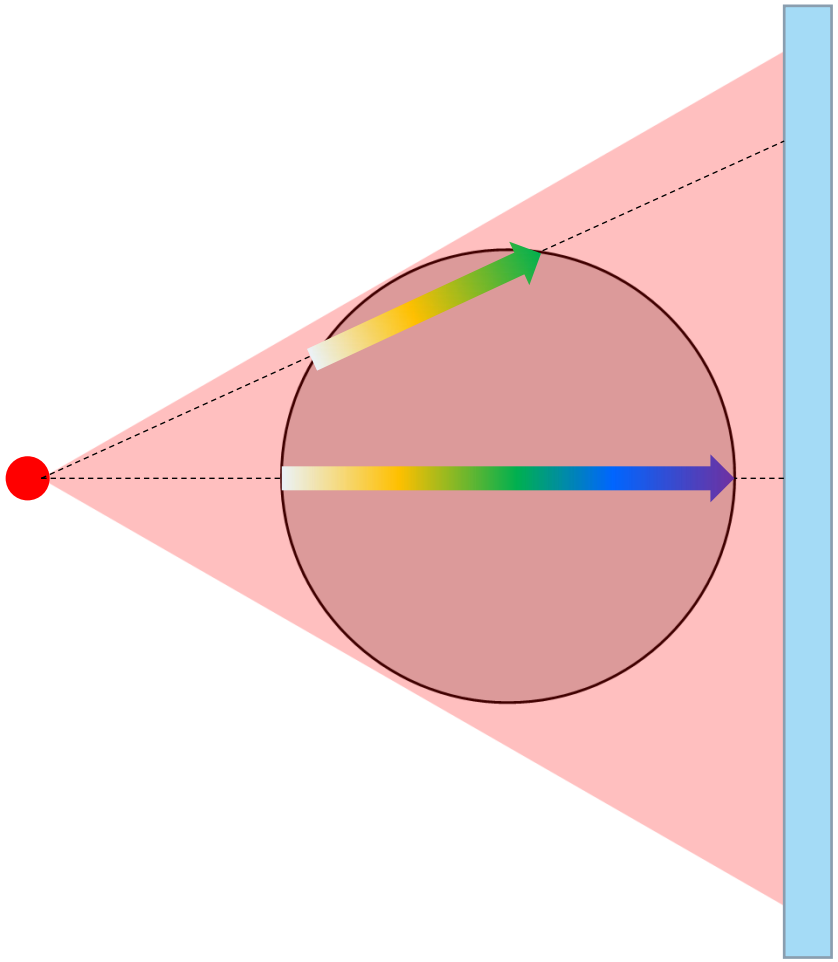
Polychromatic radiation





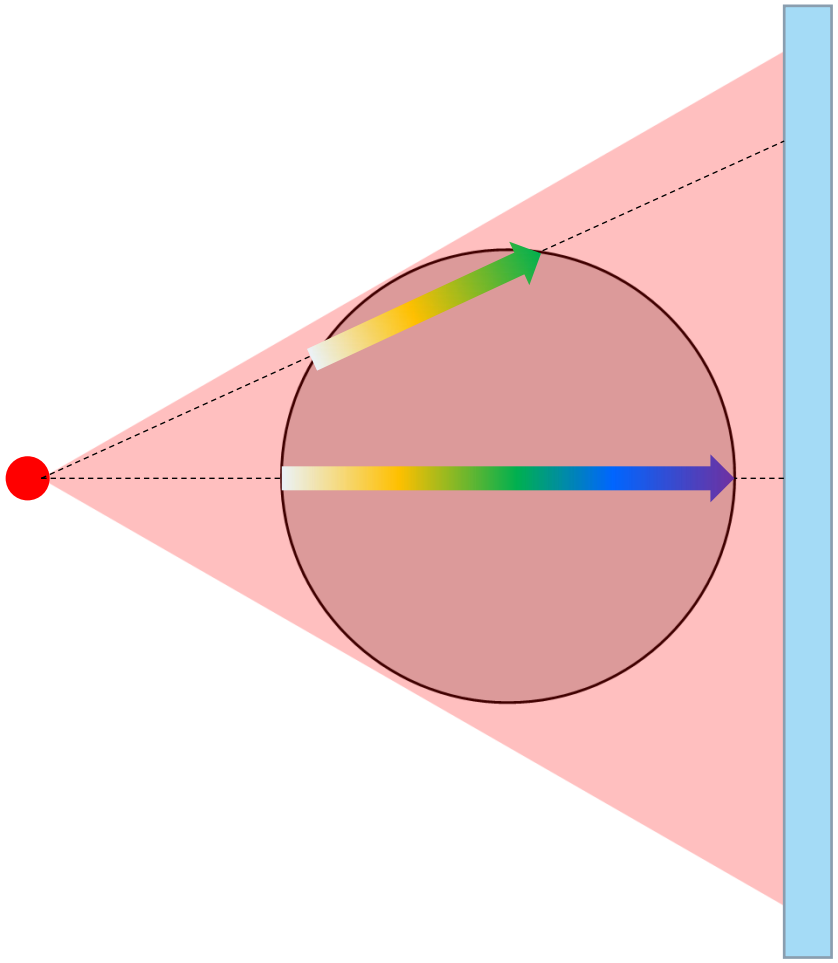
Cupping/shading artifact


X-ray intensity
X-ray Energy
X-ray intensity
X-ray Energy



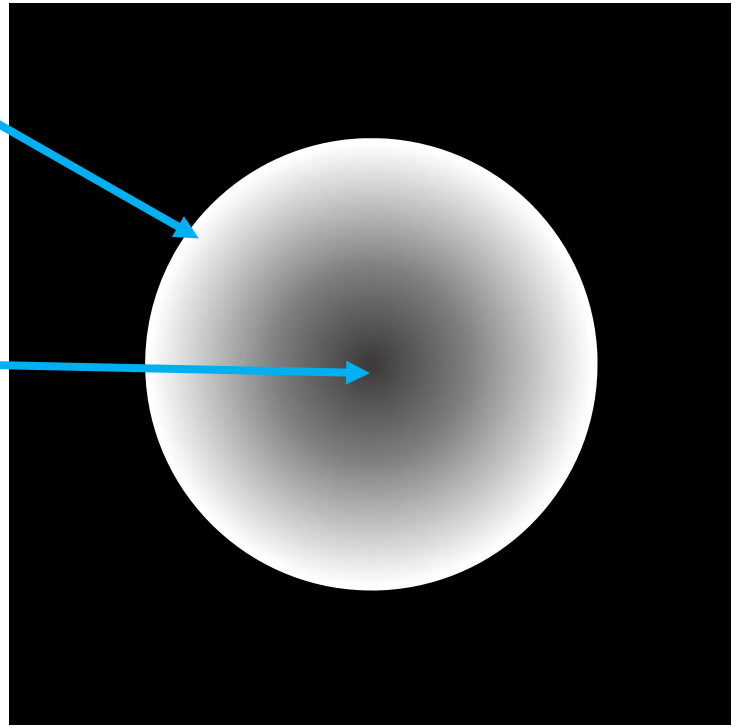
Softer X-rays → High absorption rate

Harder X-rays → Low absorption rate



High absorption

Low absorption

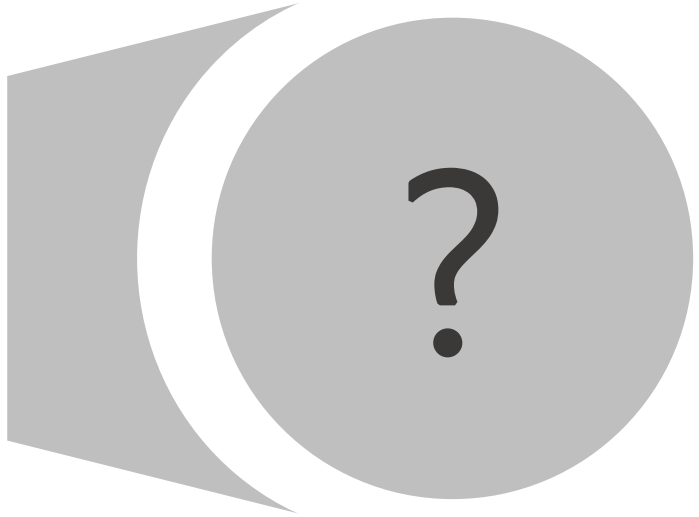


WHAT SHOULD WE DO?

Numerical correction

Image correction

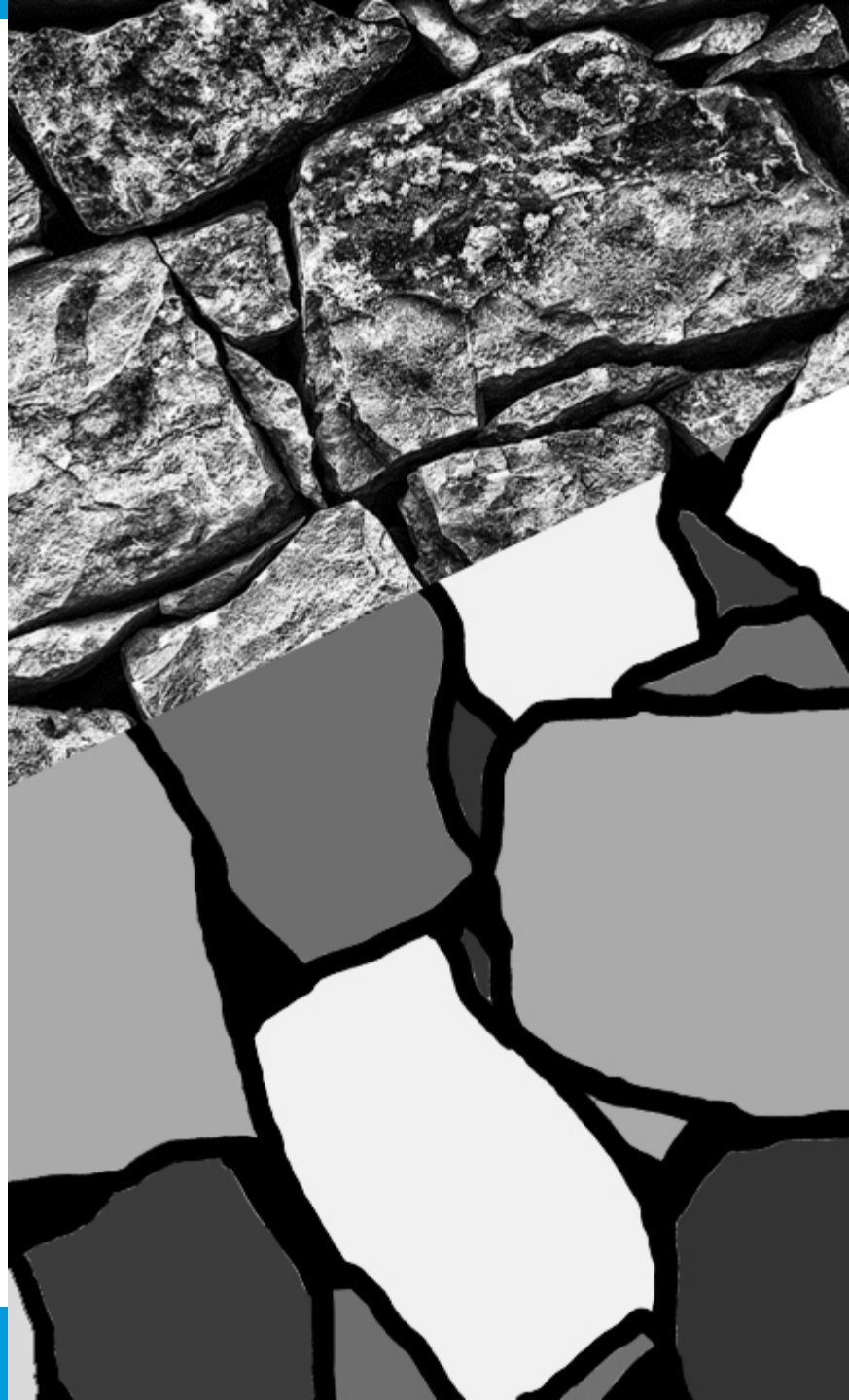
Physical correction



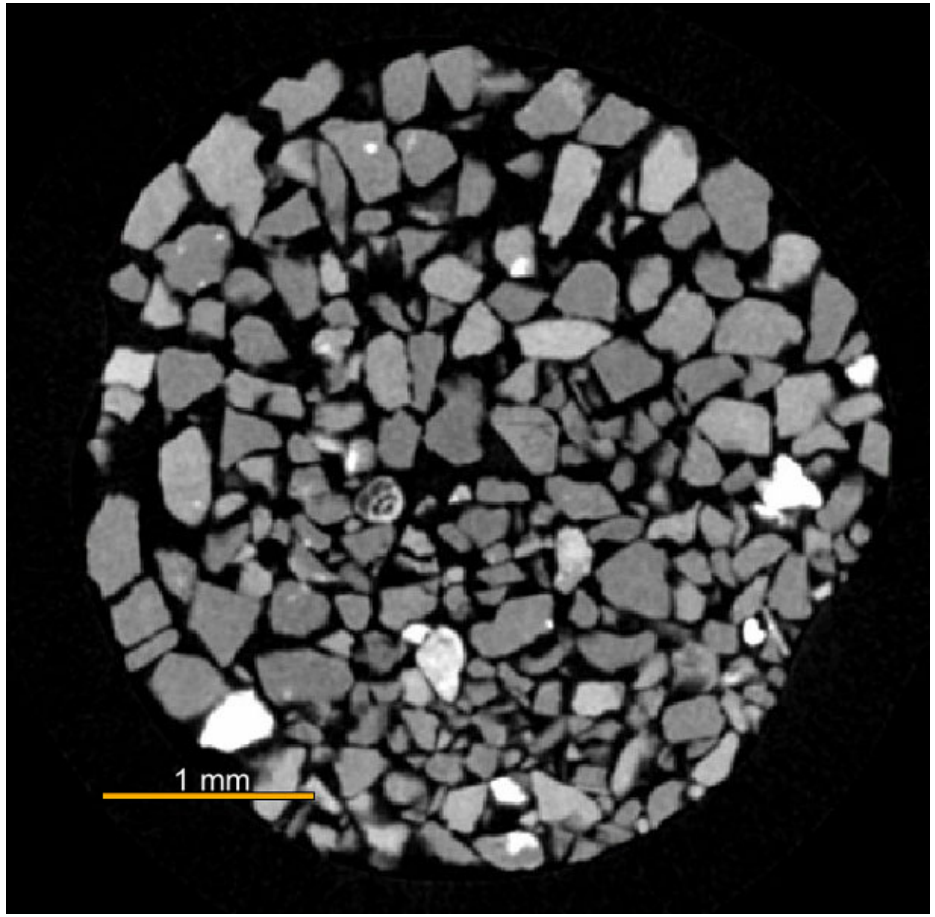
WHAT IS OUR GOAL?

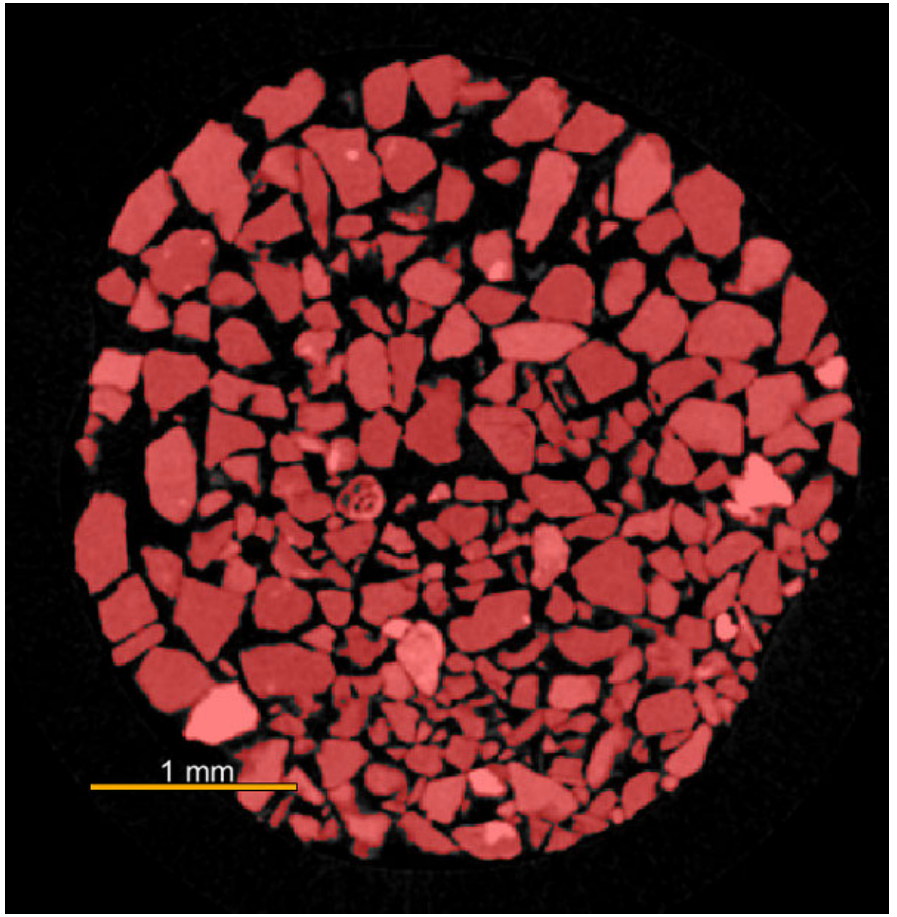
Image segmentation

Quantitative analysis



Sandstone





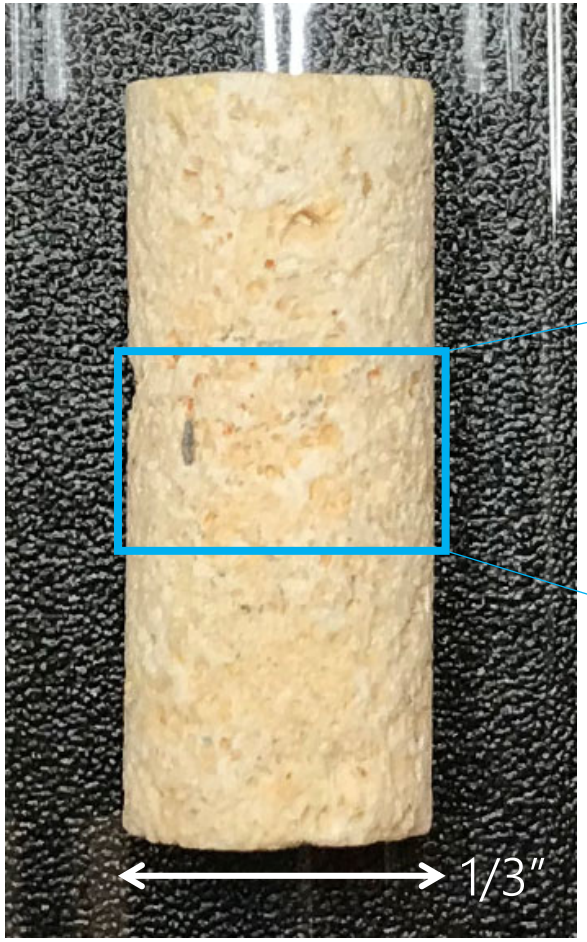
Thresholding (Otsu)

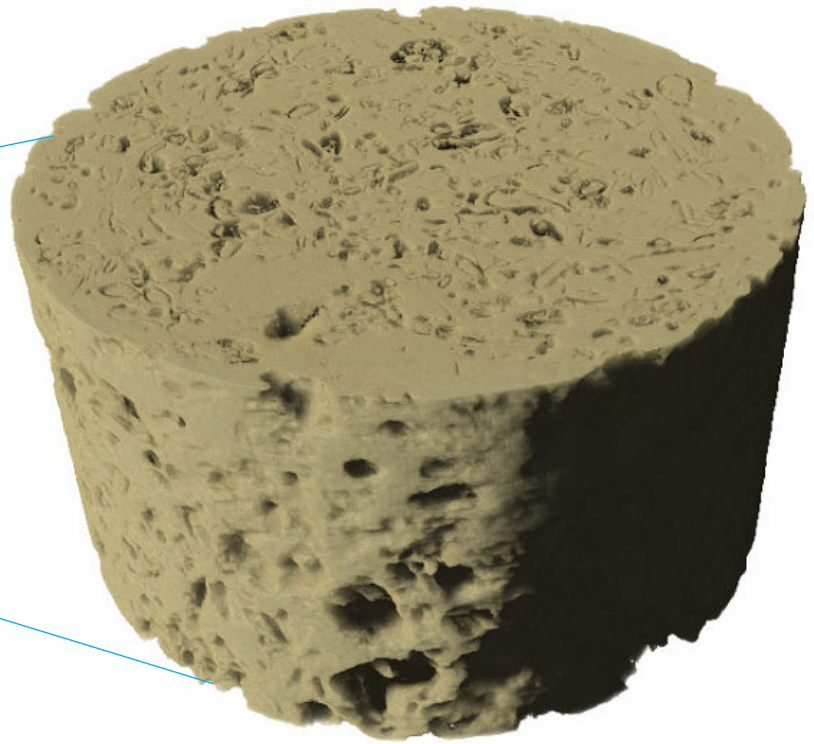
Histogram thresholding

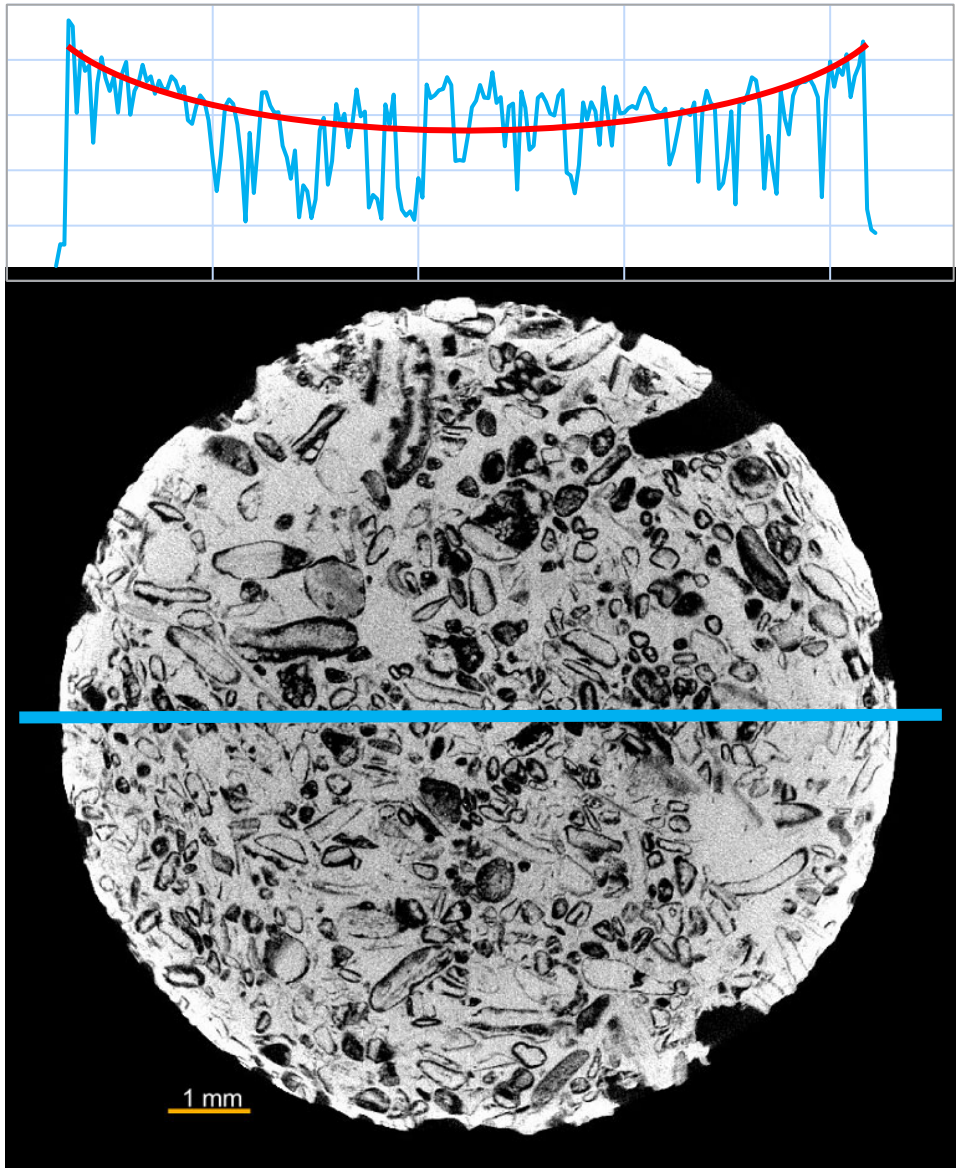
Histographic segmentation

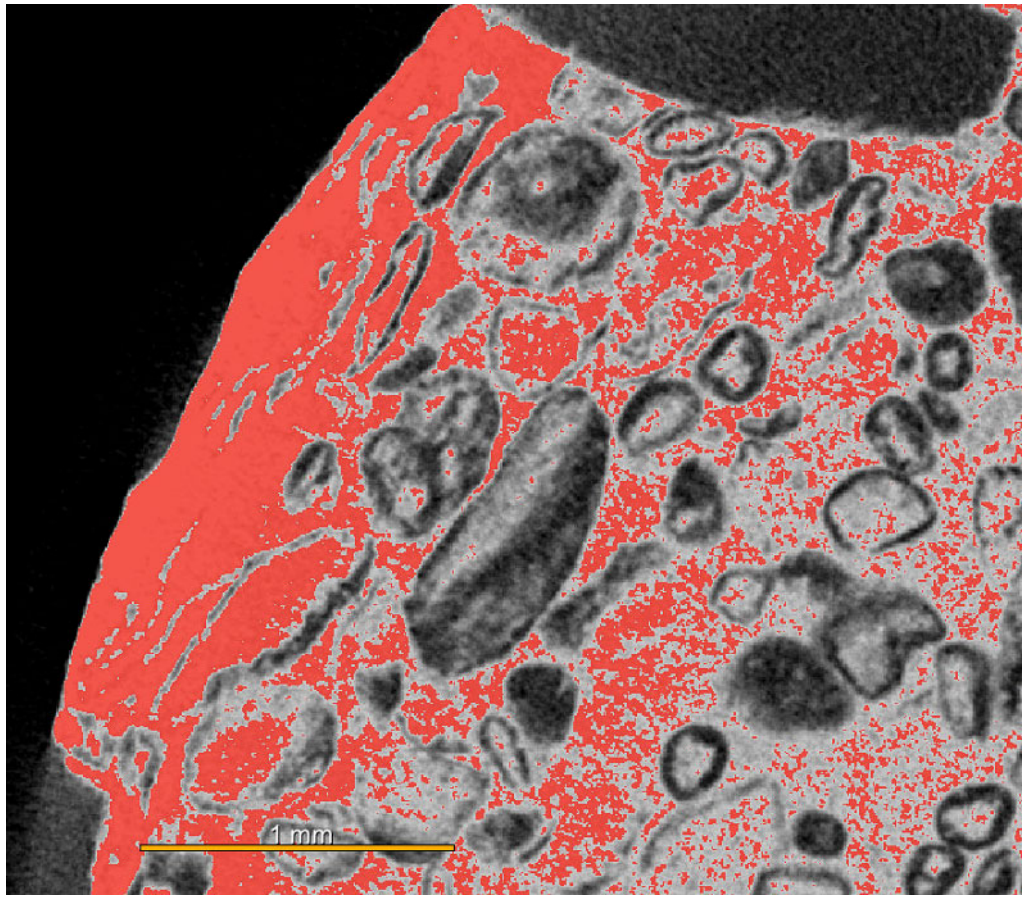
Machine/deep learning segmentation

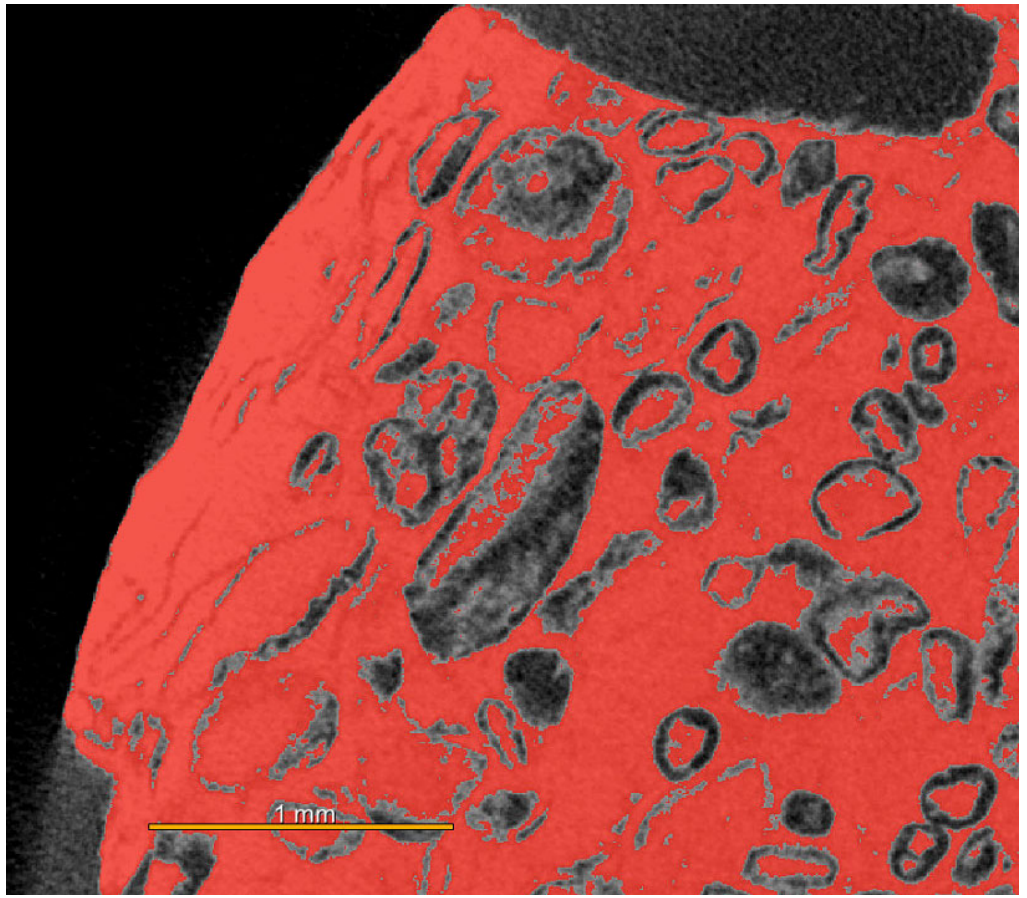
Carbonate



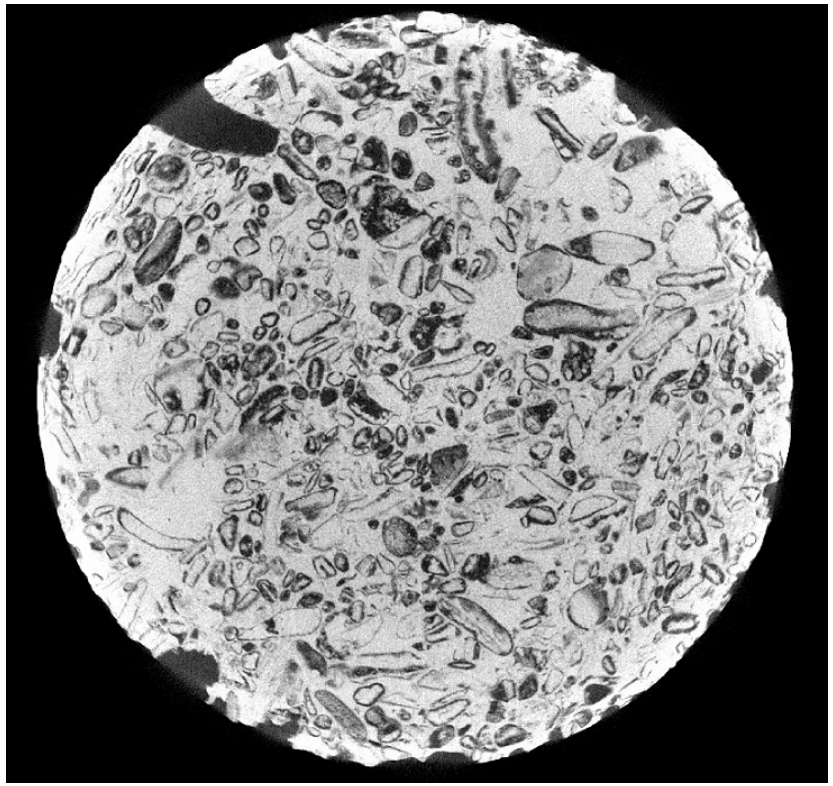



1 mm

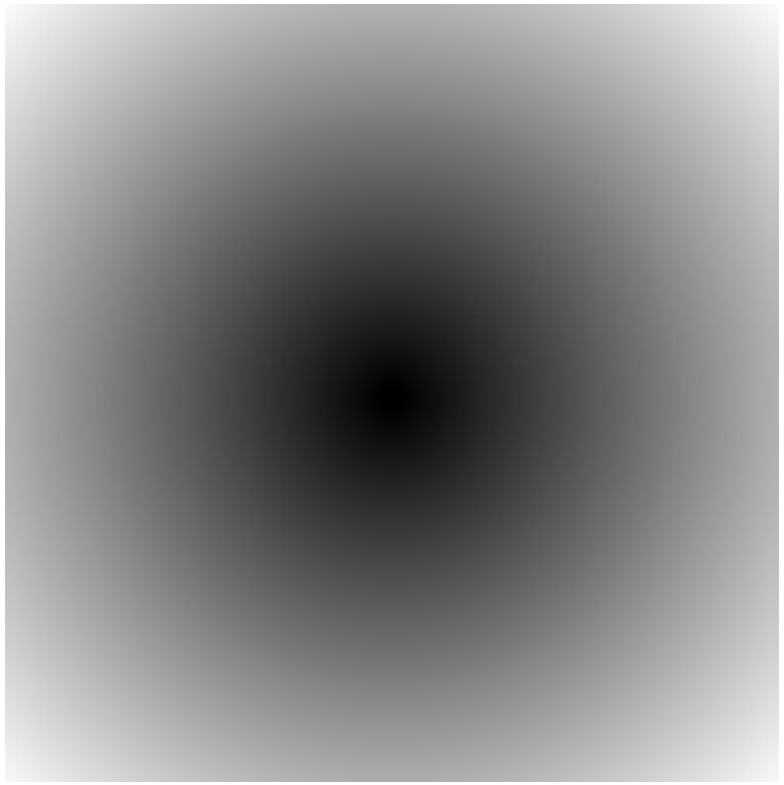




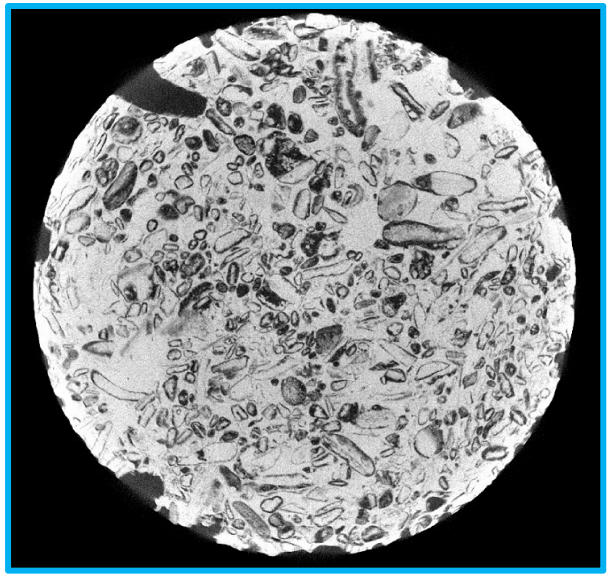
Threshold depends on the distance from the center.

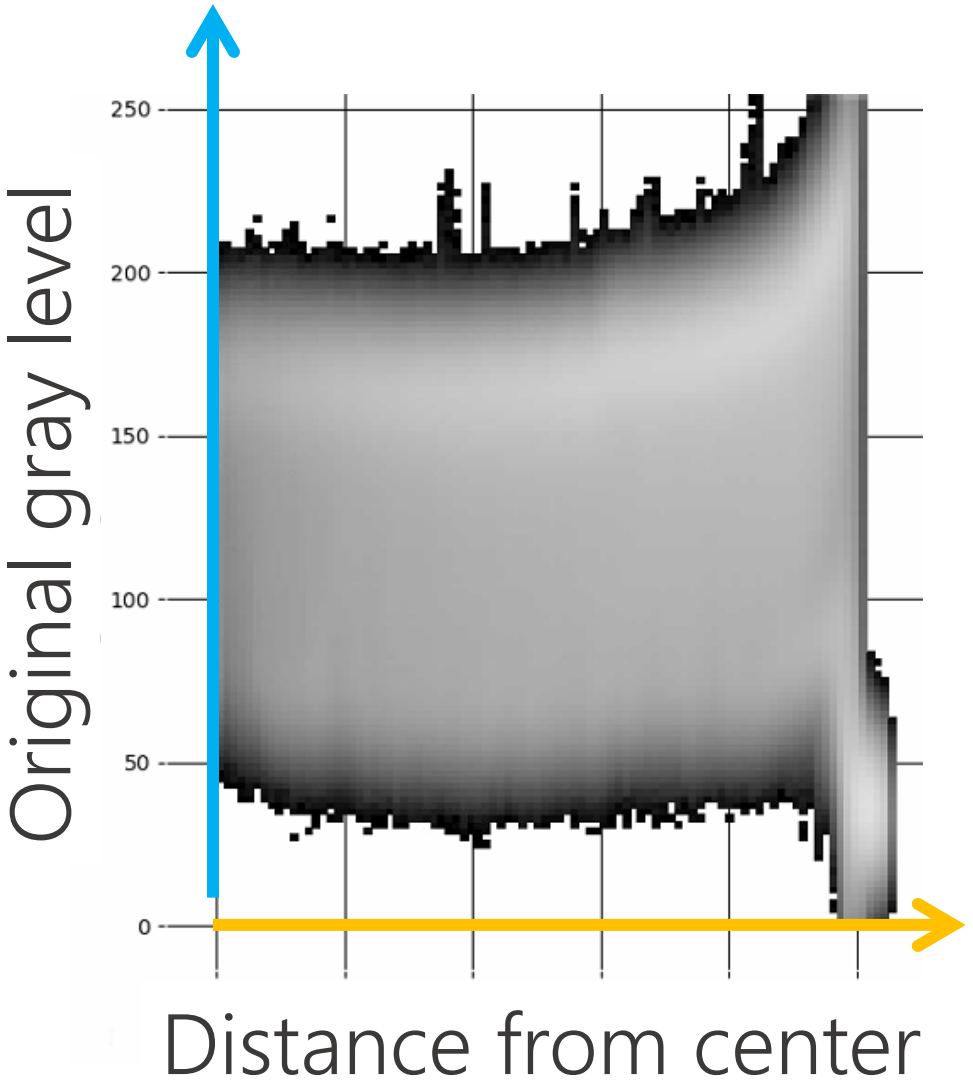


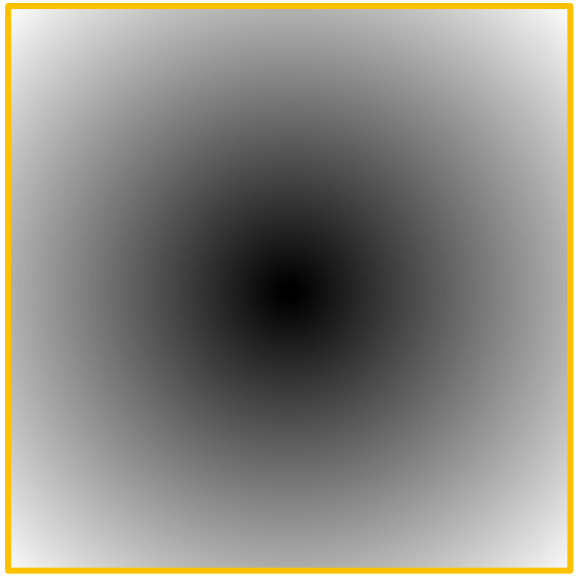
Original image

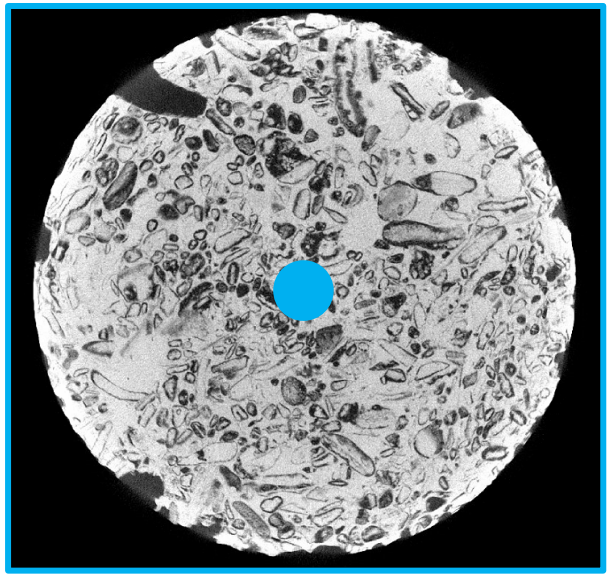


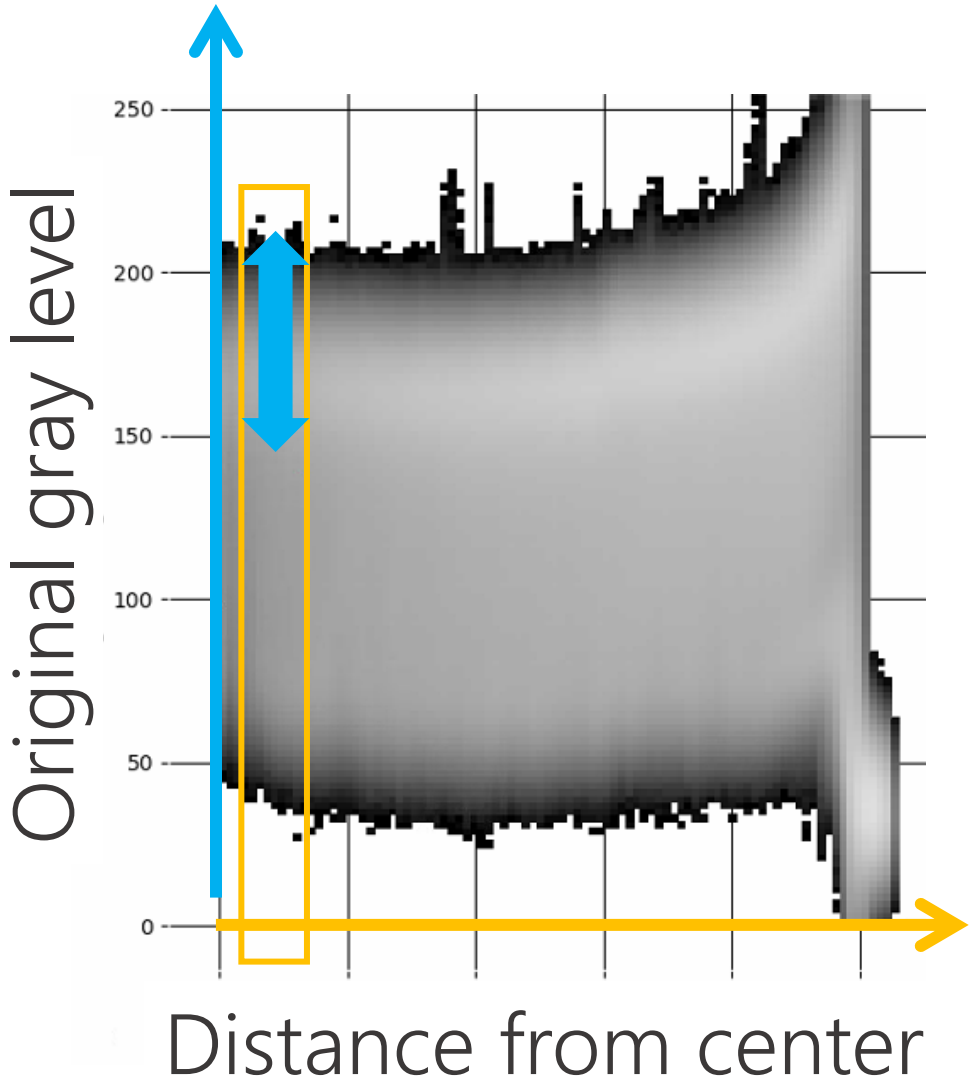
Distance map

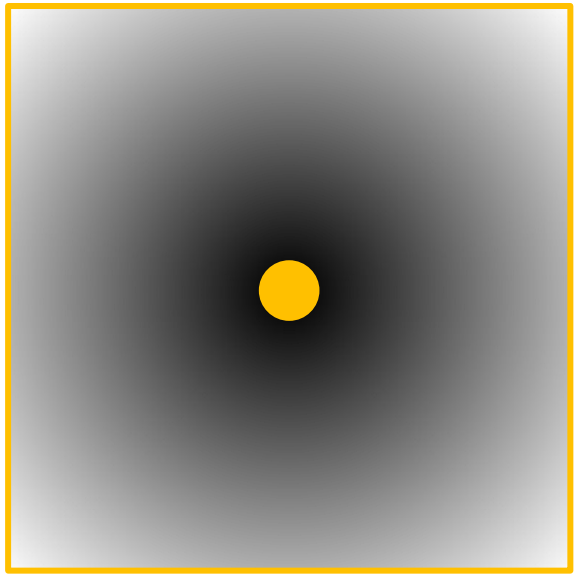


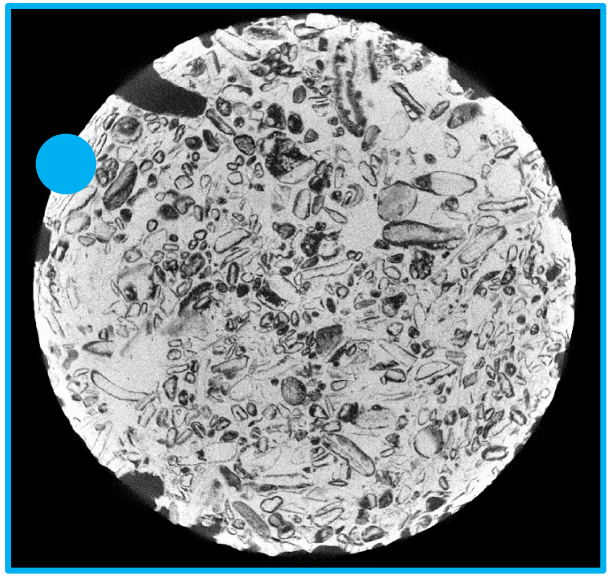

Original gray level
250
200
150
100
50
0
Distance from center

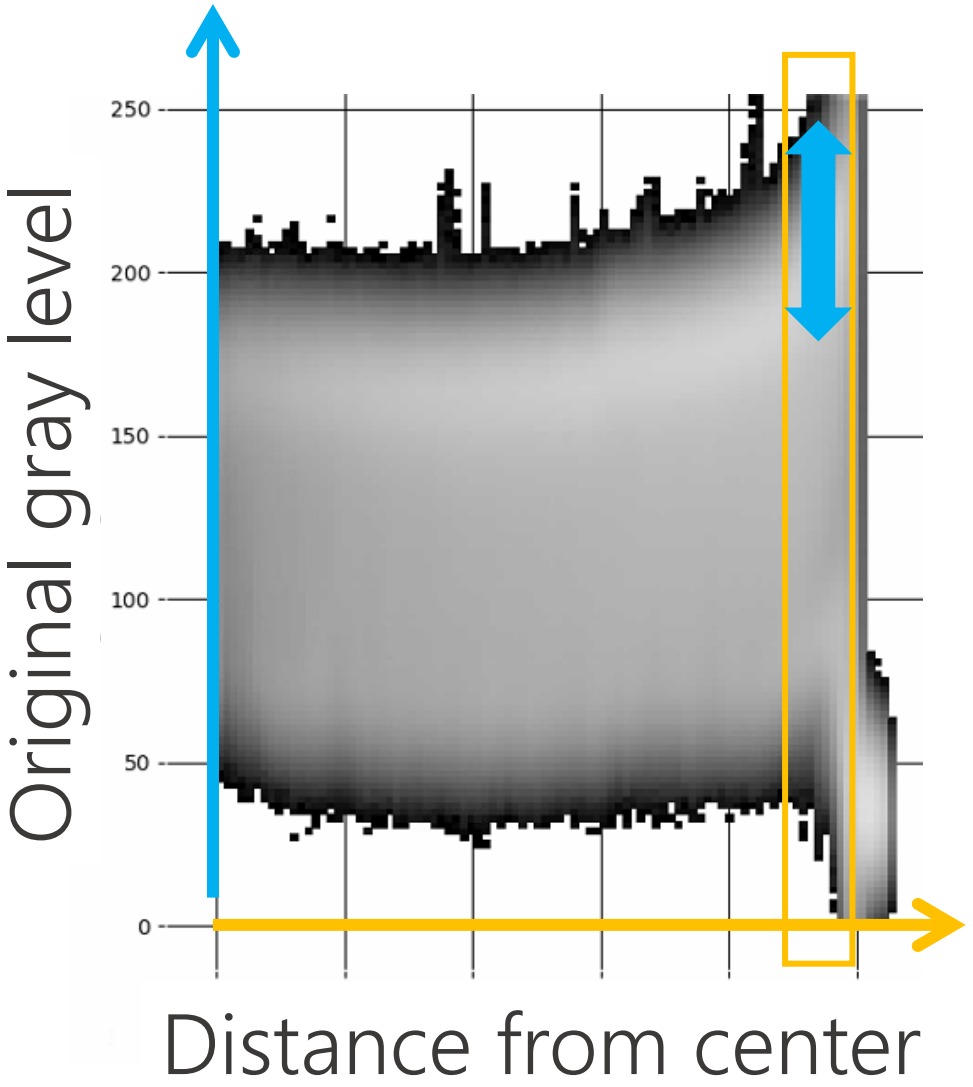





Original gray level
250
200
150
100
50
0
Distance from center



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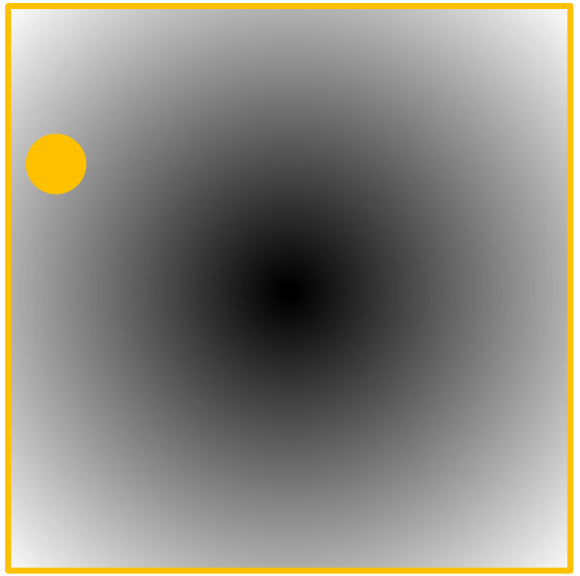
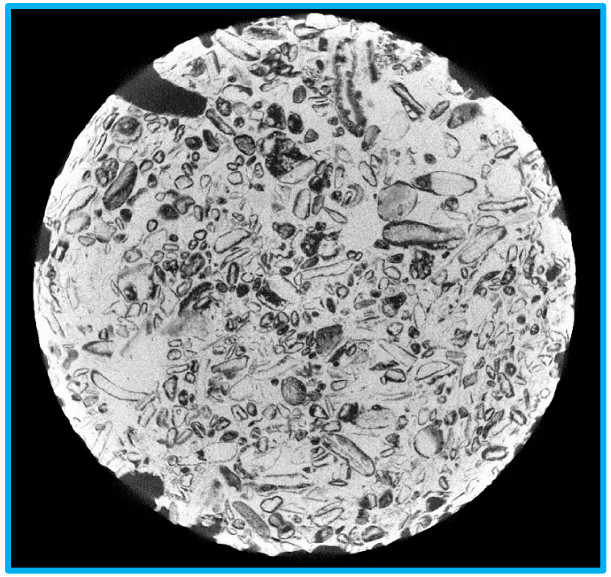
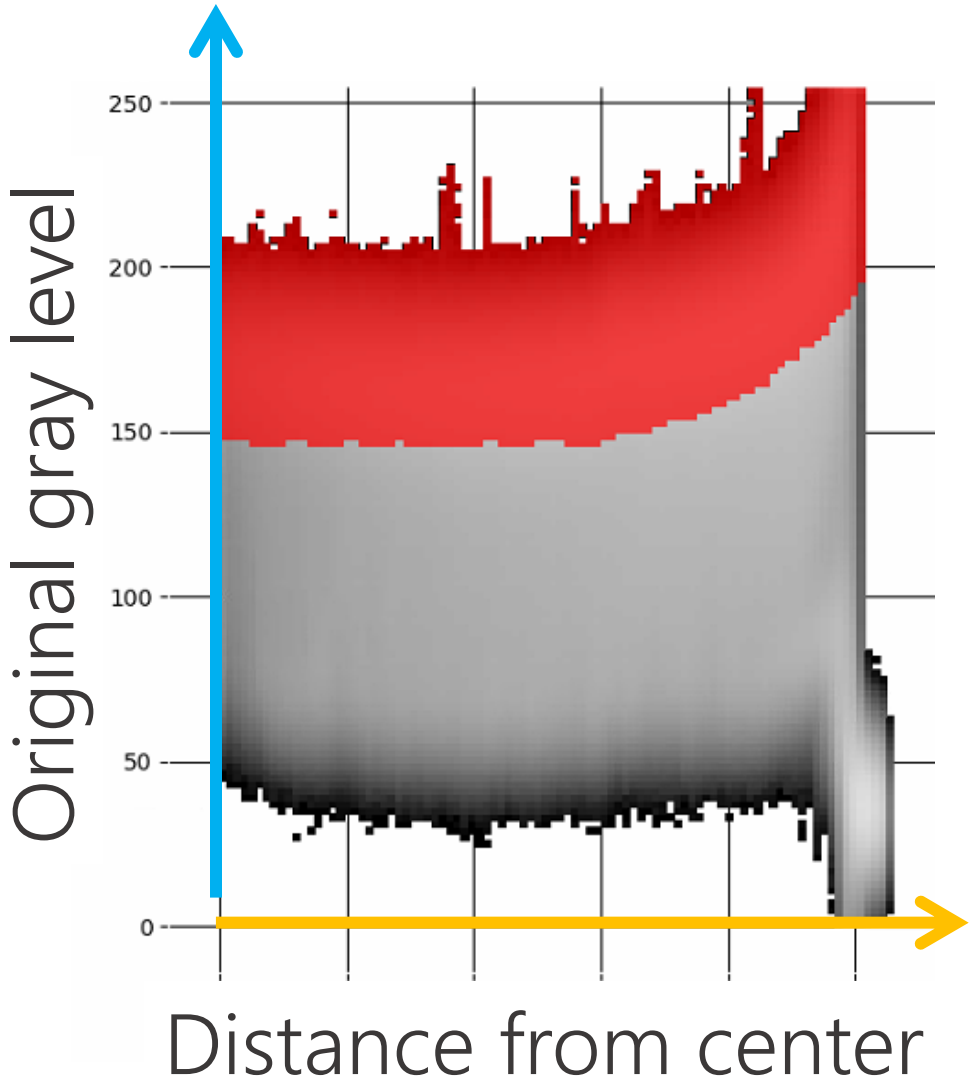
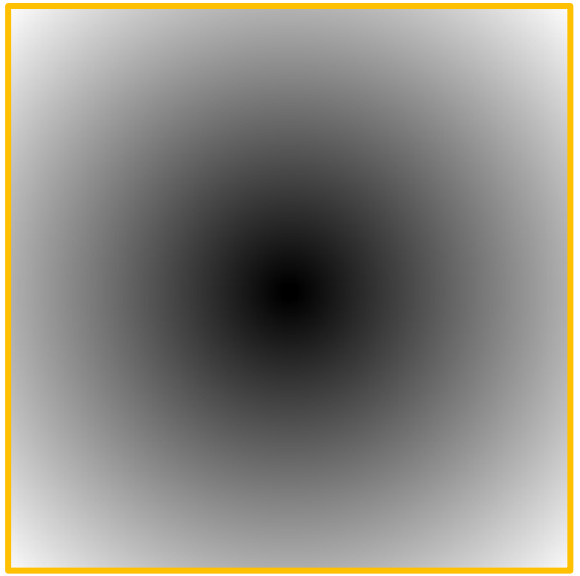
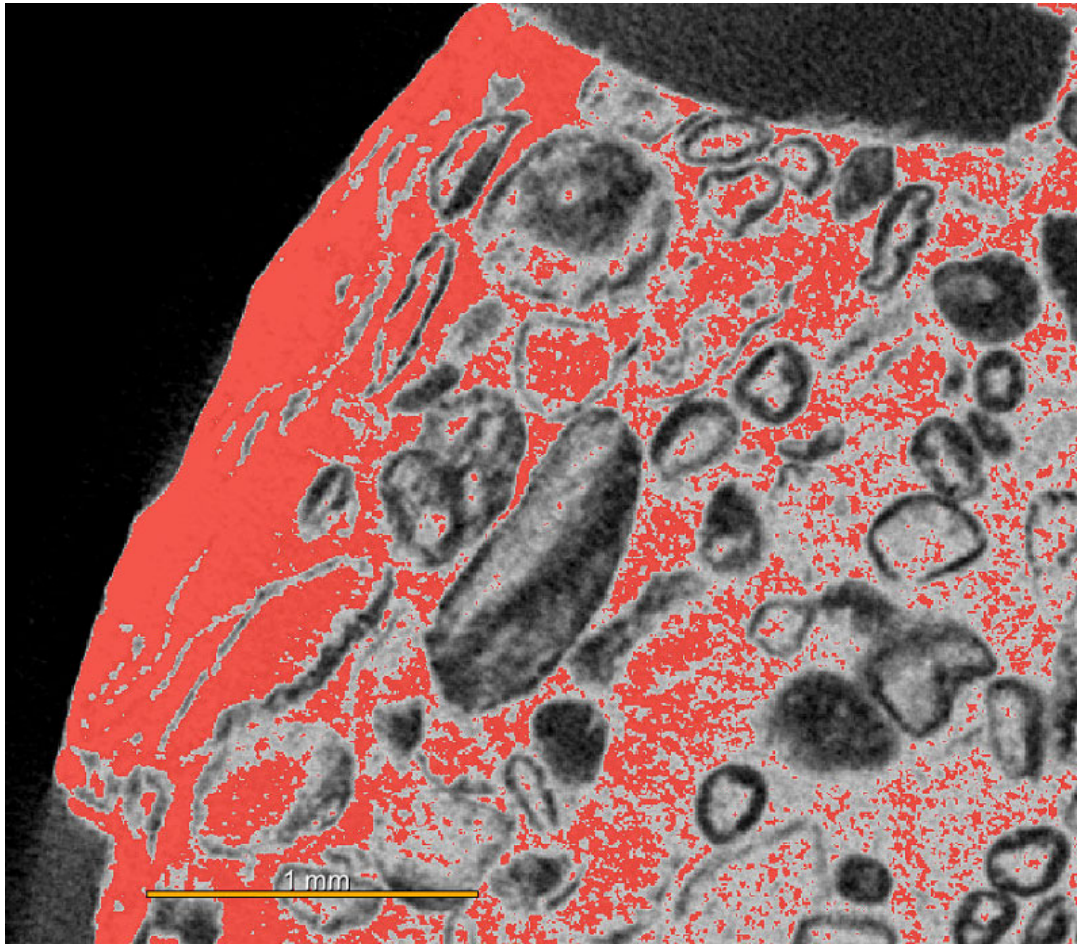
200
150
100
50
0
Distance from center



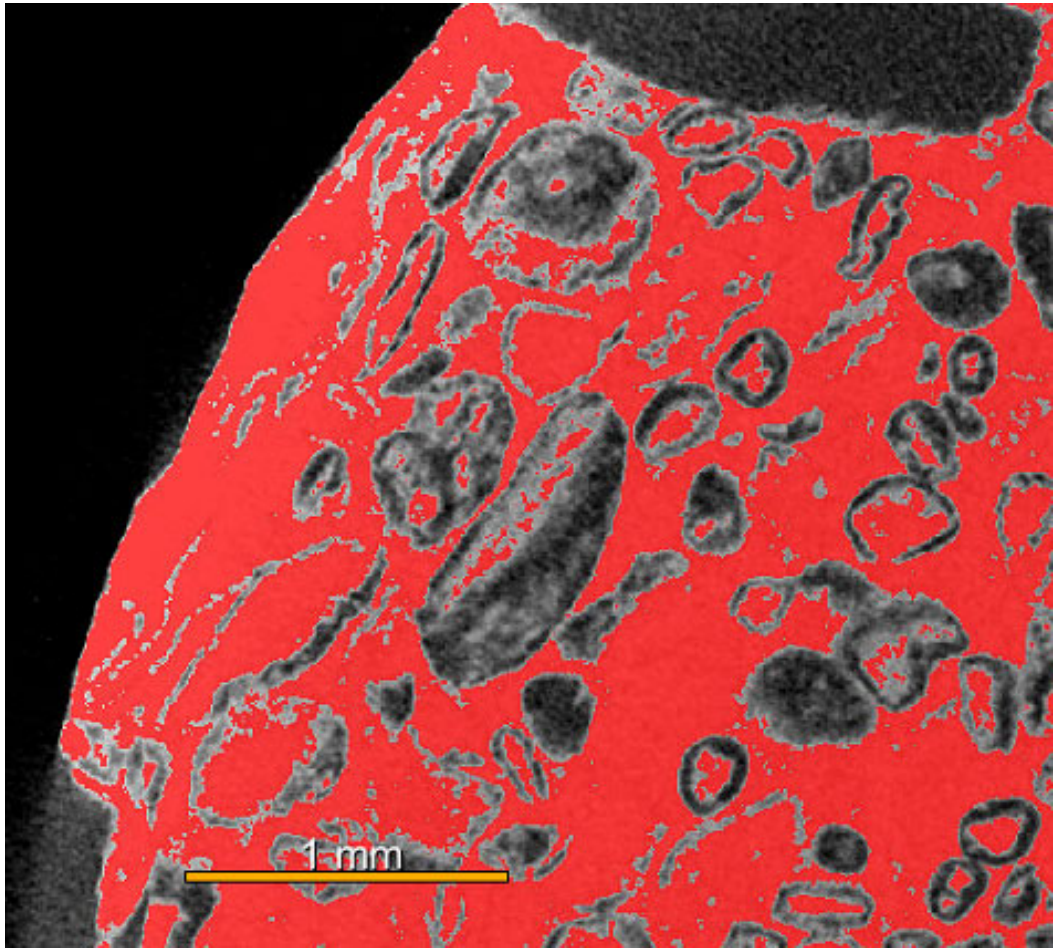



Original gray level
250
200
150
100
50
0
Distance from center

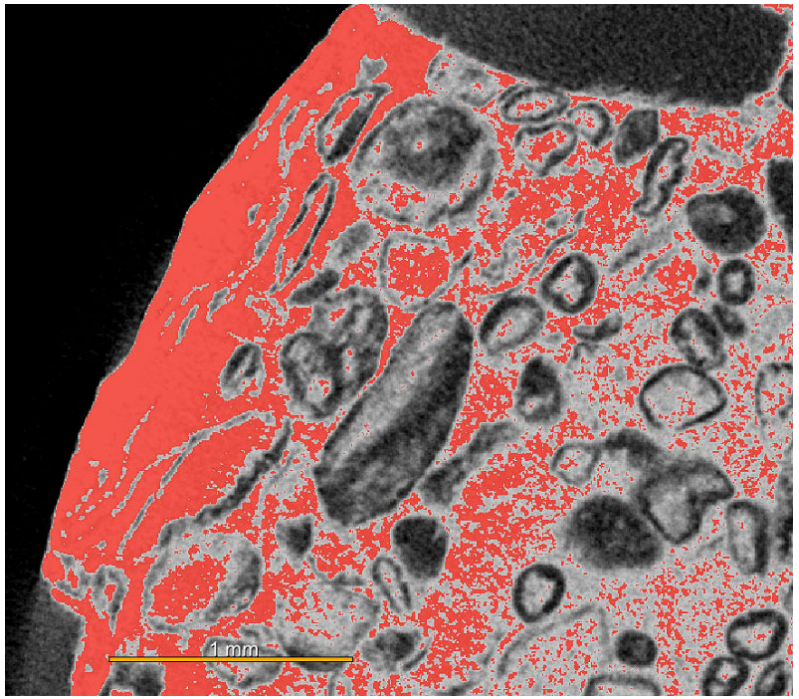




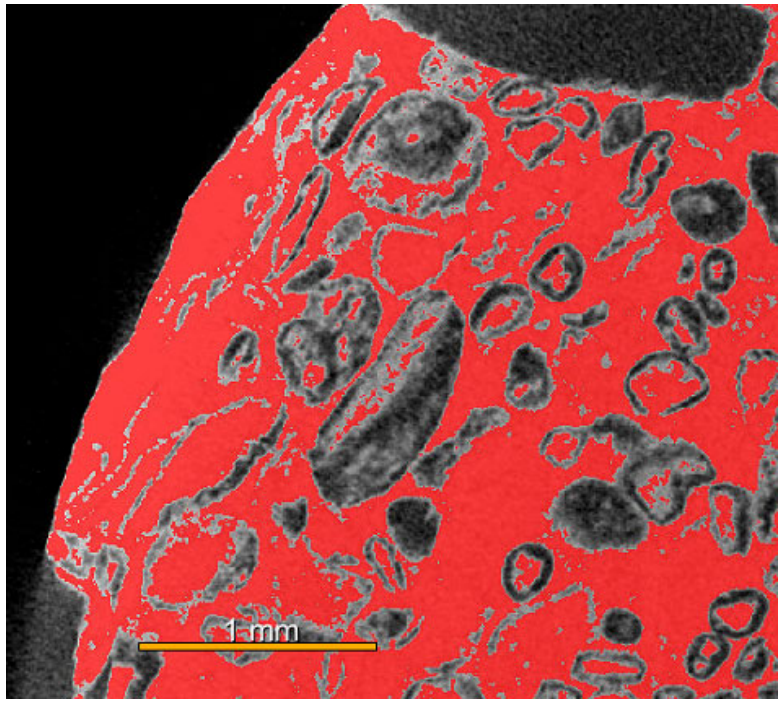
Thresholding
Original image only



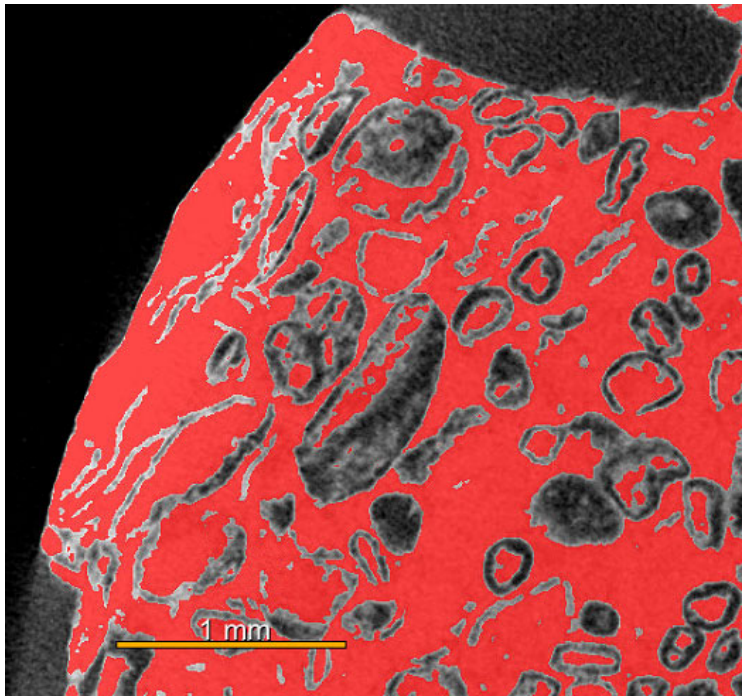
Histographic
Original + distance map



Thresholding

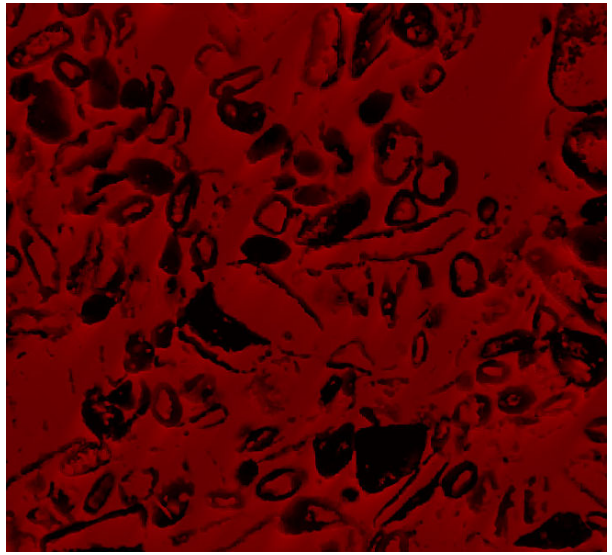


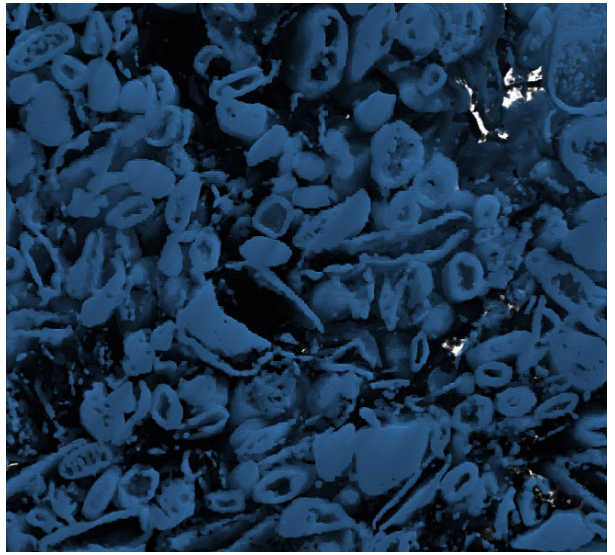
Histographic



Deep learning

Segmented solid volume → Void volume %





Thresholding
72.9 vol%

Histographic
34.9 vol%

Deep learning
34.7 vol%

WHICH IS THE BEST METHOD?

Histogram thresholding

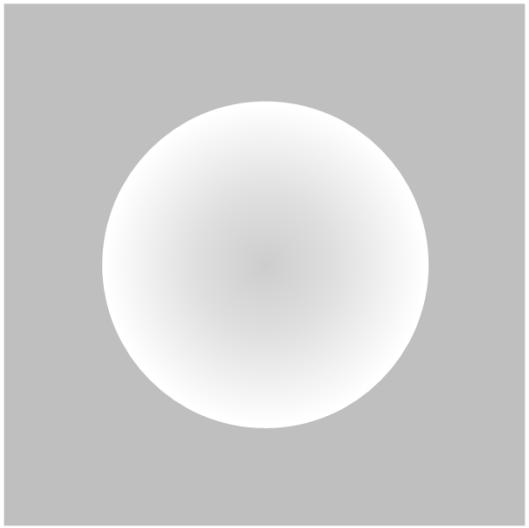
Histographic segmentation

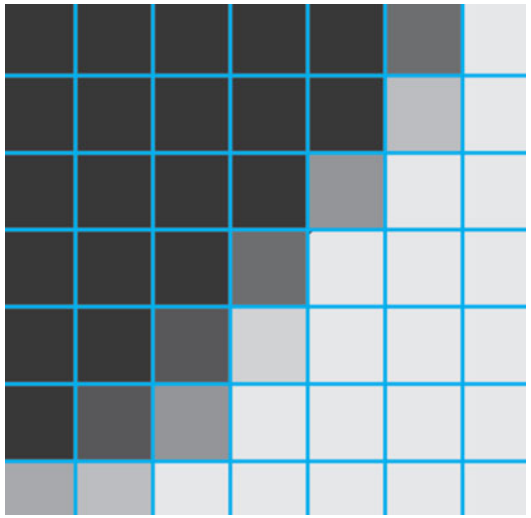
Binary
High-contrast

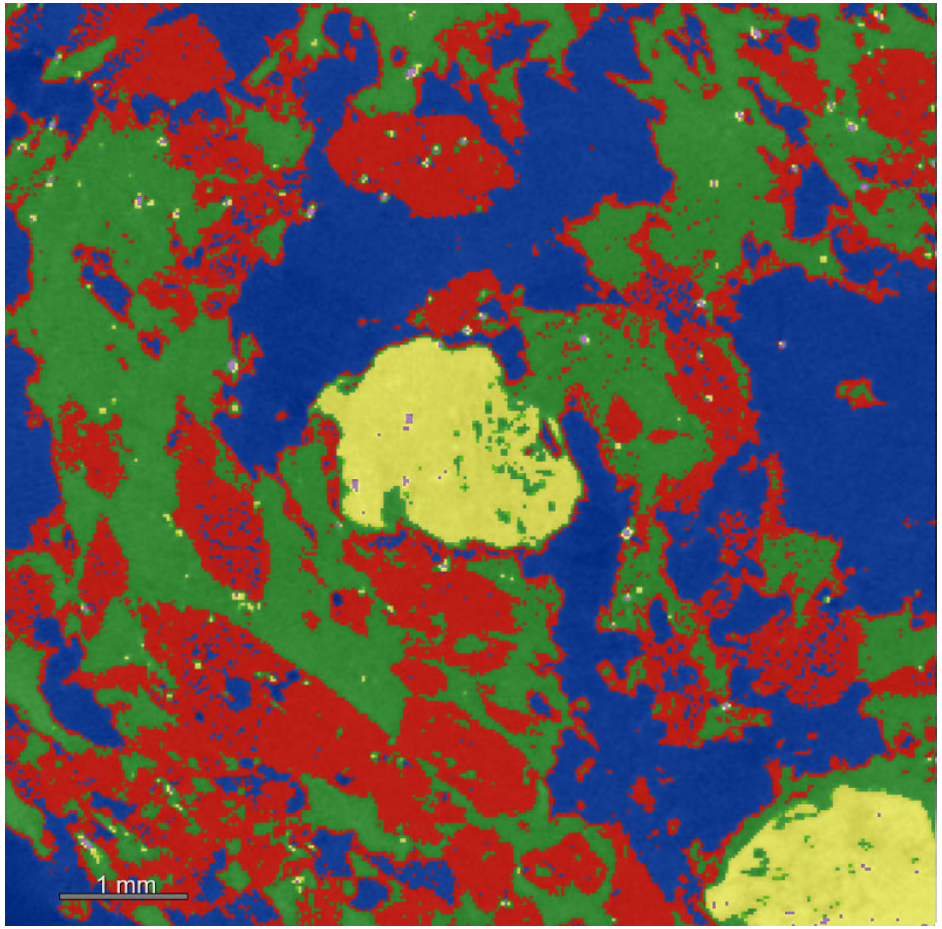
Machine/deep learning segmentation

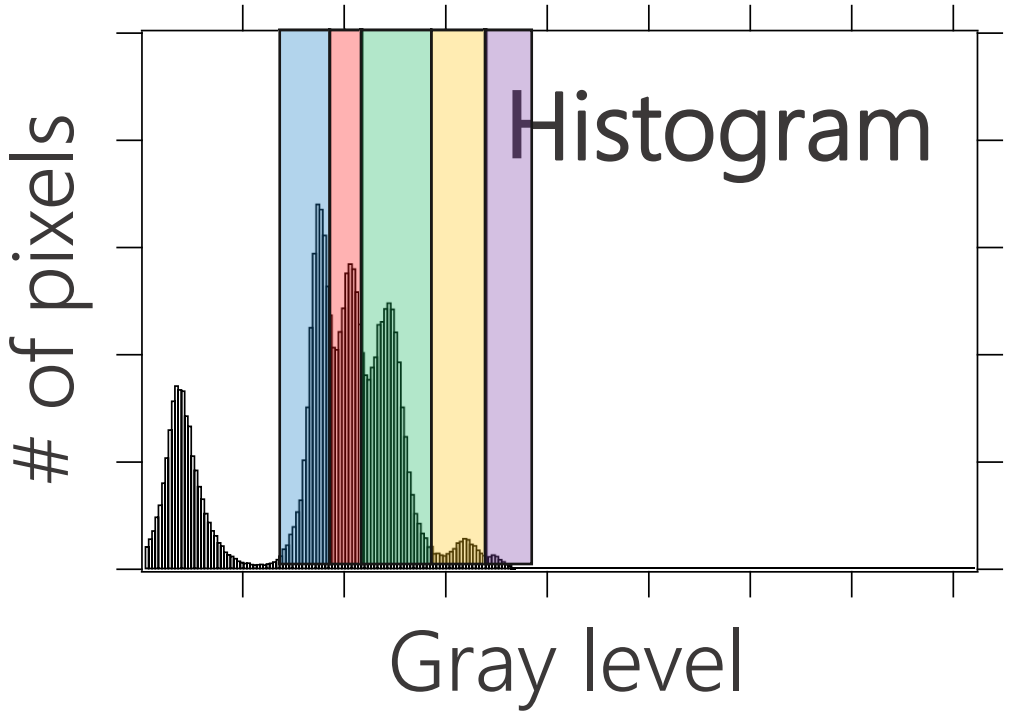
Beam hardening

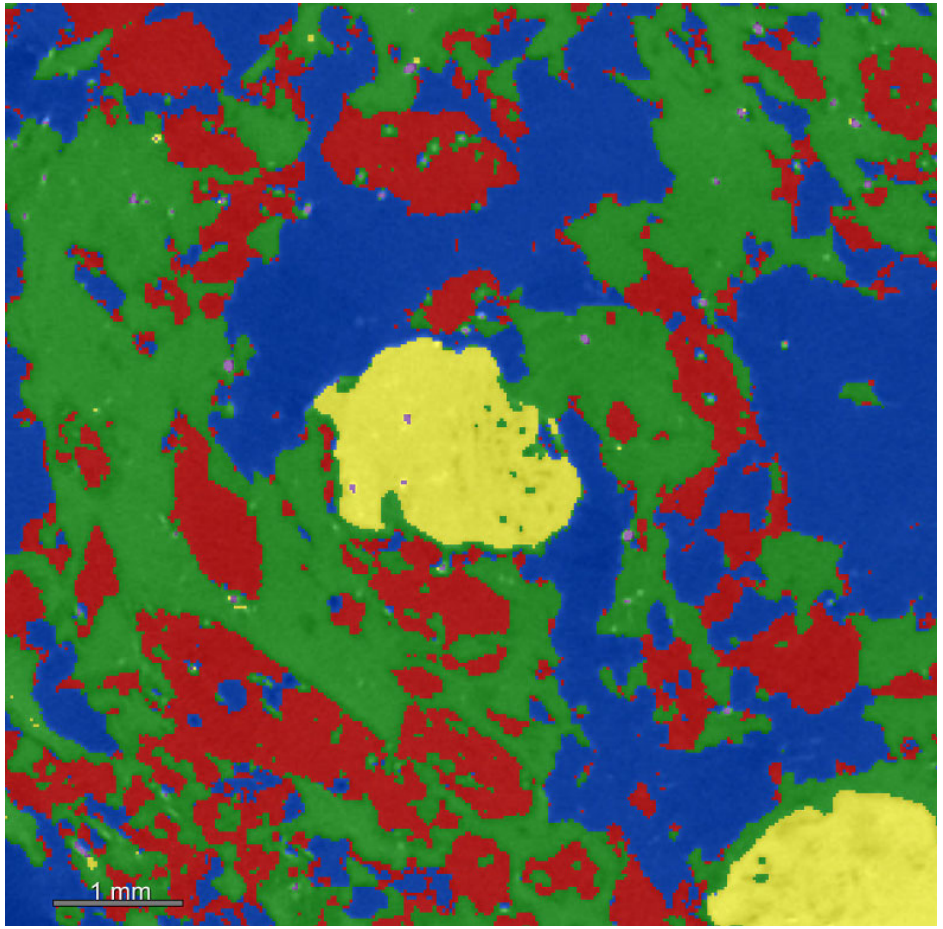
Partial volume effect

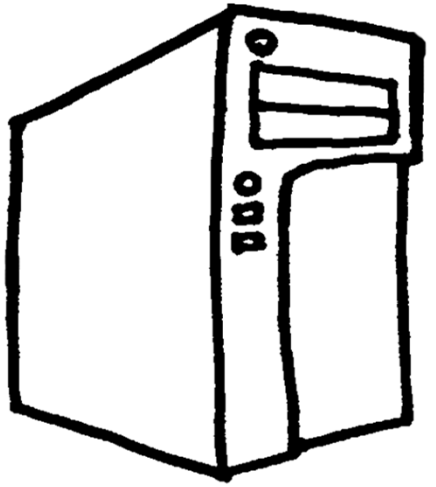




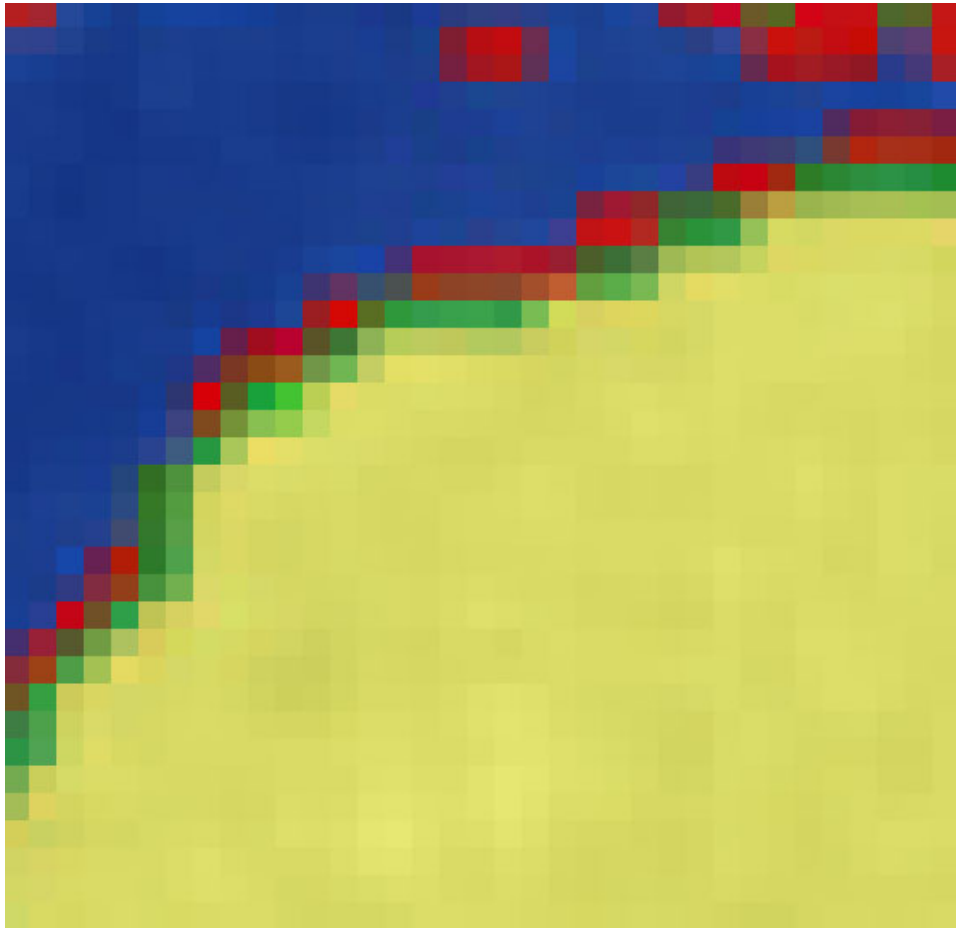

1 mm


Histogram
# of pixels
Gray level

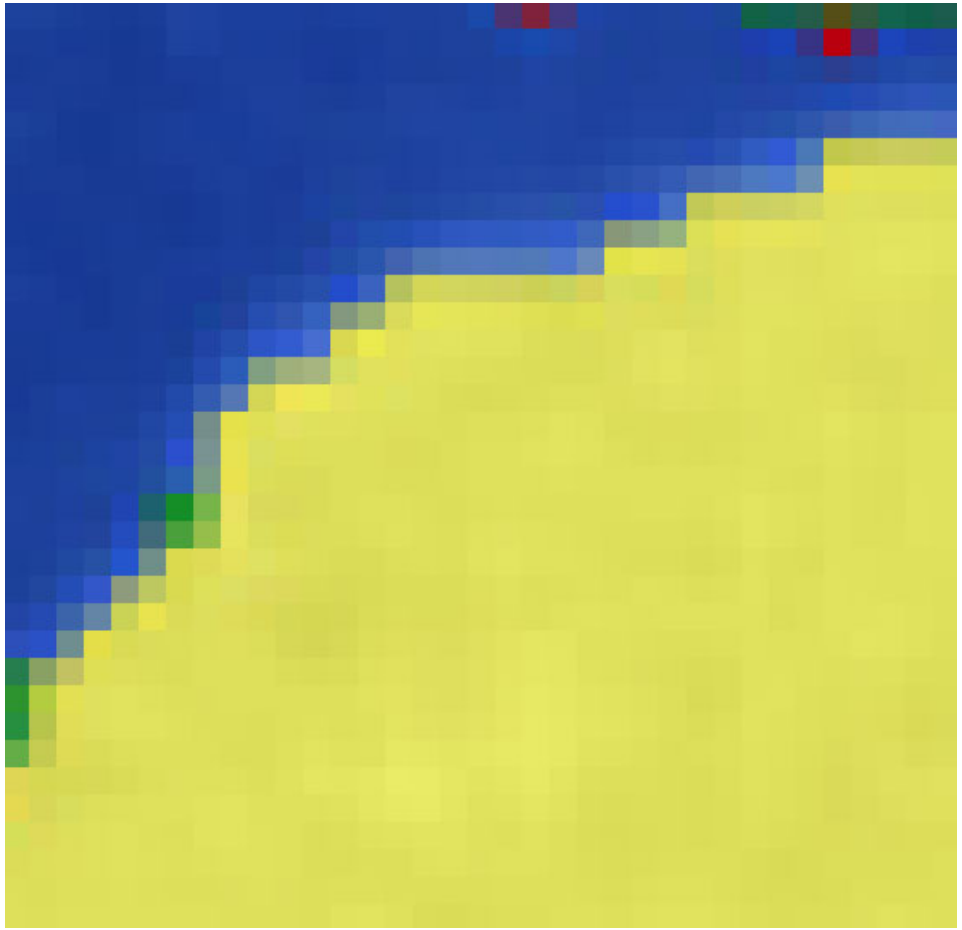




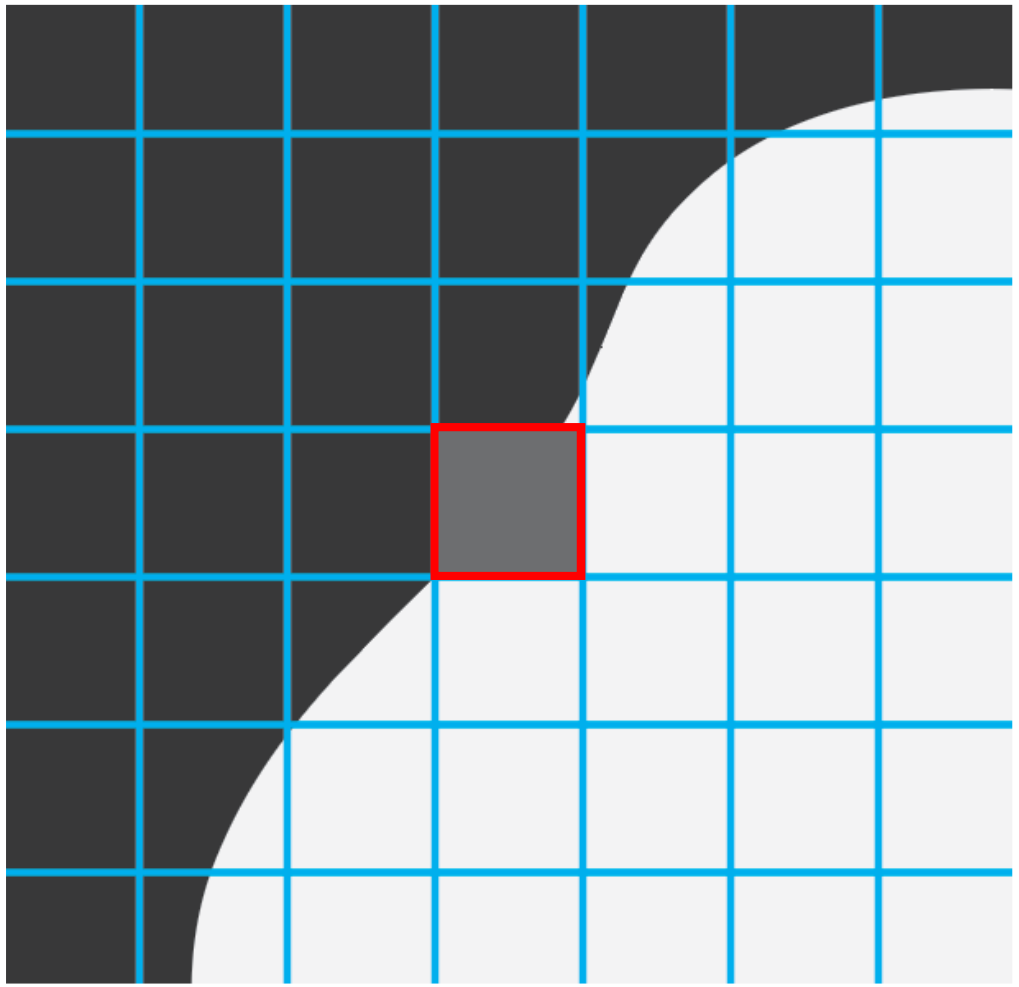
Machine learning
(Random Forest)

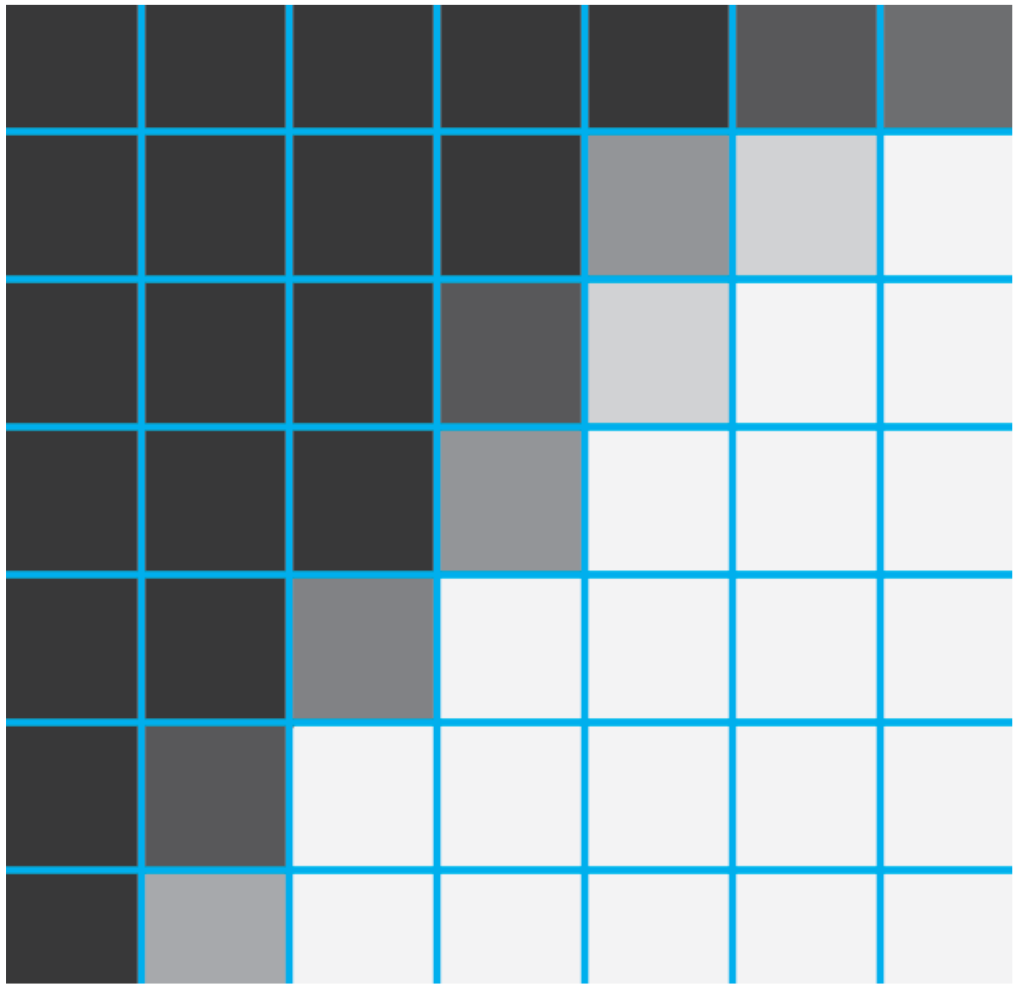


Histogram threshold

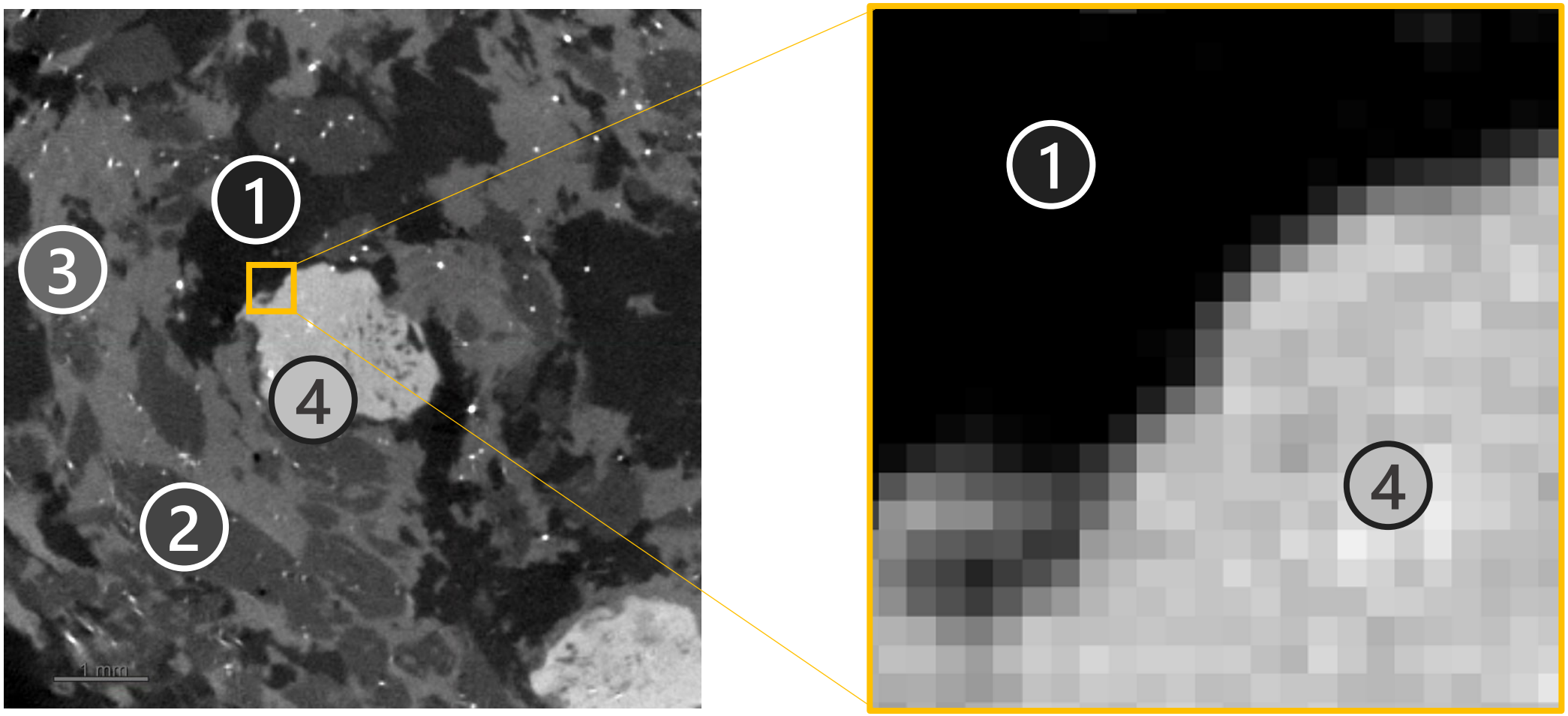


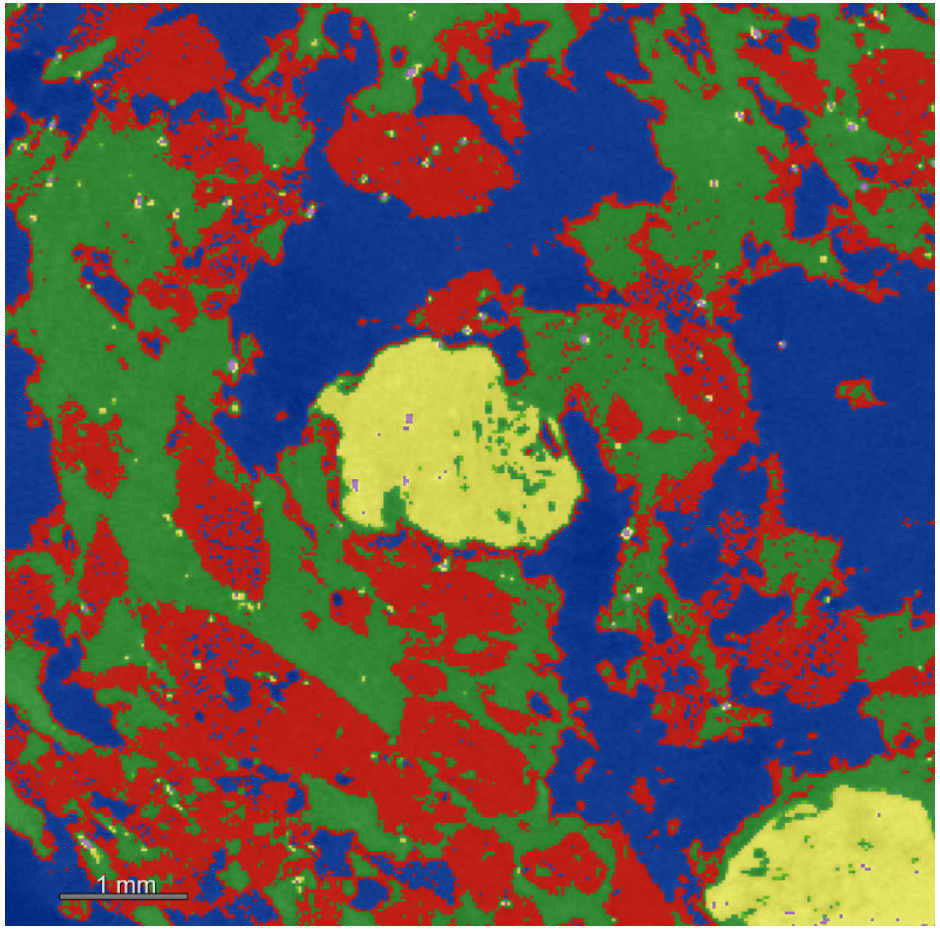
Machine learning



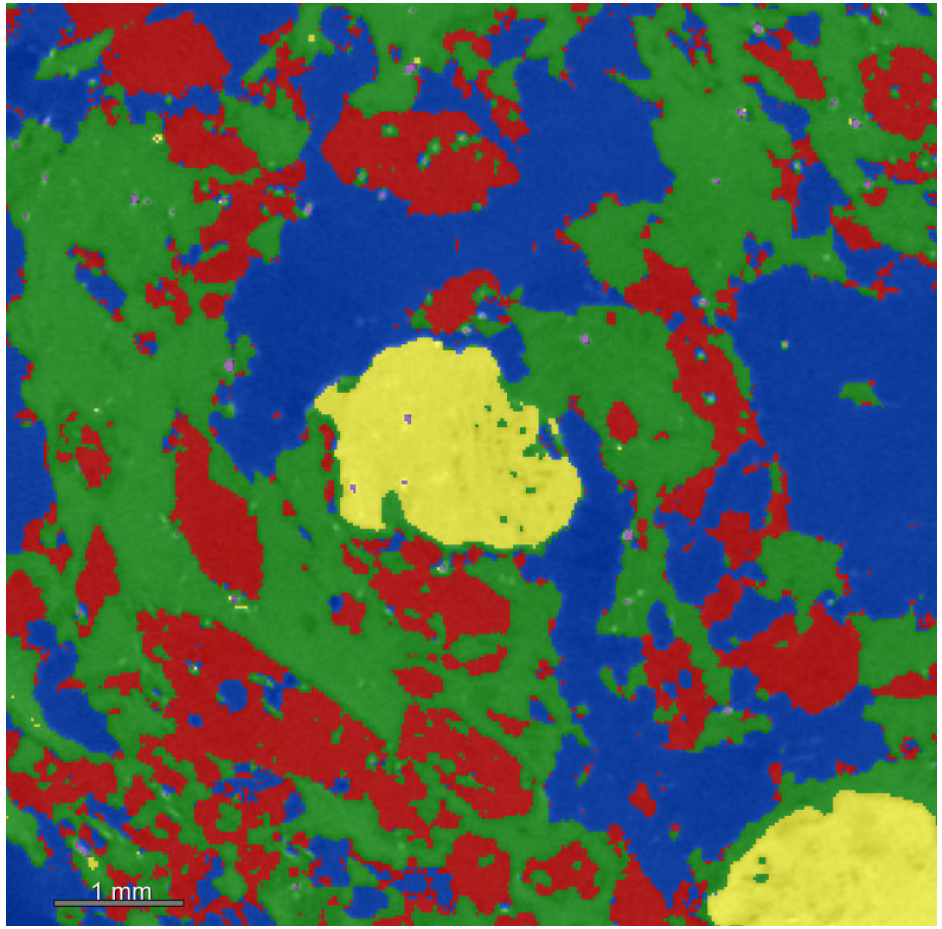


Partial volume effect


1
3
4
2
1 mm
1
4

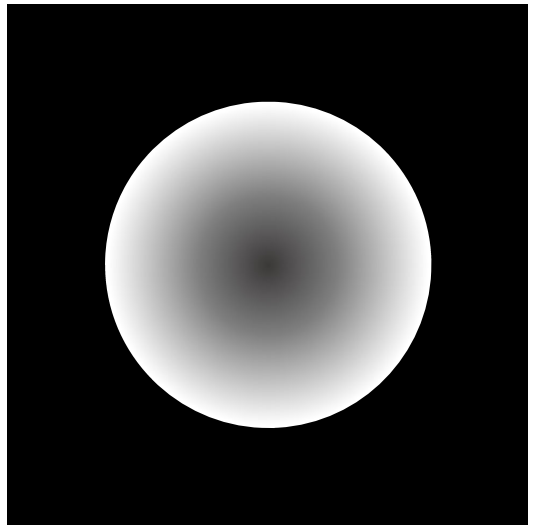


Histogram threshold

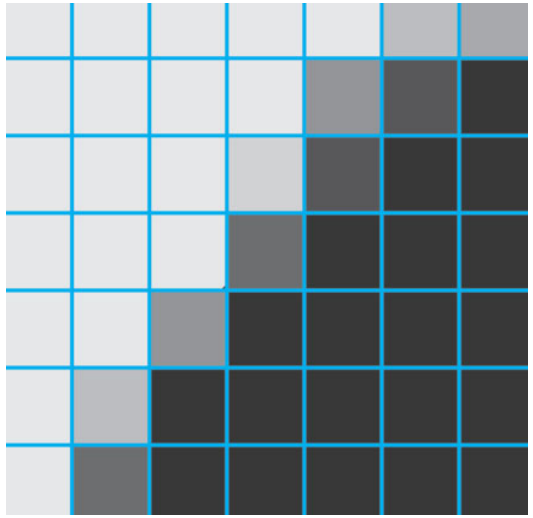


Machine learning

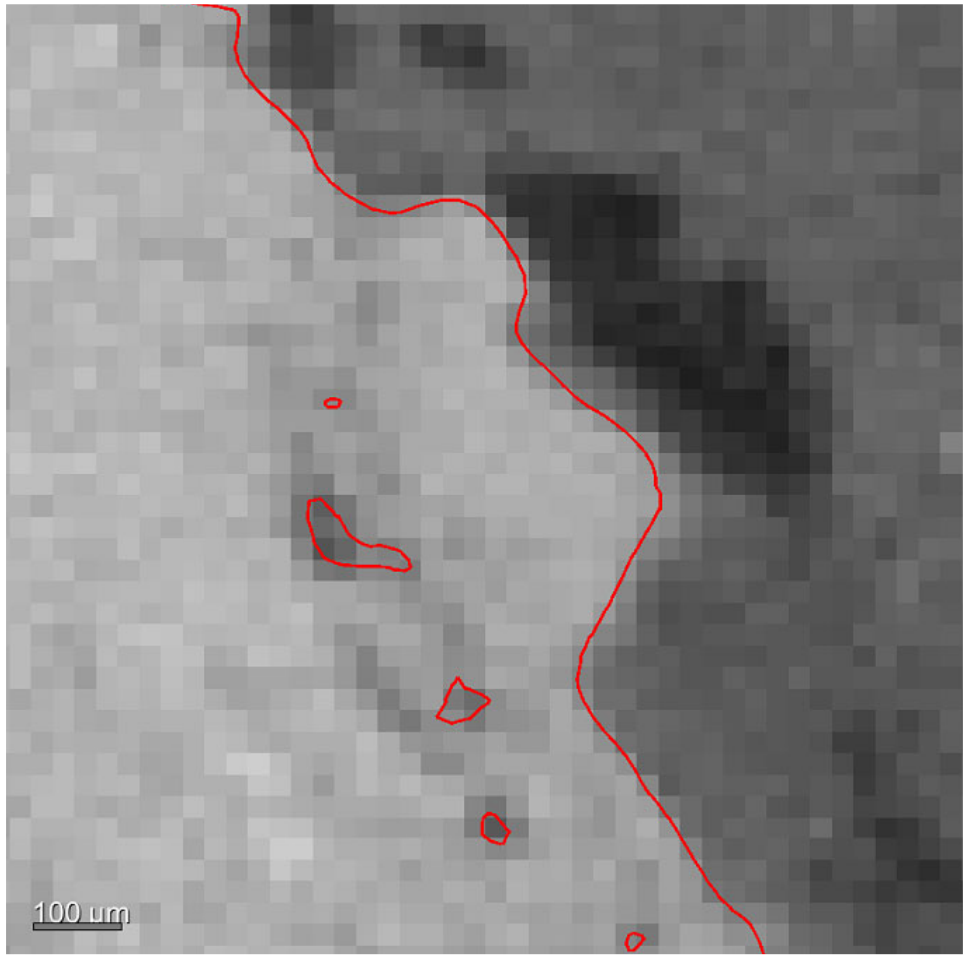
Beam hardening

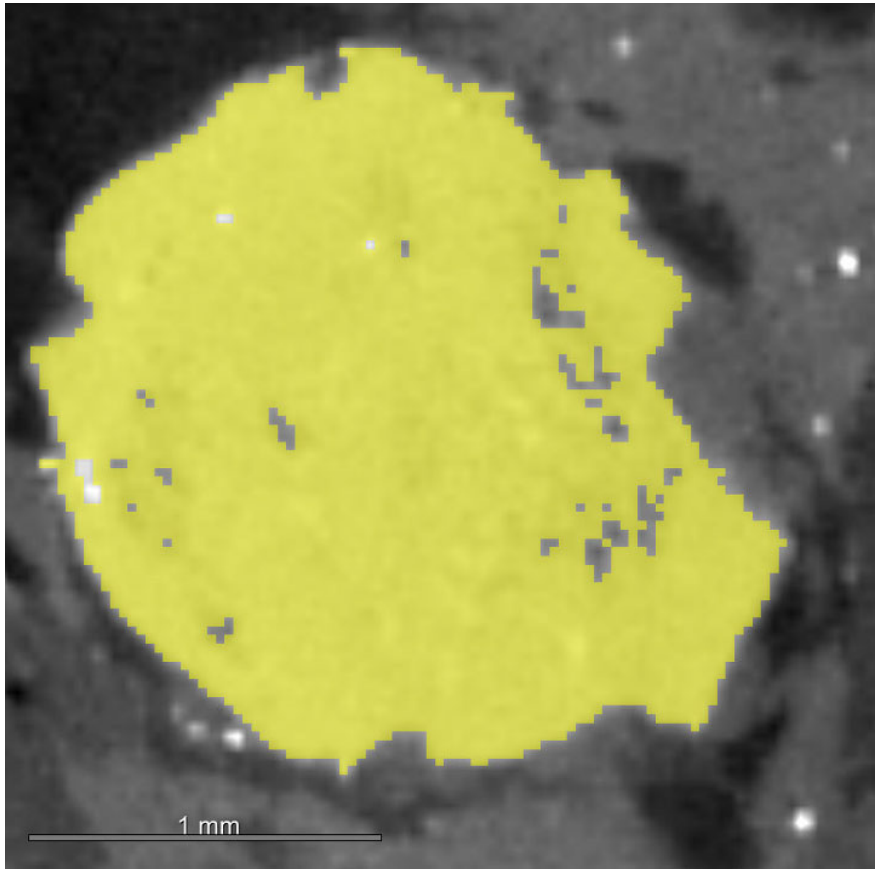


Partial volume effect

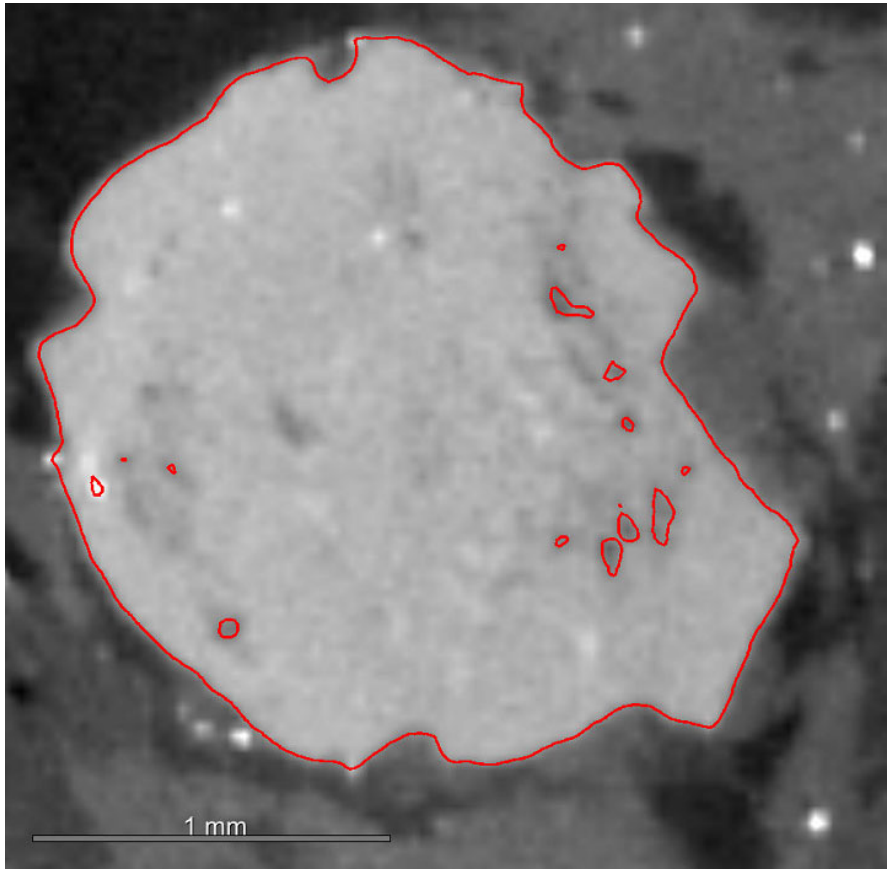


WHAT IF WE CARE ABOUT THE SHAPE?

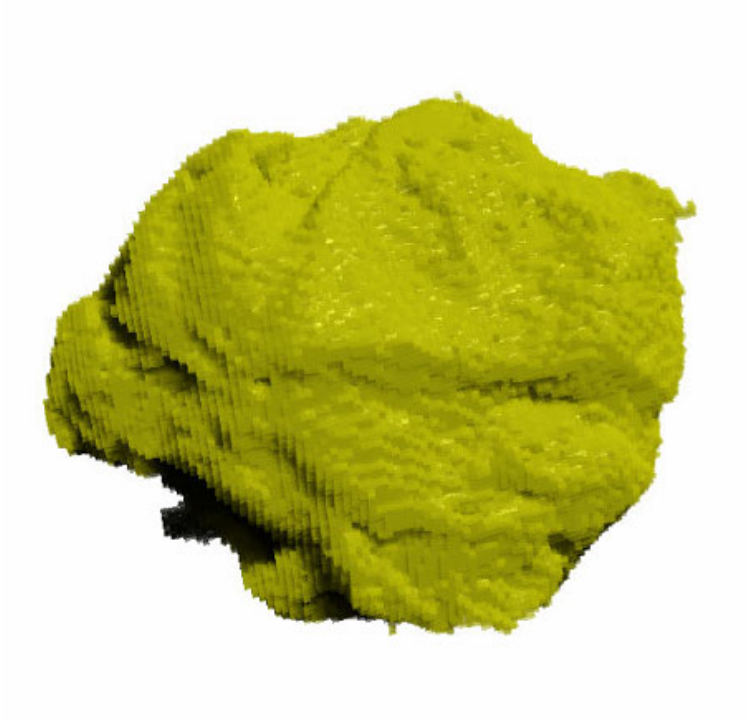

100 um



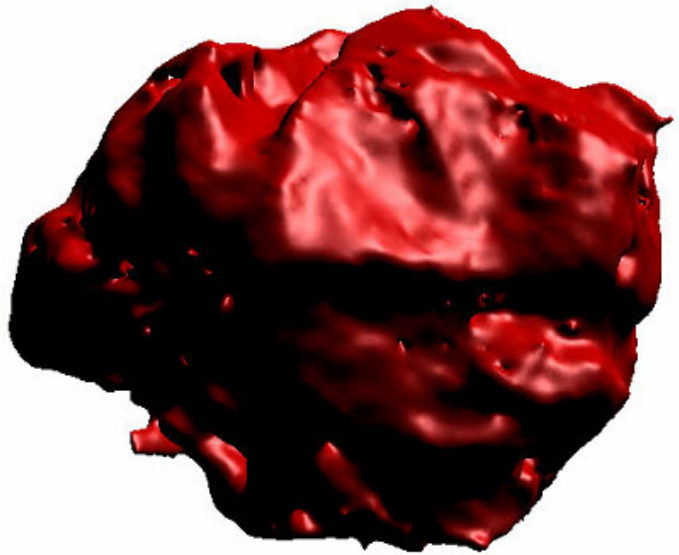
Pixel segmentation



Surface mesh



Pixel segmentation



Surface mesh

Resolution & FOV

Contrast

Analysis purpose

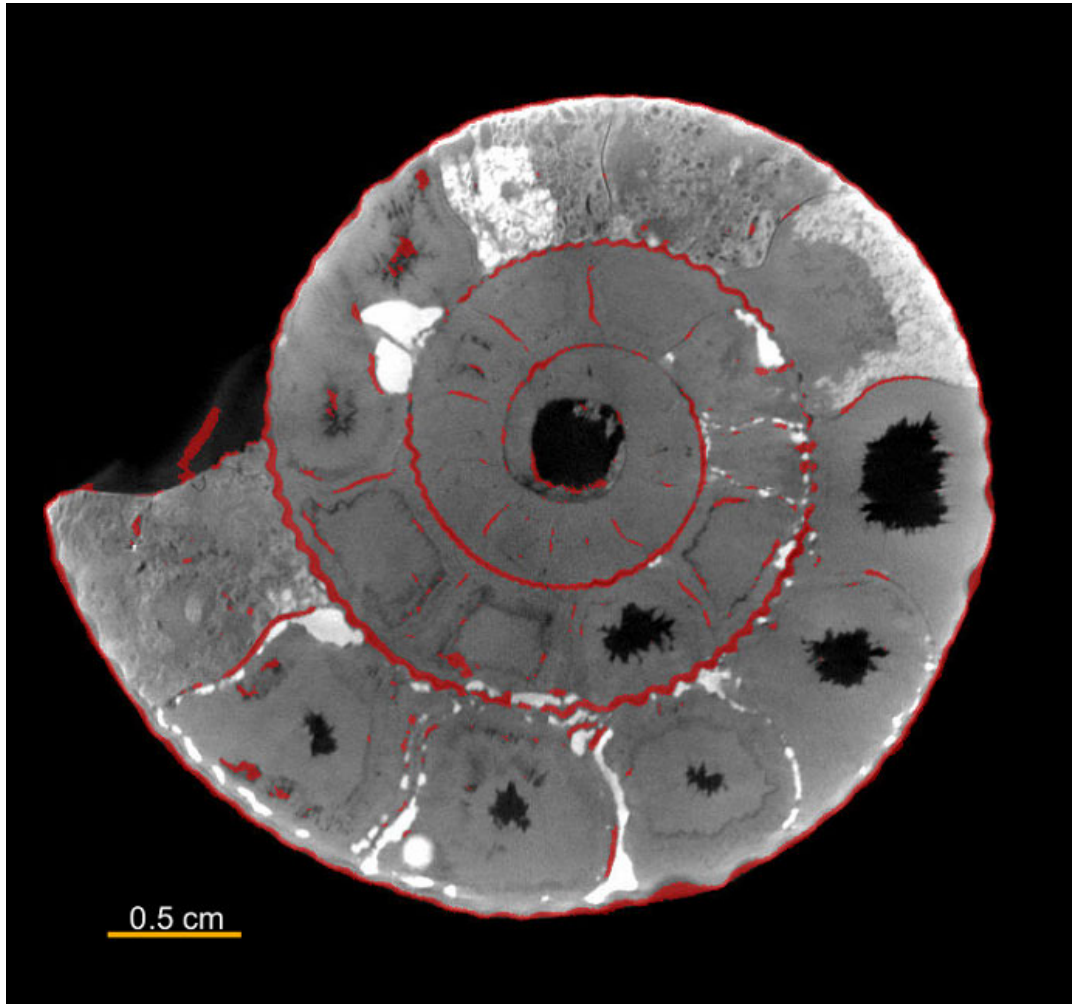
WHAT CAN WE DO WITH CT FOR GEOLOGICAL SAMPLES?

GEOLOGY APPLICATIONS

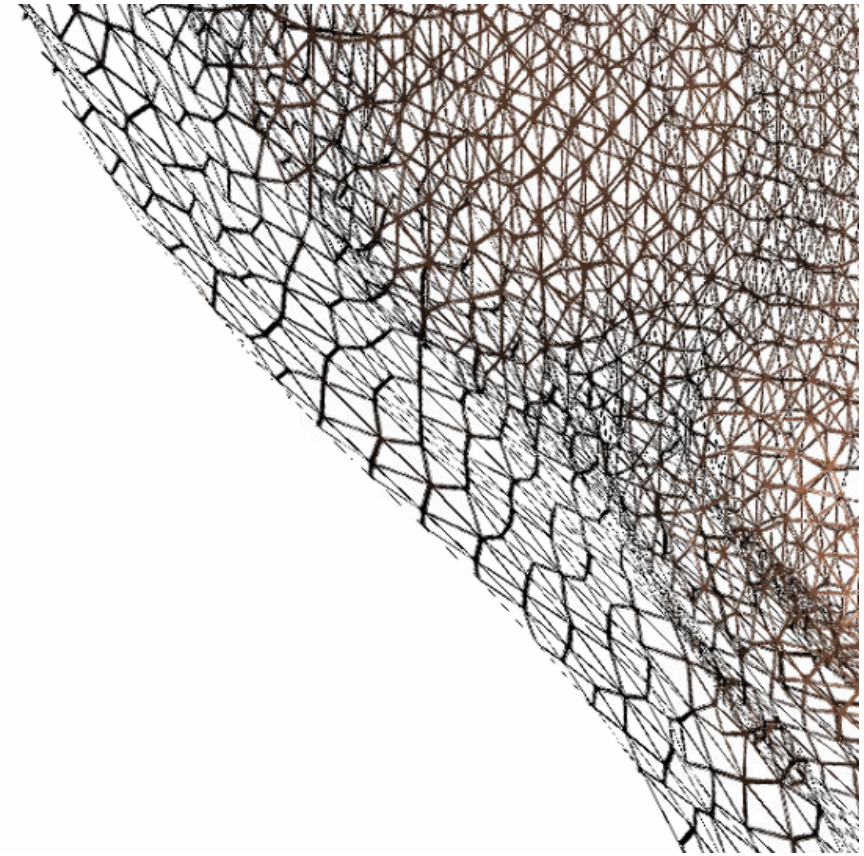
- Pore structures
- Cracks and fractures
- Phase textures
- Grain size
- Formation process
- Weathering process
- Meteorites imaging
- Fossils imaging

WHAT CAN WE DO WITH A FOSSIL?

Ammonite fossil



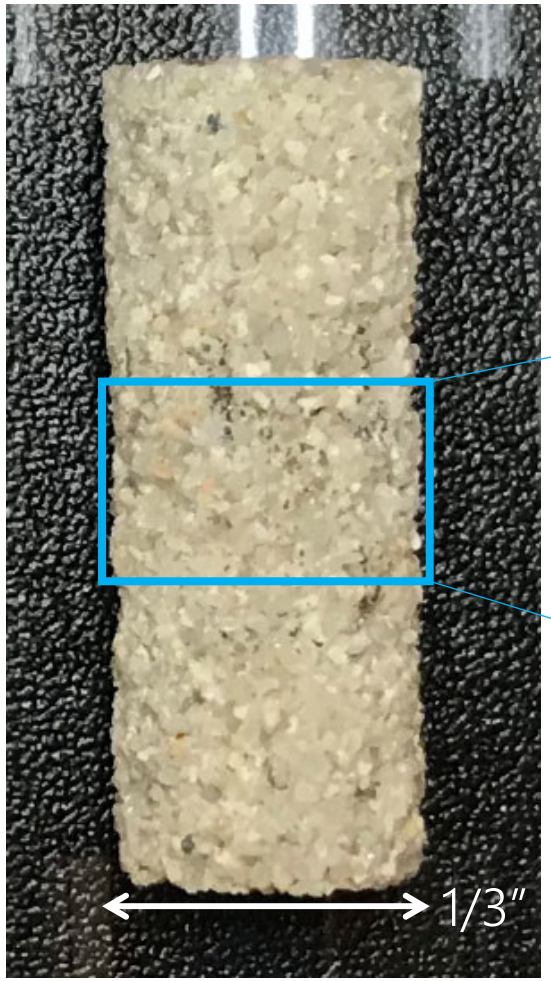
Isolated shell

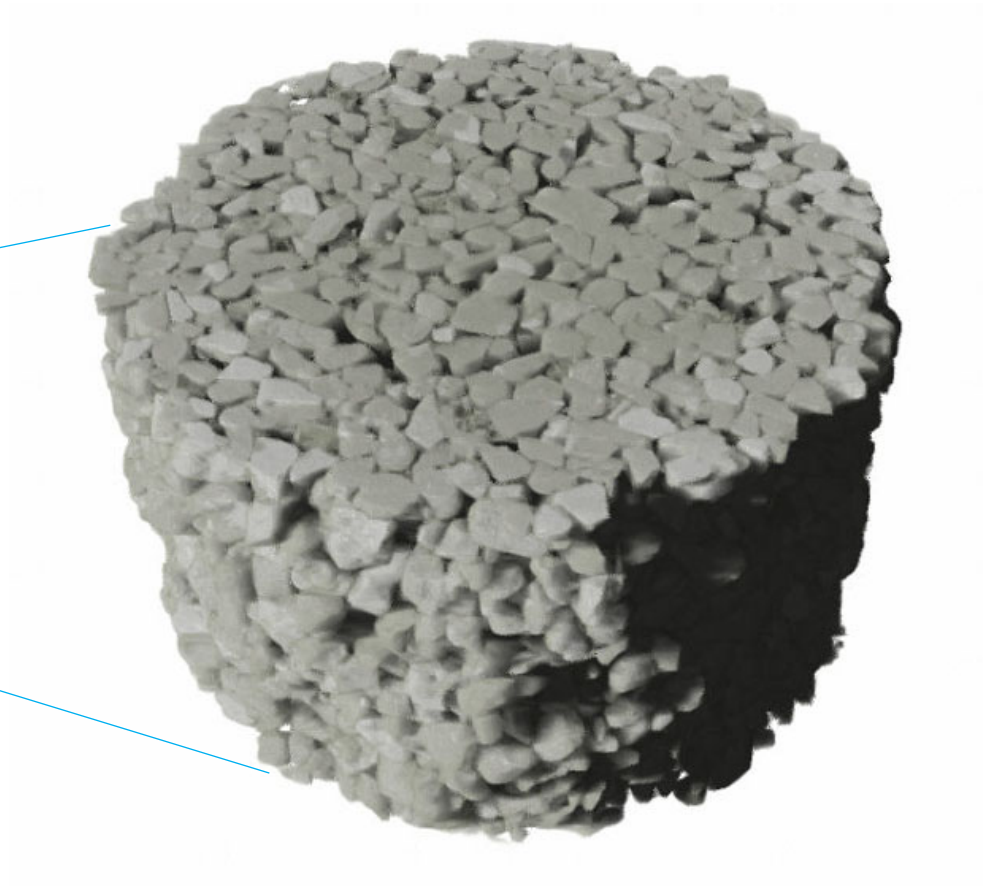


Surface mesh

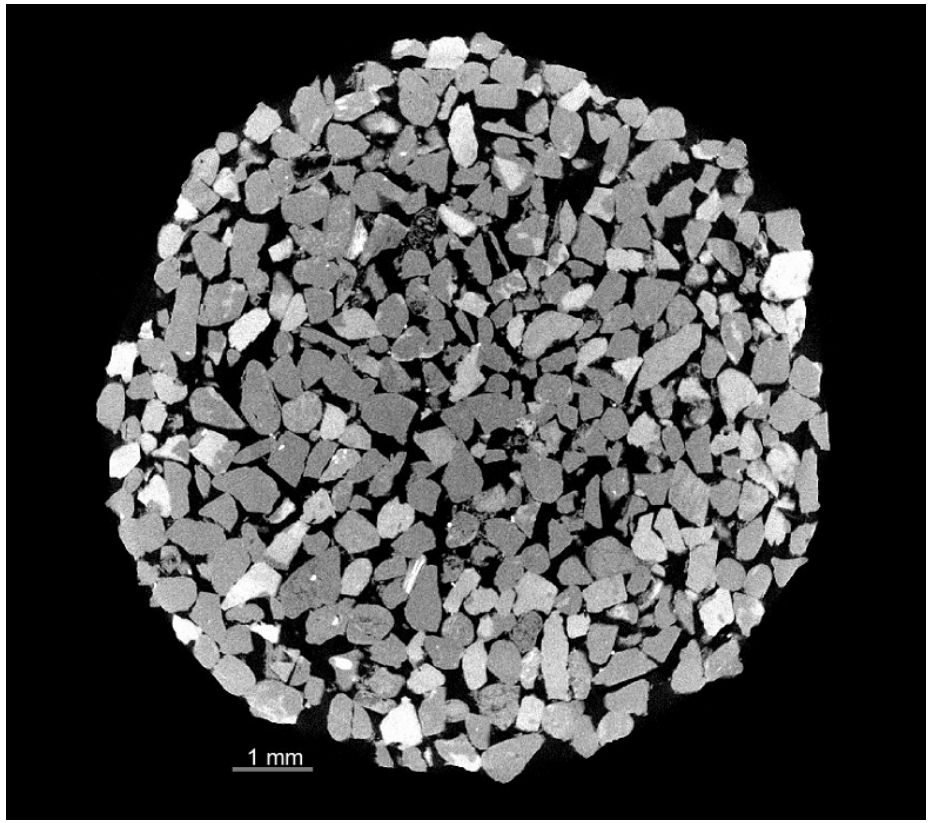
CAN WE QUANTIFY VOIDS IN ROCKS?

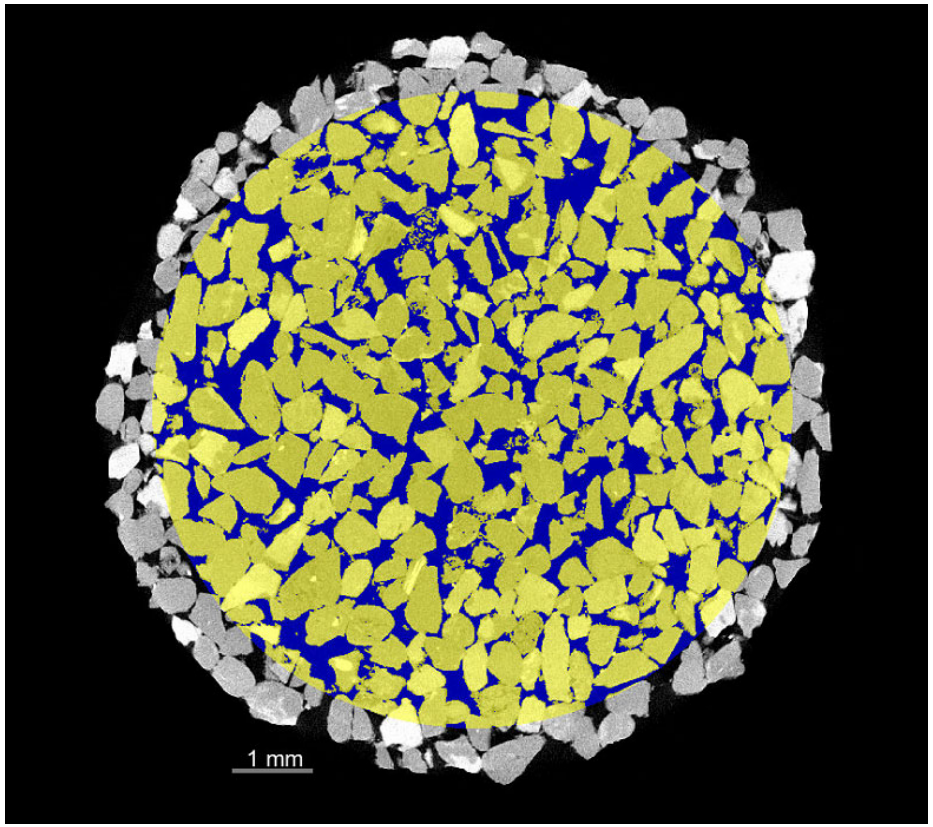
Sand stone





Sand stone

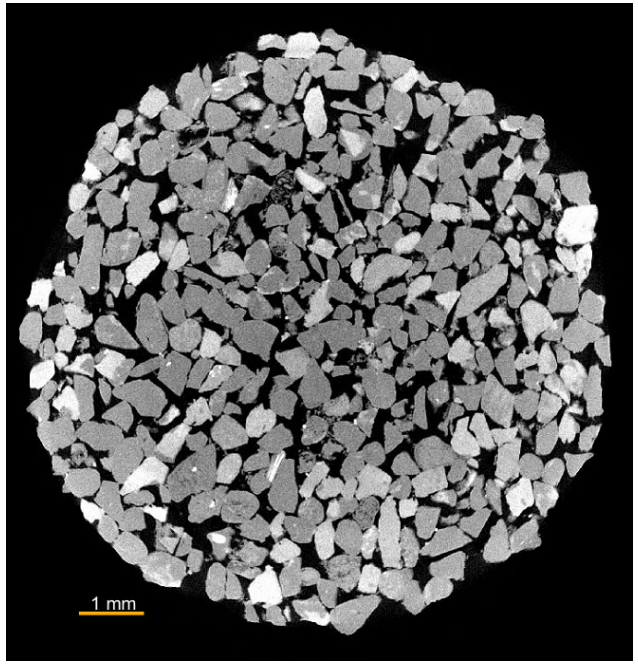




Voids: 22.9 vol%

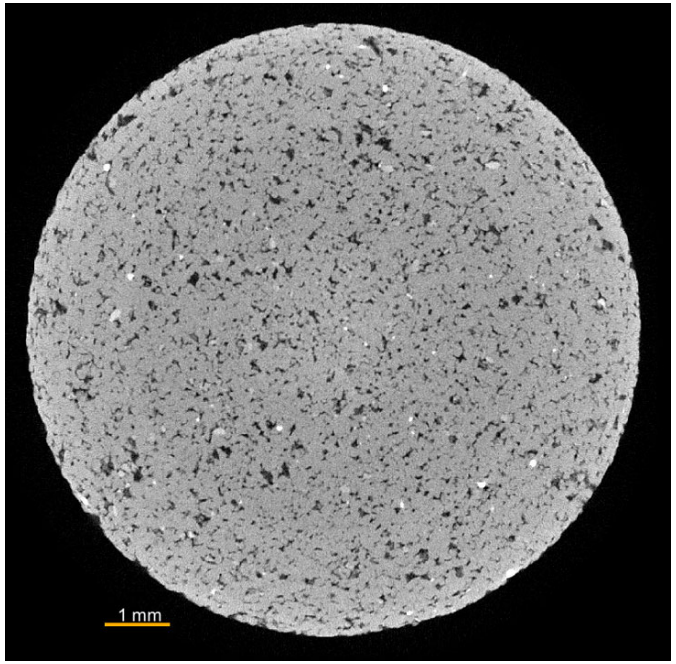
Sandstones void %

Idaho gray



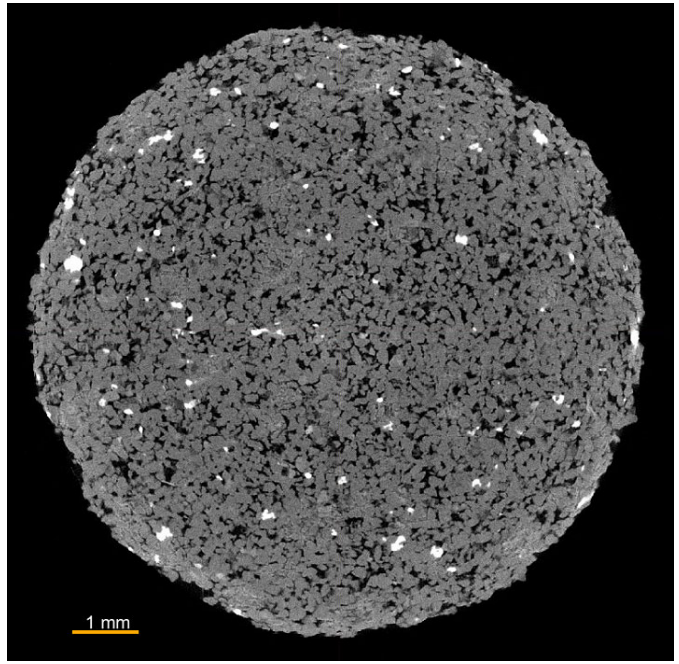
22.9 vol%

Crab orchard



9.0 vol%

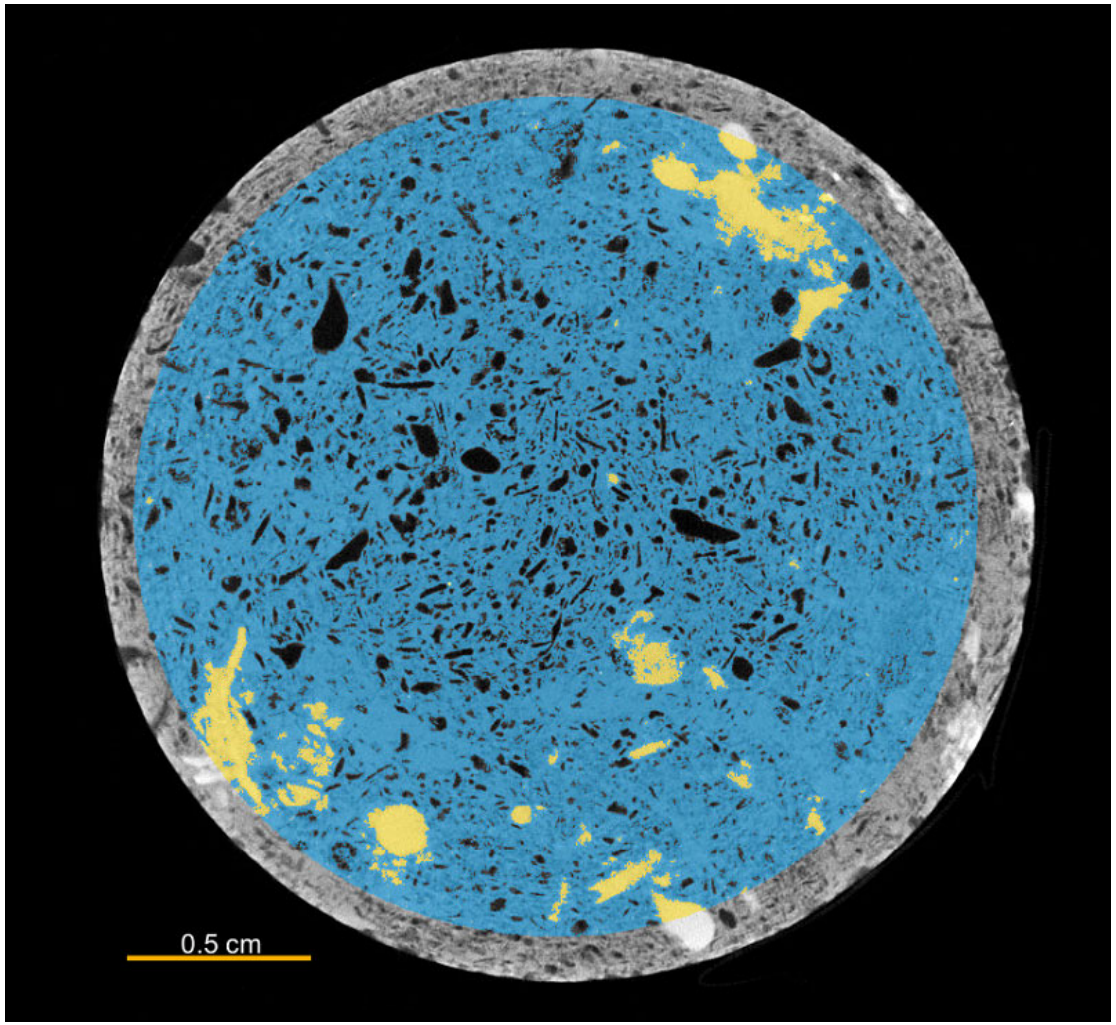
Liver rock



9.7 vol%

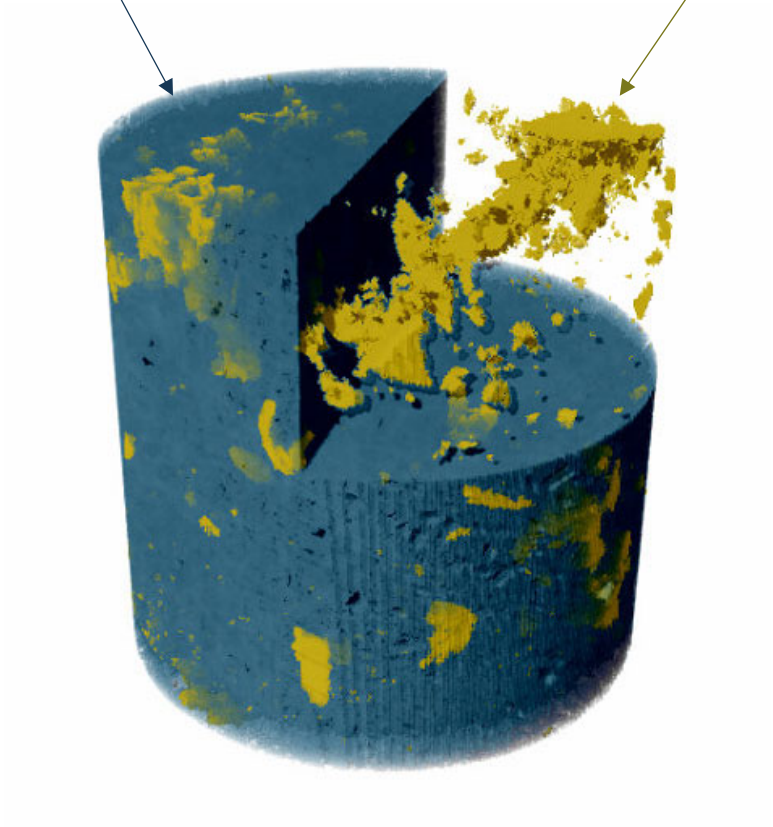
WHAT ABOUT DIFFERENT PHASES?

Carbonate

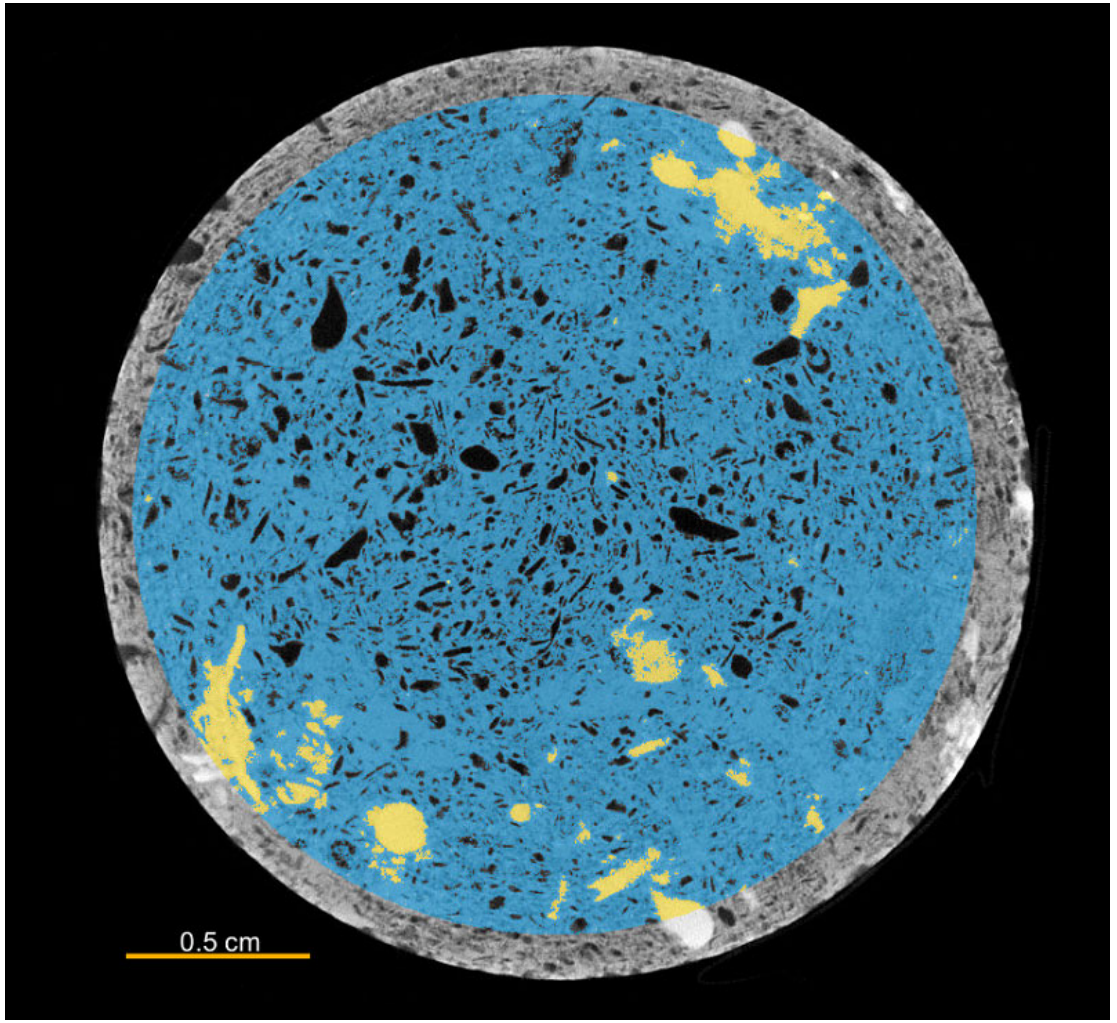


80.6 vol%

17.4 vol%

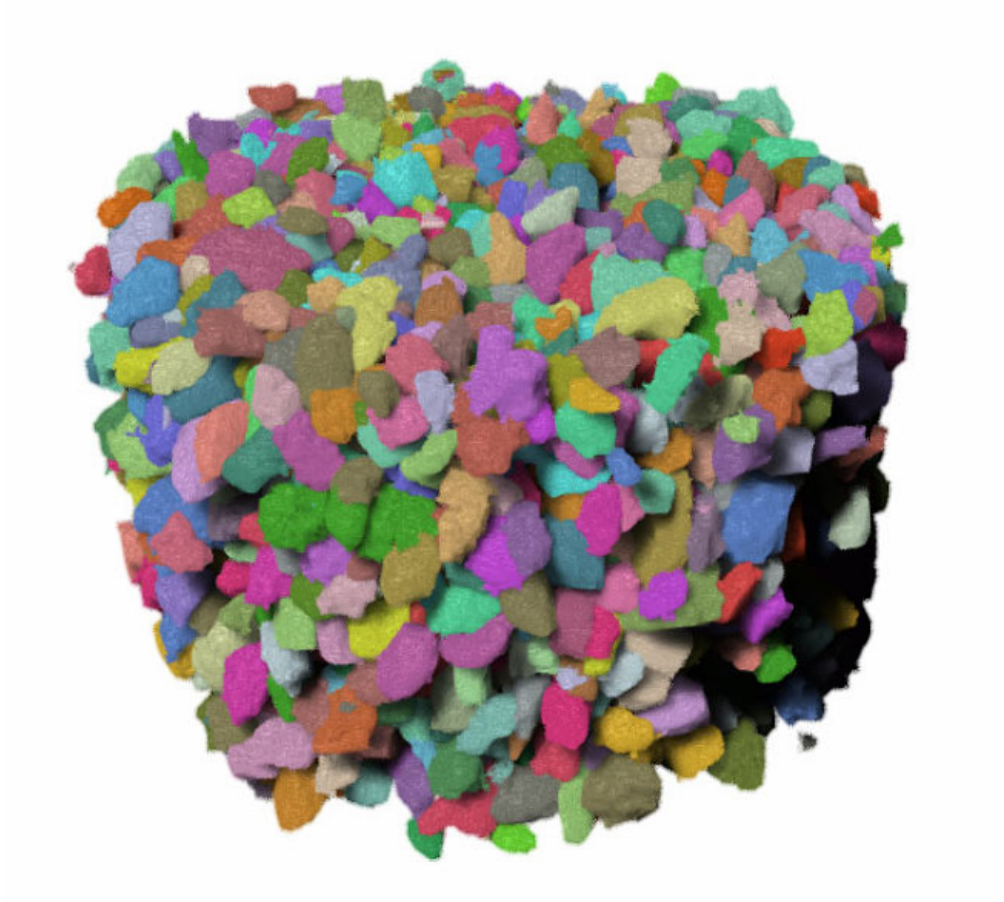


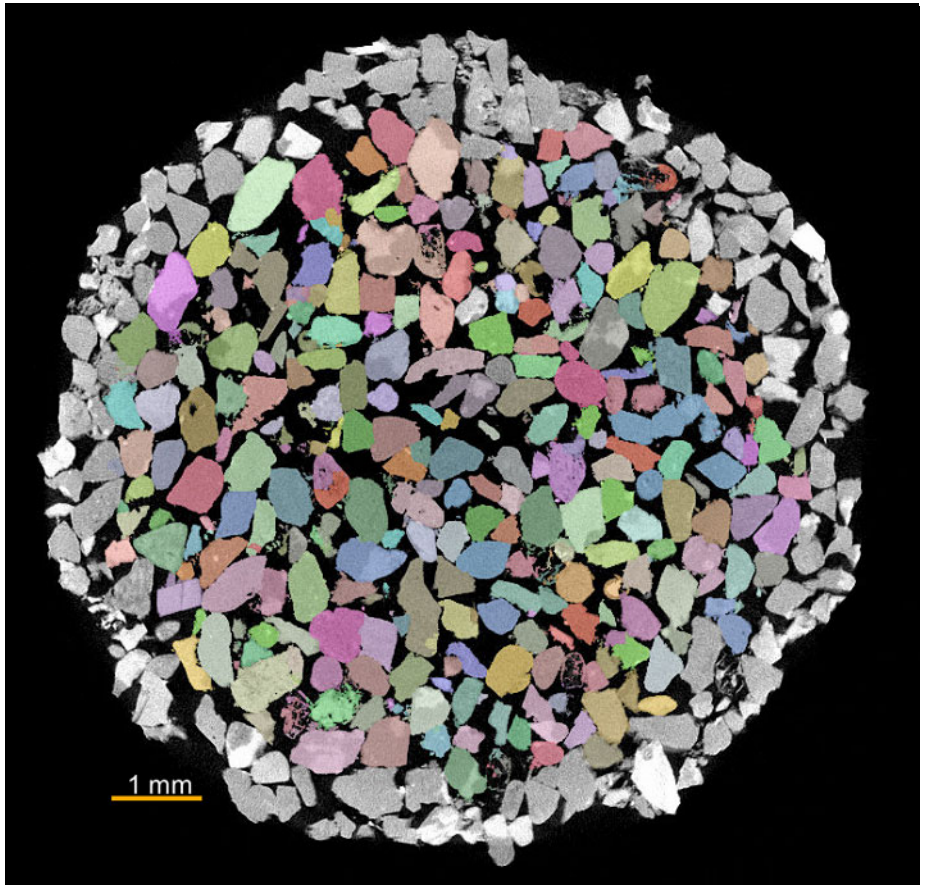
Voids 2.0 vol%



WHAT ABOUT GRAIN SIZE?

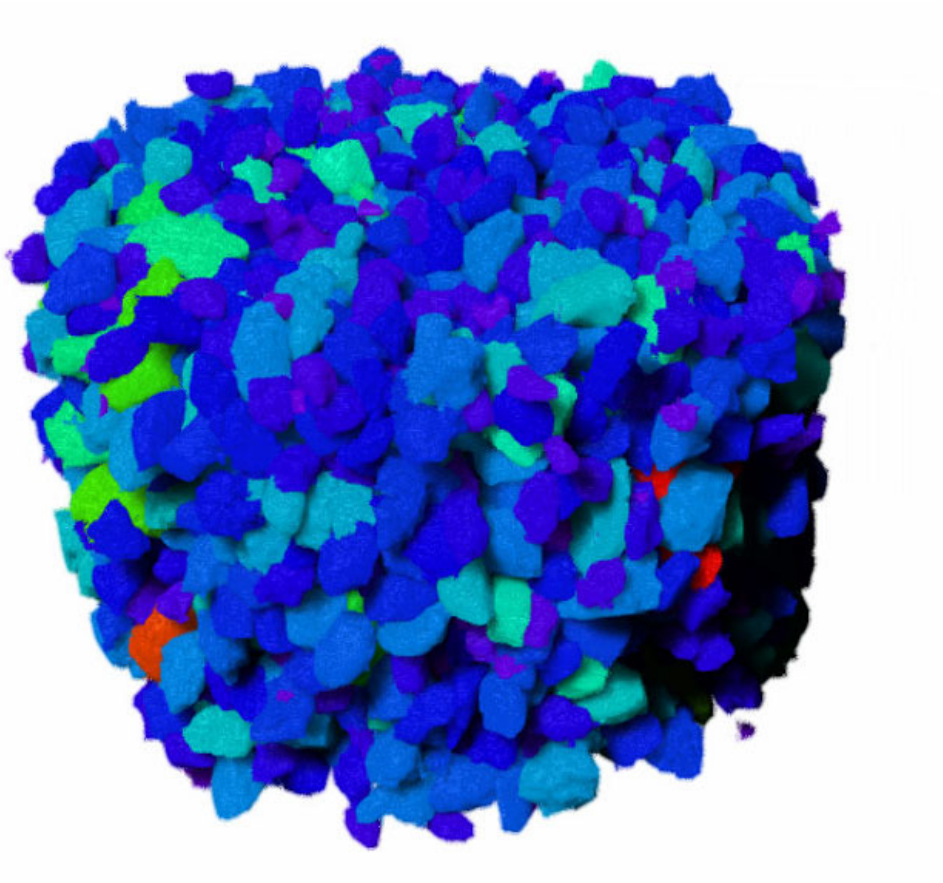
Sandstone

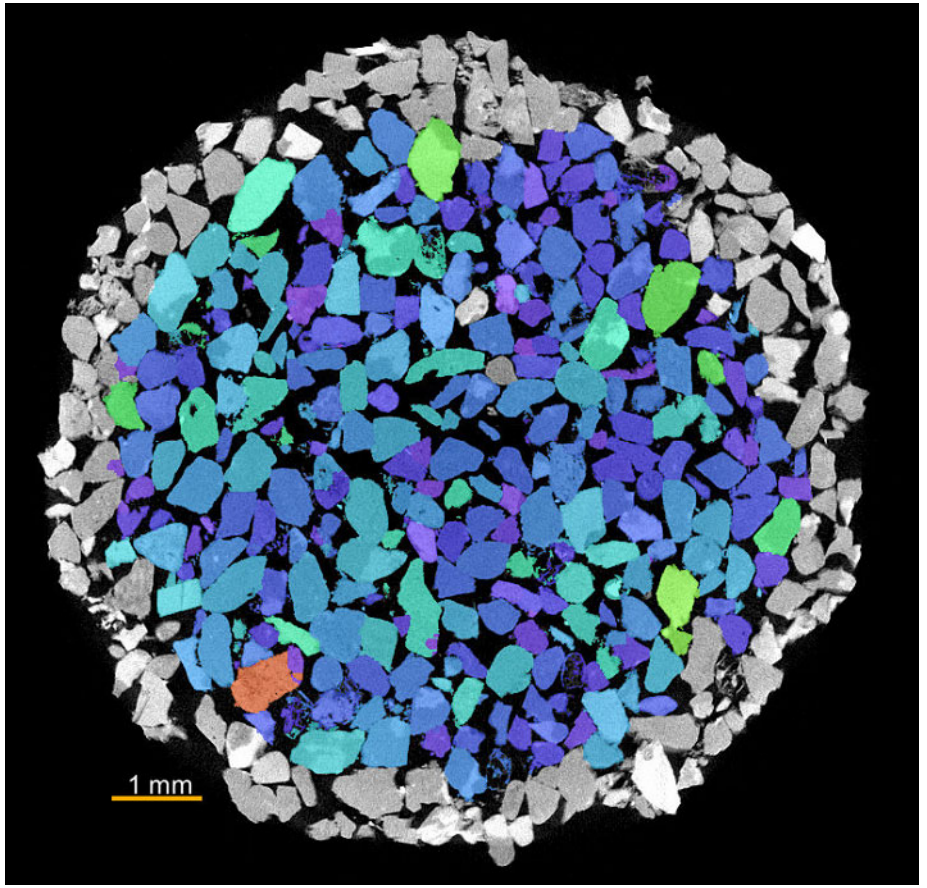




Object separation

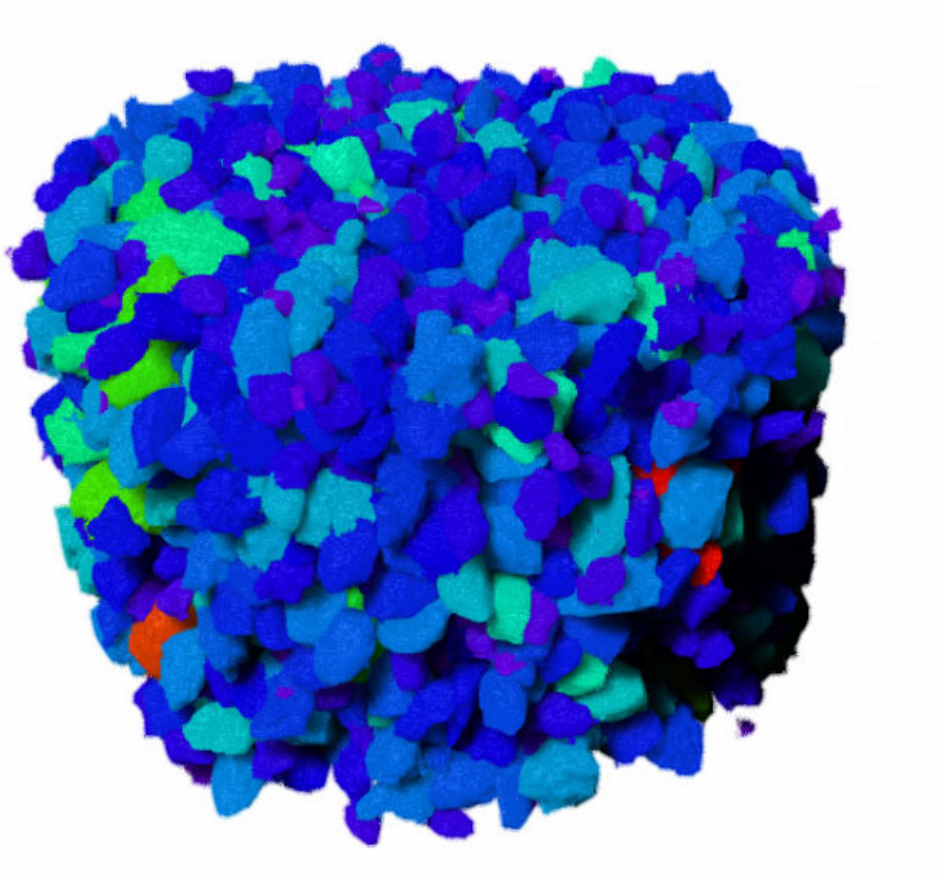
Sandstone

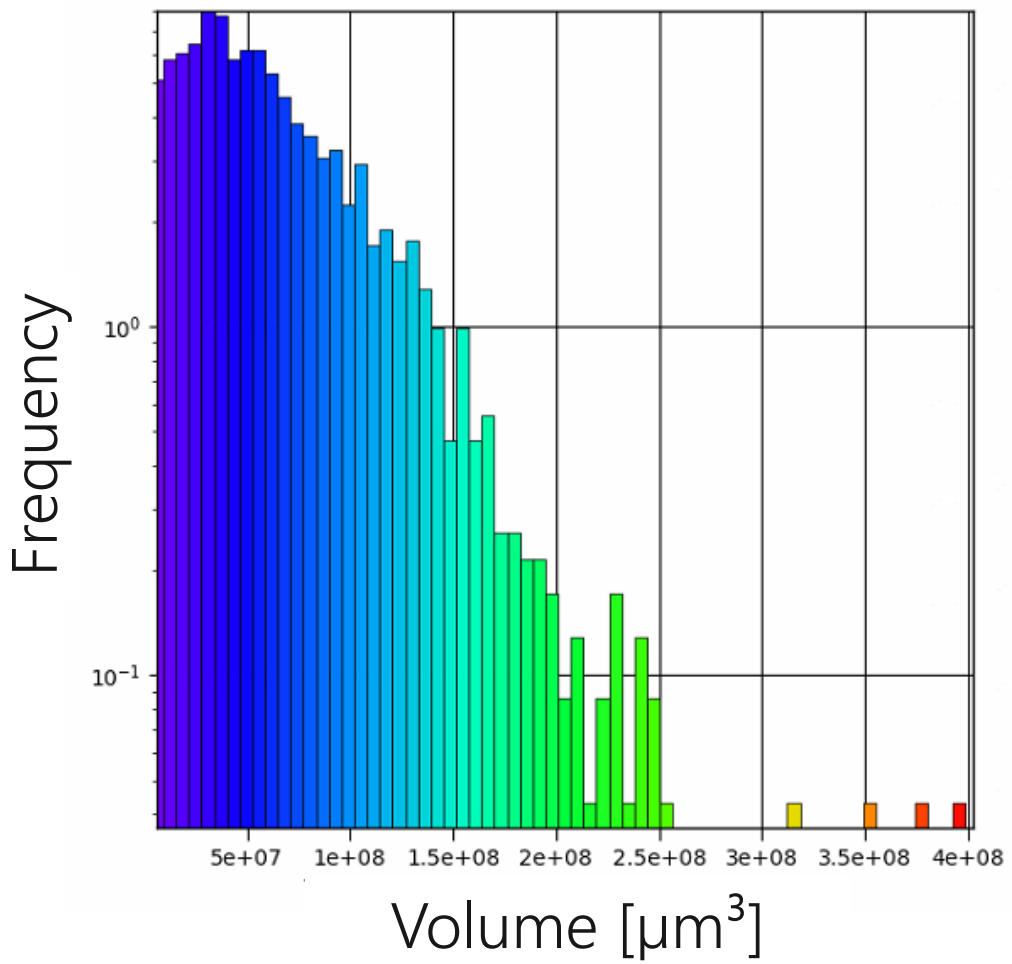




Grain size distribution

Sandstone

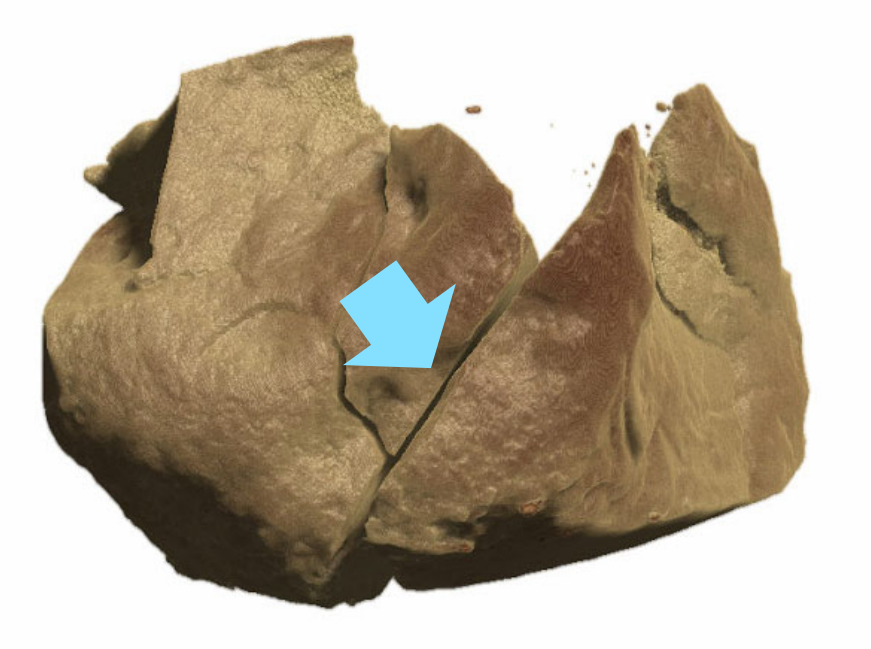


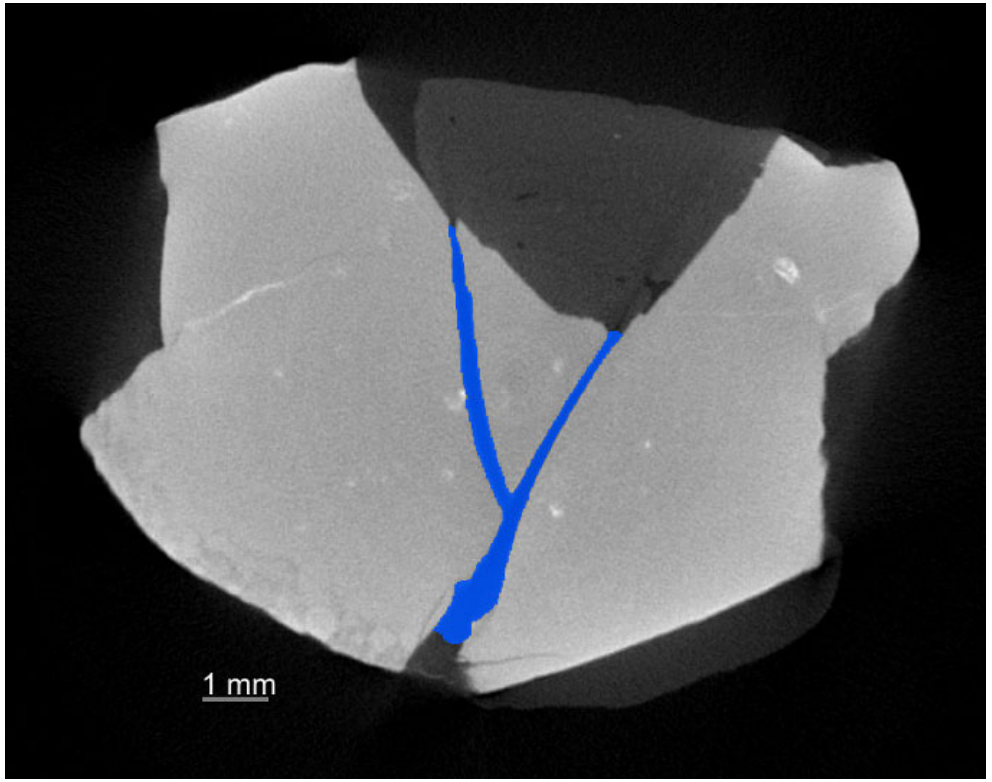


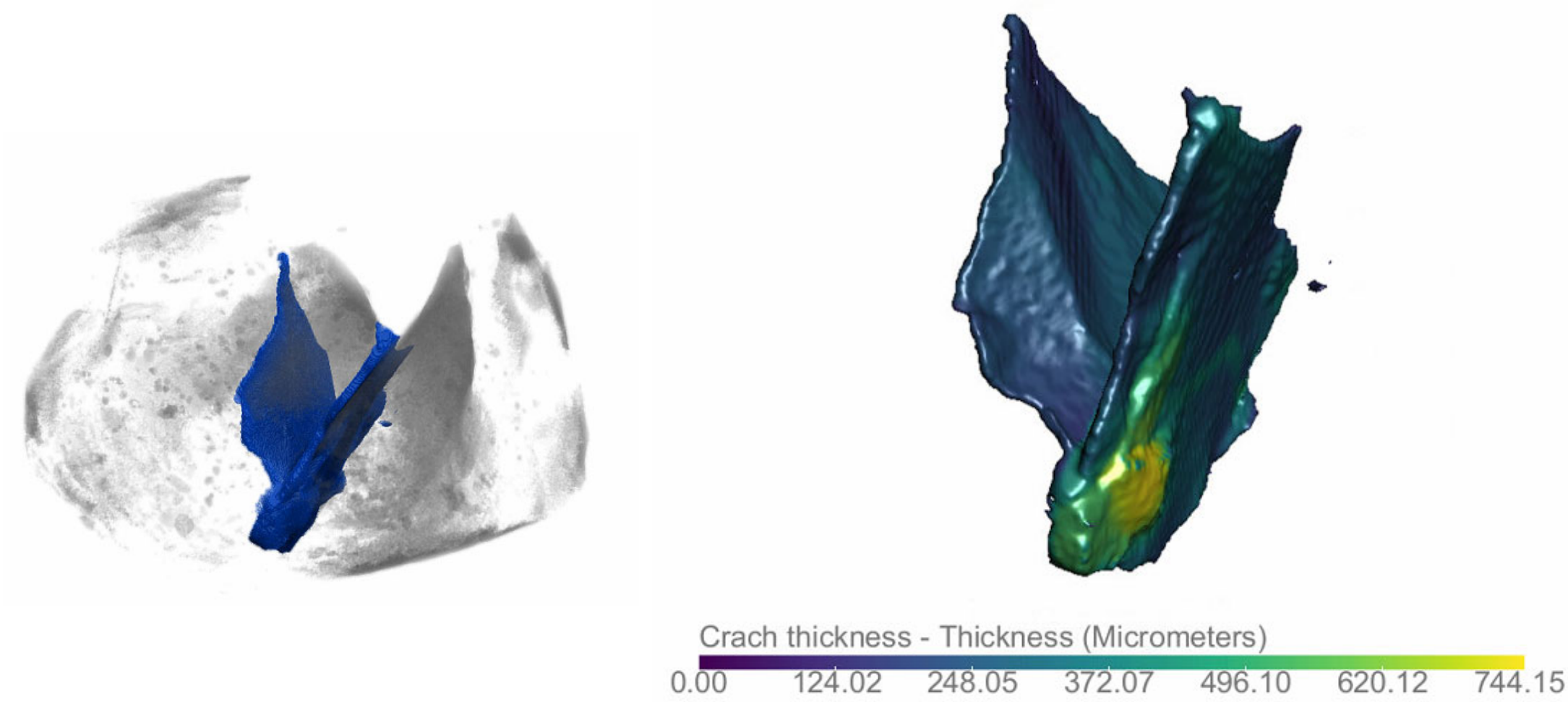
Mean volume: 5.5 x 10^7 μm³

CAN WE SEE CRACKS?

Cracked rock



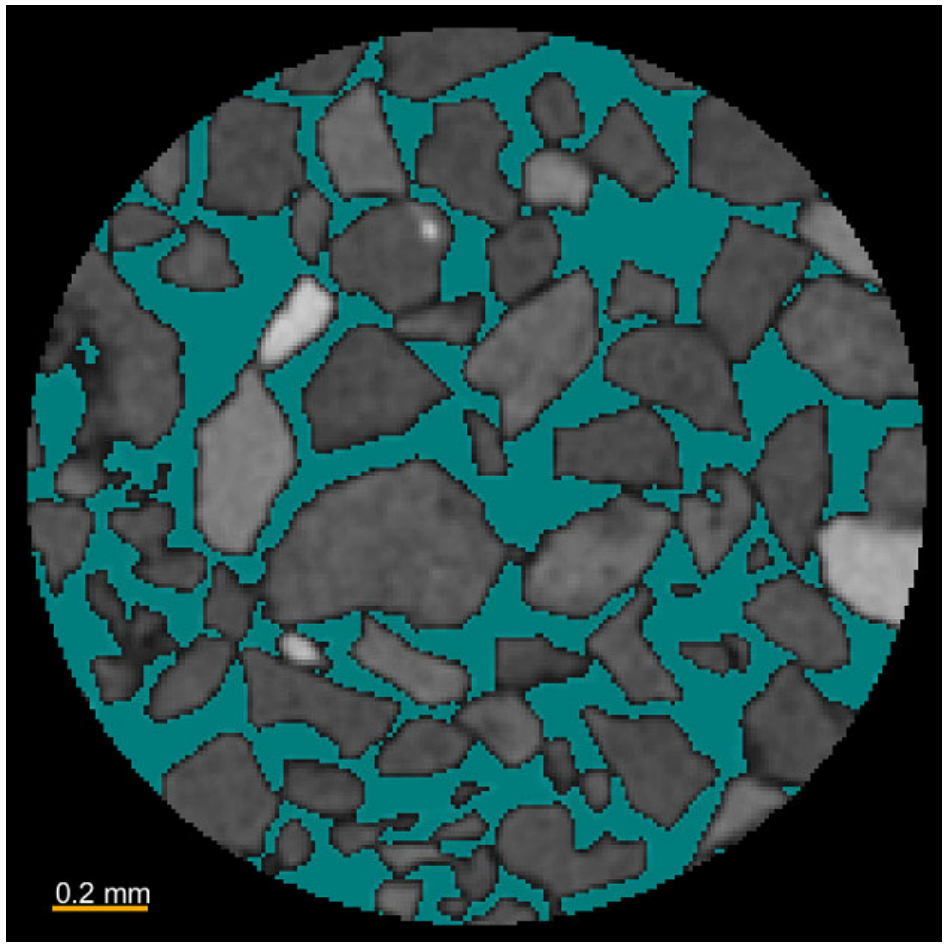


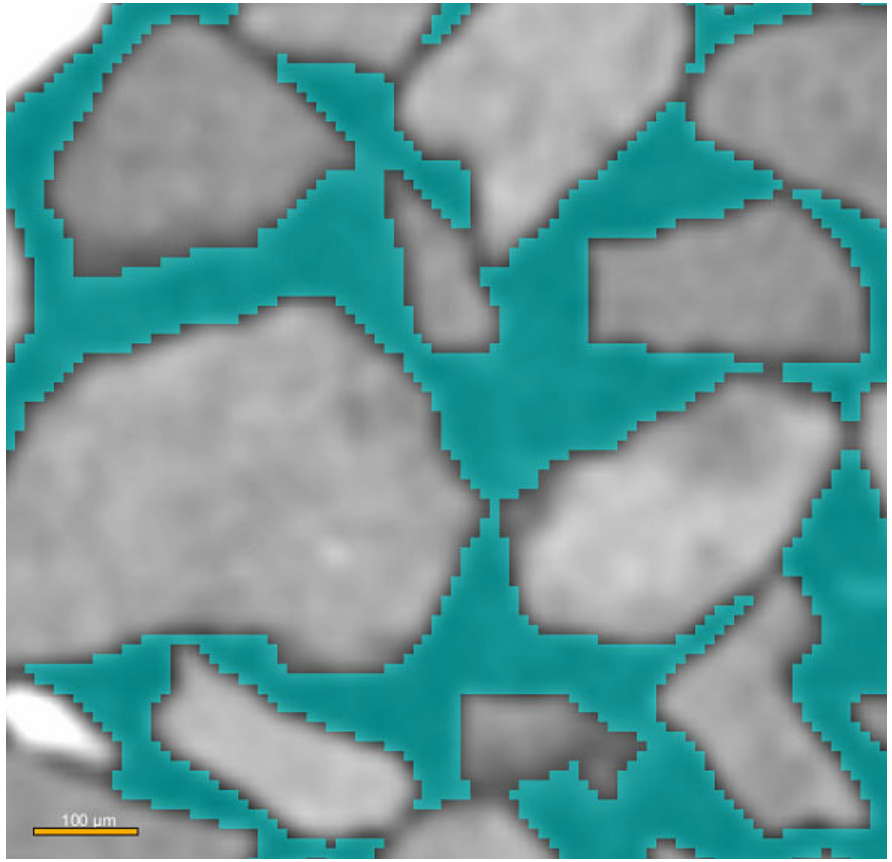


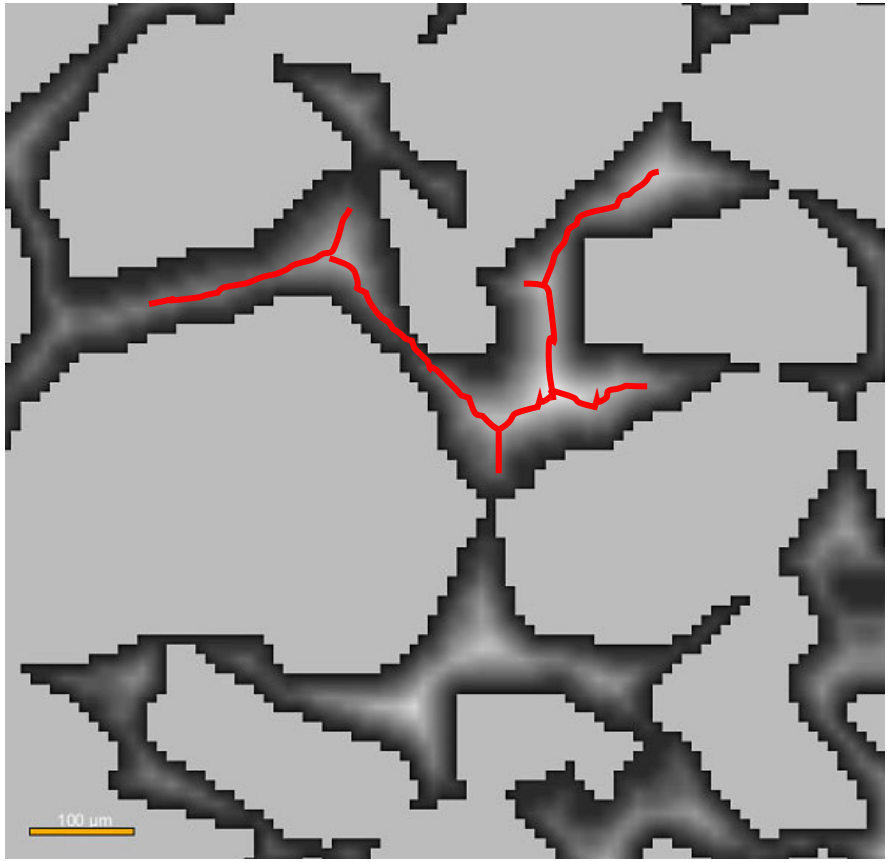
Crack width analysis

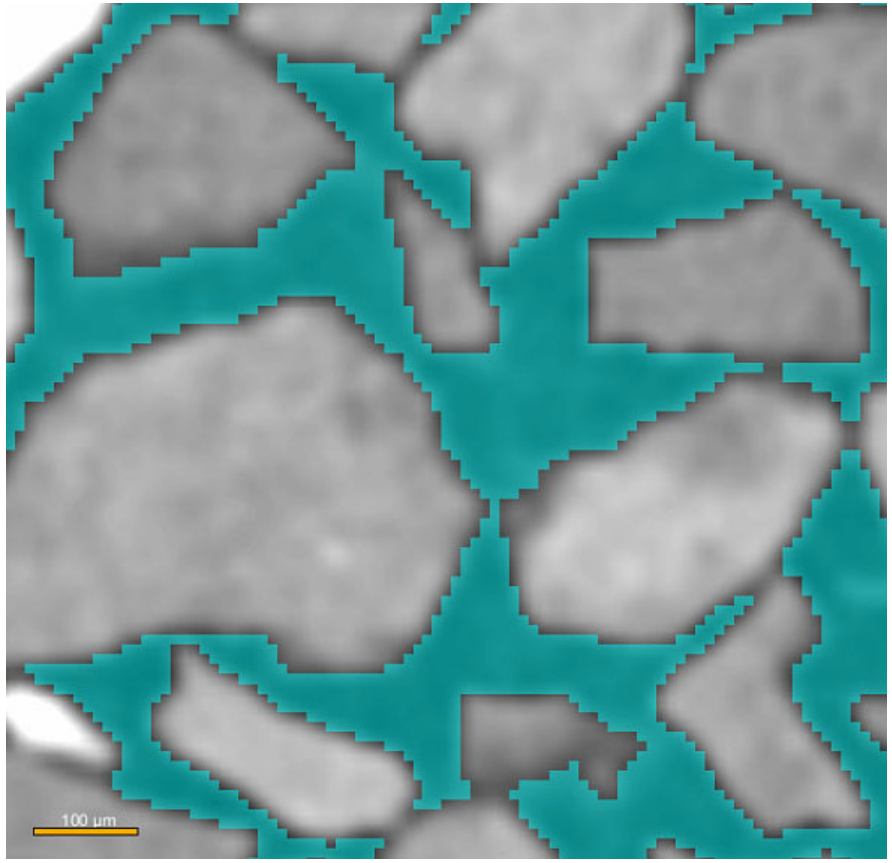
CAN WE ANALYZE A PORE NETWORK?

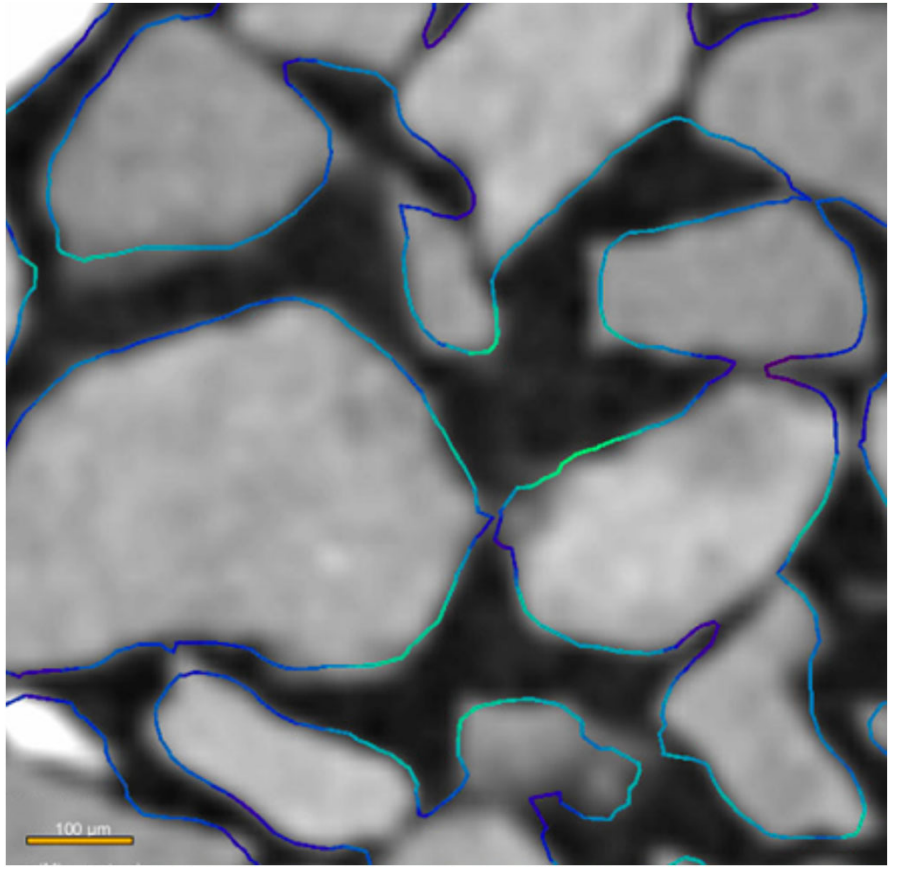
Packed sand




100 µm

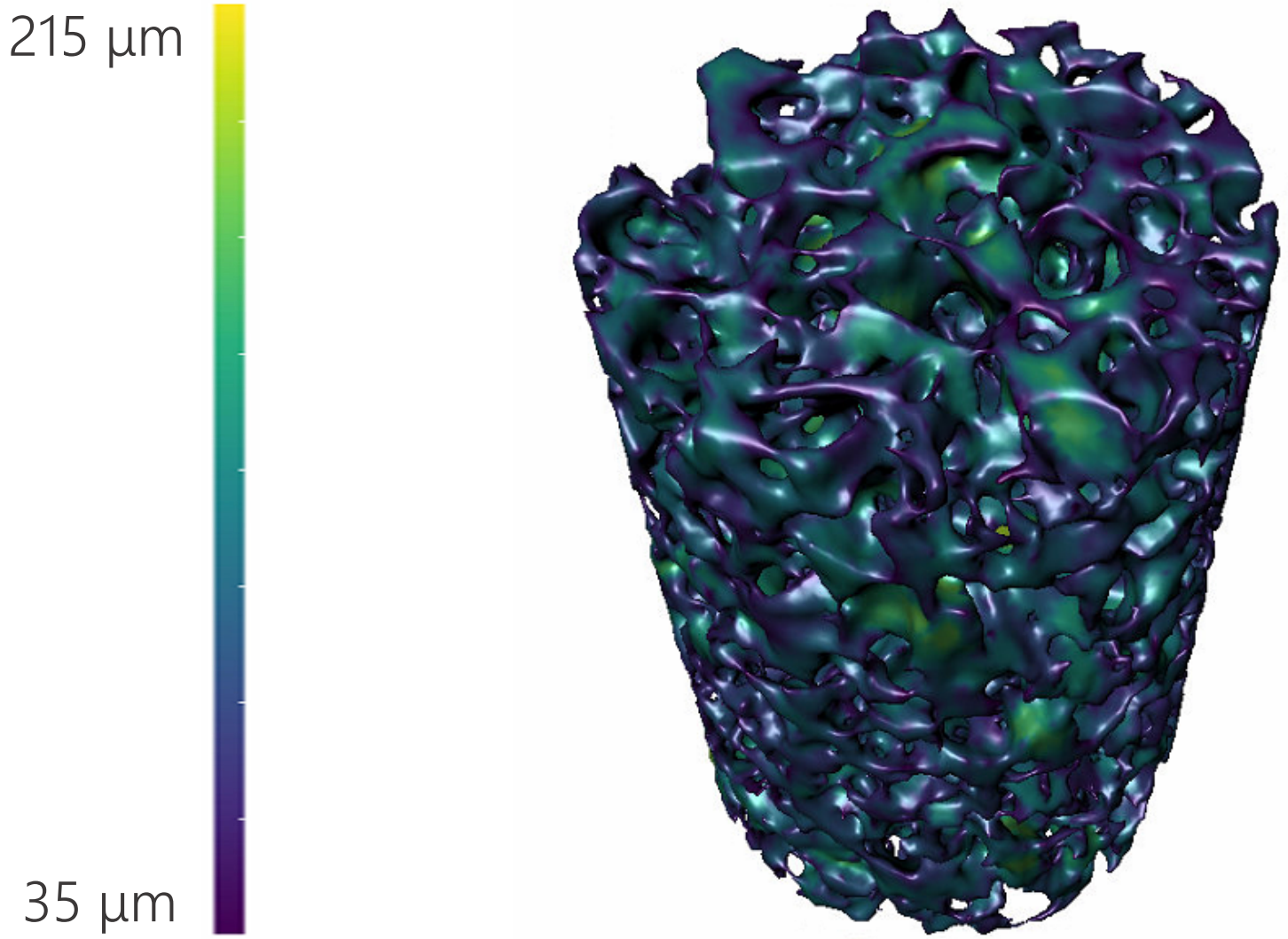

100 µm



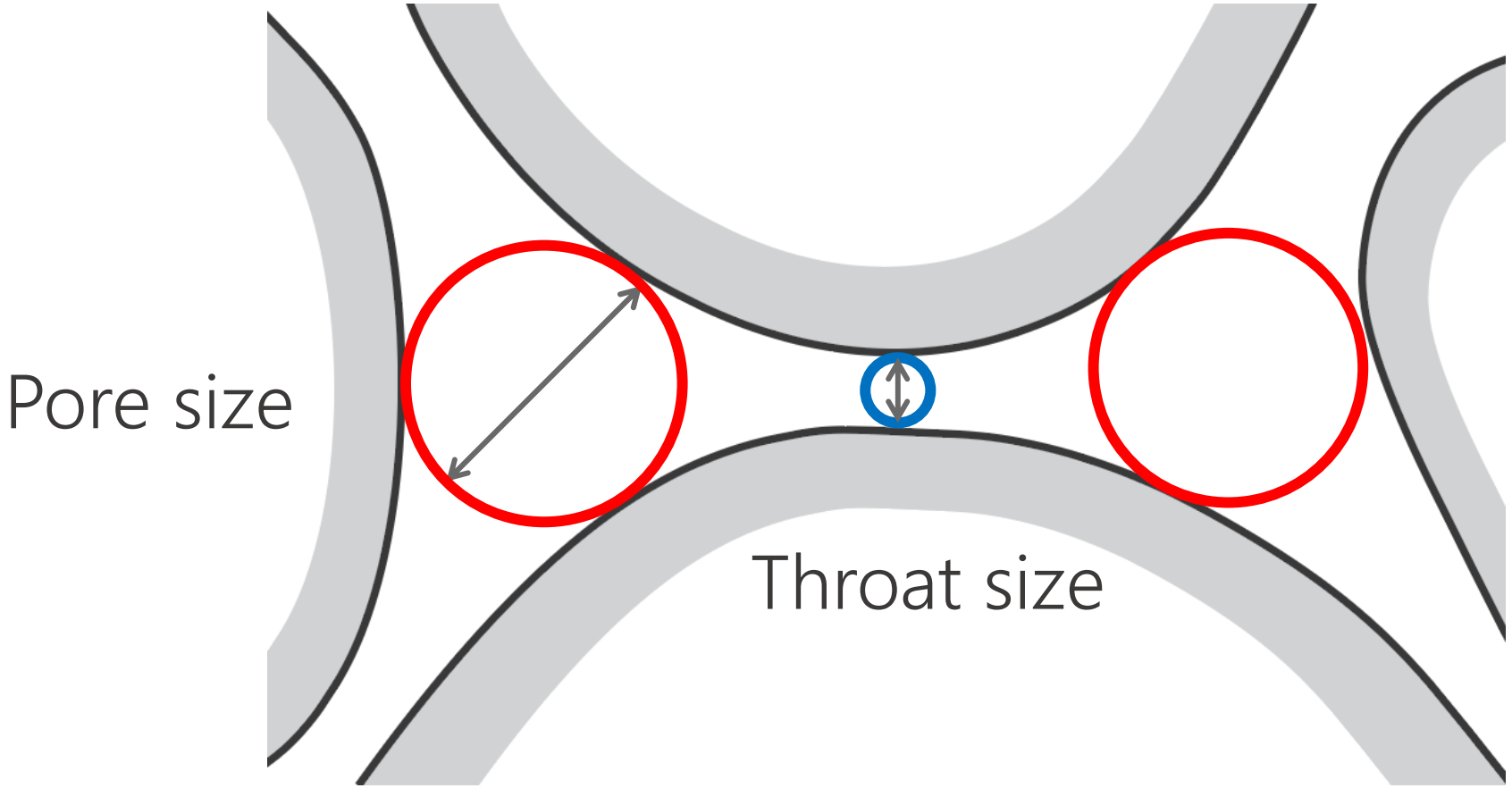


Thickness

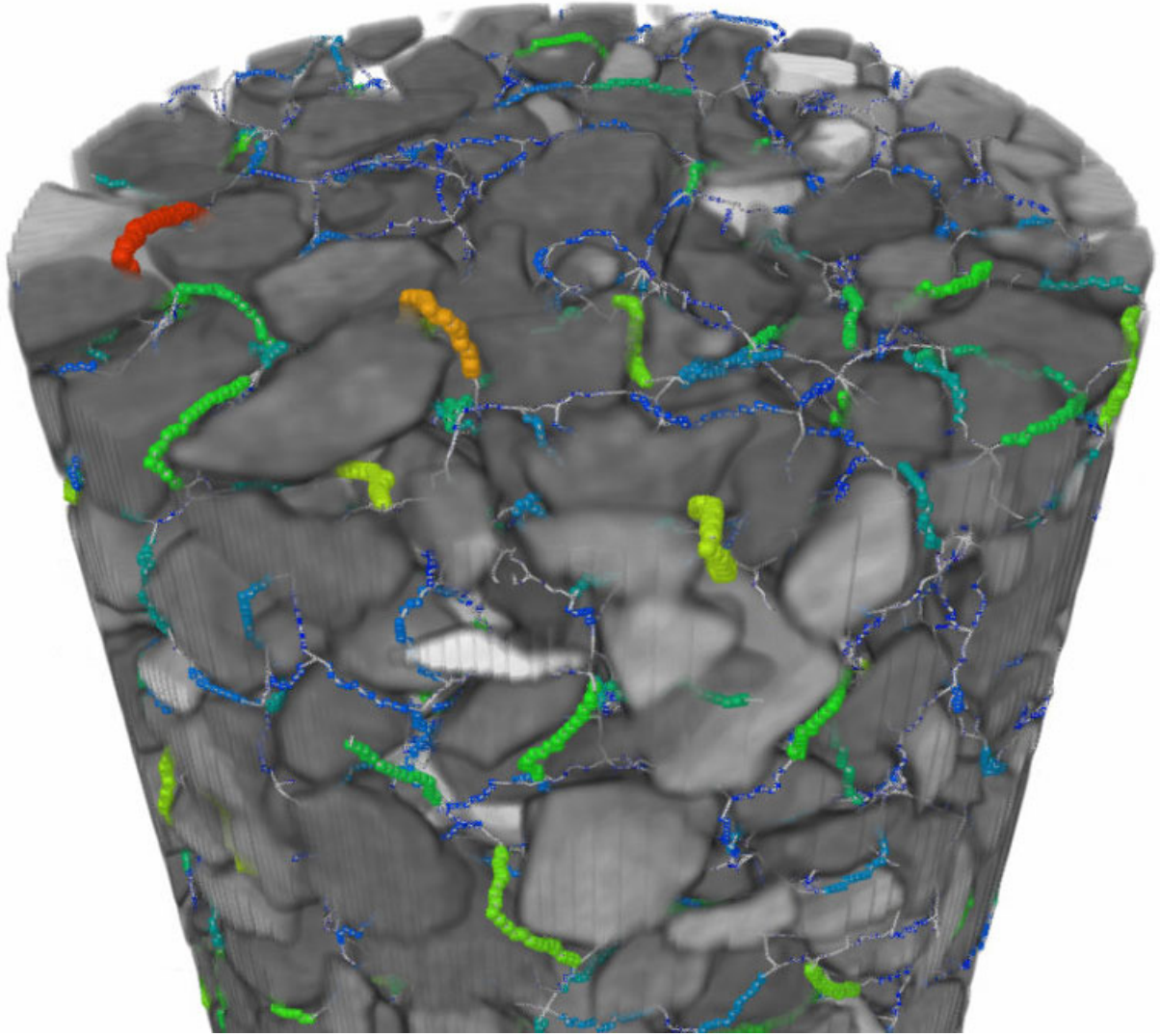
35 µm 215 µm



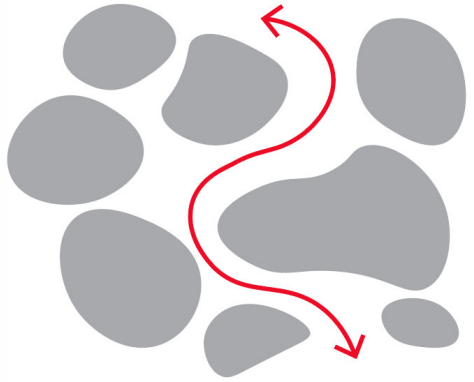
Thickness


Pore size
Throat size

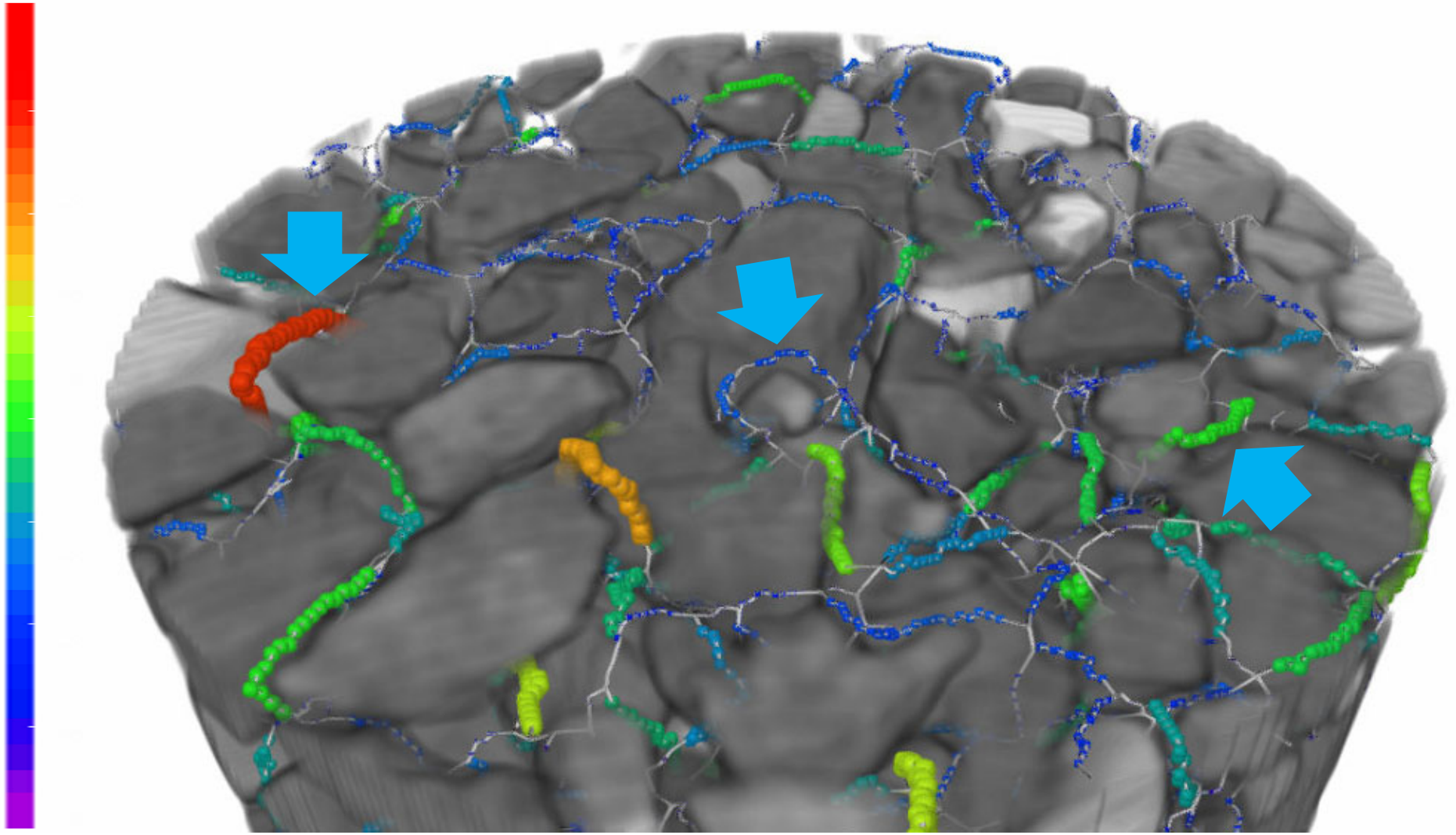
550 µm



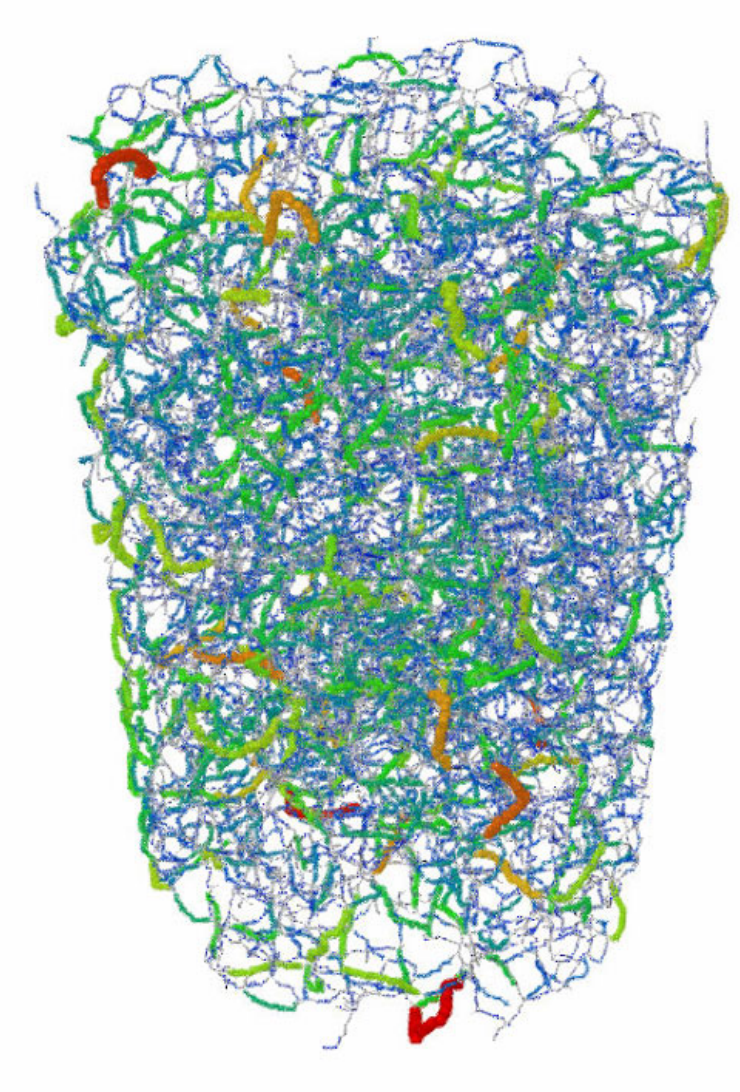
0 µm



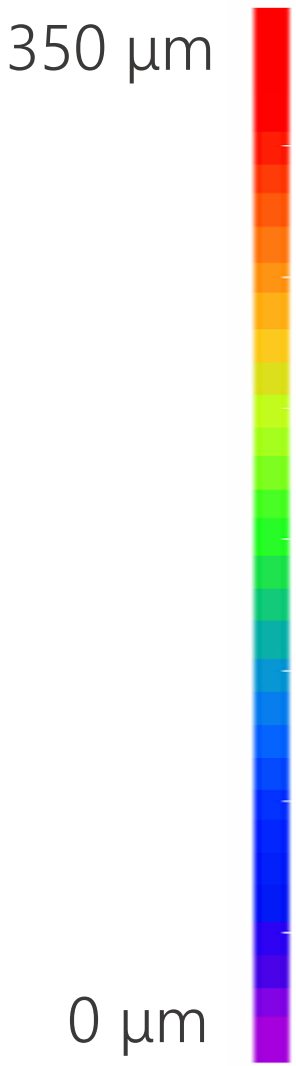
Path length

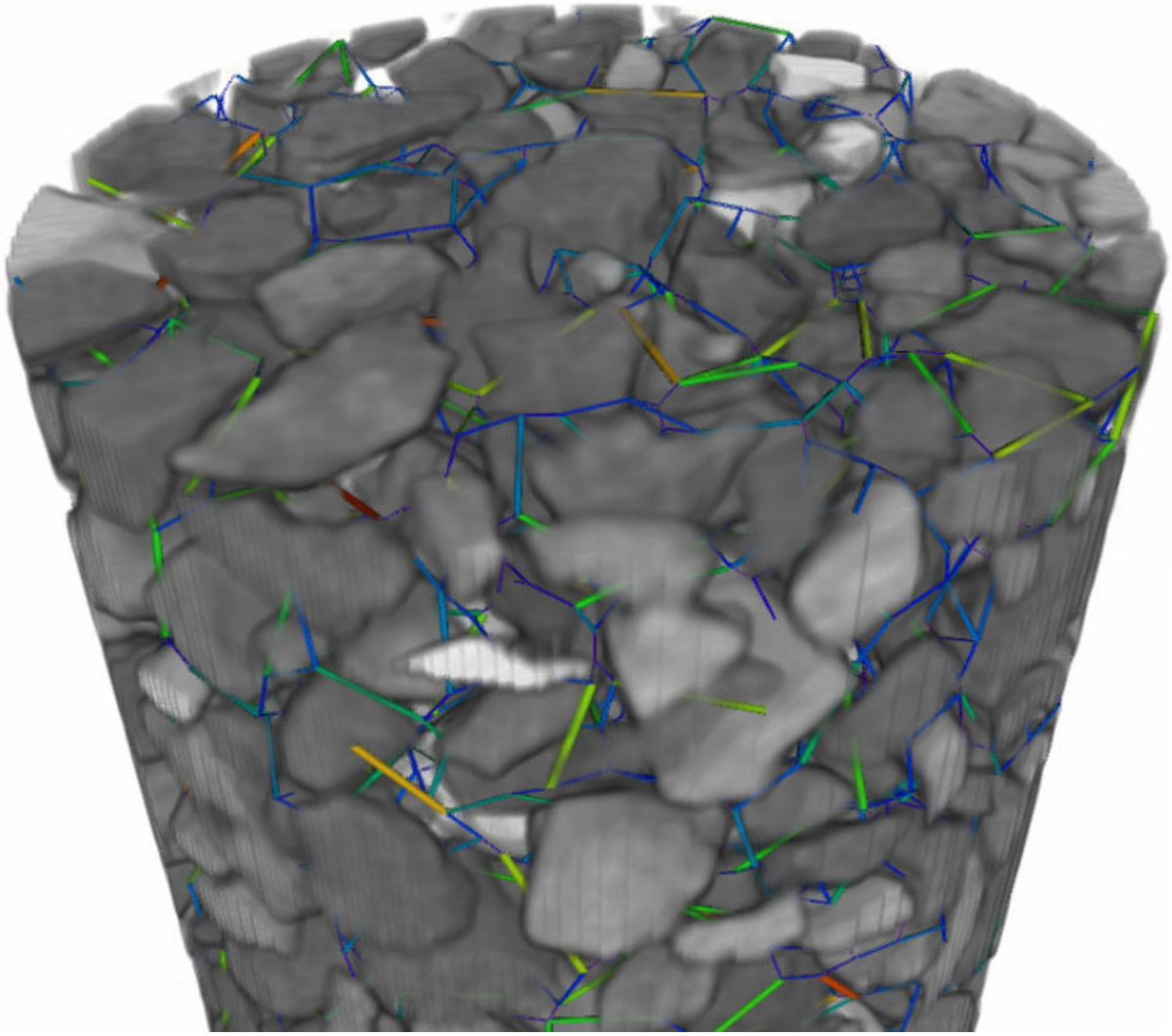


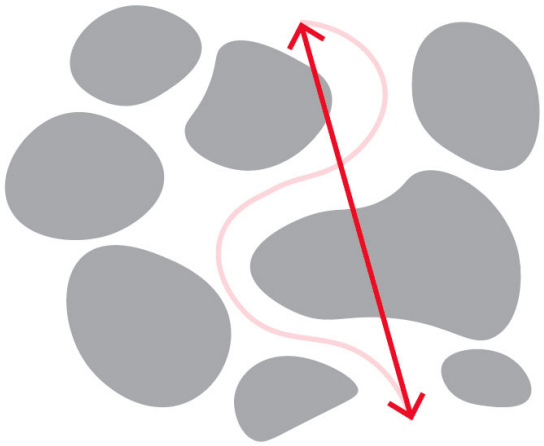
Path length



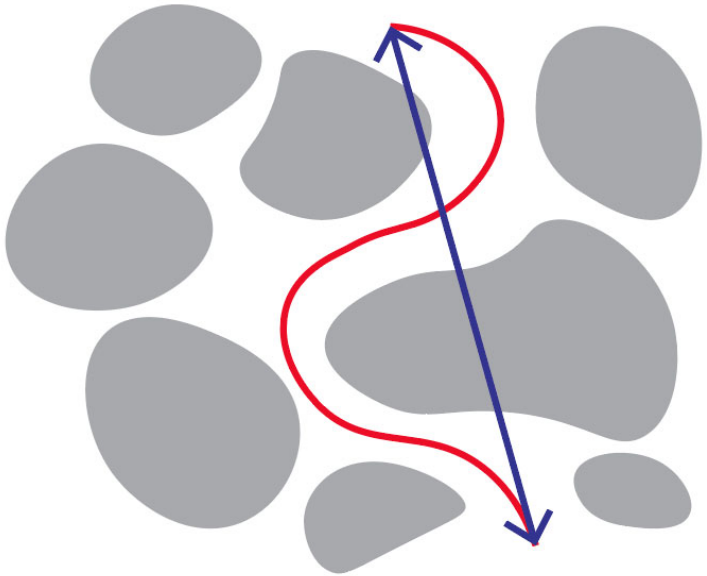
Path length



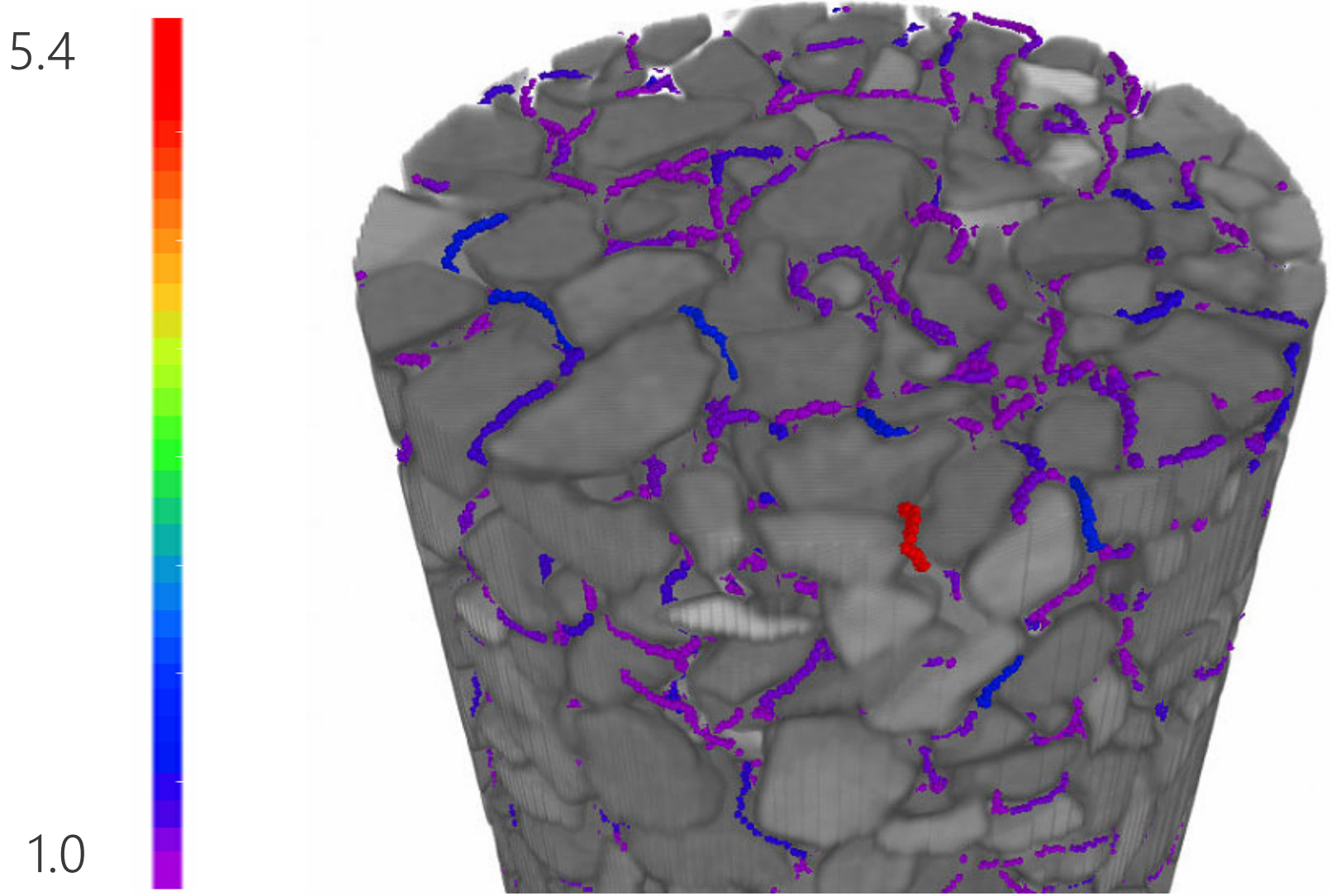




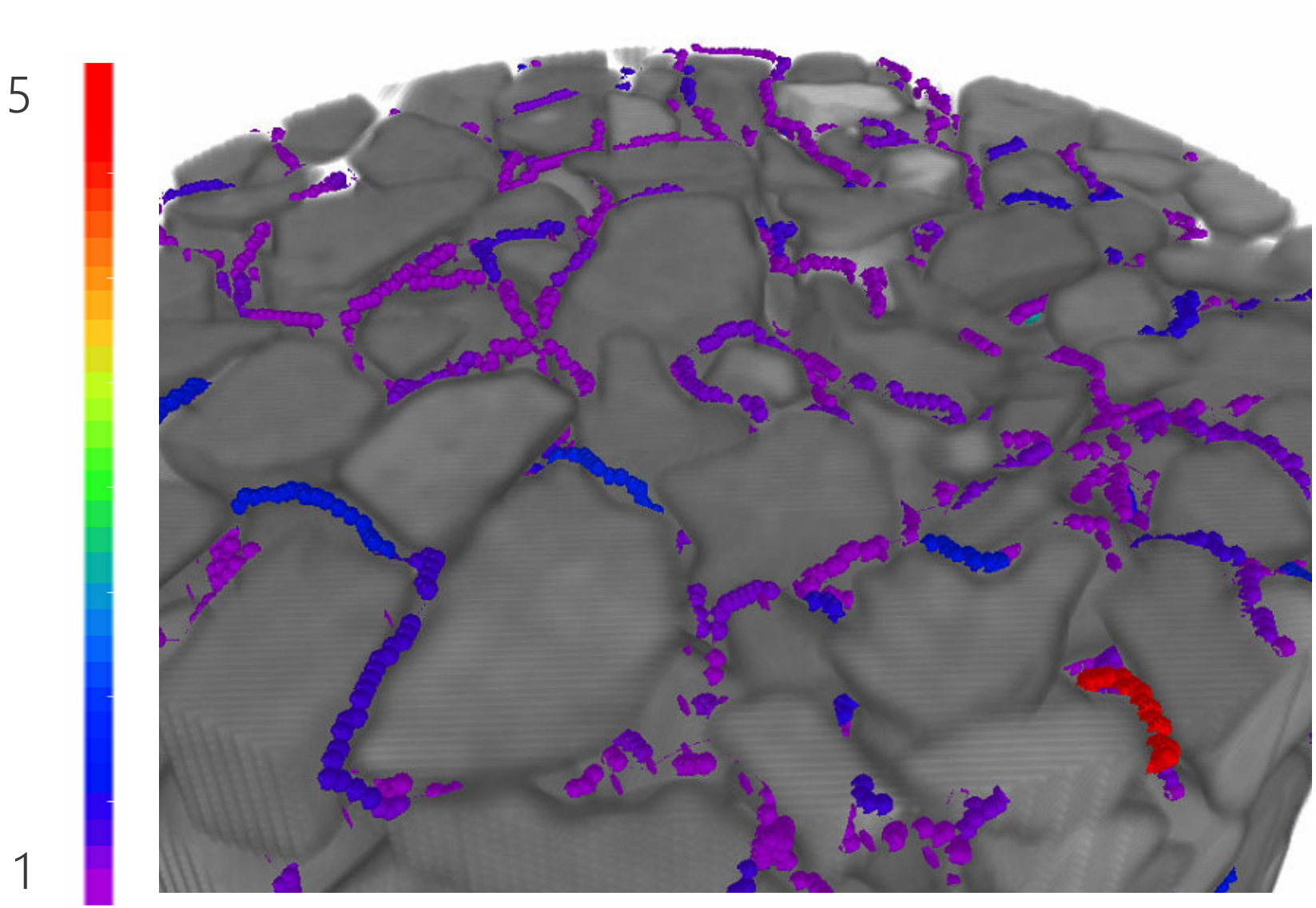
Direct path distance



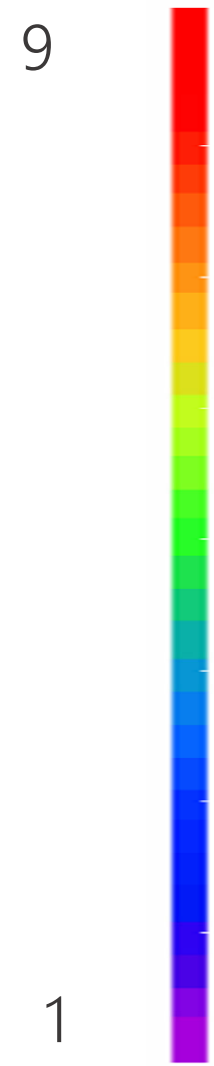
$$\frac{\text{Indirect path distance}}{\text{Direct path distance}} = \text{Tortuosity}$$

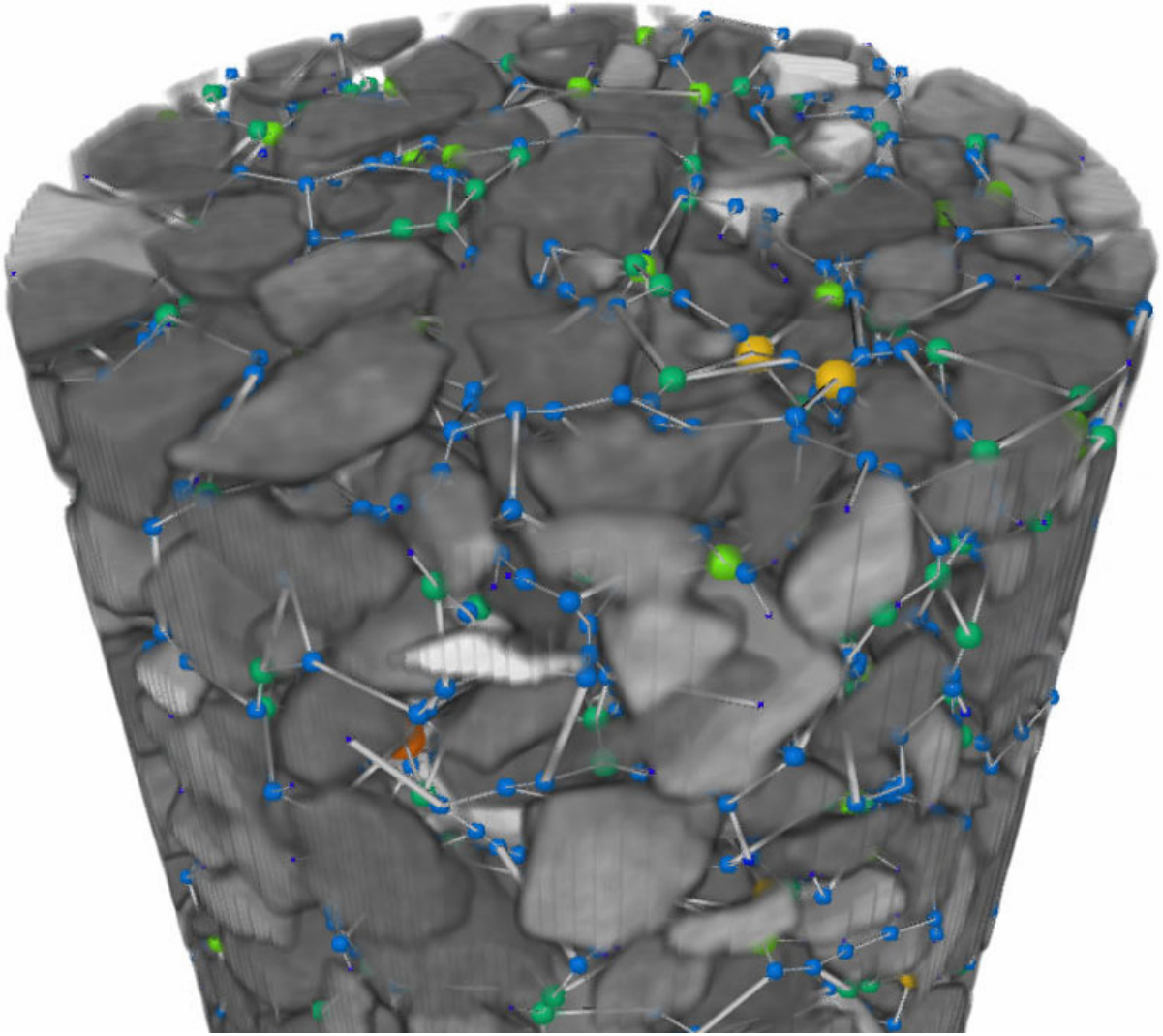


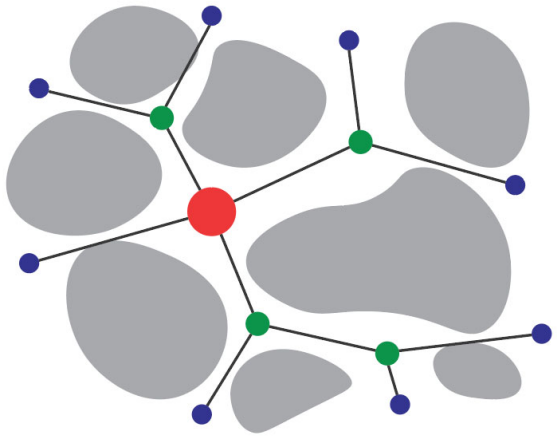
Tortuosity



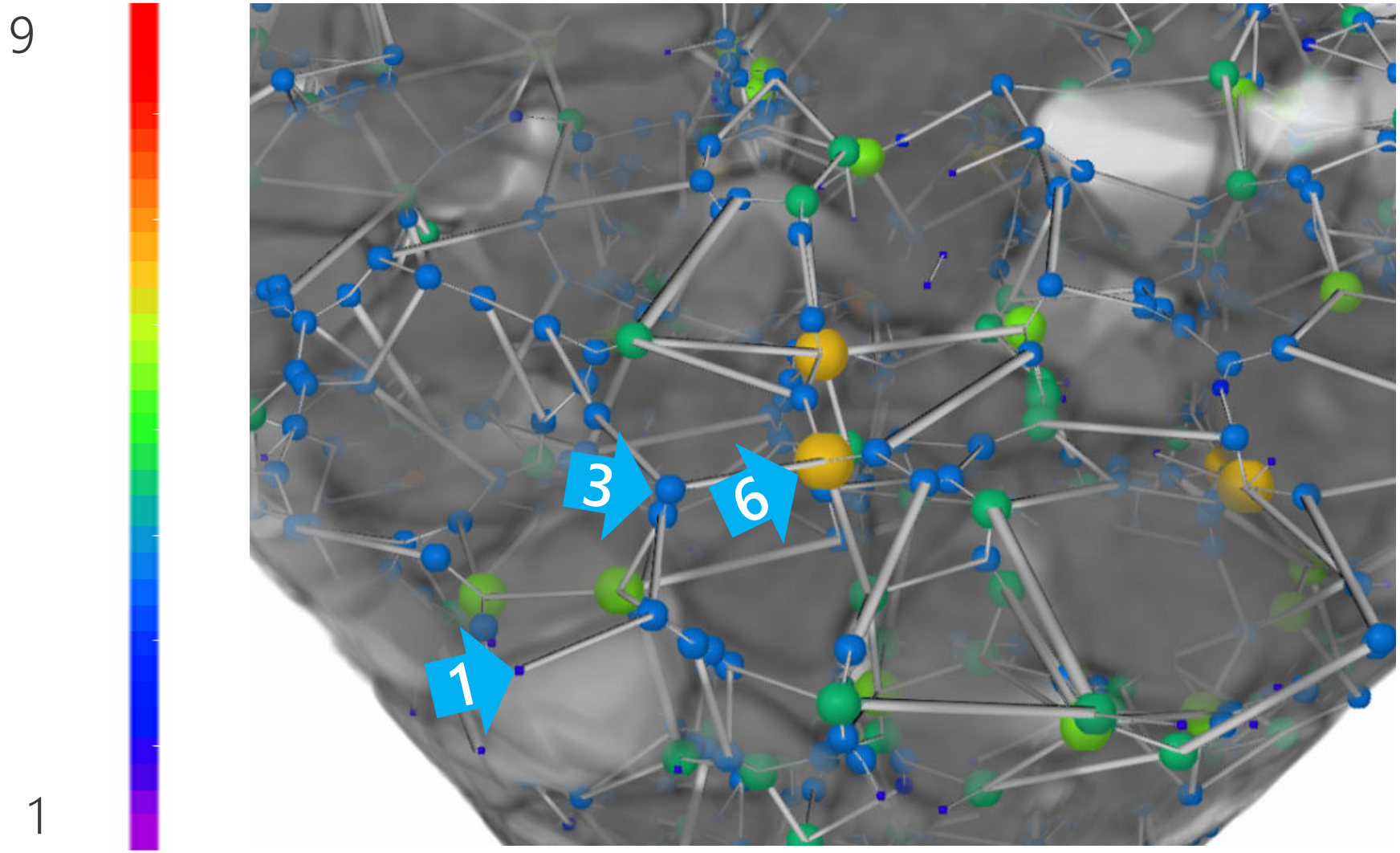
Tortuosity







Connectivity



Connectivity

ORS OBJECT RESEARCH SYSTEMS

https://www.theobjects.com/dragonfly/

DRAGONFLY welcome | FEATURES key benefits | DEEP LEARNING advanced processing | SHOWCASE dragonfly results | LEARN develop skills | SUPPORT get help | GET DRAGONFLY achieve real results

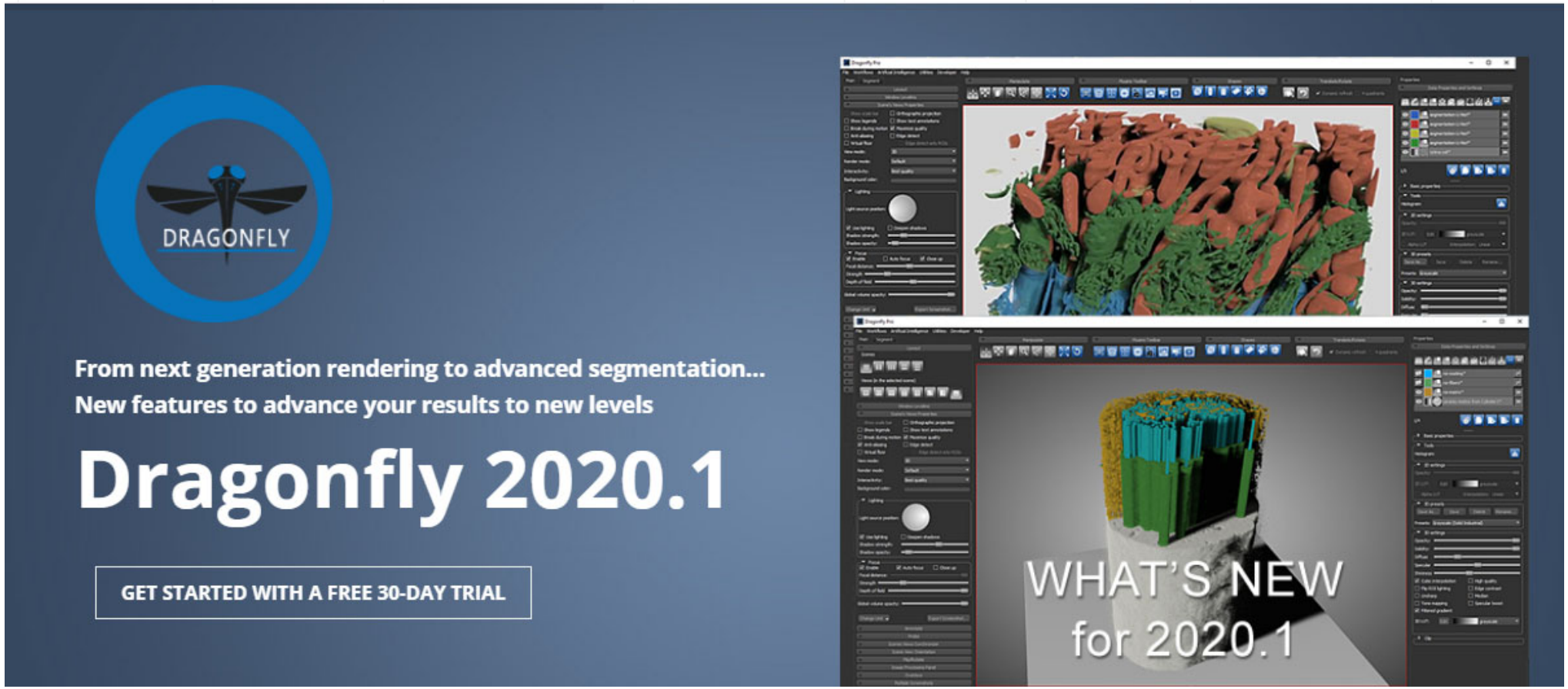
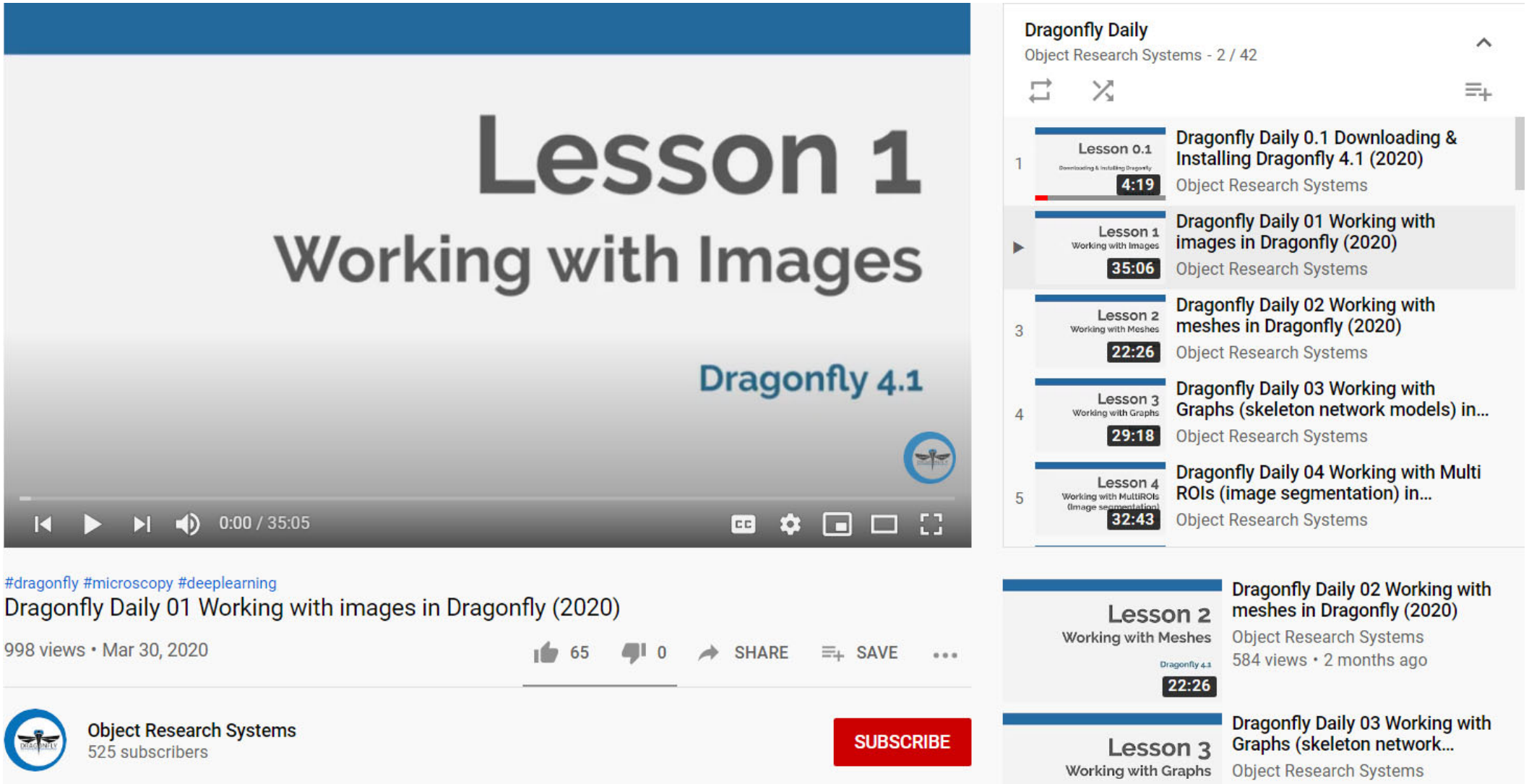



image
data
meshes
datasets
interest
views
objects
regions
filters
segmentation
extension
images
tools
multiple
selected
measurements
multi-ROIs
dataset
within
Gaussian
histogram
Histogram
include
intensity
operations
reference
analysis
Quickly
oblique
Create
Automatically
learning
segmented
thresholding
automatically
filtering
Generate
Interactive
working
version
range
functions
K-Means
Discrete
models
graphs
Transform
projections
Dynamic
registration
orystitch
files
points
intensities
Mean
Adaptive
Apply
Compute
stacks
printing
surface
Local
filter
slices
Surface
removing
opacity
time
record
interactive
applying
color-coded
results
effects
Equalization
enhancement
polygonal
different
orientation
Filters
volume
automatic
tasks
Beta
tool
thickness
Fourier
dependant
sequences
interactively
volumetric
fusion
Otsu
Support
networks
whole
object
create
small clip
Extract
visualizations
adjust
Feret
angles
get
areas
extracting
mean
deep
structures
Graph
extensions
Dragonfly
Advanced
Export
Image
information
look-up
simulations
Brush
single
nodes
paths
remove
table
high-resolution
2D/3D
mesh
new
train
segment
extract
parameters

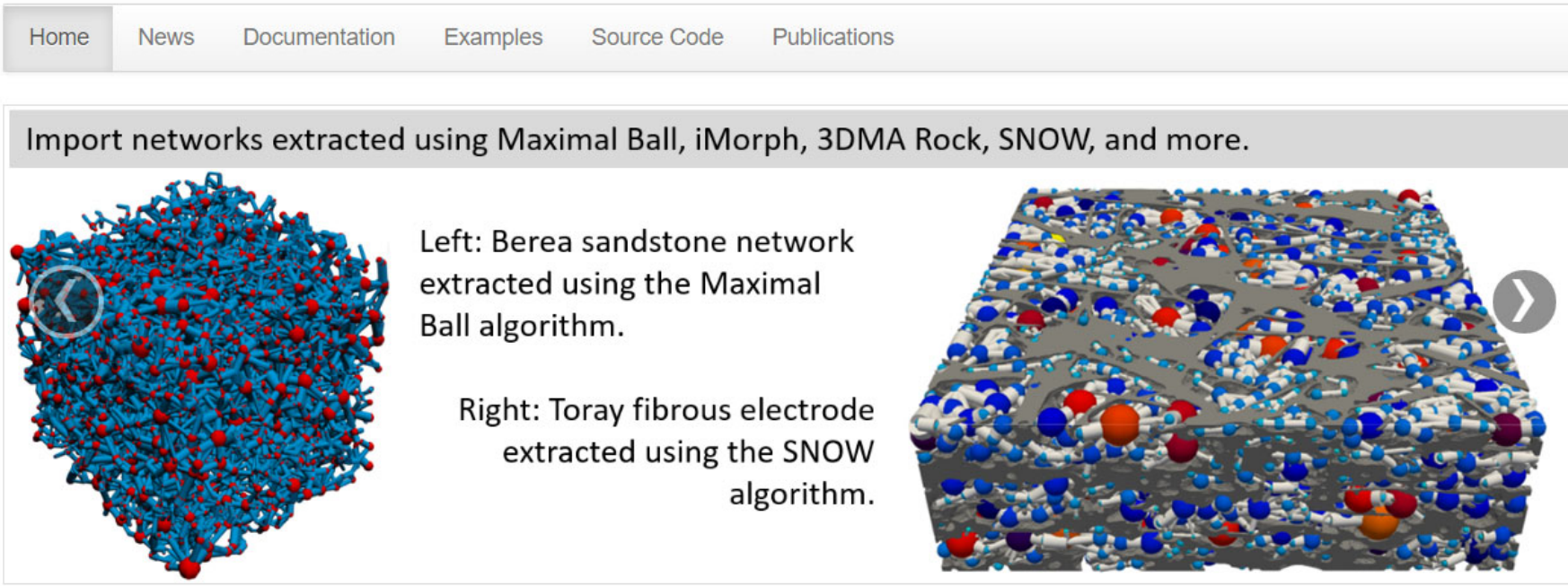
http://orss.ca/ytp2



openpnm

An Open Source Pore Network Modeling Package

http://openpnm.org/

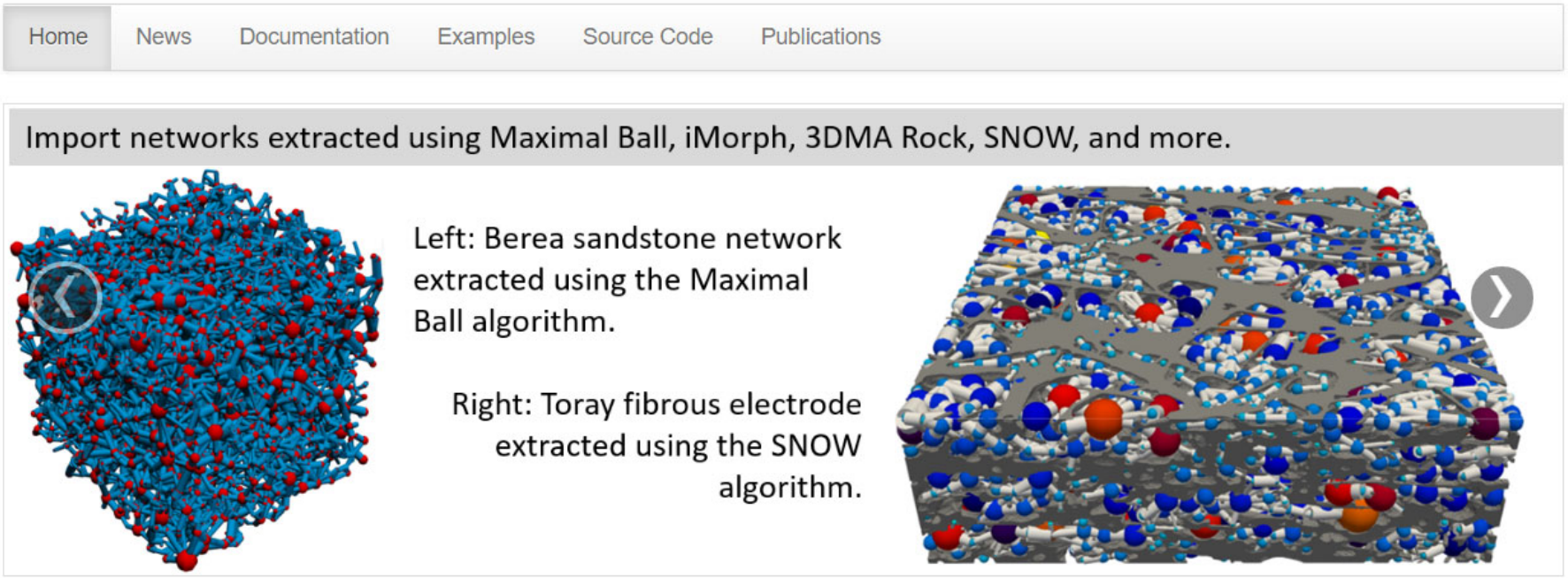


Developed by the PMEAL Group at the University of Waterloo

openpnm

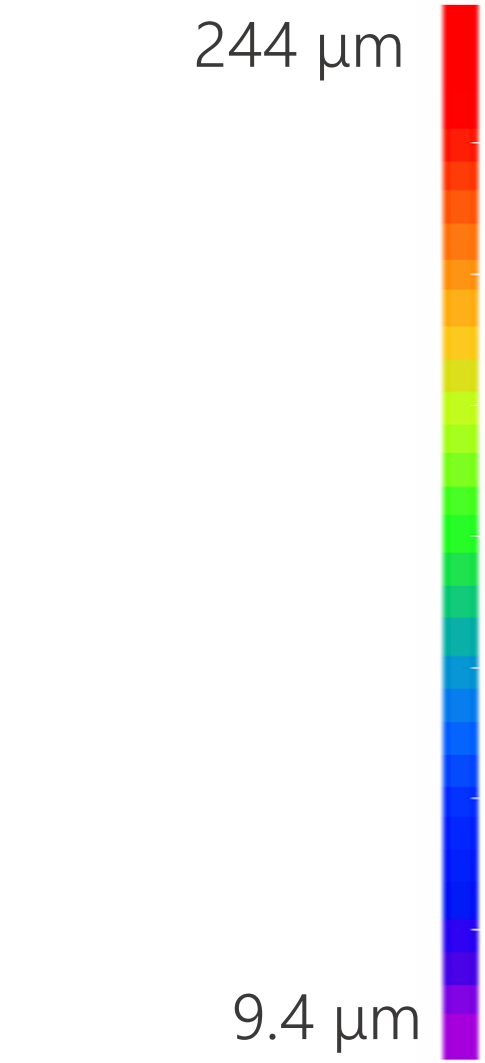
An Open Source Pore Network Modeling Package

http://openpnm.org/

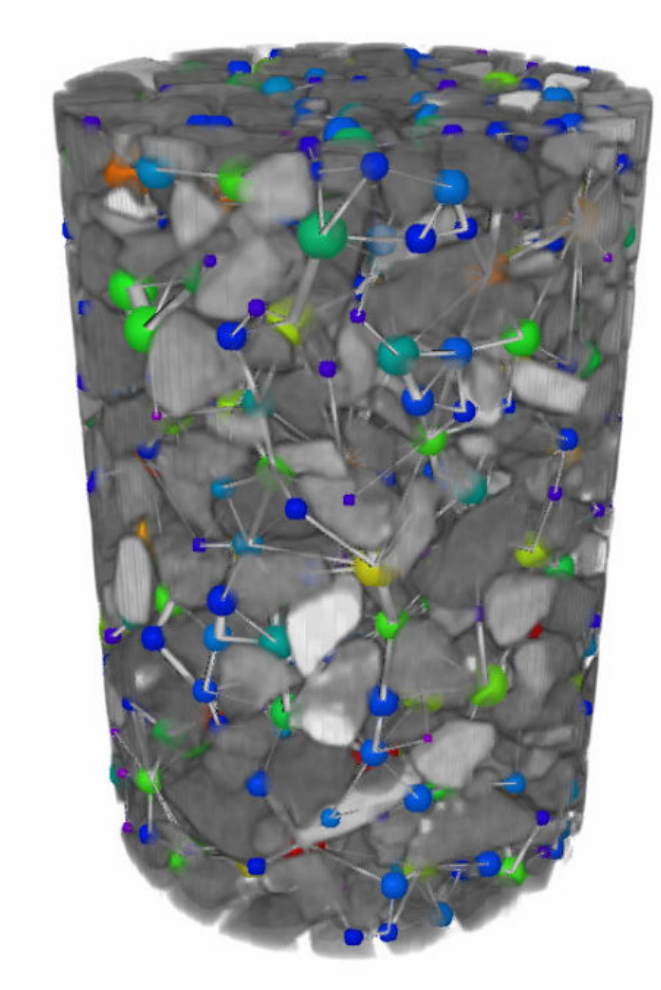


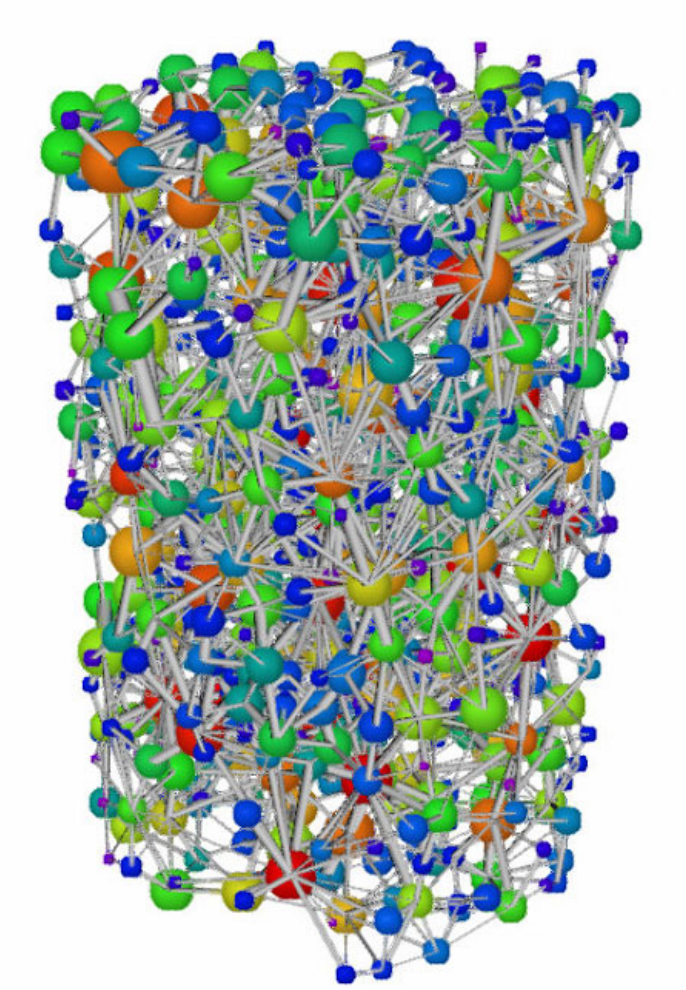
"OpenPNM: A pore network modeling package"
Gostick et al. Computing in Science & Engineering. 18(4), p60-74 (2016).

244 µm



9.4 µm



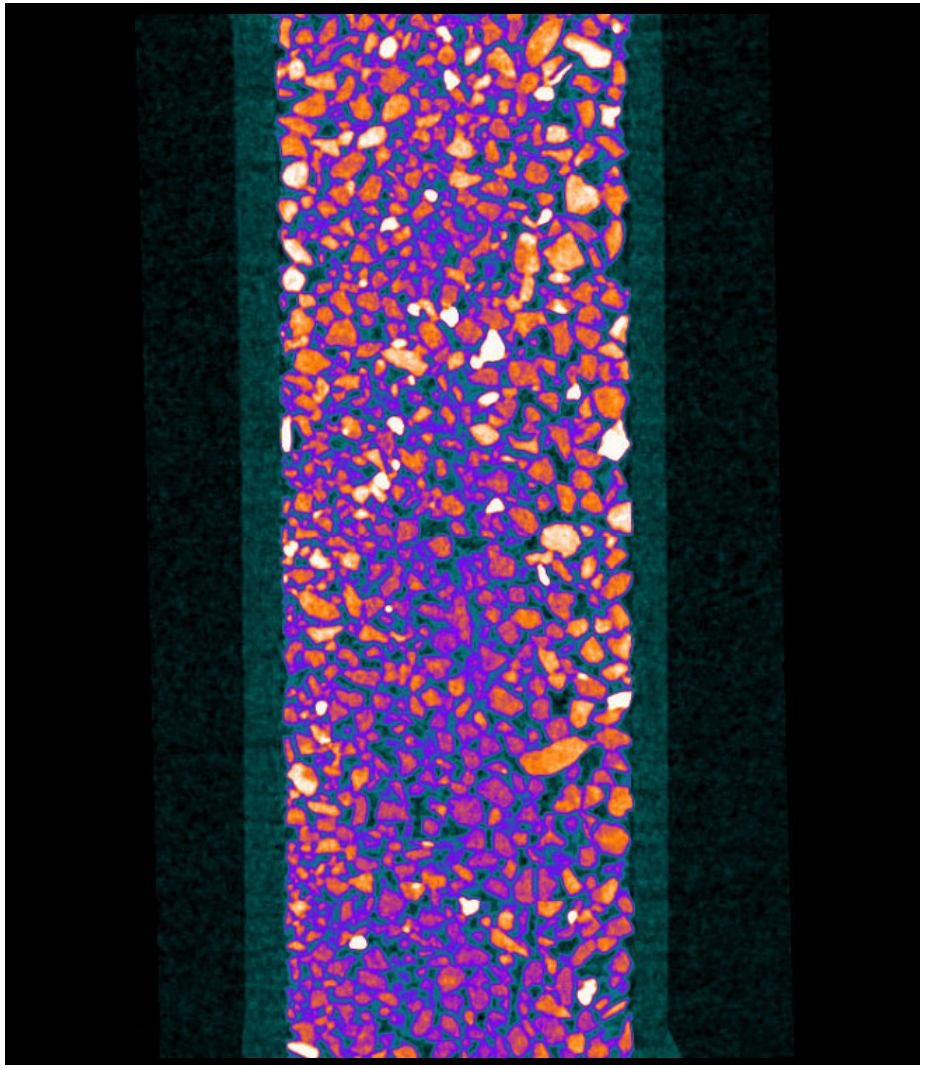


Equivalent diameter

CAN WE SEE FLUID IN PORES/VOIDS?

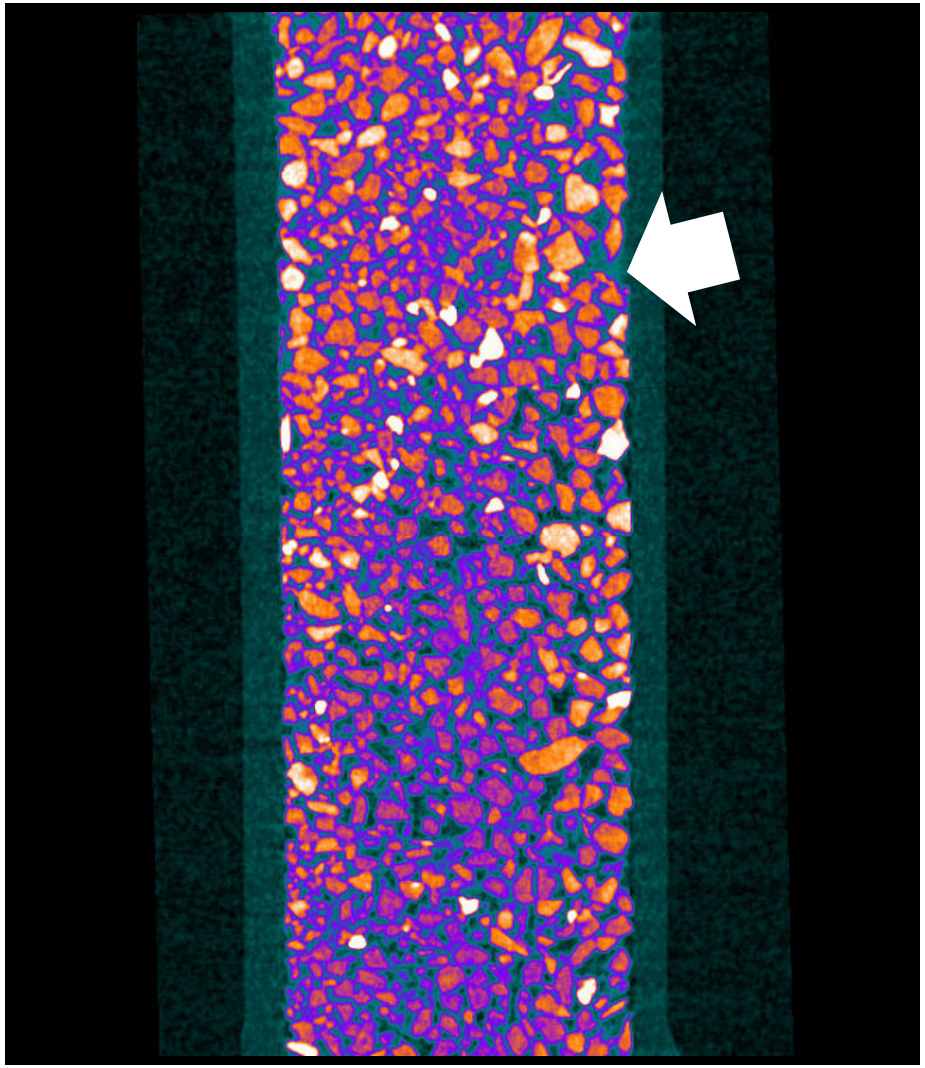
Packed sand + oil

0 min



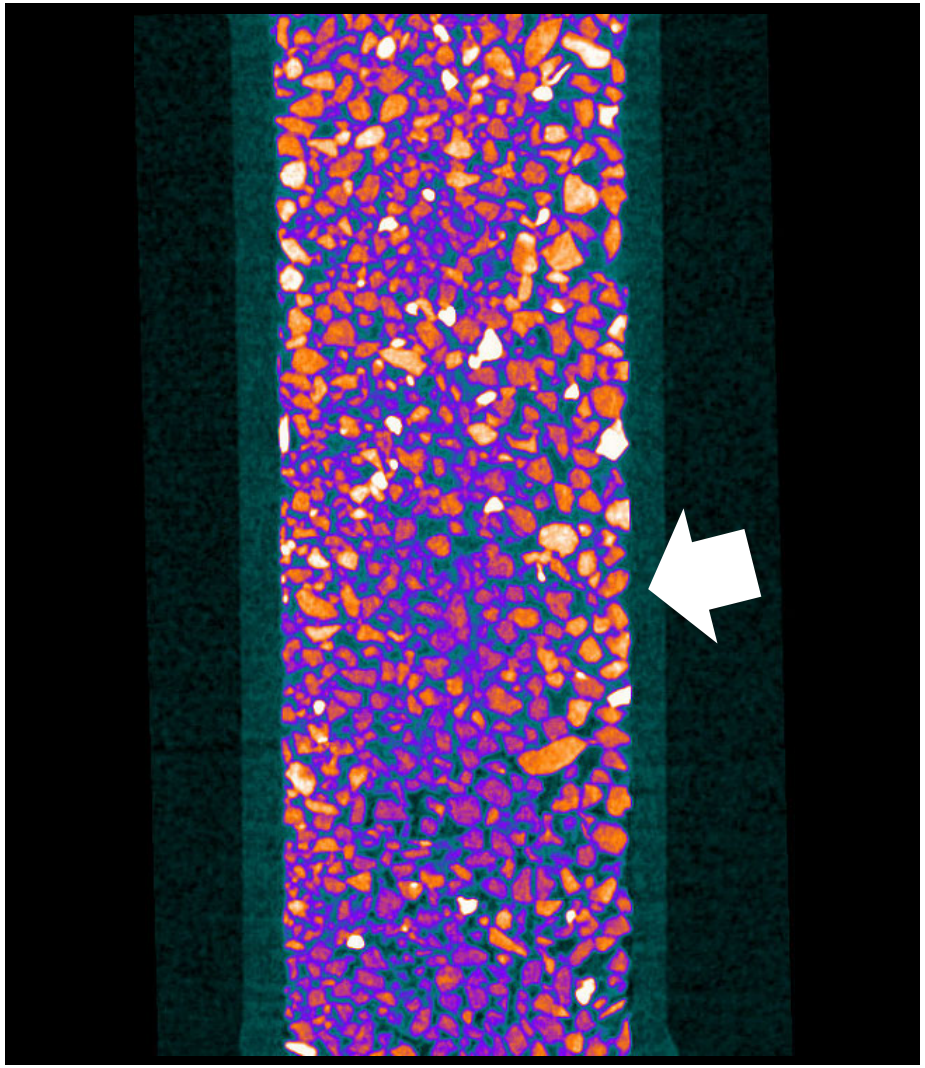
Packed sand + oil

15 min



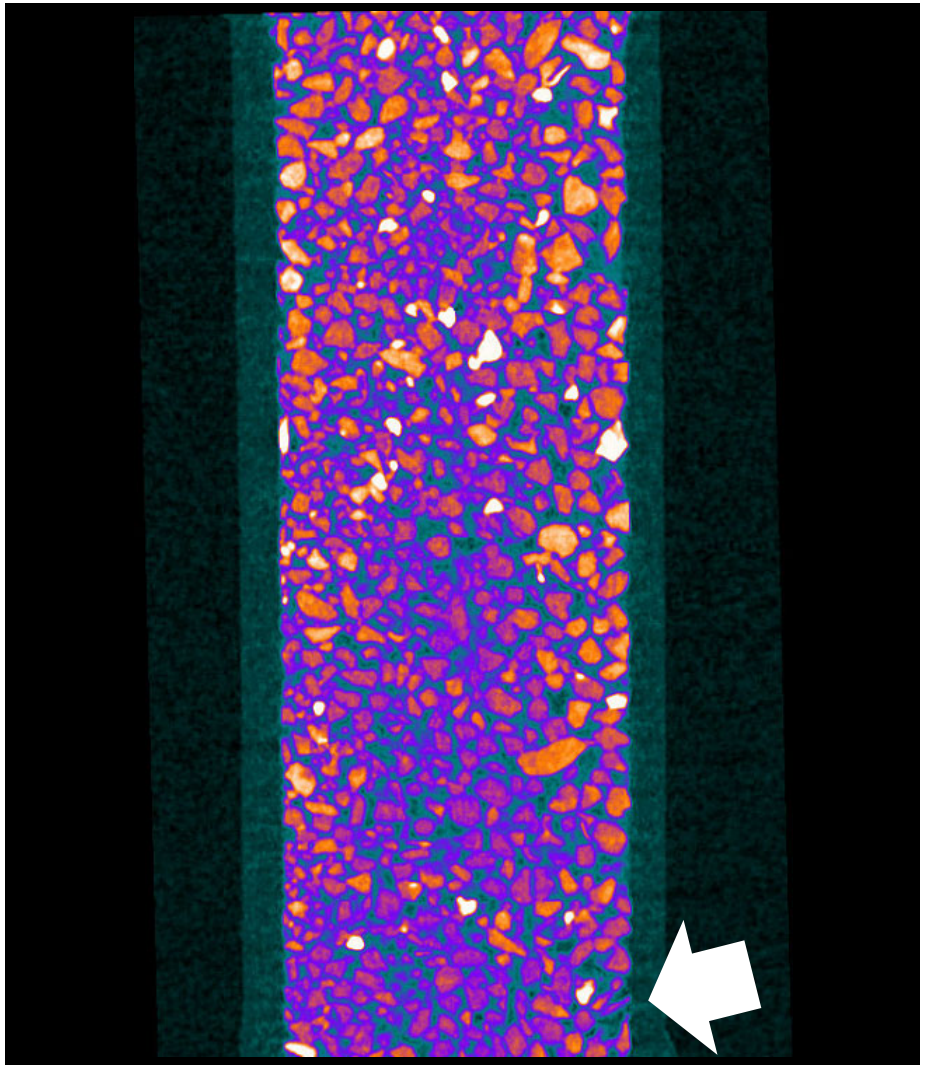
Packed sand + oil

20 min

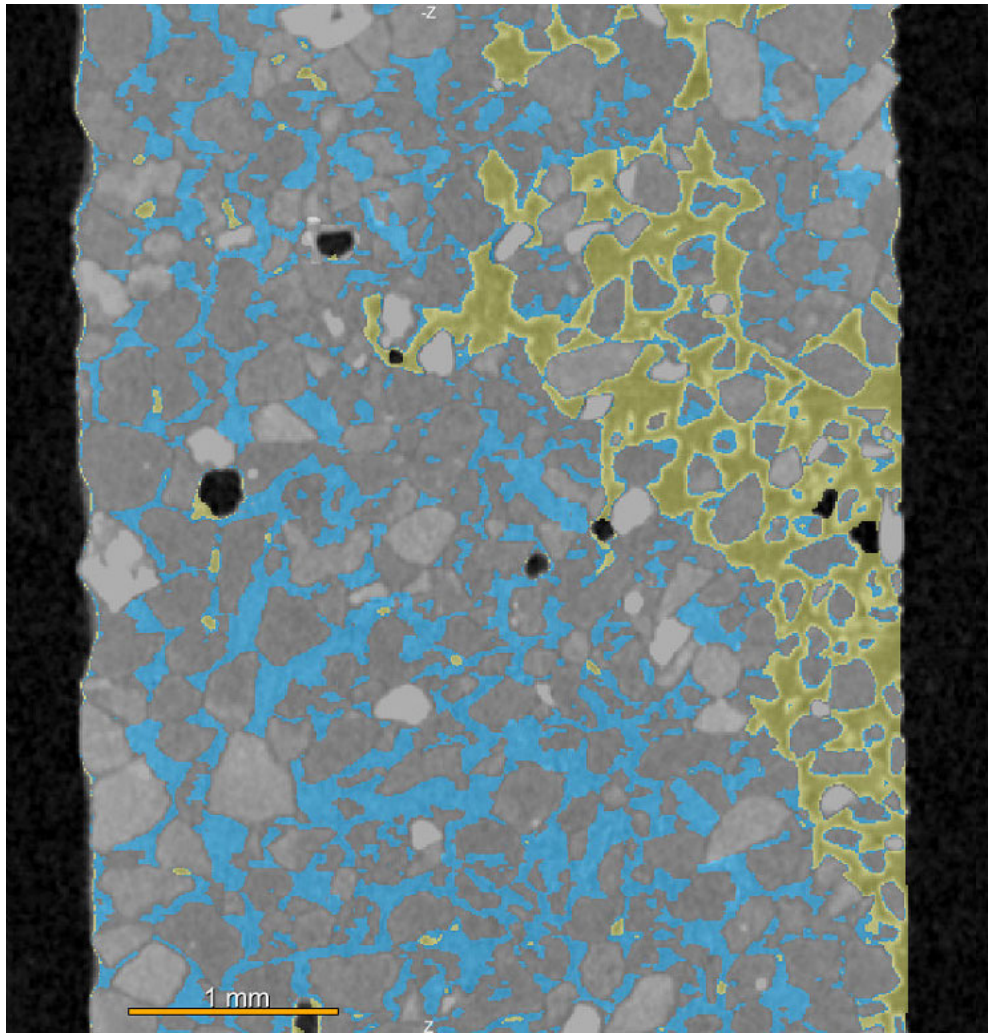


Packed sand + oil

25 min



Packed sand + oil + brine



GEOLOGY APPLICATIONS

- Pore structures
- Cracks and fractures
- Phase textures
- Grain size
- Formation process
- Weathering process
- Meteorites imaging
- Fossils imaging

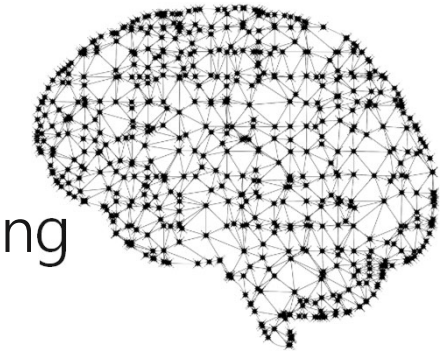
USEFUL RESOURCES

- Dragonfly webinars
  http://orss.ca/ytp2
- OpenPNM
  http://openpnm.org/

Introduction of
Radon transform
Johann Radon

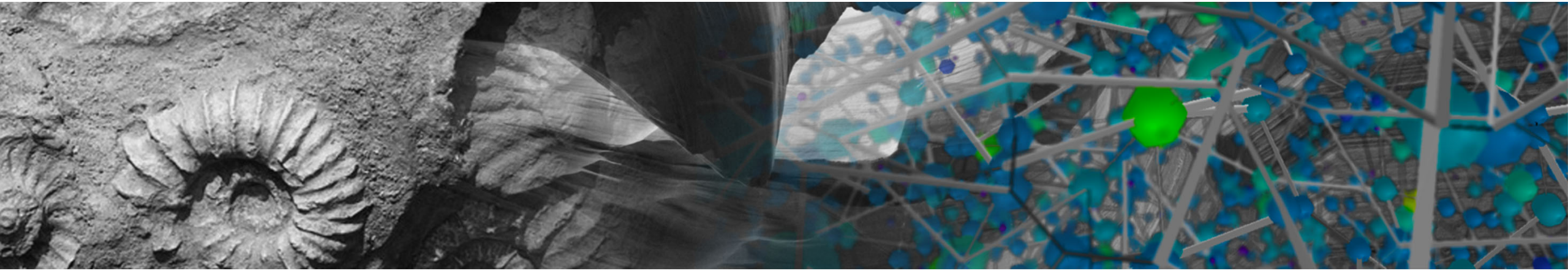
1940s
Neural network

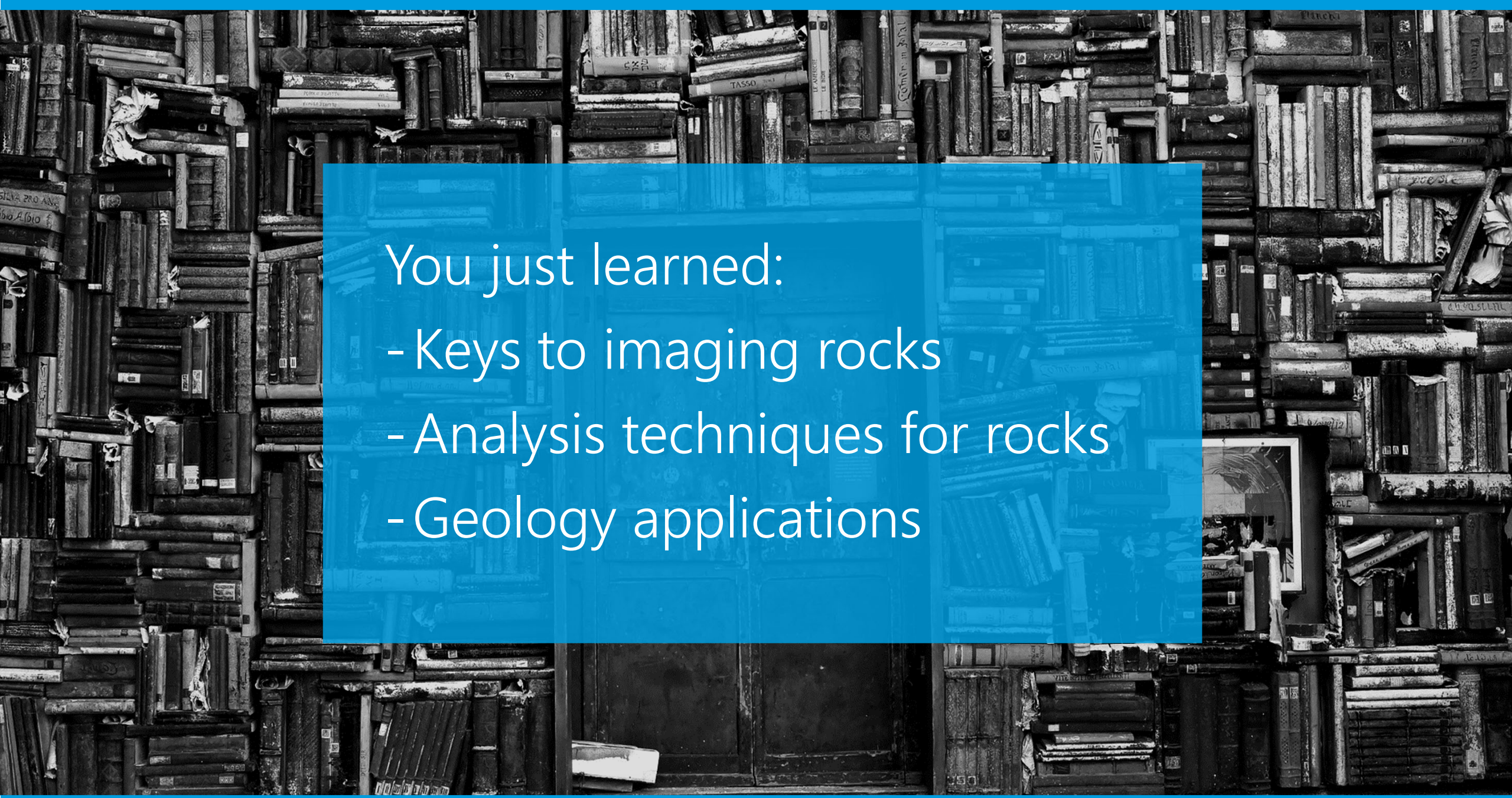
2000s
AI
Deep learning



1917

2020





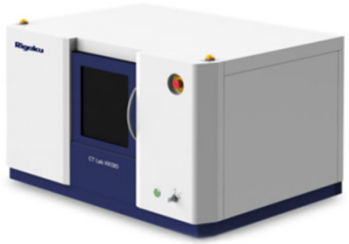
You just learned:

- Keys to imaging rocks
- Analysis techniques for rocks
- Geology applications

ALL IMAGES WERE COLLECTED ON…

nano3DX

CT Lab HX



CT Lab GX

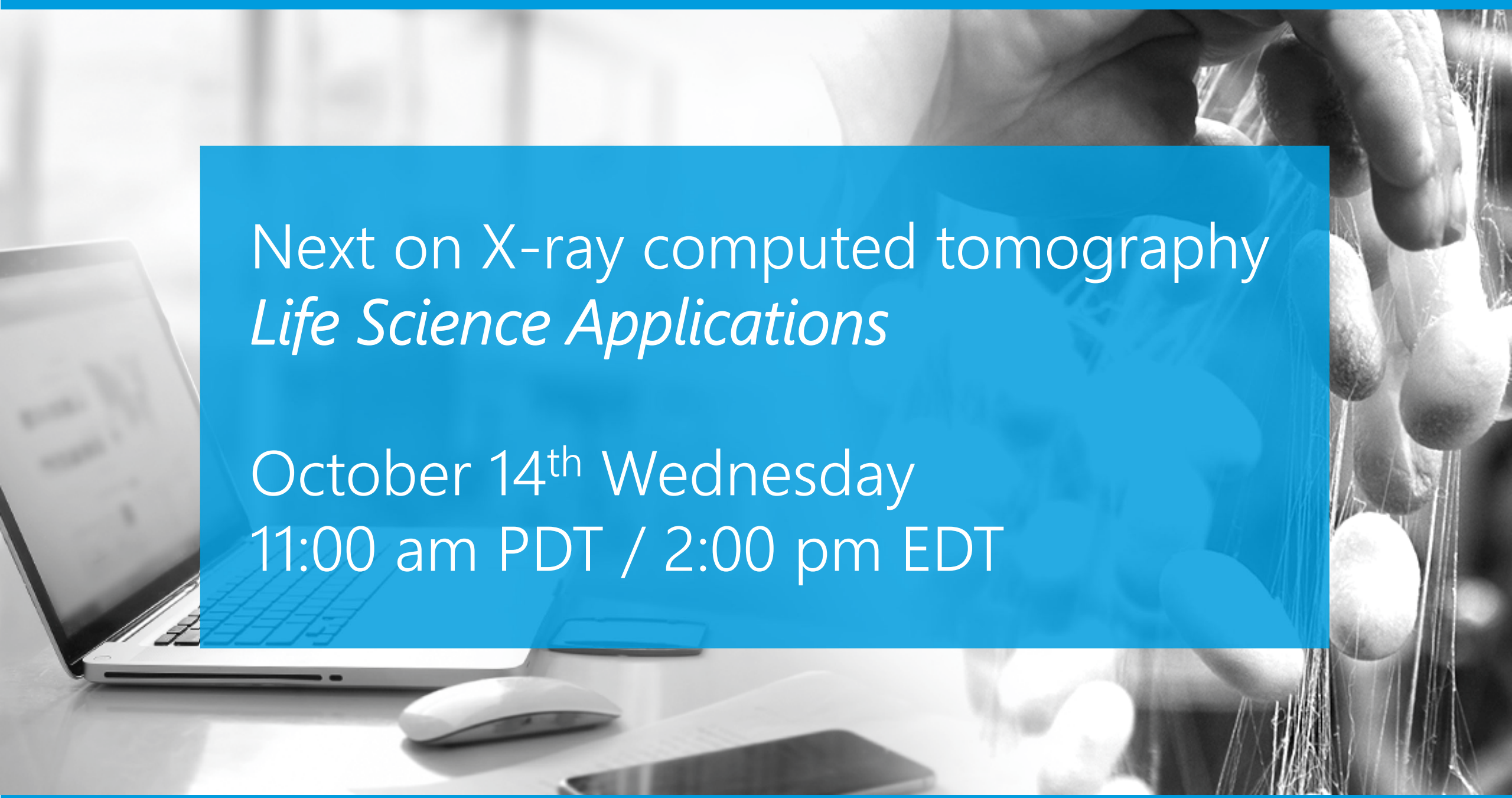
To learn more …


Rigaku.com → Contact

PREVIOUS WEBINARS

www.rigaku.com/en/webinars/x-ray_ct_introduction

Rigaku webinar



Next on X-ray computed tomography
Life Science Applications

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

https://www.rigaku.com/convention/

Q & A SESSION

Aya Takase

Tom McNulty

We'll follow up with your questions.

Recording will be available tomorrow.

Register for the 7th webinar.


THANK YOU FOR JOINING US
SEE YOU NEXT TIME!