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Micro-CT Scanning + 3D Image Analysis for Porosity Studies of Historic Bricks and Archaeological Ceramics

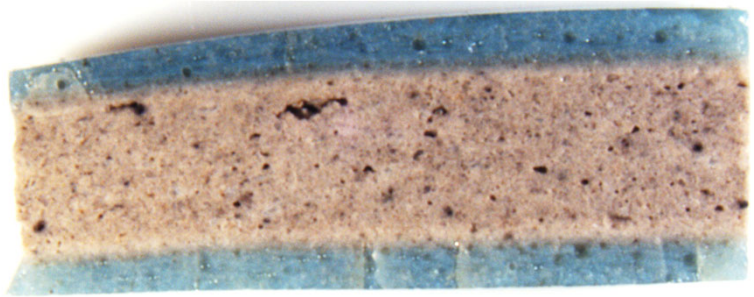
Chandra L. Reedy

Center for Historic Architecture and Design

UNIVERSITY OF DELAWARE

Joseph R. Biden, Jr. School of Public Policy & Administration

- Why study porosity in these materials?
- Issues in micro-CT scanning of historic bricks and archaeological ceramics
- Choices made for the image analysis protocols
- Additional issues with ceramic sherds and other remaining problems



Why study porosity in historic bricks and archaeological ceramics?

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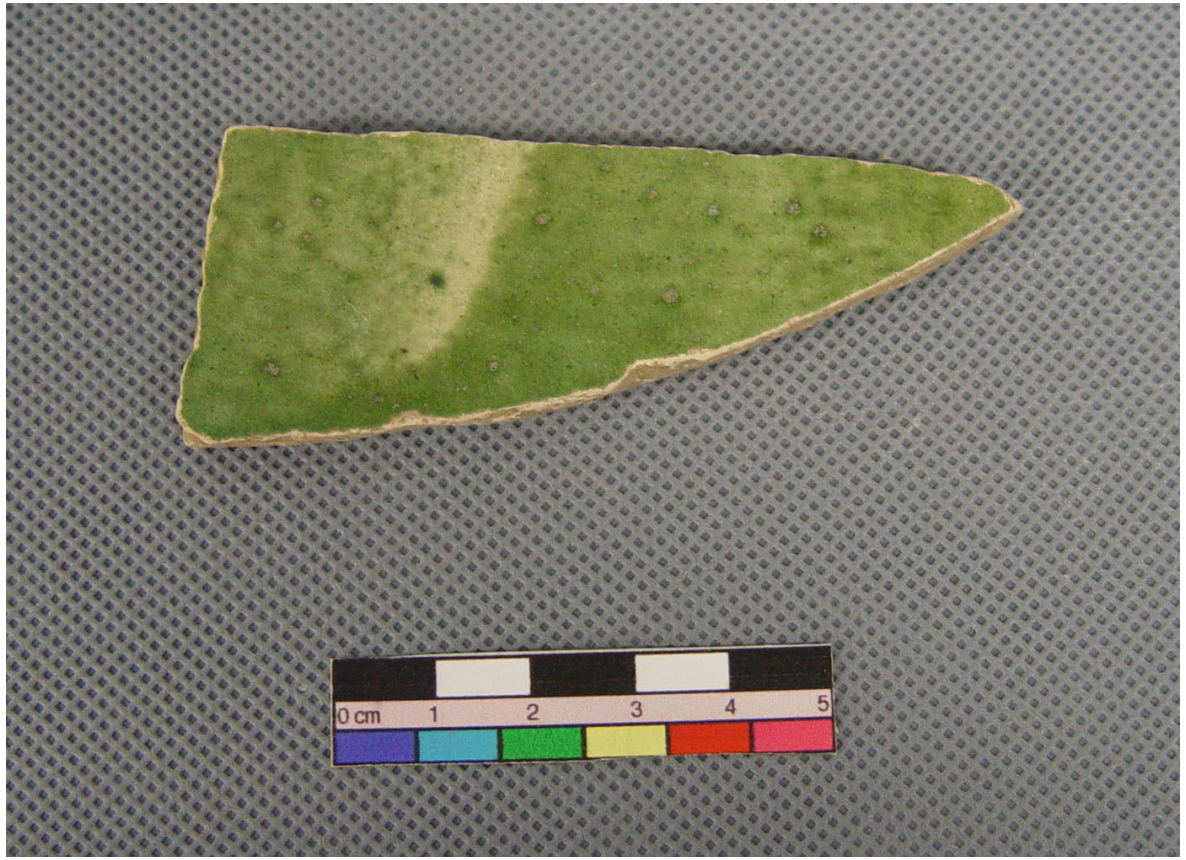
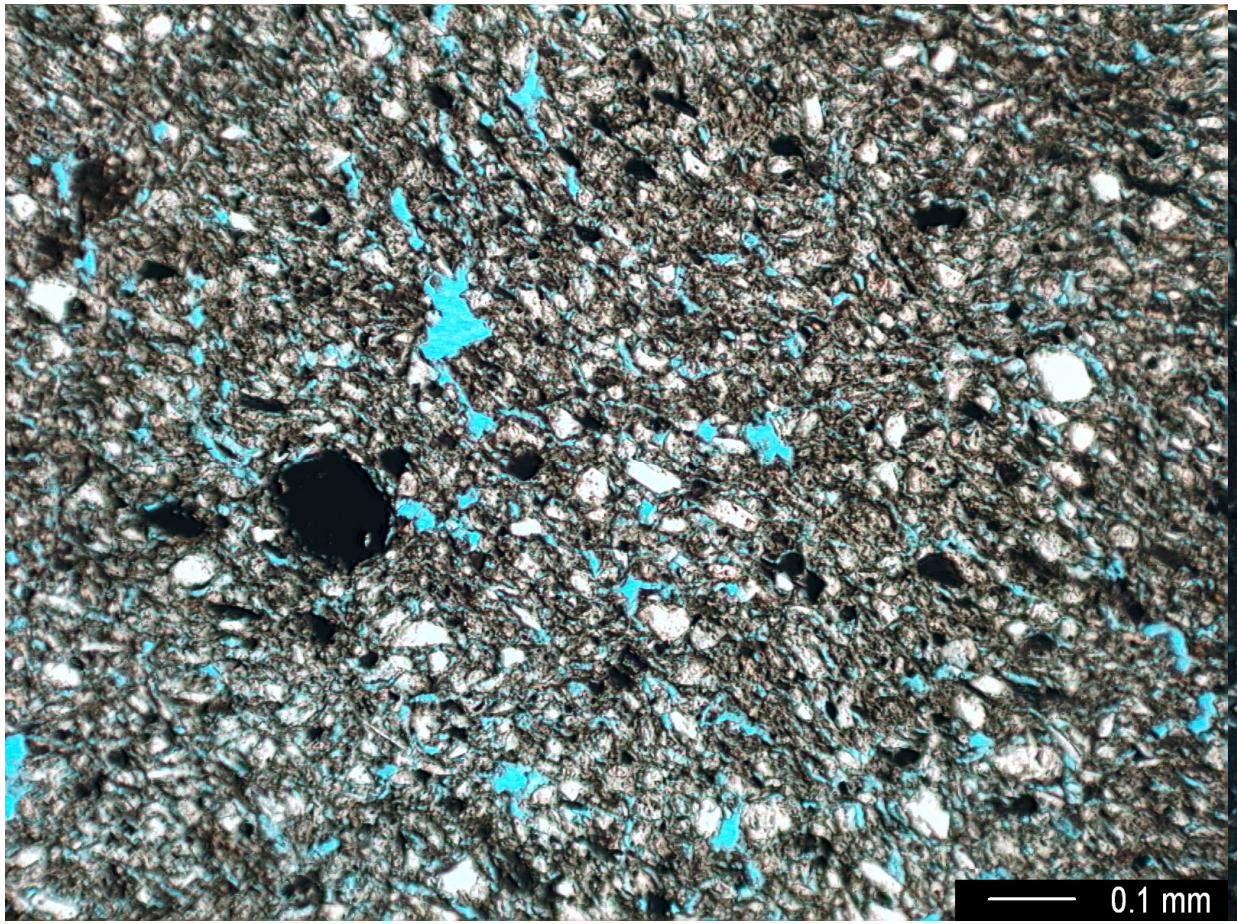
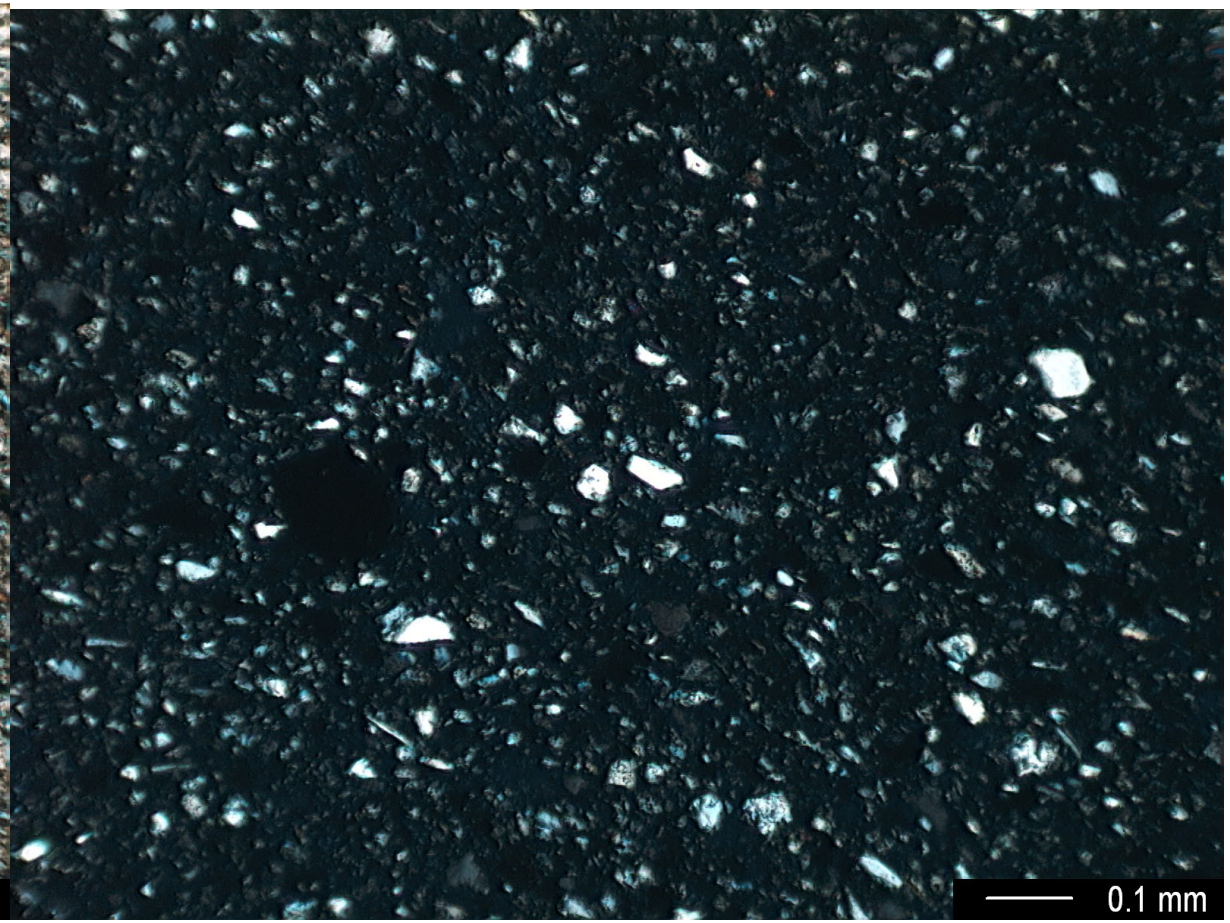


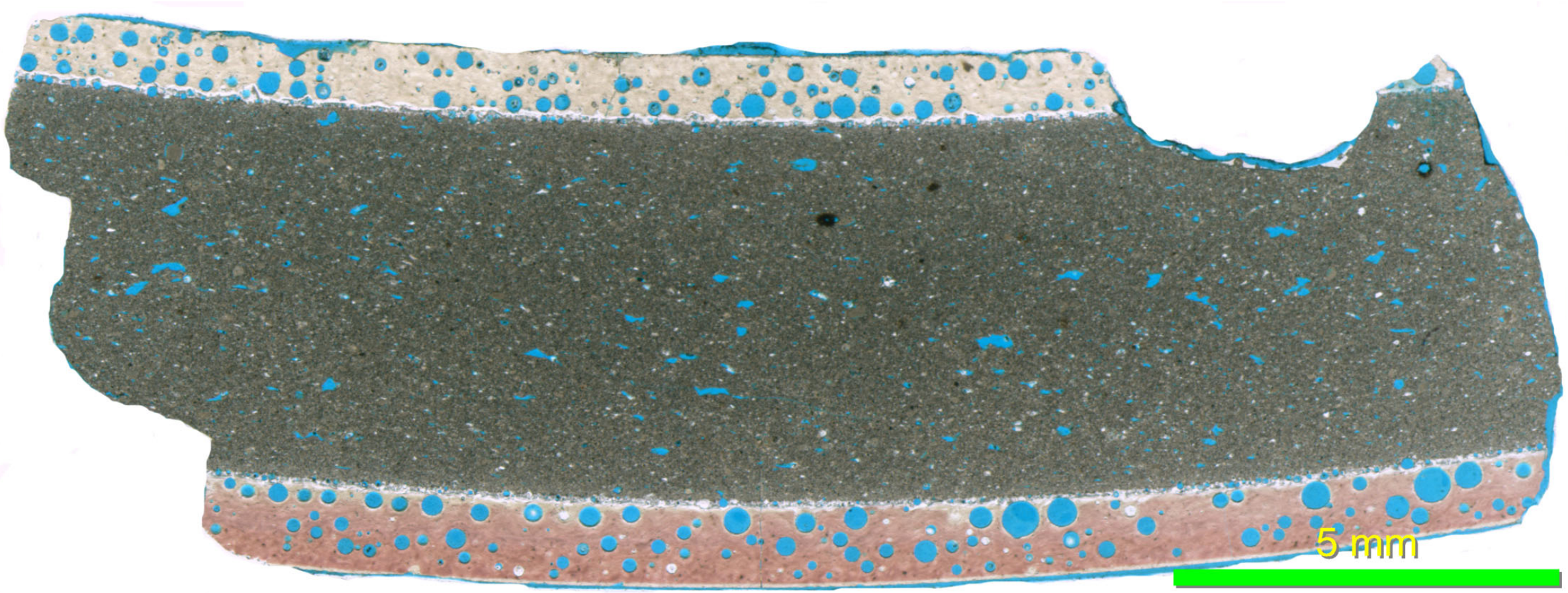
Thin-section Petrography (Chinese black tile)



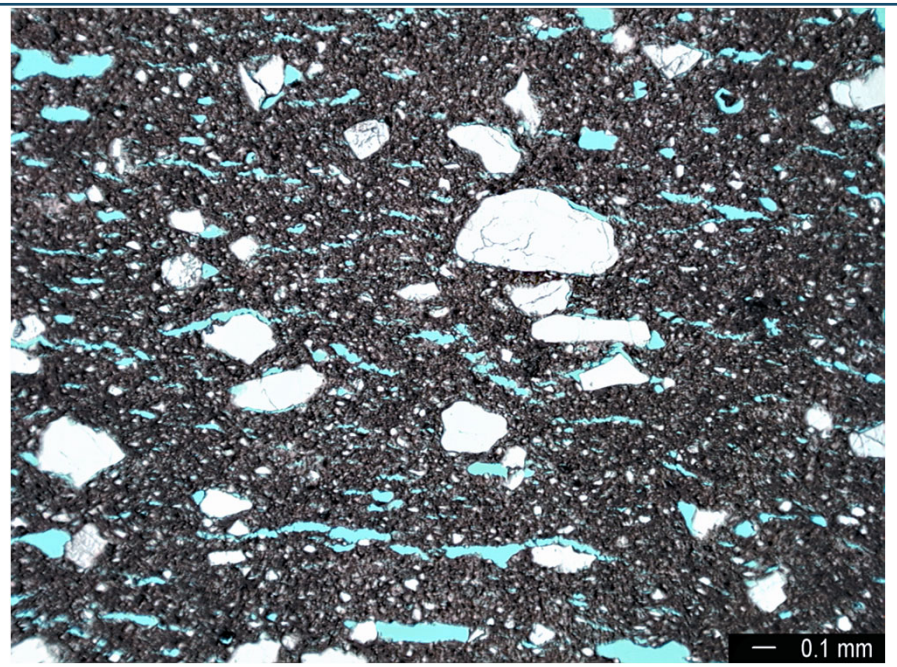
Plane polarized light

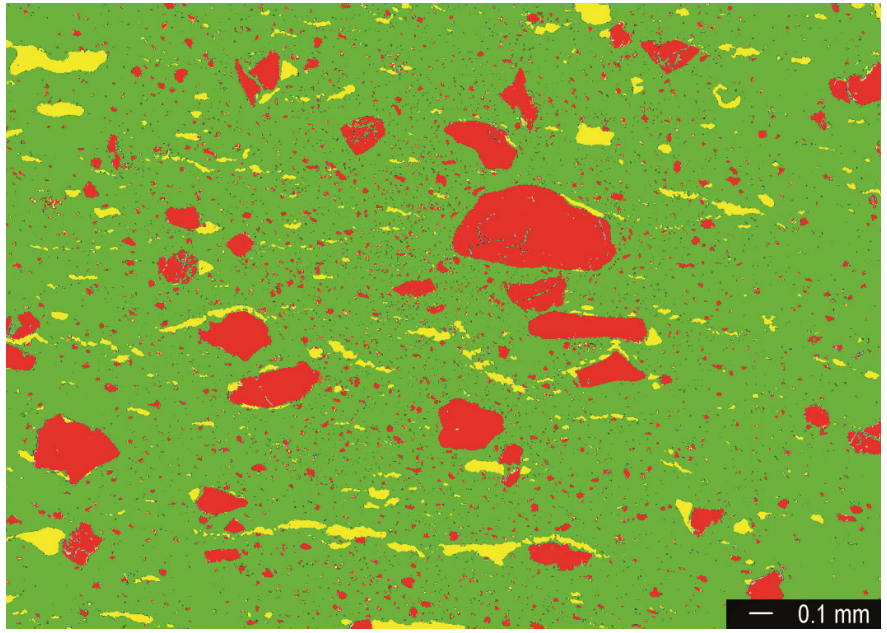


Crossed polarized light


5 mm

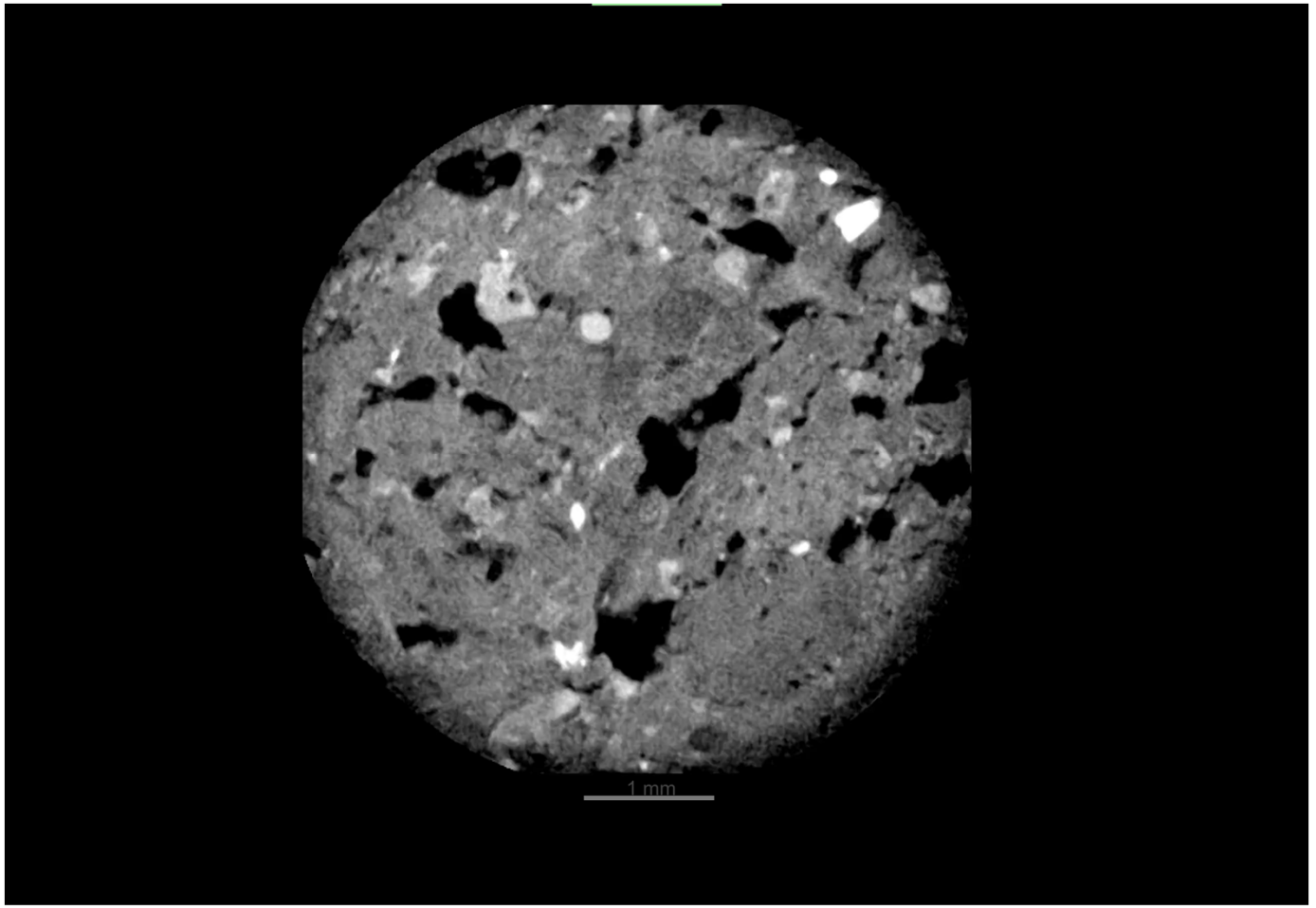
German stoneware ceramic, thin section with 2D image analysis



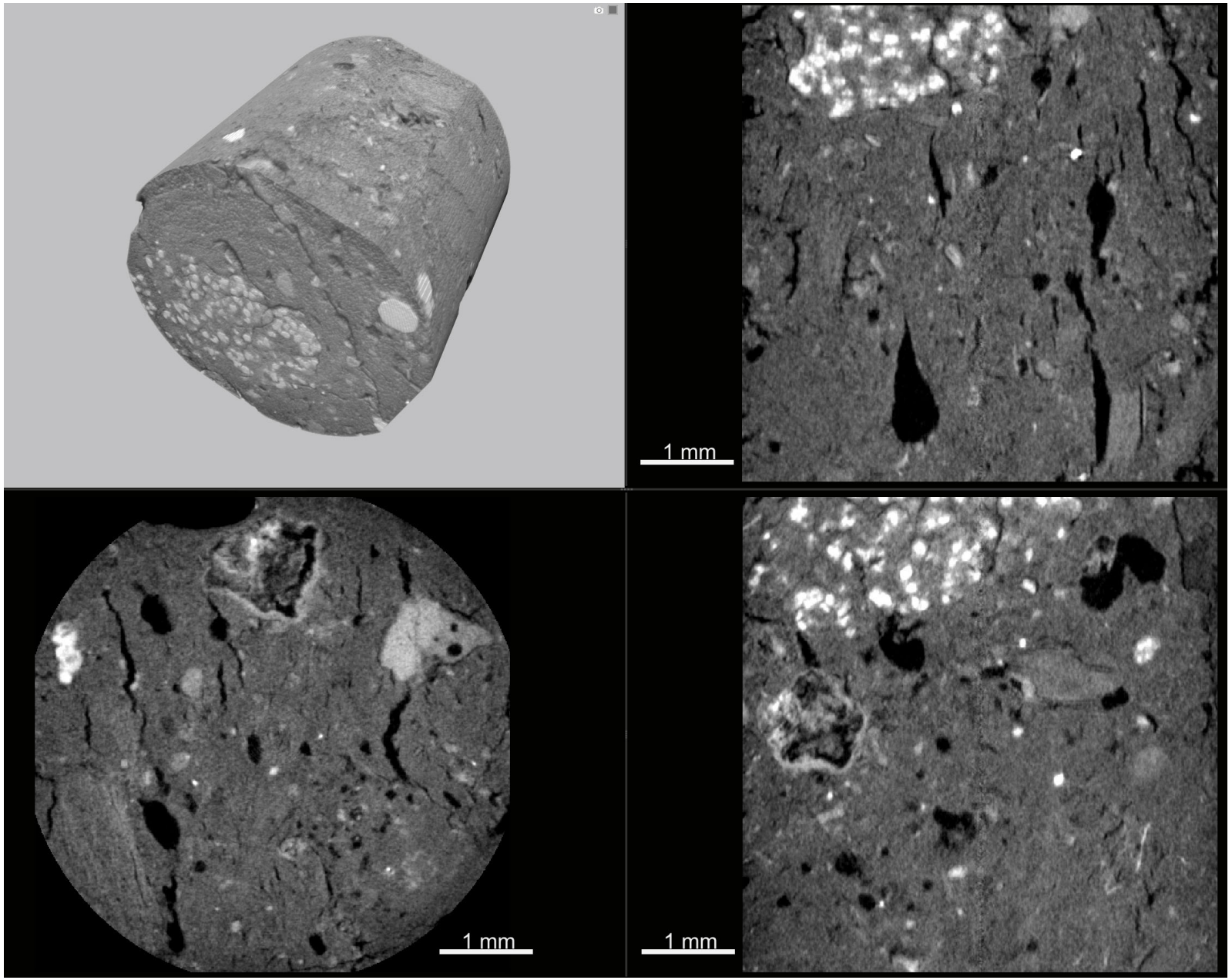


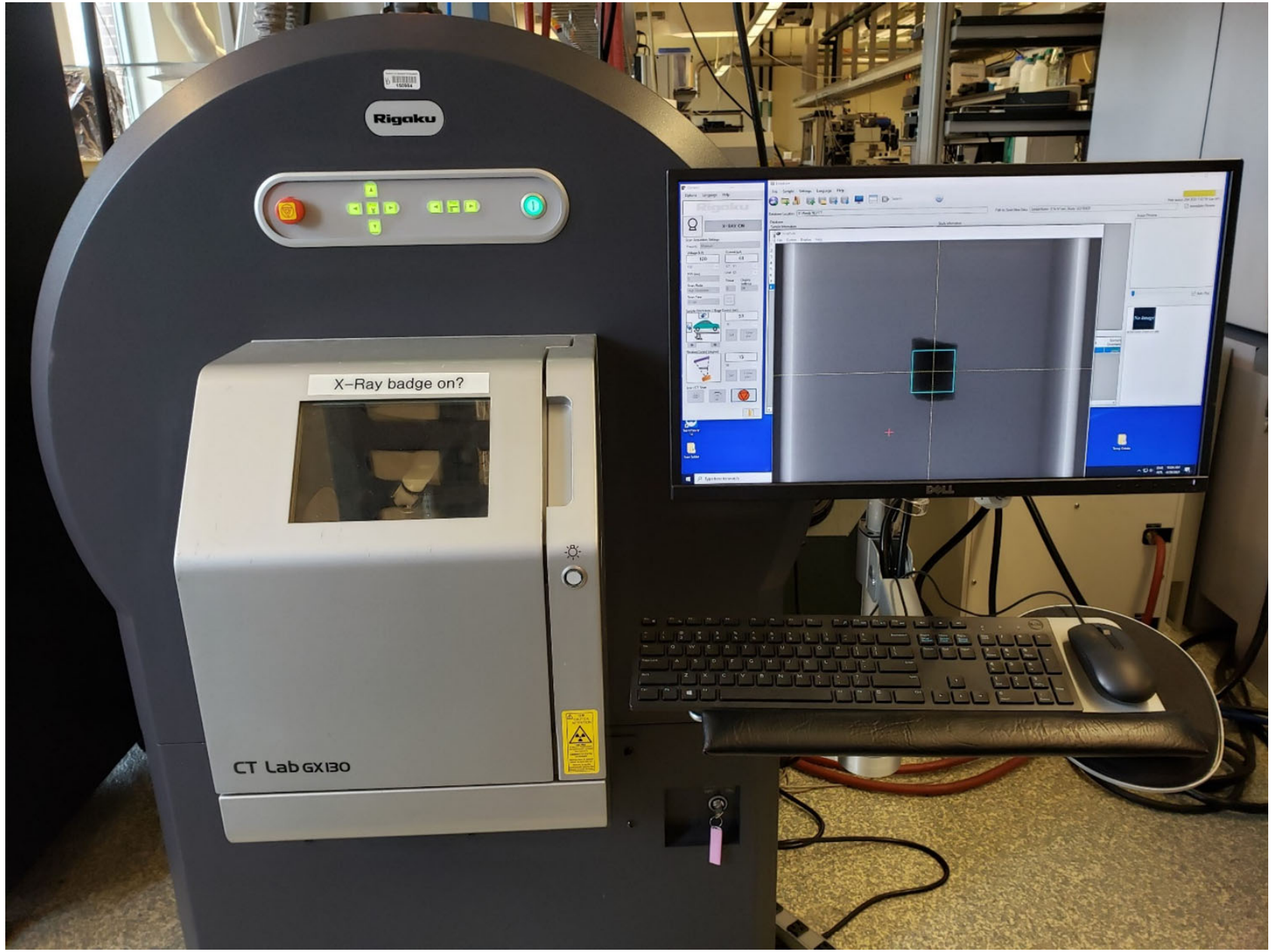
Sand 13% (red)
Pores 4% (yellow)
Clay 83% (green)

Micro-CT scan with 512 slices through a brick

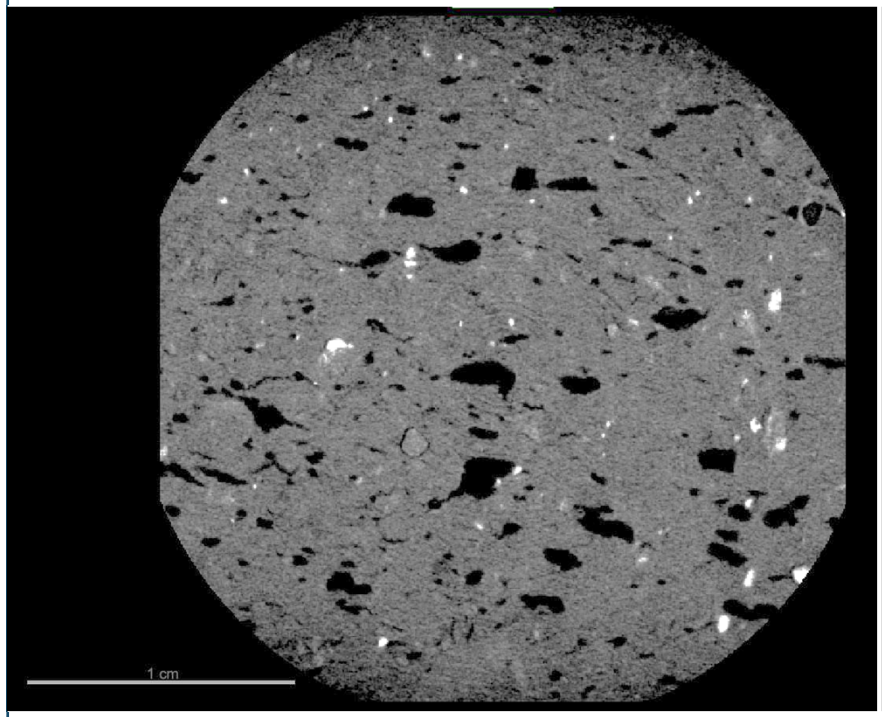


Micro-CT scan of a brick sample, 5x5 mm FOV



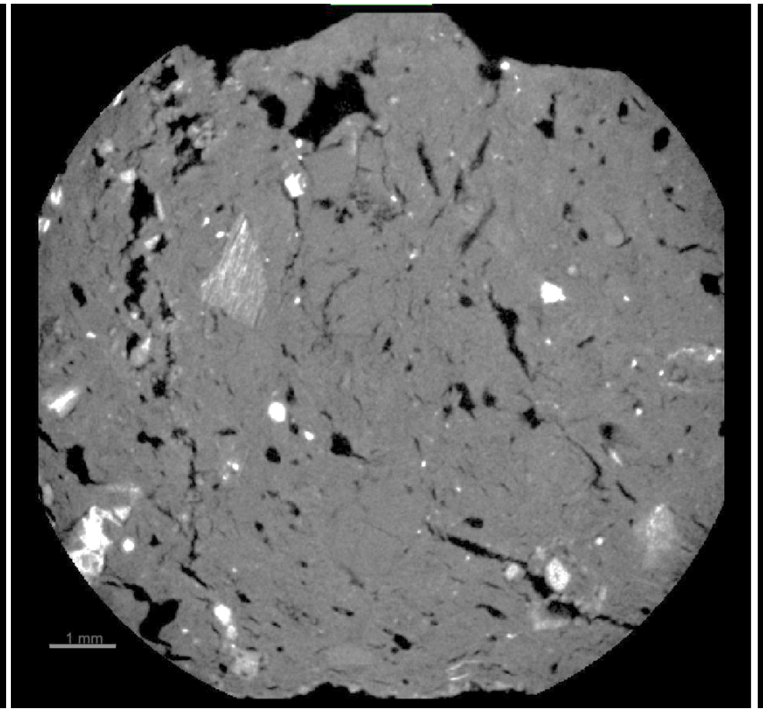

Rigaku
X-Ray badge on?
CT Lab GX130
DELL

25 x 25 mm FOV
57-minute scan



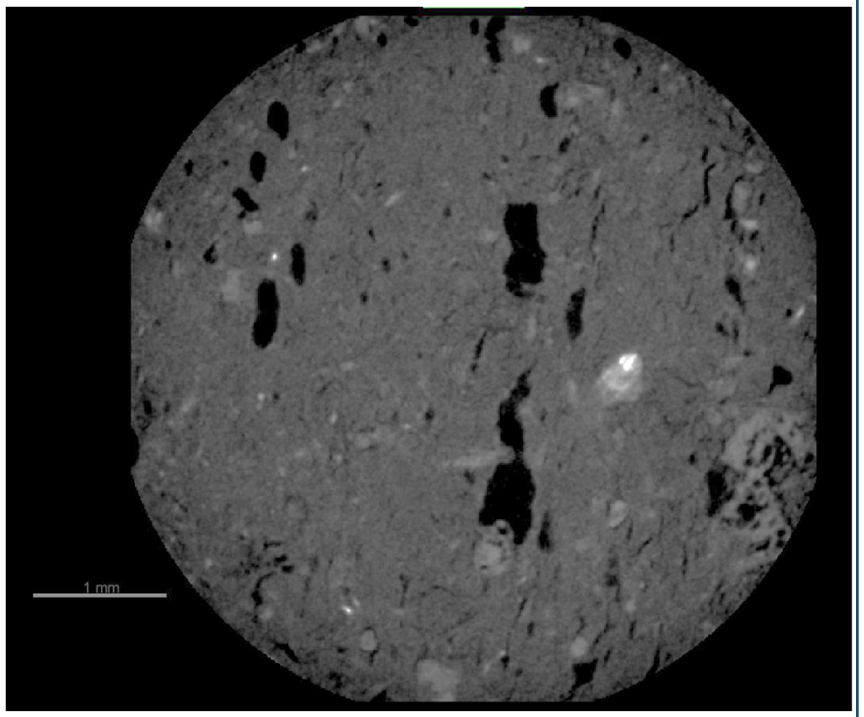
Spatial resolution = 50 μm

10 x 10 mm FOV
57-minute scan



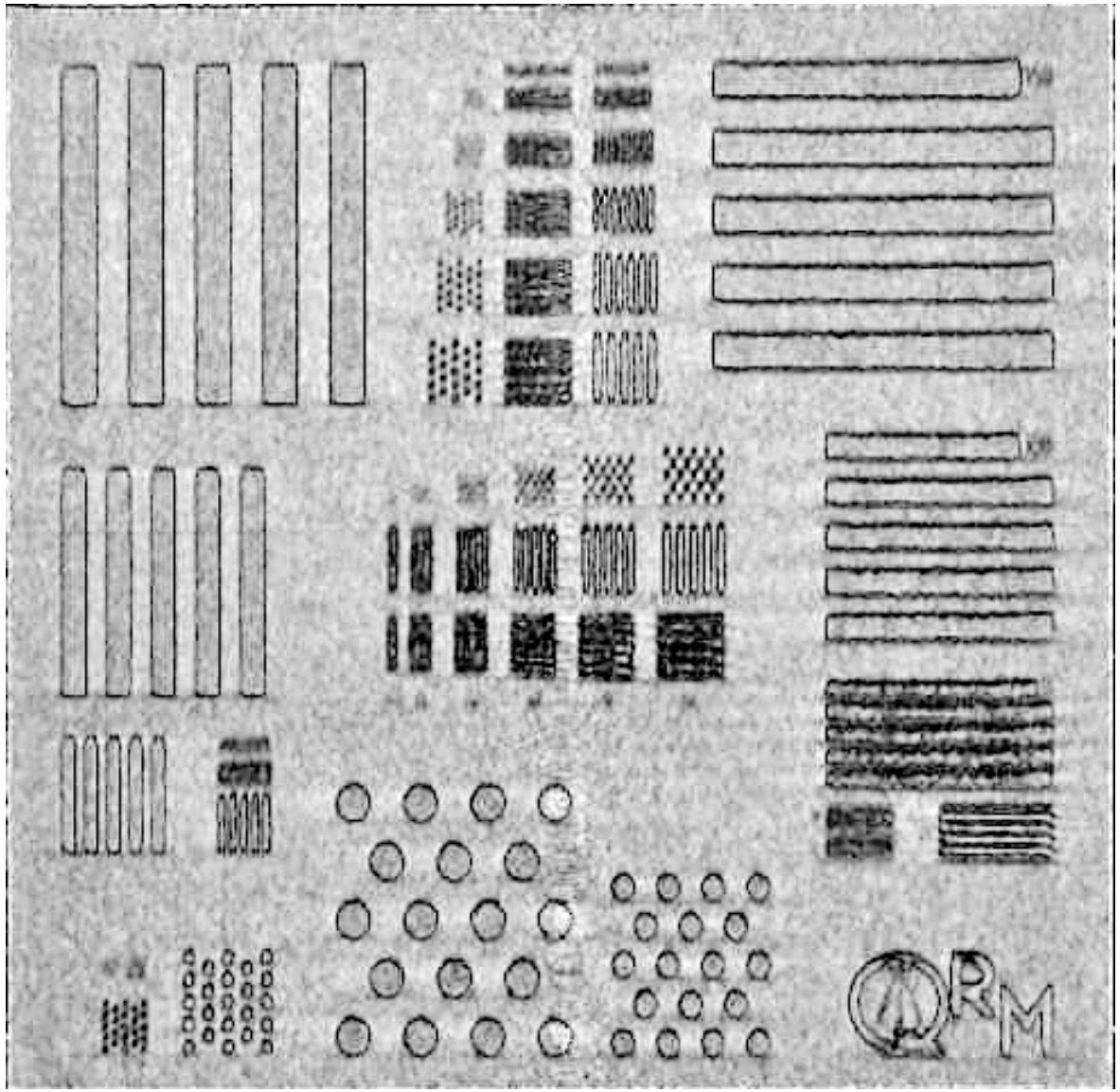
Spatial resolution = 20 μm

5 x 5 mm FOV
57-minute scan

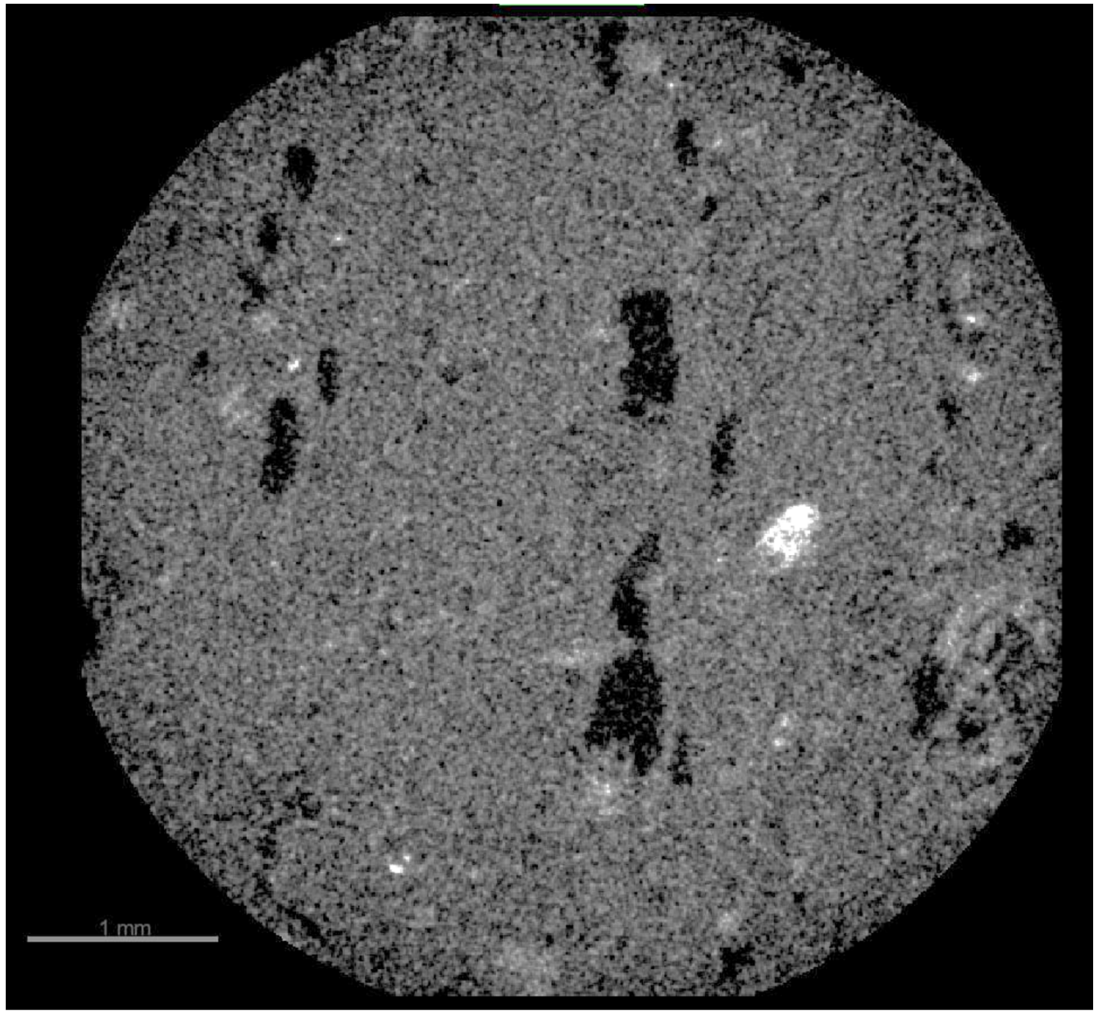


Spatial resolution = 10 μm

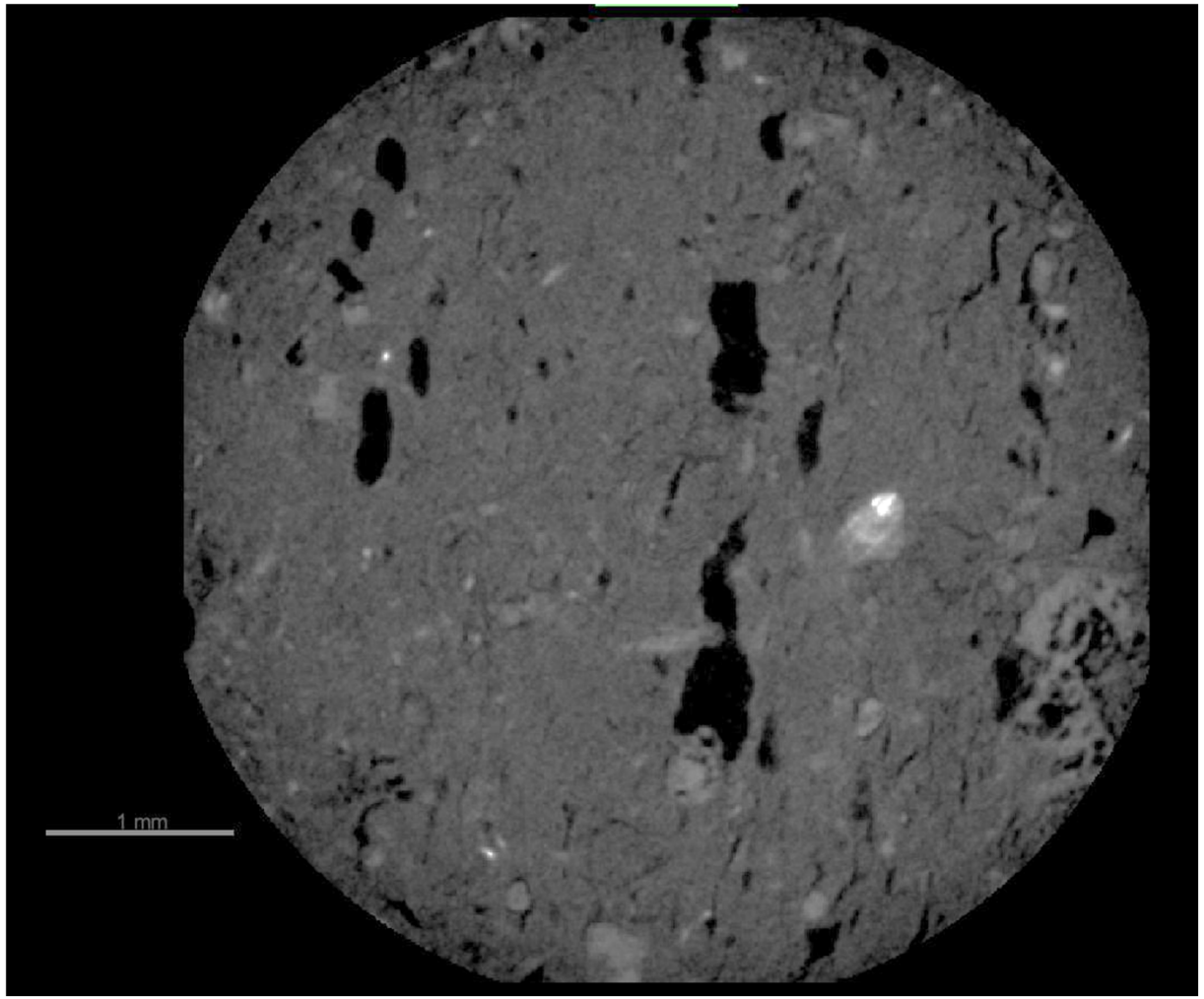
QRM micro-CT bar pattern chip phantom, scanned under same conditions as samples



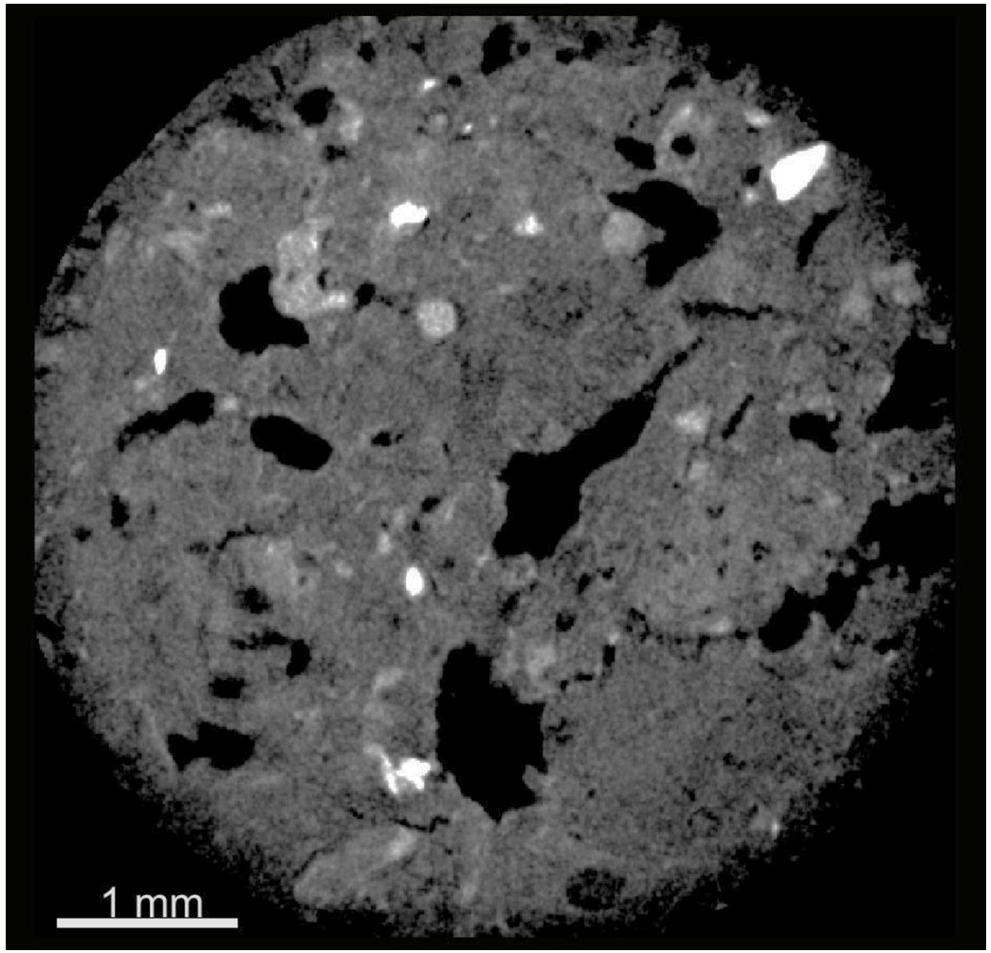
5 x 5 mm FOV, 4-minute scan



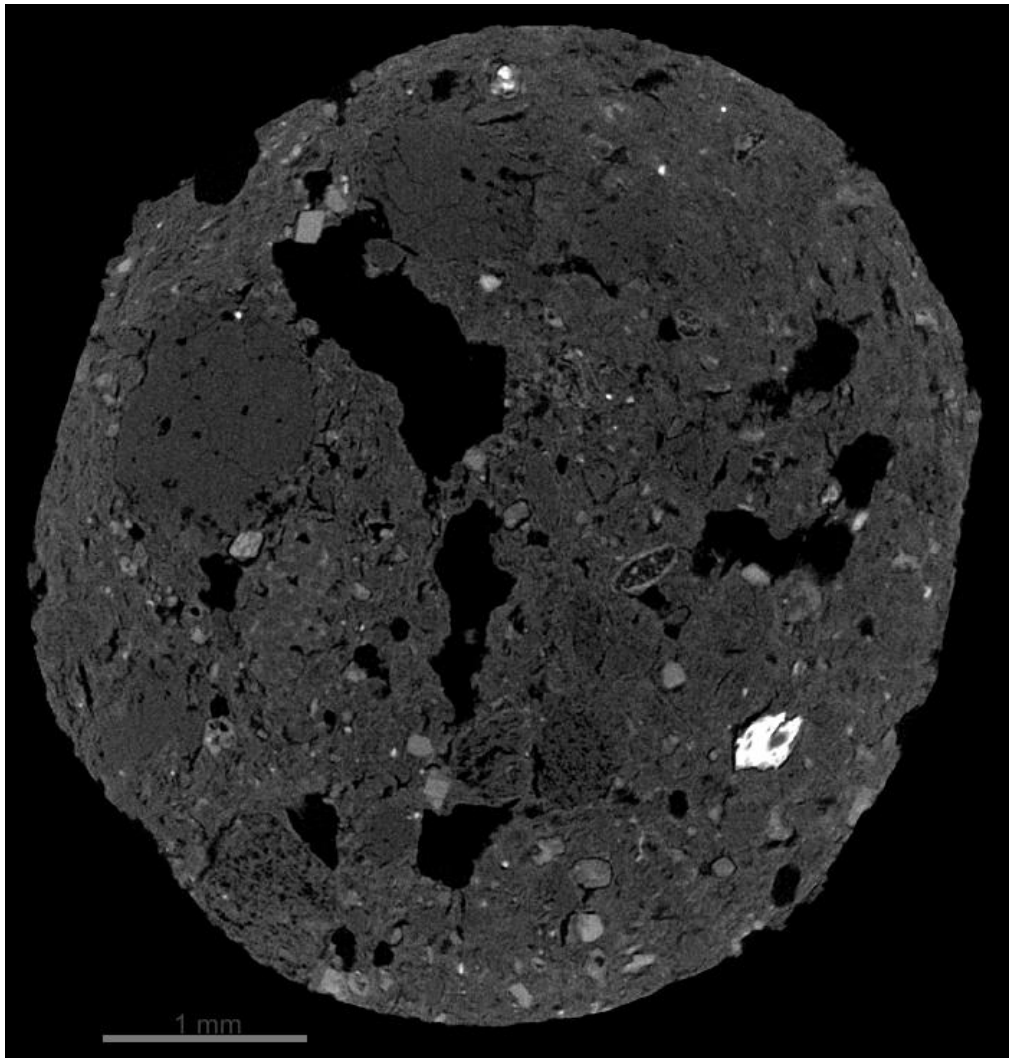
5 x 5 mm FOV, 57-minute scan

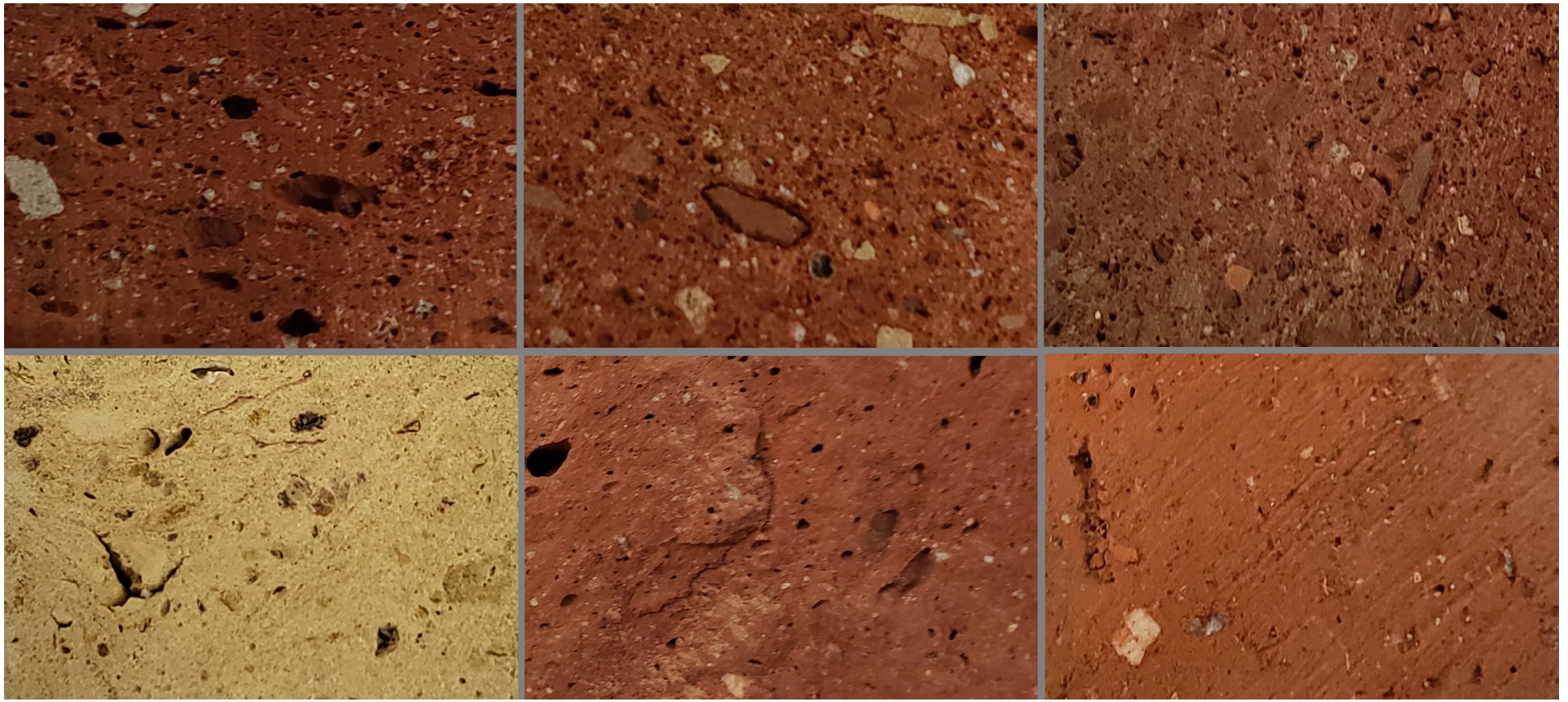


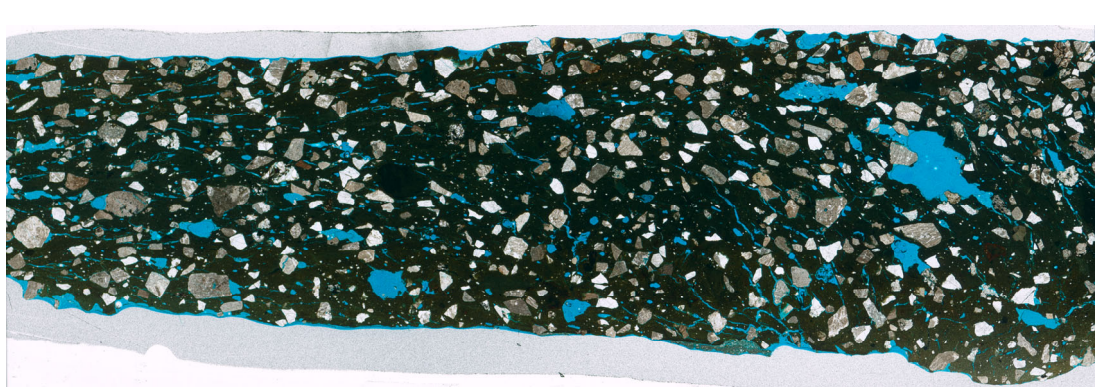
5 x 5 mm FOV, 10 µm

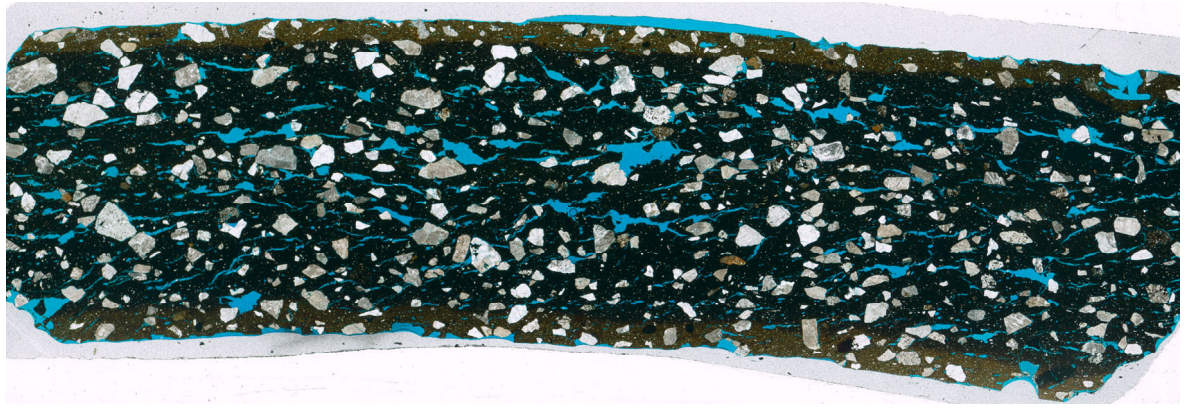


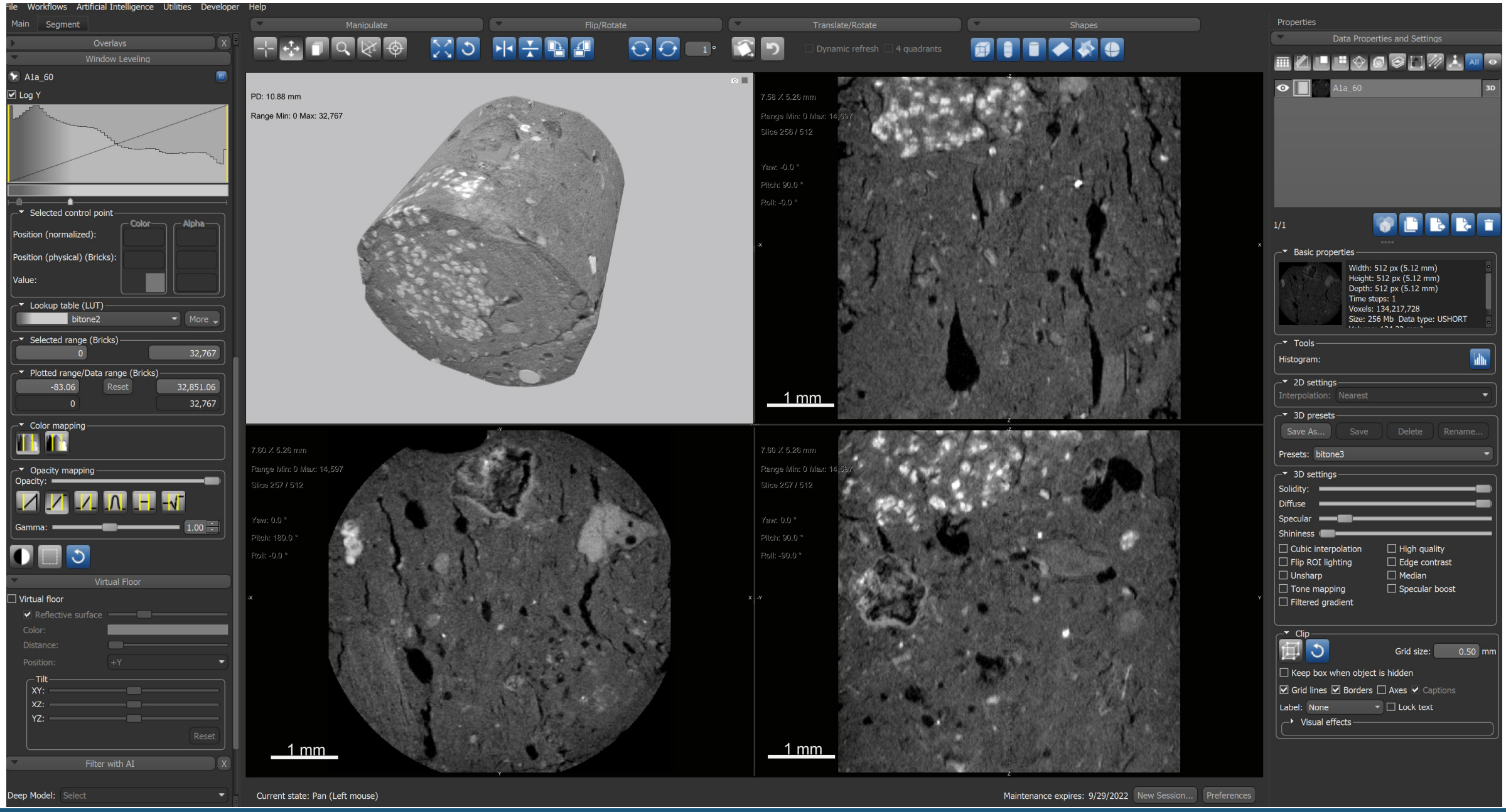
5 x 5 mm FOV, 2.13 µm







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Main Segment
Manipulate
Flip/Rotate
Translate/Rotate
Shapes
Dynamic refresh
4 quadrants
Overlays
Window Leveling
A1a_60
Log Y
Selected control point
Color
Alpha
Position (normalized):
Position (physical) (Bricks):
Value:
Lookup table (LUT)
bitone2
More
Selected range (Bricks)
0
32,767
Plotted range/Data range (Bricks)
-83.06
Reset
32,851.06
0
32,767
Color mapping
Opacity mapping
Opacity:
Gamma:
1.00
Virtual Floor
Virtual floor
Reflective surface
Color:
Distance:
Position:
+Y
Tilt
XY:
XZ:
YZ:
Reset
Filter with AI
Deep Model:
Select
PD: 10.88 mm
Range Min: 0 Max: 32,767
7.58 X 5.26 mm
Range Min: 0 Max: 14,597
Slice 256 / 512
Yaw: -0.0 °
Pitch: 90.0 °
Roll: -0.0 °
1 mm
7.60 X 5.26 mm
Range Min: 0 Max: 14,597
Slice 257 / 512
Yaw: 0.0 °
Pitch: 180.0 °
Roll: -0.0 °
1 mm
Yaw: 0.0 °
Pitch: 90.0 °
Roll: -90.0 °
1 mm
Current state: Pan (Left mouse)
Maintenance expires: 9/29/2022
New Session...
Preferences
Properties
Data Properties and Settings
A1a_60
1/1
Basic properties
Width: 512 px (5.12 mm)
Height: 512 px (5.12 mm)
Depth: 512 px (5.12 mm)
Time steps: 1
Voxels: 134,217,728
Size: 256 Mb Data type: USHORT
Tools
Histogram:
2D settings
Interpolation: Nearest
3D presets
Save As...
Save
Delete
Rename...
Presets: bitone3
3D settings
Solidity:
Diffuse
Specular
Shininess
Cubic interpolation
High quality
Flip ROI lighting
Edge contrast
Unsharp
Median
Tone mapping
Specular boost
Filtered gradient
Clip
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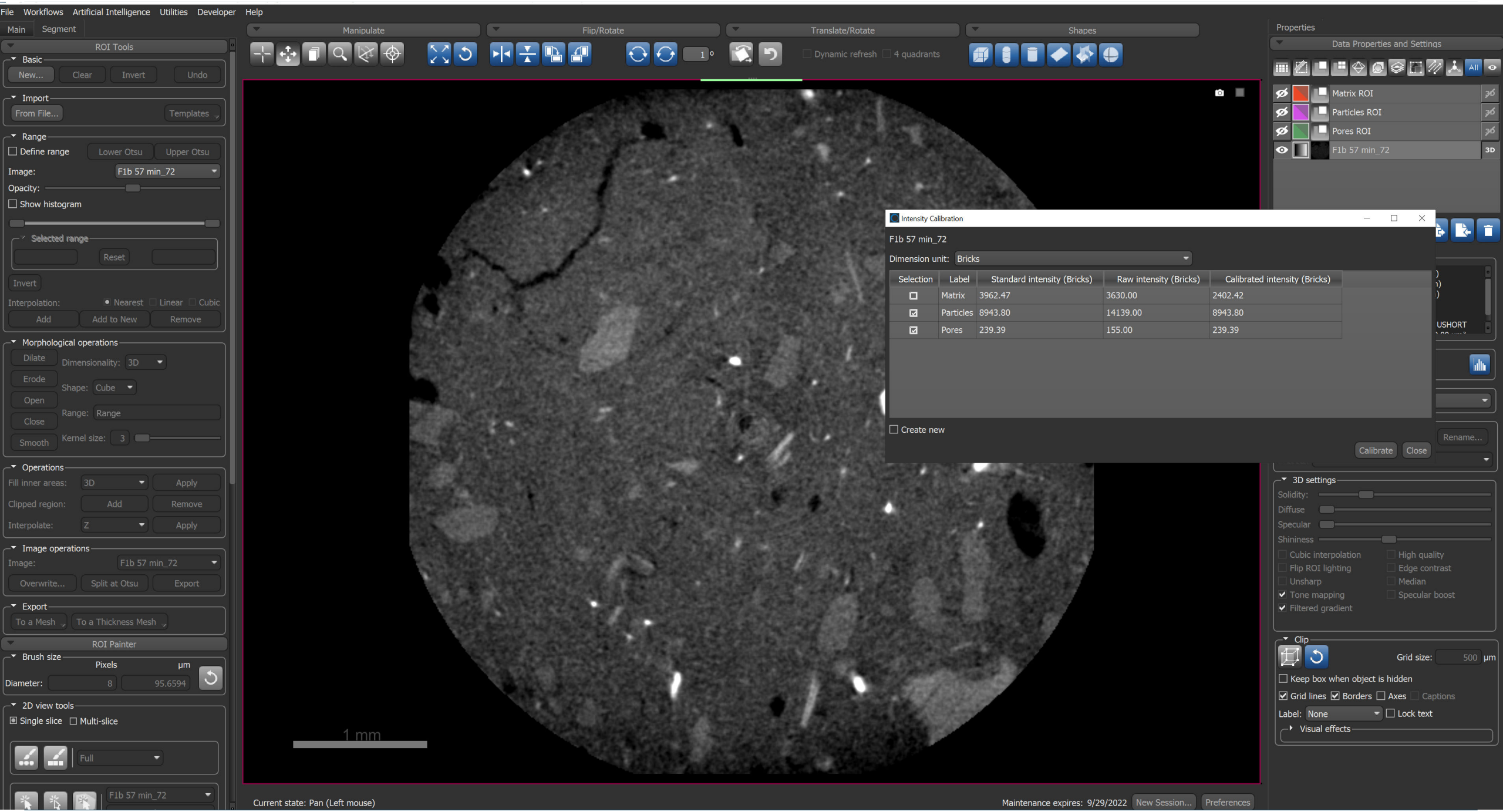
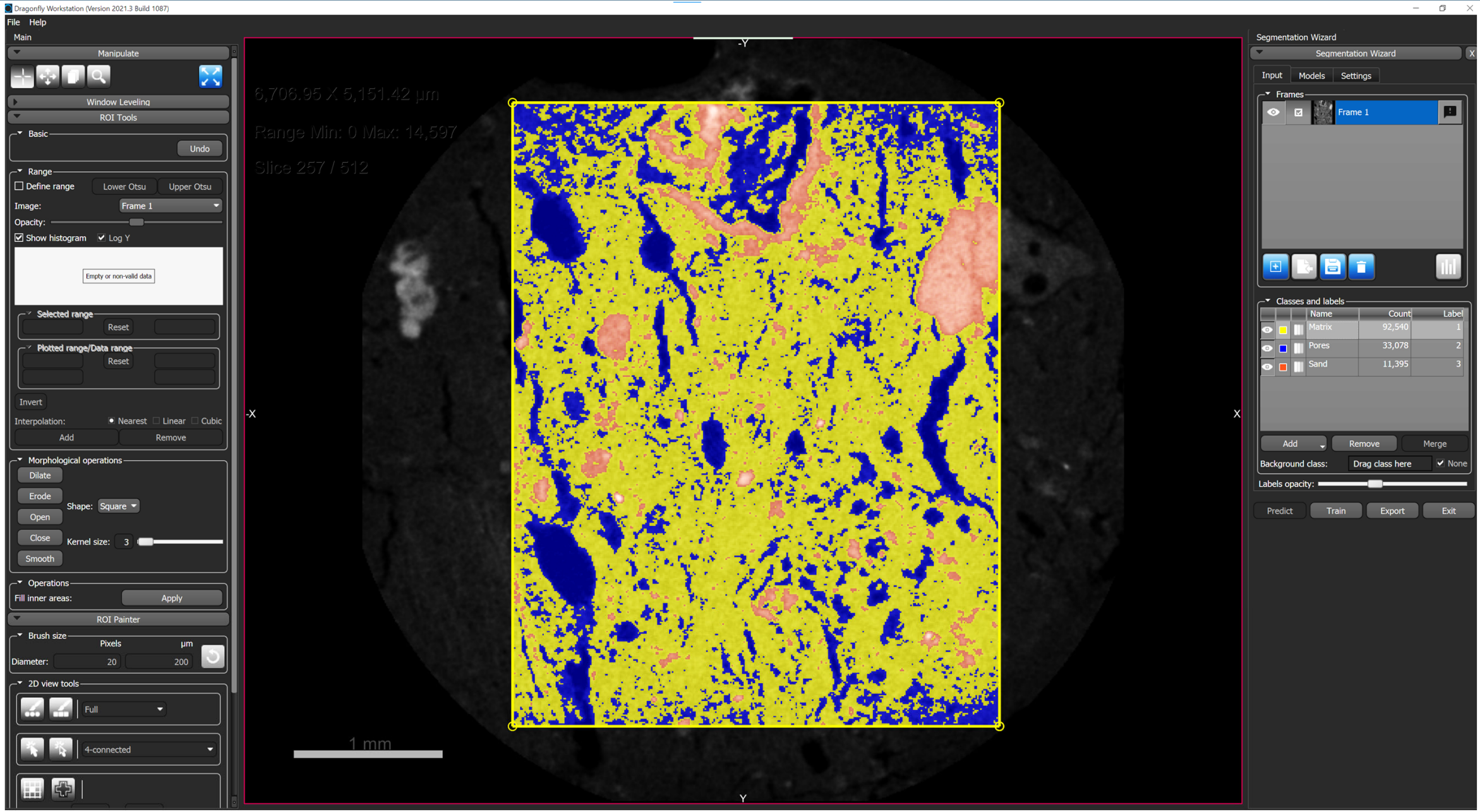
Keep box when object is hidden
Grid lines
Borders
Axes
Captions
Label: None
Lock text
Visual effects


File Workflows Artificial Intelligence Utilities Developer Help
Main Segment
Manipulate
Flip/Rotate
Translate/Rotate
Shapes
Properties
ROI Tools
Basic
New... Clear Invert Undo
Import
From File... Templates
Range
Define range Lower Otsu Upper Otsu
Image: F1b 57 min_72
Opacity:
Show histogram
Selected range
Reset
Invert
Interpolation: Nearest Linear Cubic
Add Add to New Remove
Morphological operations
Dilate
Erode
Open
Close
Smooth
Dimensionality: 3D
Shape: Cube
Range: Range
Kernel size: 3
Operations
Fill inner areas: 3D Apply
Clipped region: Add Remove
Interpolate: Z Apply
Image operations
Image: F1b 57 min_72
Overwrite... Split at Otsu Export
Export
To a Mesh To a Thickness Mesh
ROI Painter
Brush size
Pixels µm
Diameter: 8 95.6594
2D view tools
Single slice Multi-slice
Full
F1b 57 min_72
Data Properties and Settings
Matrix ROI
Particles ROI
Pores ROI
F1b 57 min_72
3D
Intensity Calibration
F1b 57 min_72
Dimension unit: Bricks
Selection Label Standard intensity (Bricks) Raw intensity (Bricks) Calibrated intensity (Bricks)
Matrix 3962.47 3630.00 2402.42
Particles 8943.80 14139.00 8943.80
Pores 239.39 155.00 239.39
Create new
Calibrate Close
Rename...
USHORT
3D settings
Solidity:
Diffuse
Specular
Shininess
Cubic interpolation High quality
Flip ROI lighting Edge contrast
Unsharp Median
Tone mapping Specular boost
Filtered gradient
Clip
Grid size: 500 µm
Keep box when object is hidden
Grid lines Borders Axes Captions
Label: None Lock text
Visual effects
1 mm
Current state: Pan (Left mouse)
Maintenance expires: 9/29/2022 New Session... Preferences


Dragonfly Workstation (Version 2021.3 Build 1087)
File Help
Main
Manipulate
Window Leveling
ROI Tools
Basic
Undo
Range
Define range
Lower Otsu
Upper Otsu
Image:
Frame 1
Opacity:
Show histogram
Log Y
Empty or non-valid data
Selected range
Reset
Plotted range/Data range
Reset
Invert
Interpolation:
Nearest
Linear
Cubic
Add
Remove
Morphological operations
Dilate
Erode
Shape:
Square
Open
Close
Kernel size:
3
Smooth
Operations
Fill inner areas:
Apply
ROI Painter
Brush size
Pixels
µm
Diameter:
20
200
2D view tools
Full
4-connected
6,706.95 X 5,151.42 µm
Range Min: 0 Max: 14,597
Slice 257 / 512
-Y
-X
X
Y
1 mm
Segmentation Wizard
Segmentation Wizard
Input
Models
Settings
Frames
Frame 1
Classes and labels
Name
Count
Label
Matrix
92,540
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Pores
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2
Sand
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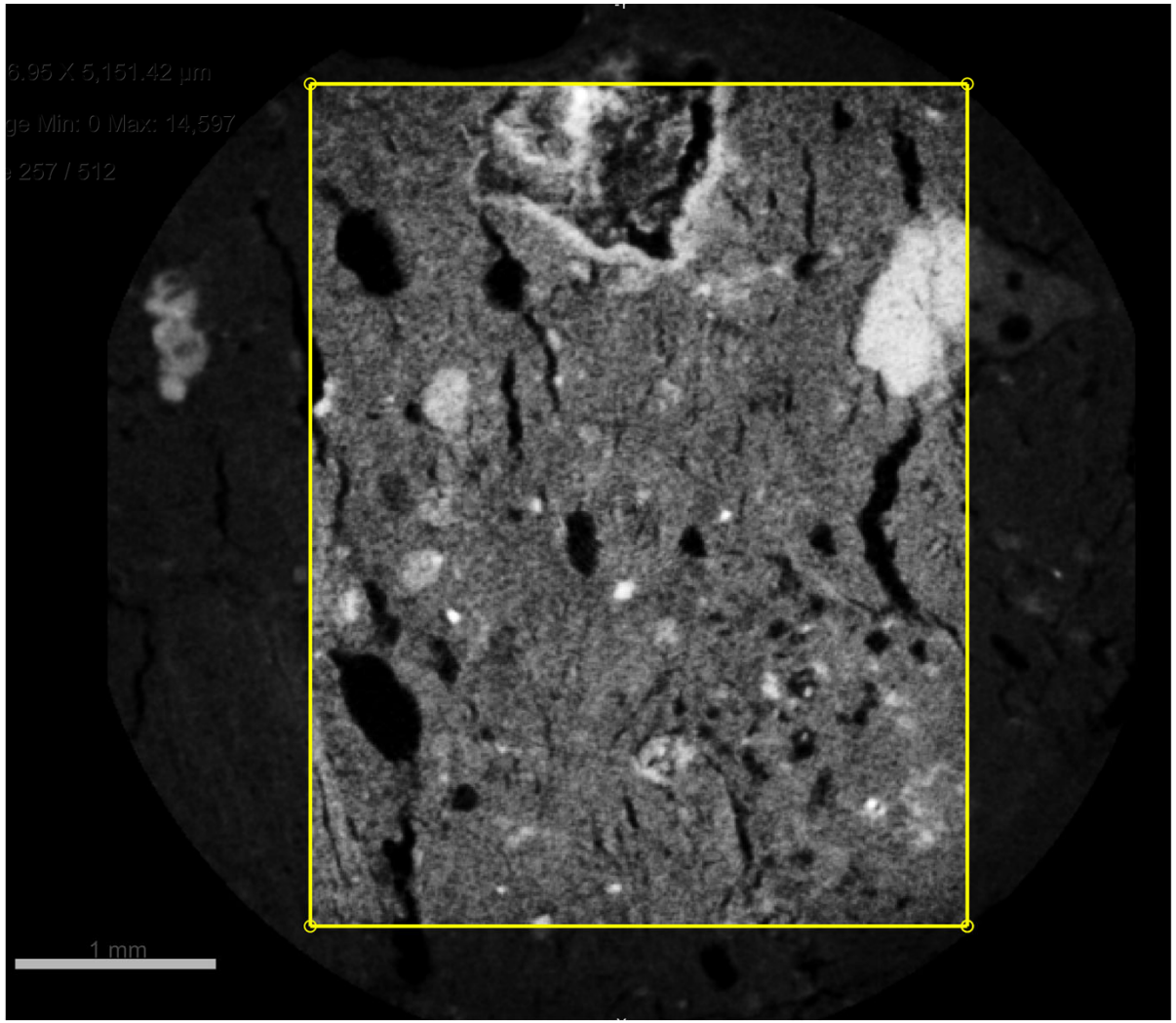
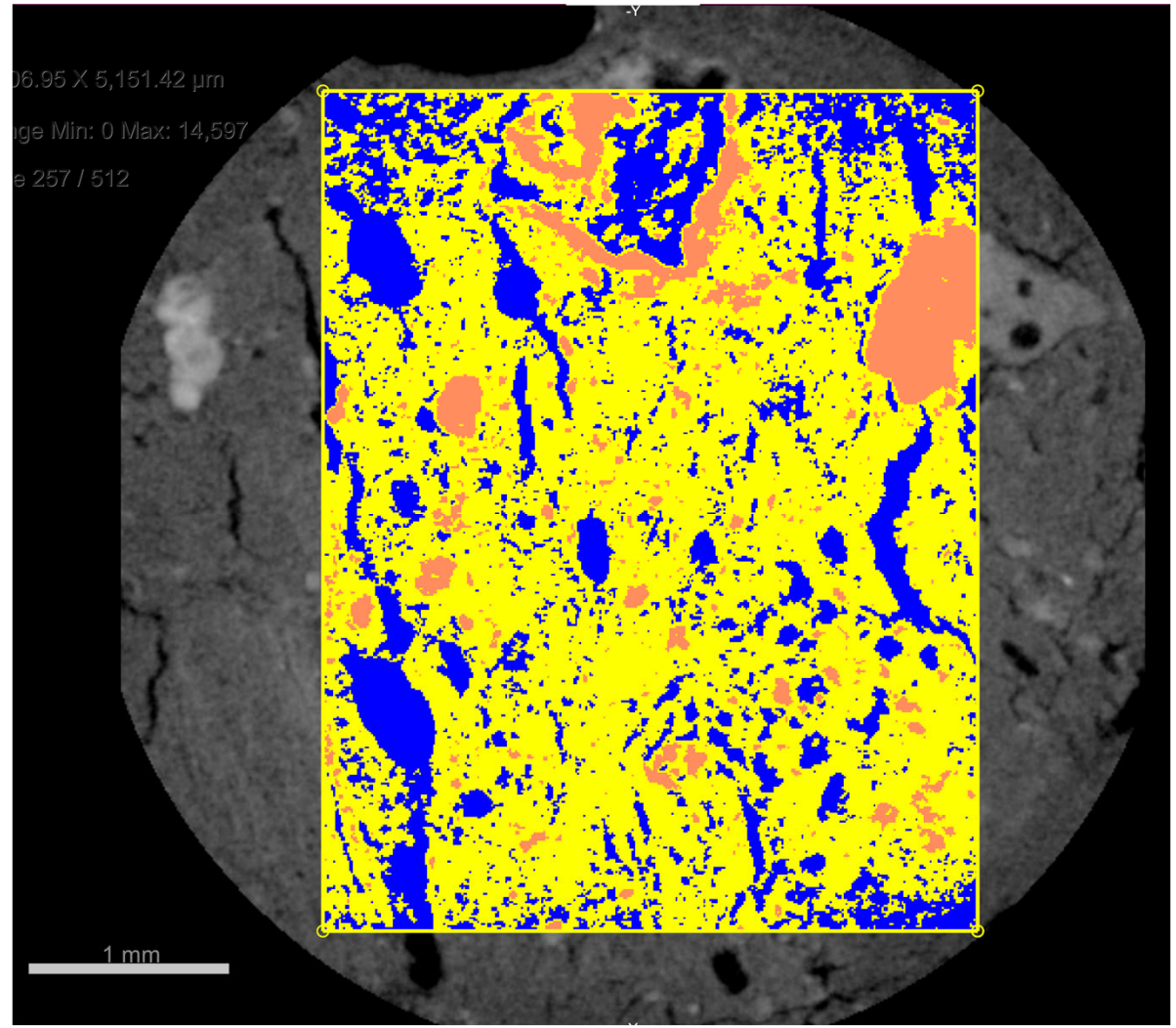
Merge
Background class:
Drag class here
None
Labels opacity:
Predict
Train
Export
Exit


6.95 X 5,151.42 µm
ge Min: 0 Max: 14,597
e 257 / 512
1 mm


06.95 X 5,151.42 µm
ge Min: 0 Max: 14,597
e 257 / 512
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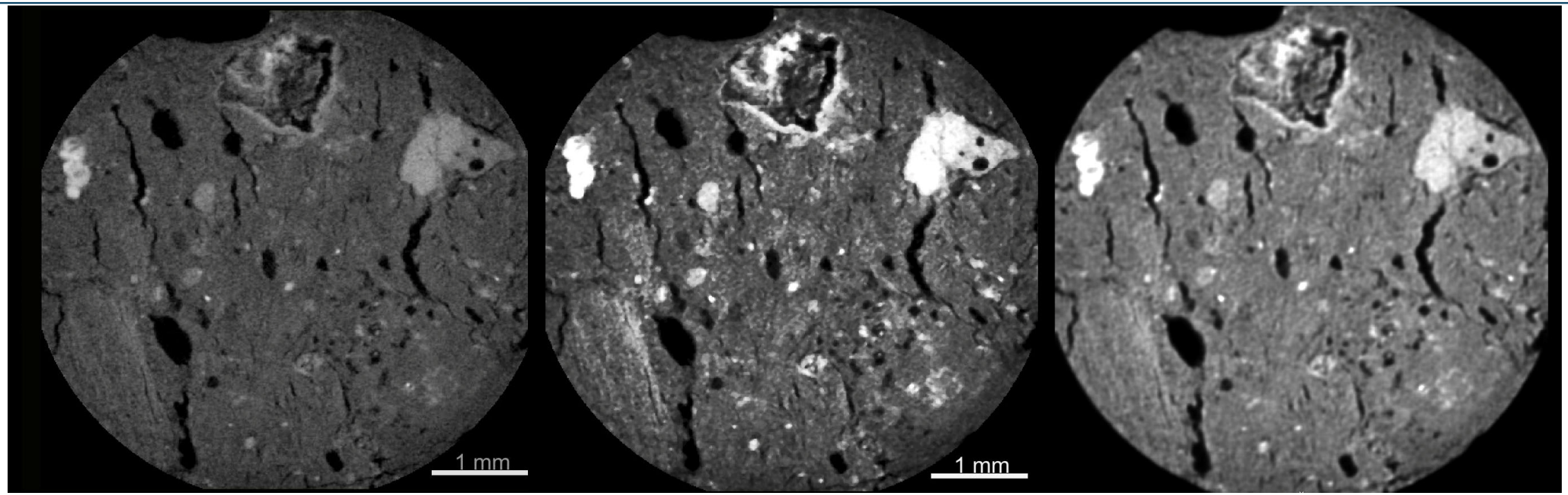
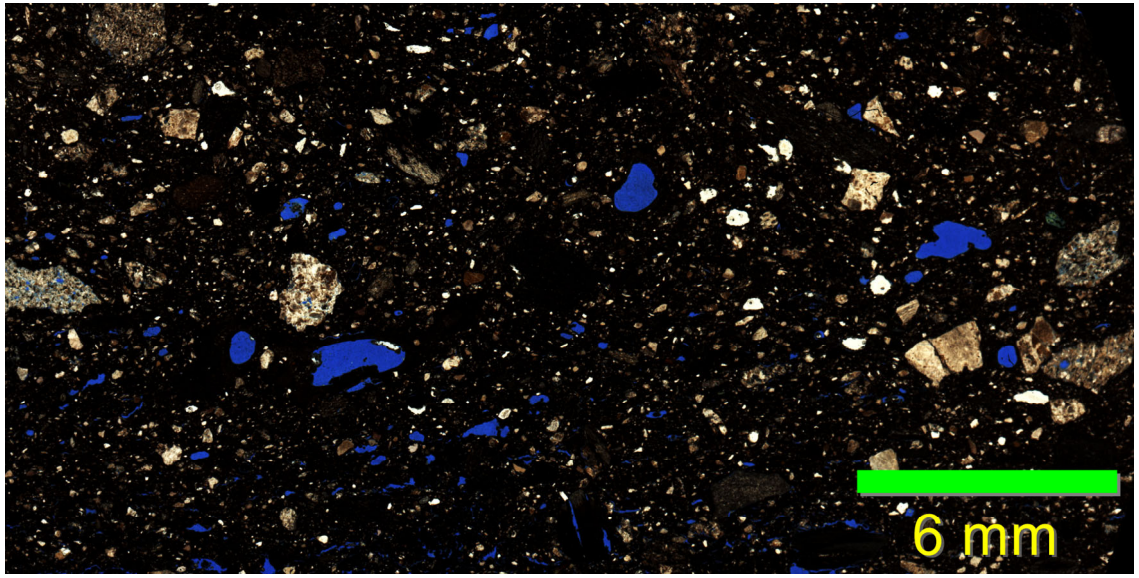


Top left, original scan;

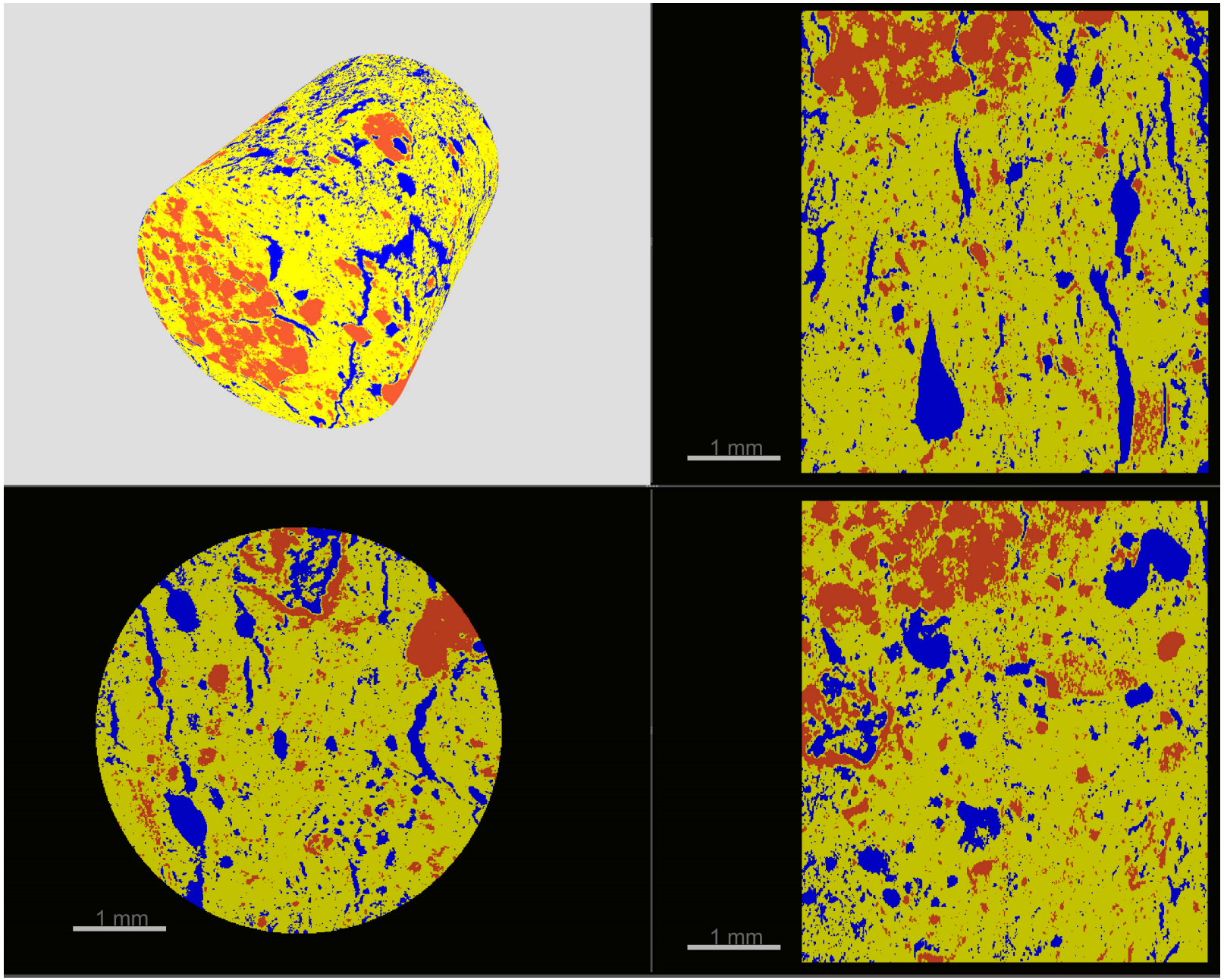
Top center, filtered image;

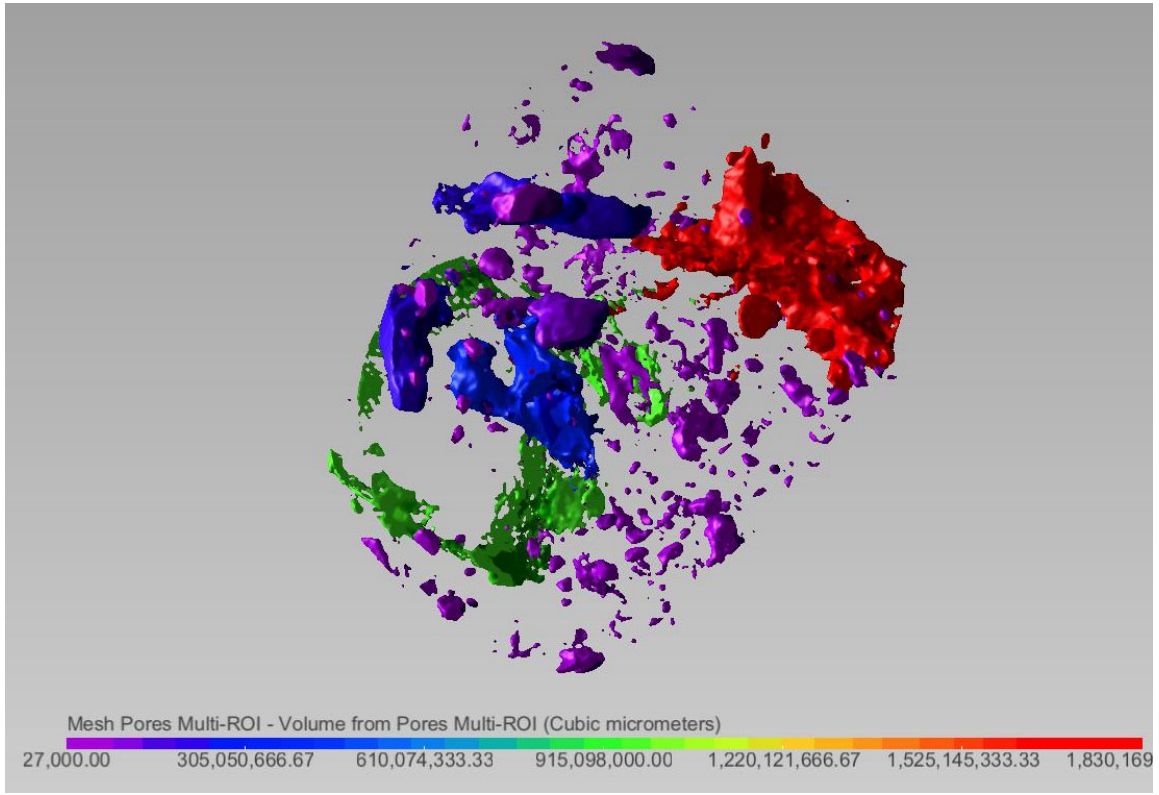
Top right, cleaned with Noise2Noise deep learning



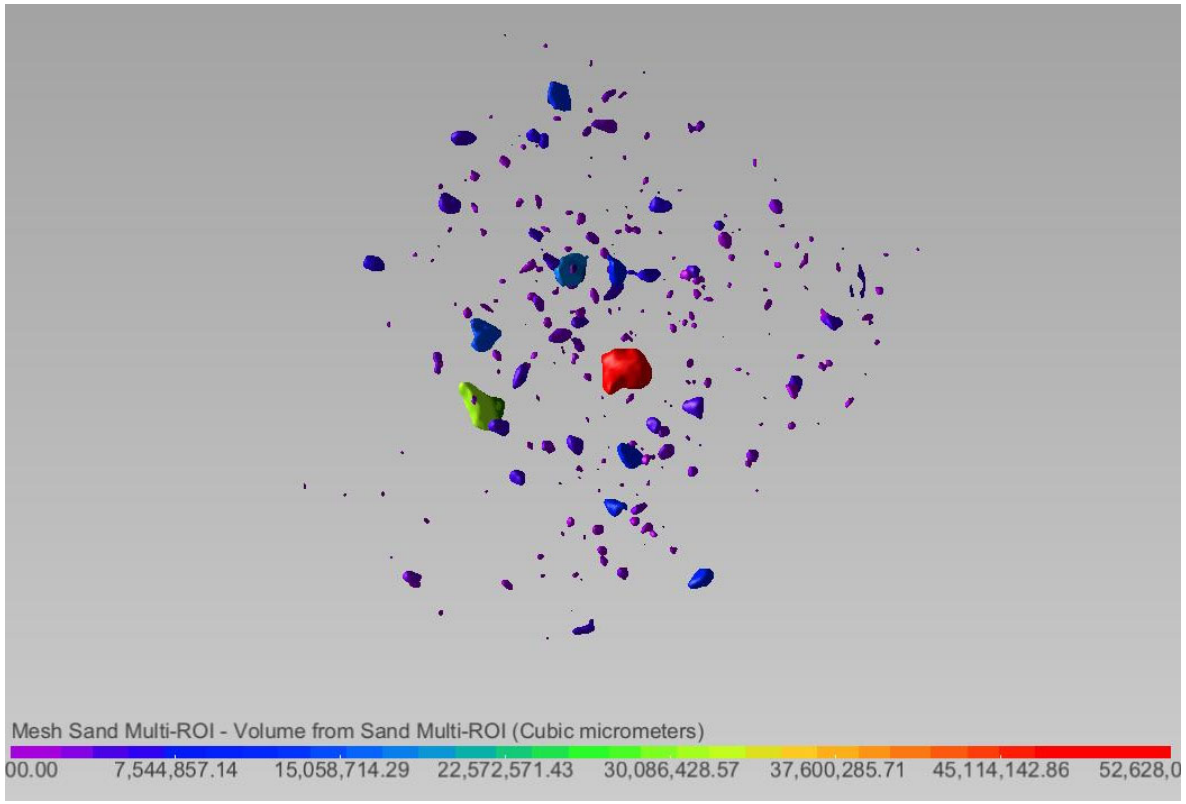
1 slice, thin section (entire thin section scanned with geological slide scanner)

Pores = blue, 14 vol.%
Quartz = red, 13 vol. %
Clay matrix = yellow, 73 vol. %



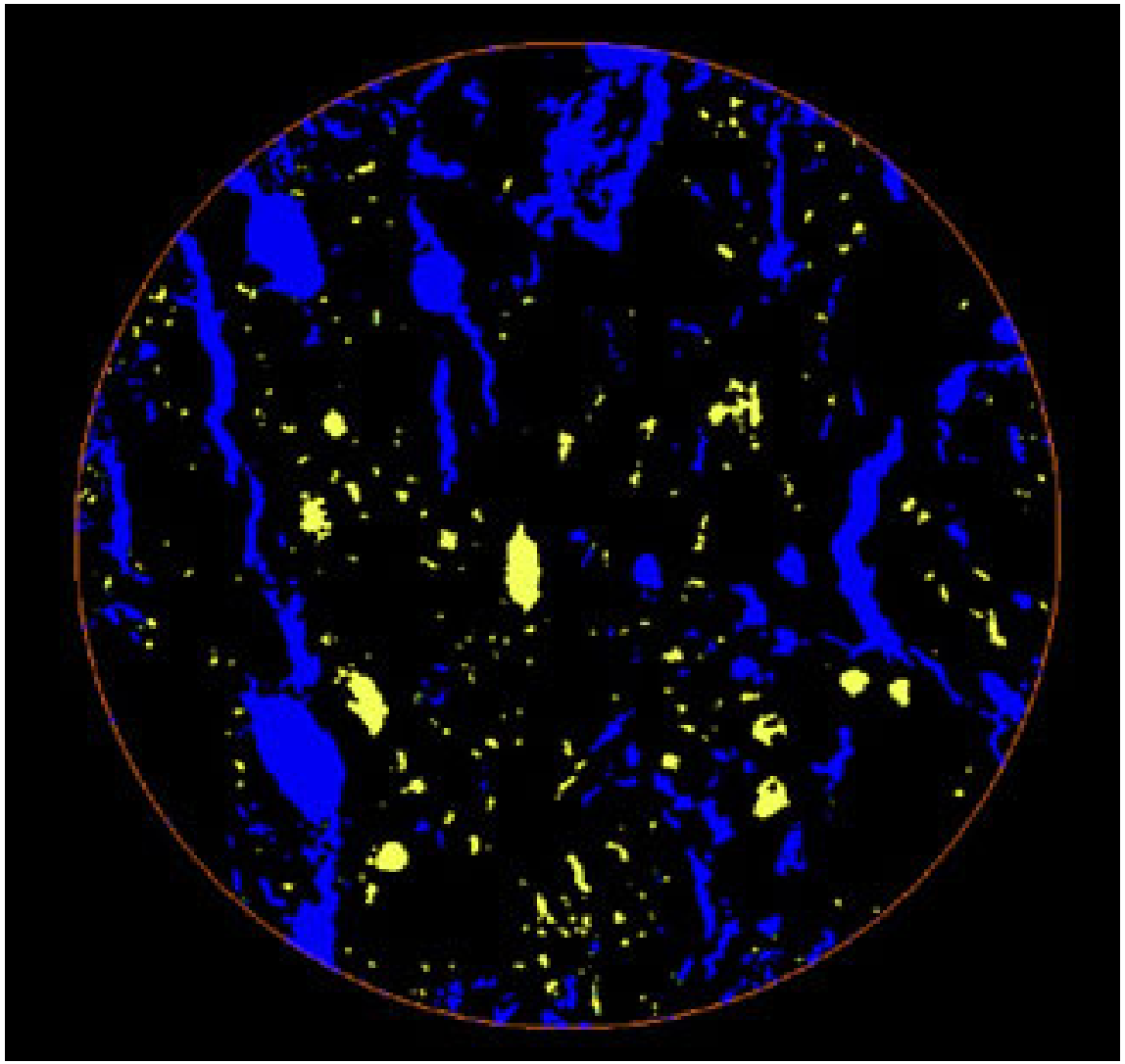


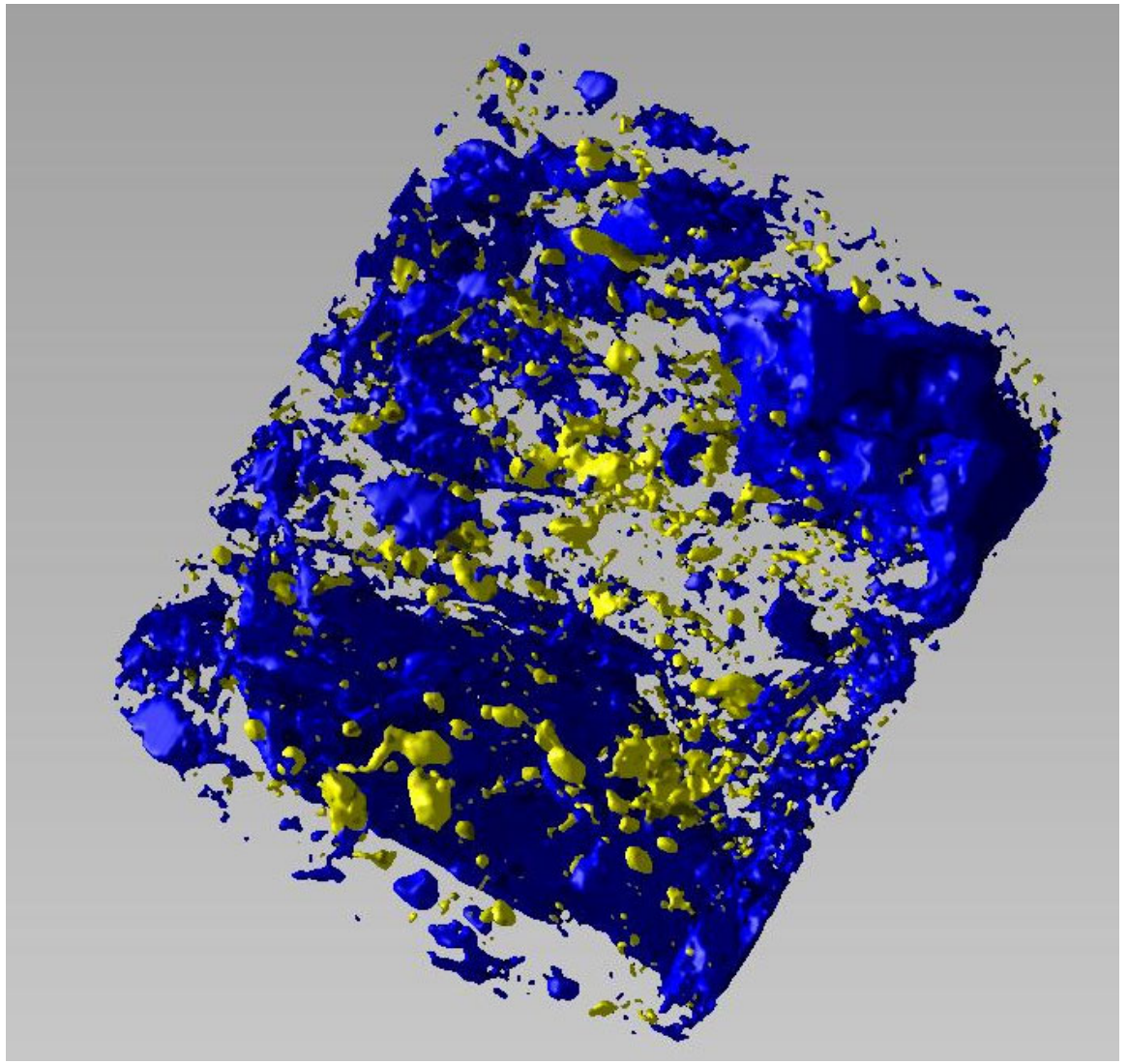
Pores, color coded by volume

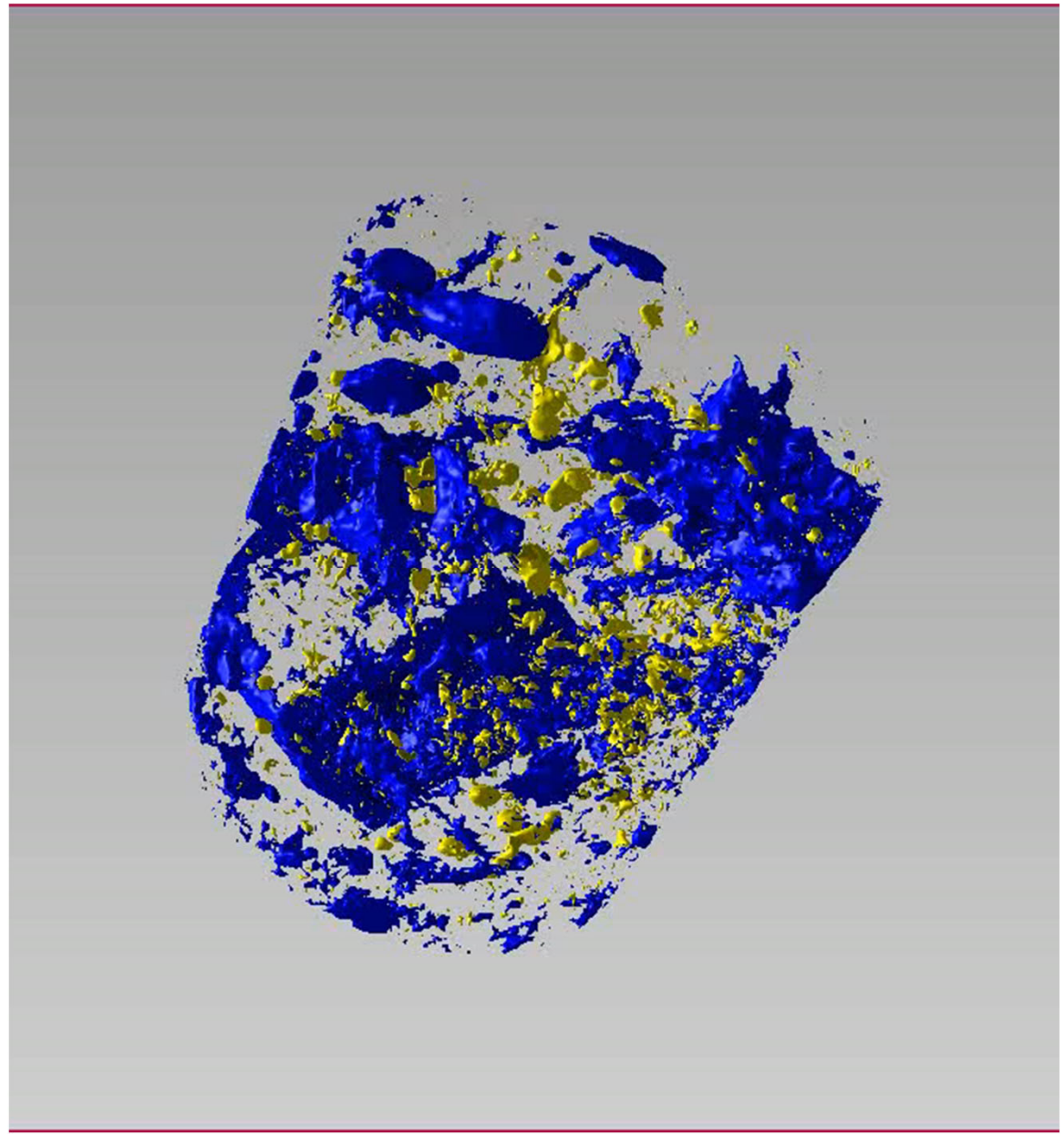


Silica-rich particles, color coded by volume

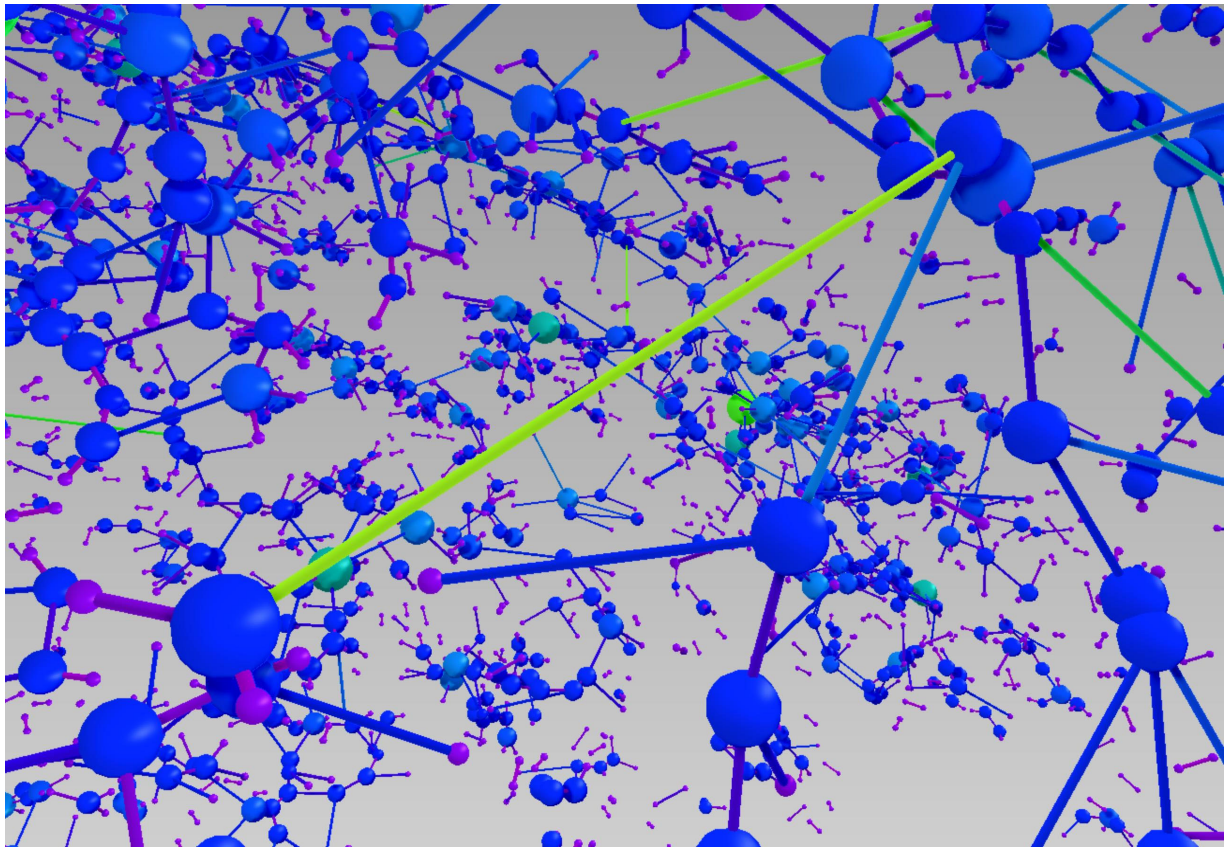
Smallest to largest: Purple, blue, green, red

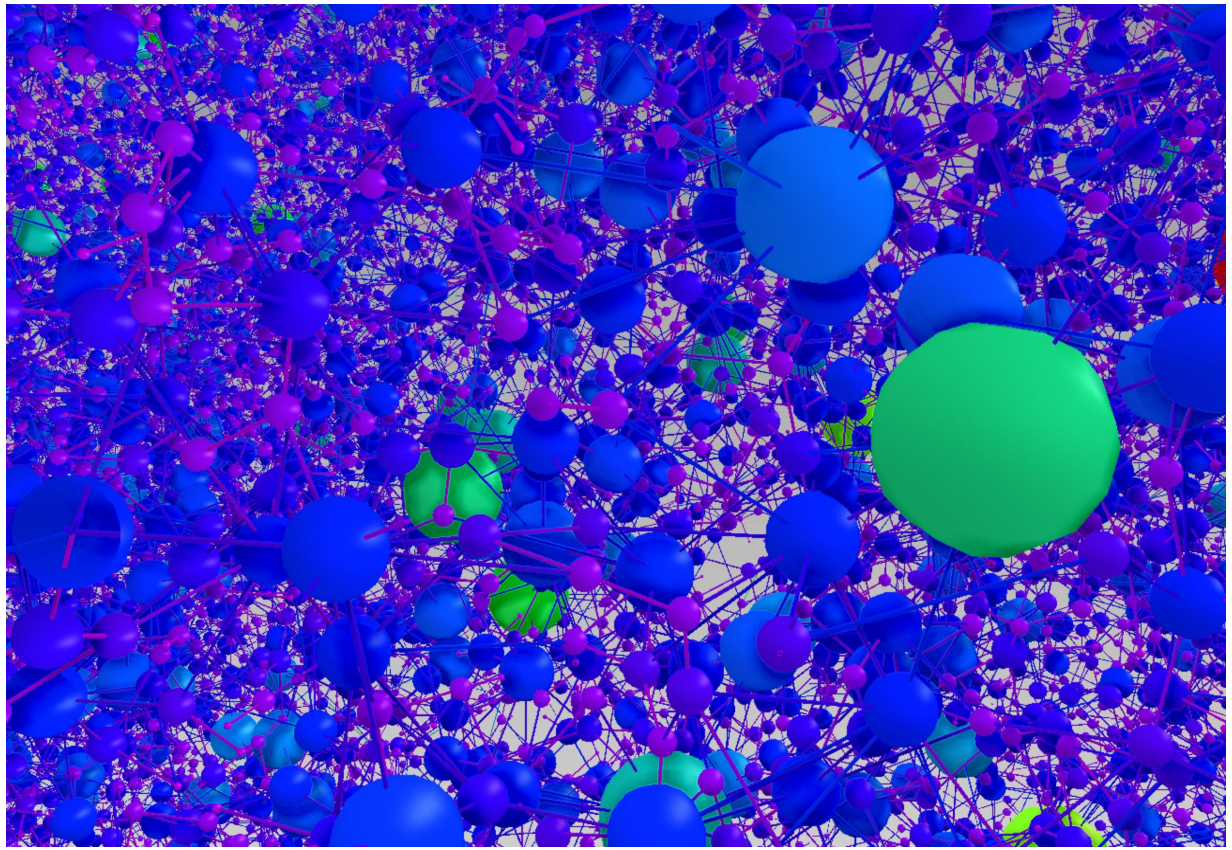




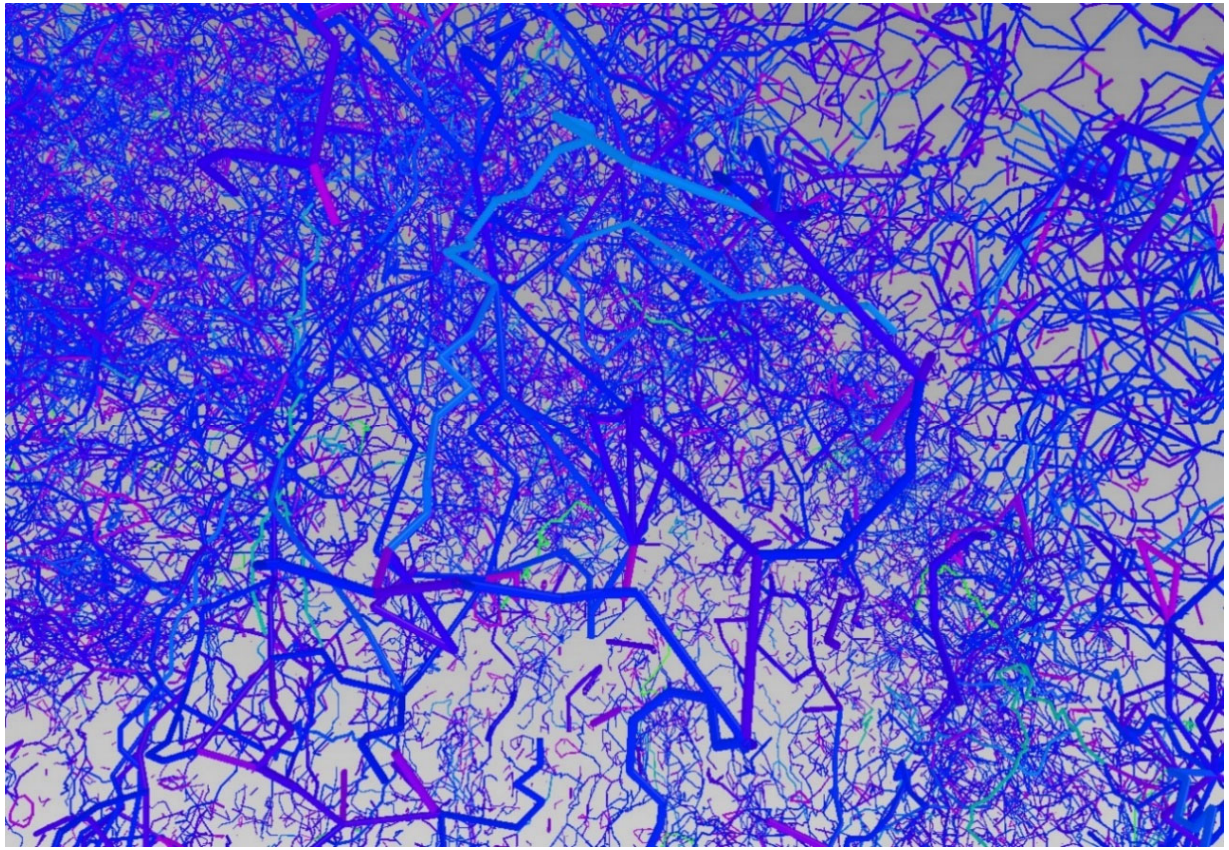


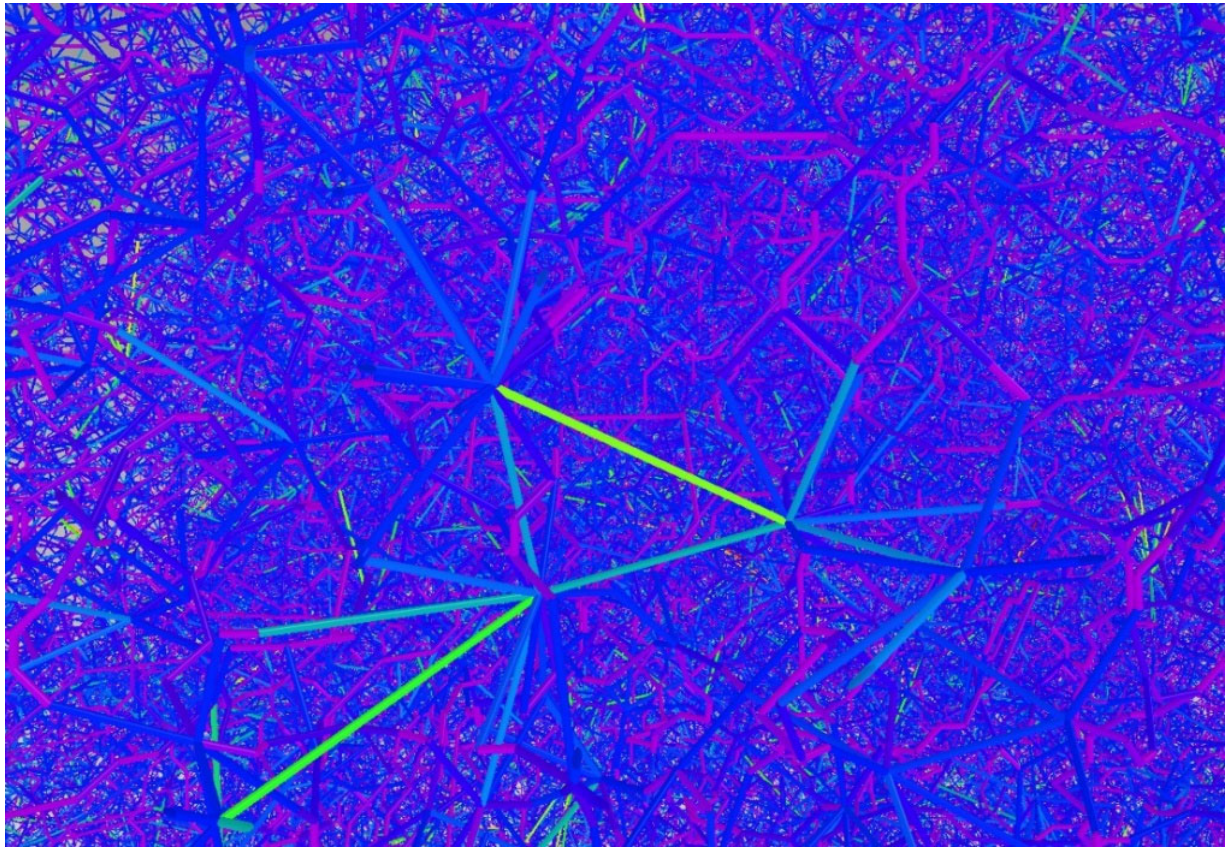
Sparse Graphs of Pores



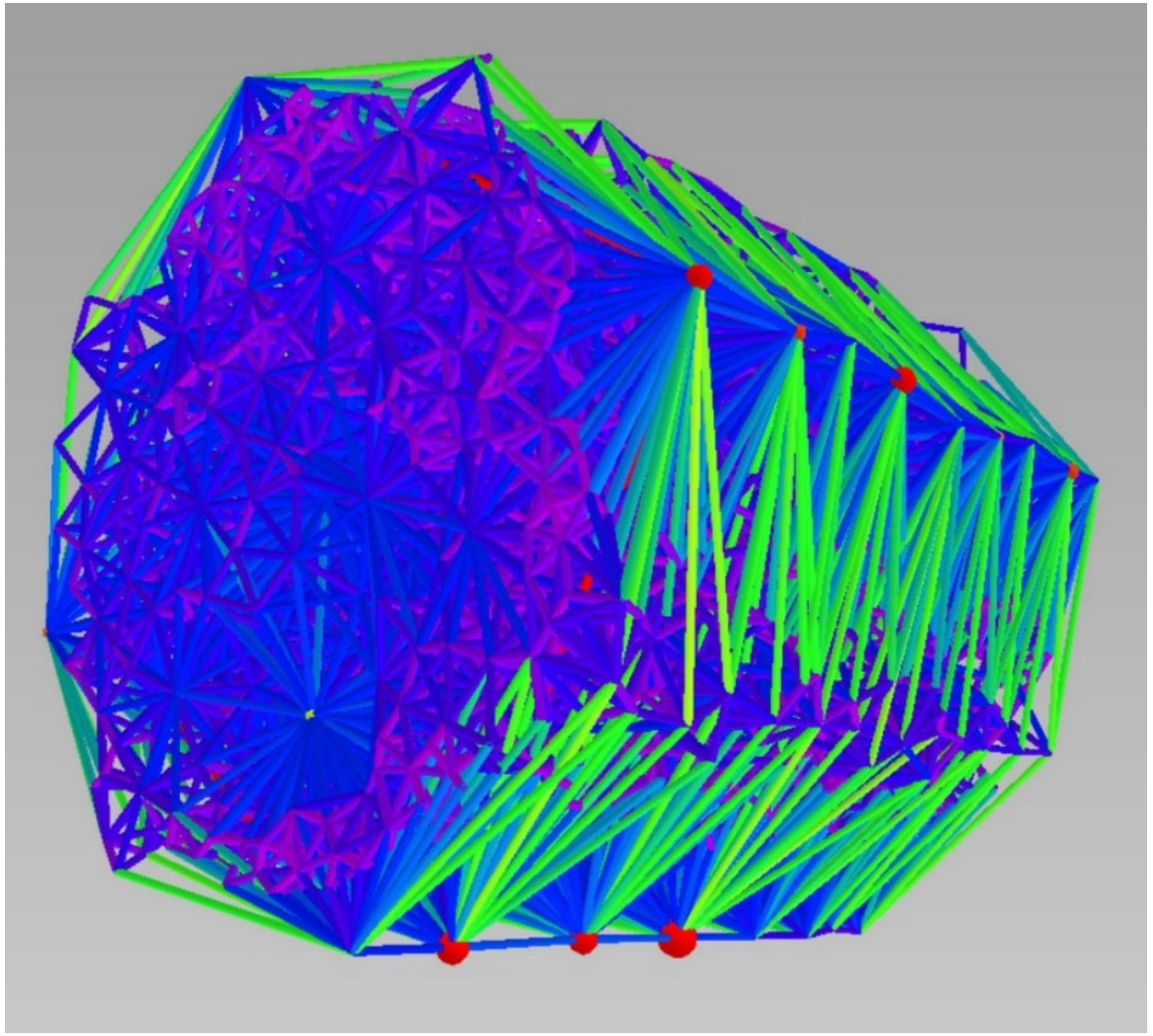


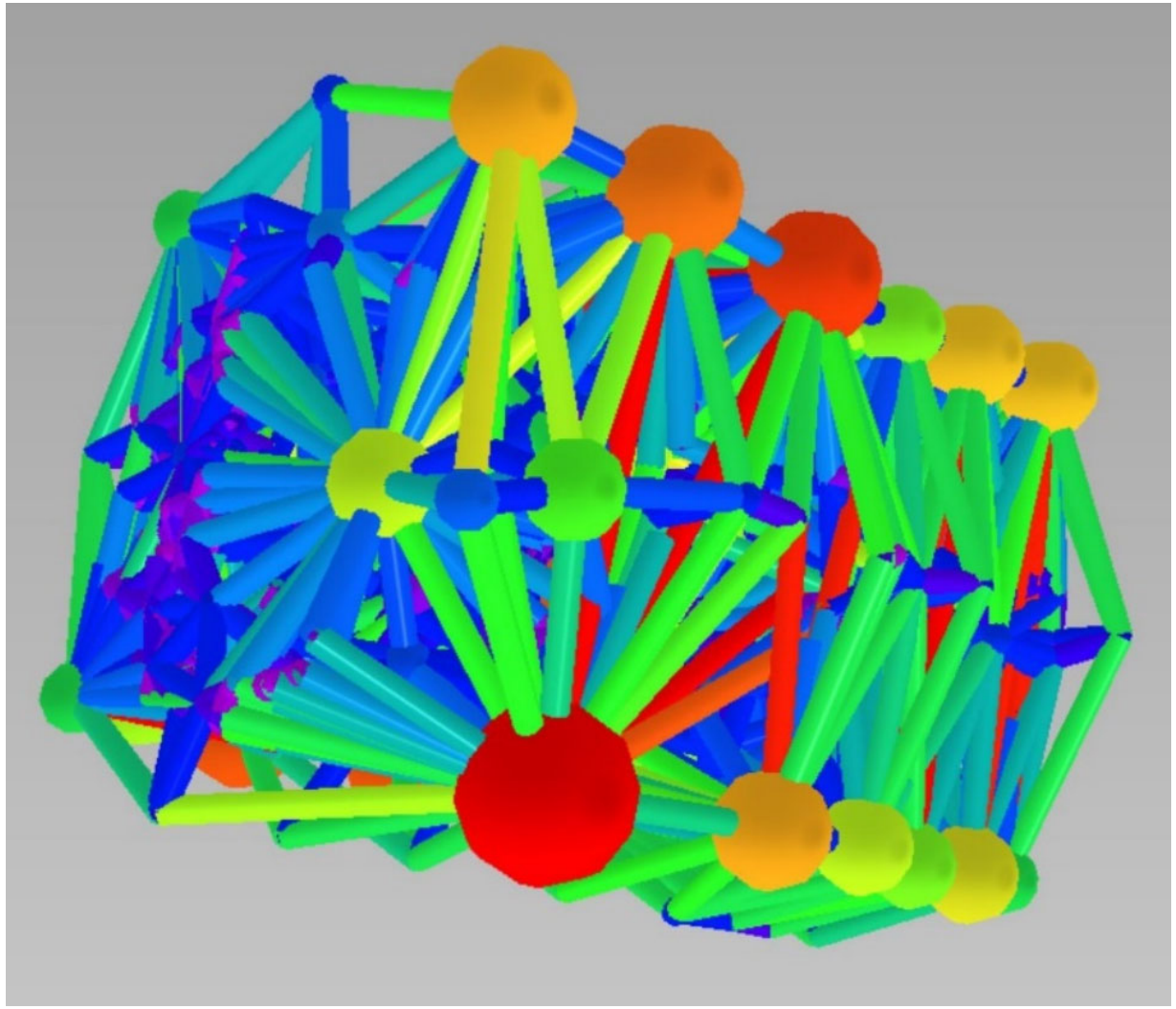
Dense Graphs of Pores



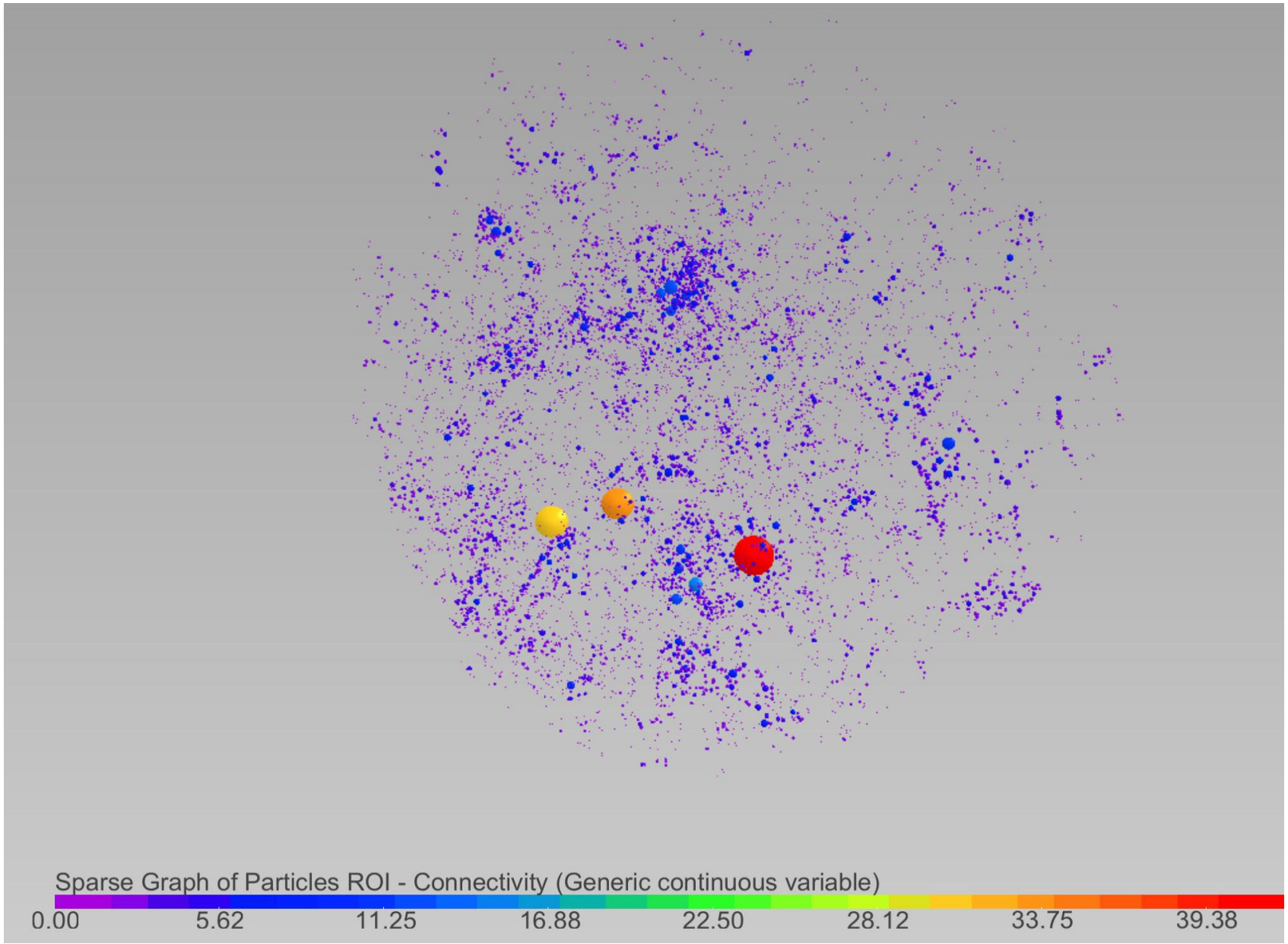


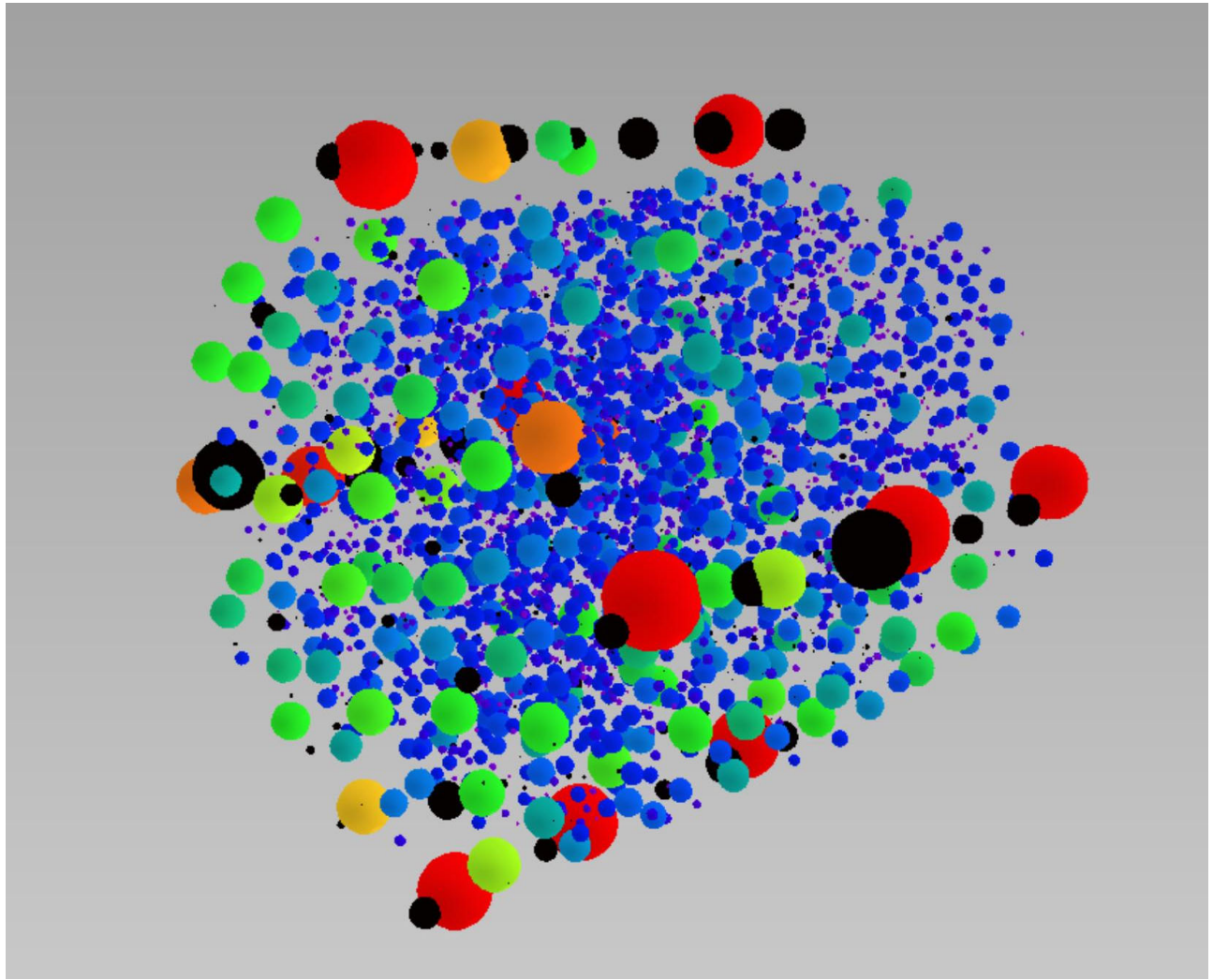
Pore Network Models (with OpenPNM)

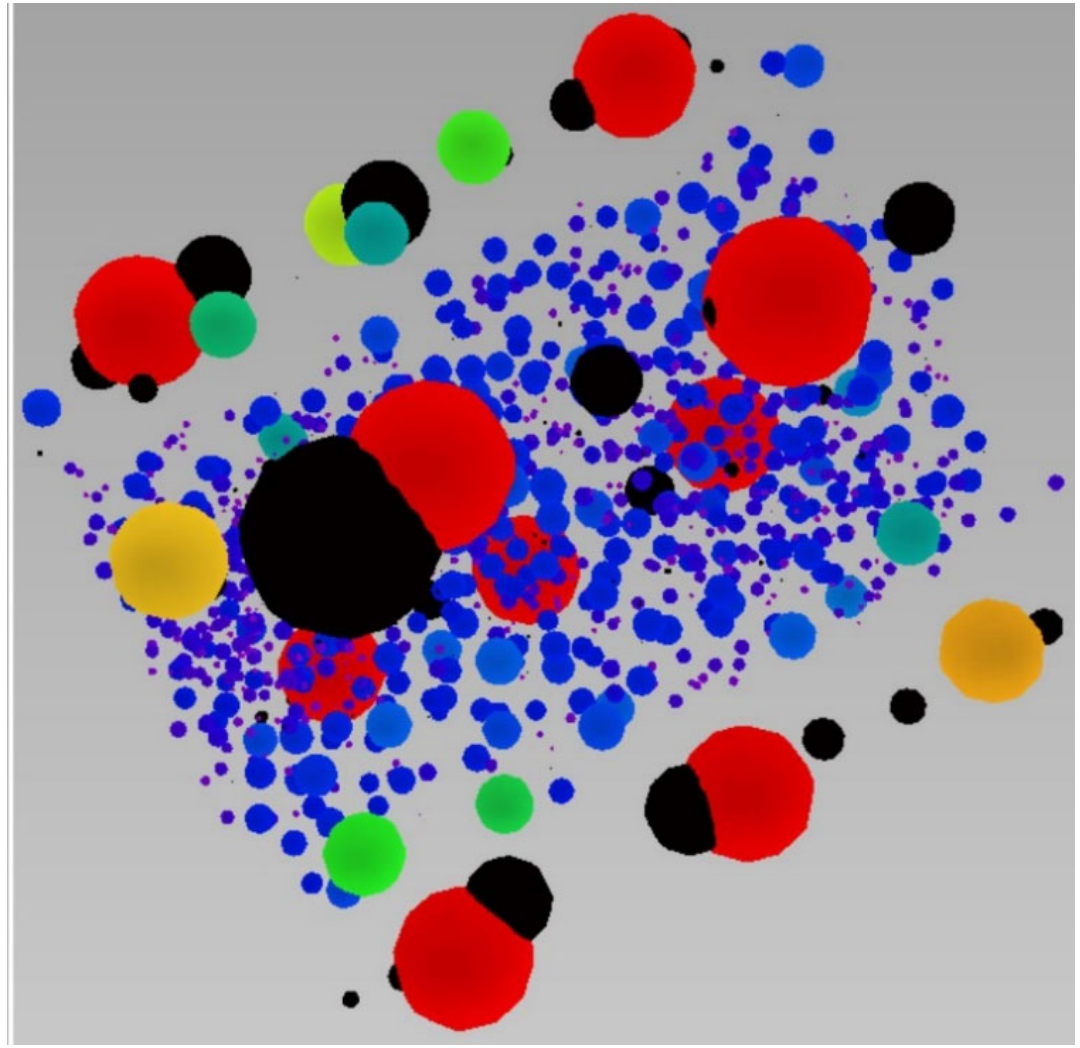




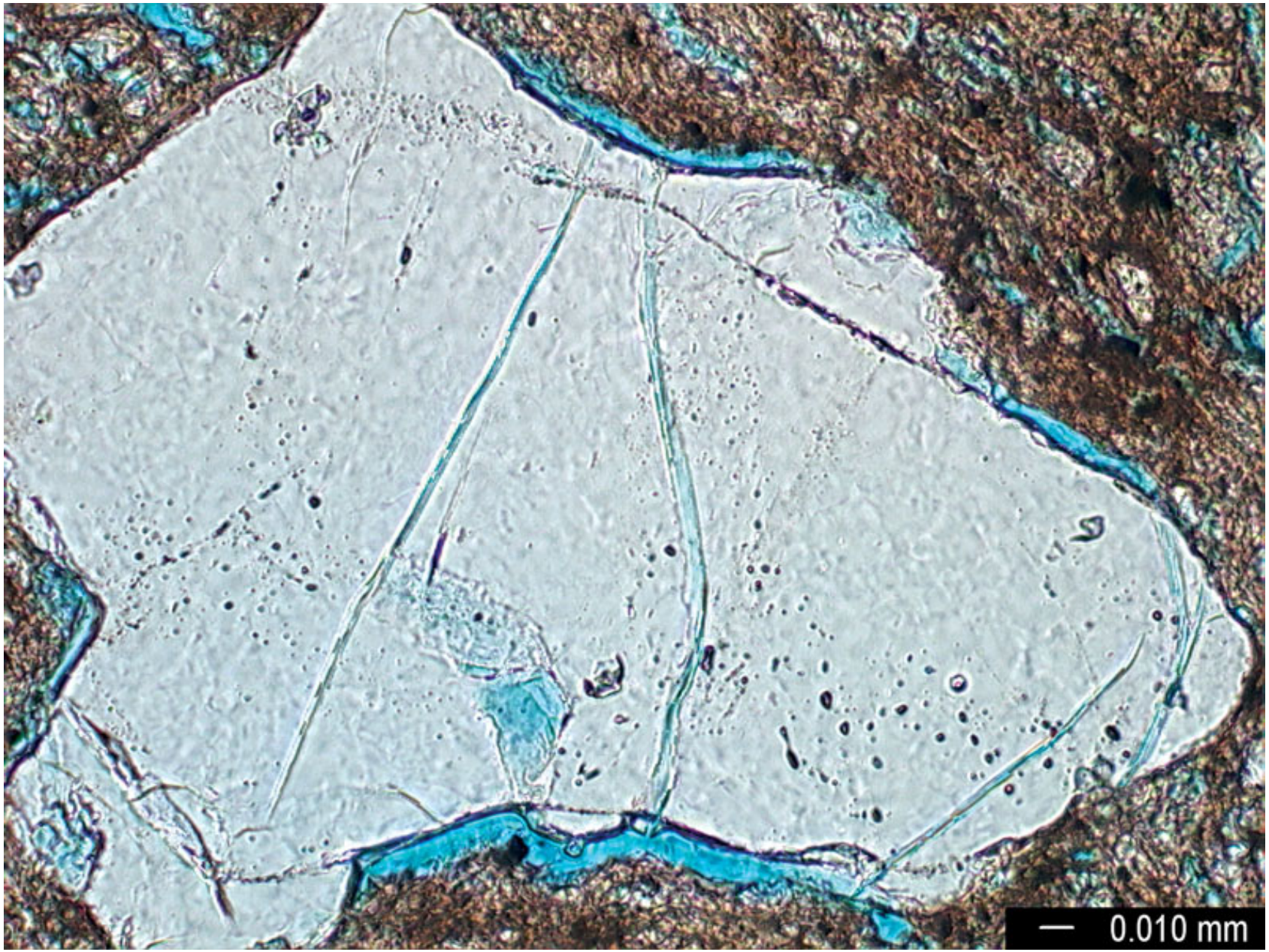
Small to large: purple, blue, green, yellow, orange, to red

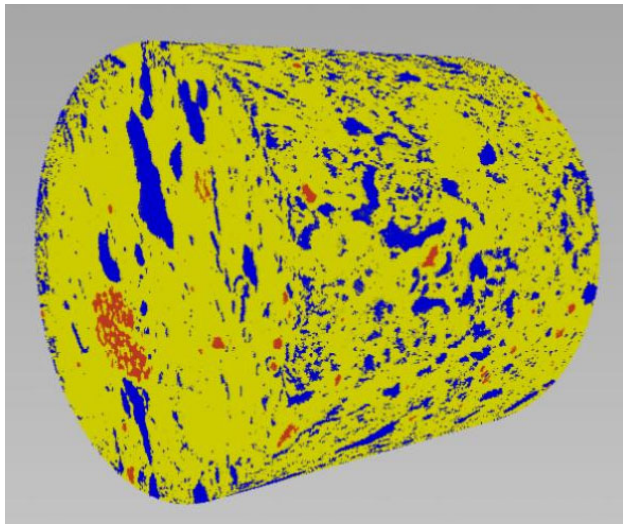

Sparse Graph of Particles ROI - Connectivity (Generic continuous variable)
0.00
5.62
11.25
16.88
22.50
28.12
33.75
39.38

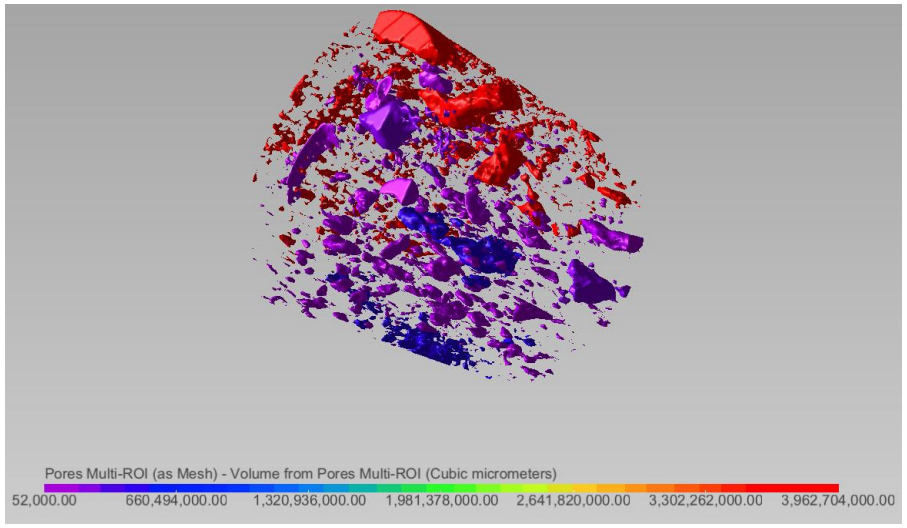


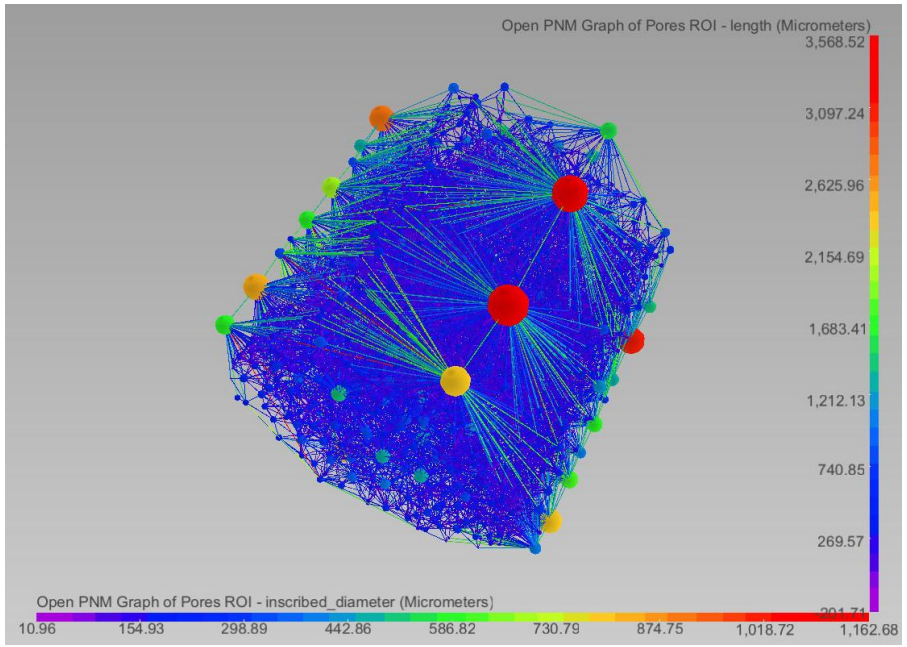


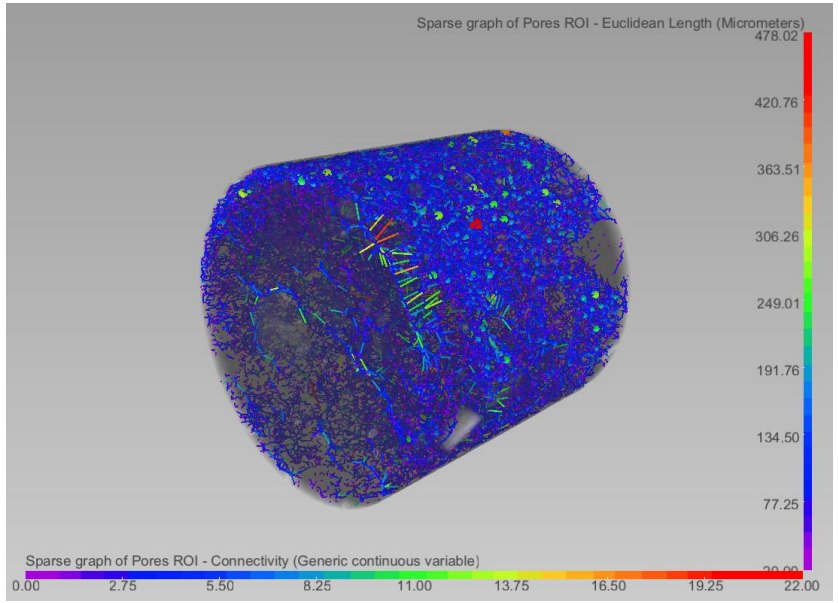
Thin section
Plane polarized light

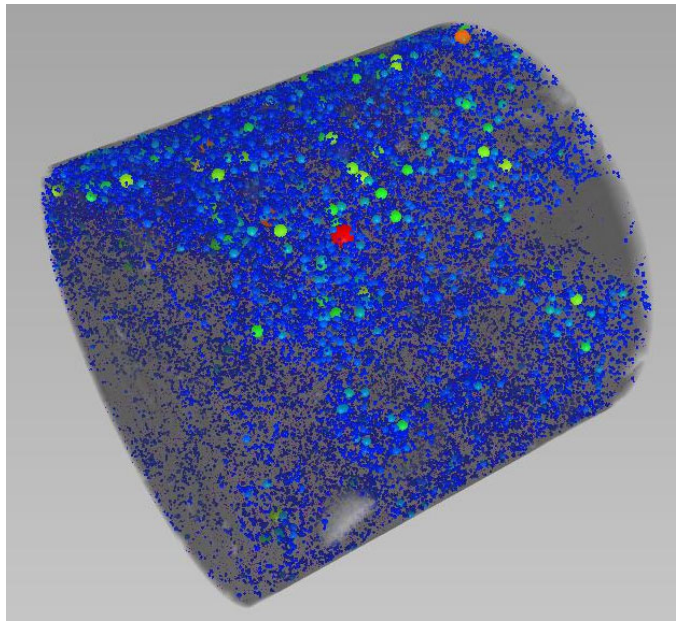


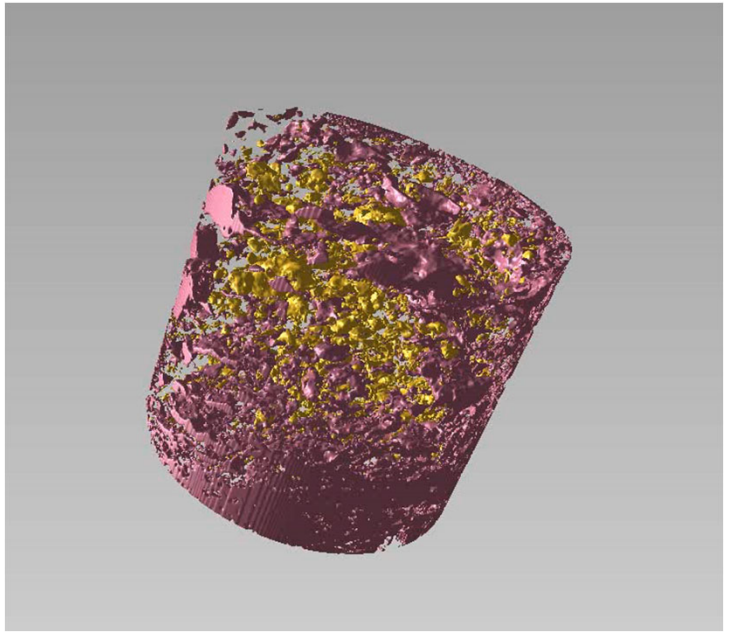



Pores Multi-ROI (as Mesh) - Volume from Pores Multi-ROI (Cubic micrometers)
52,000.00
660,494,000.00
1,320,936,000.00
1,981,378,000.00
2,641,820,000.00
3,302,262,000.00
3,962,704,000.00

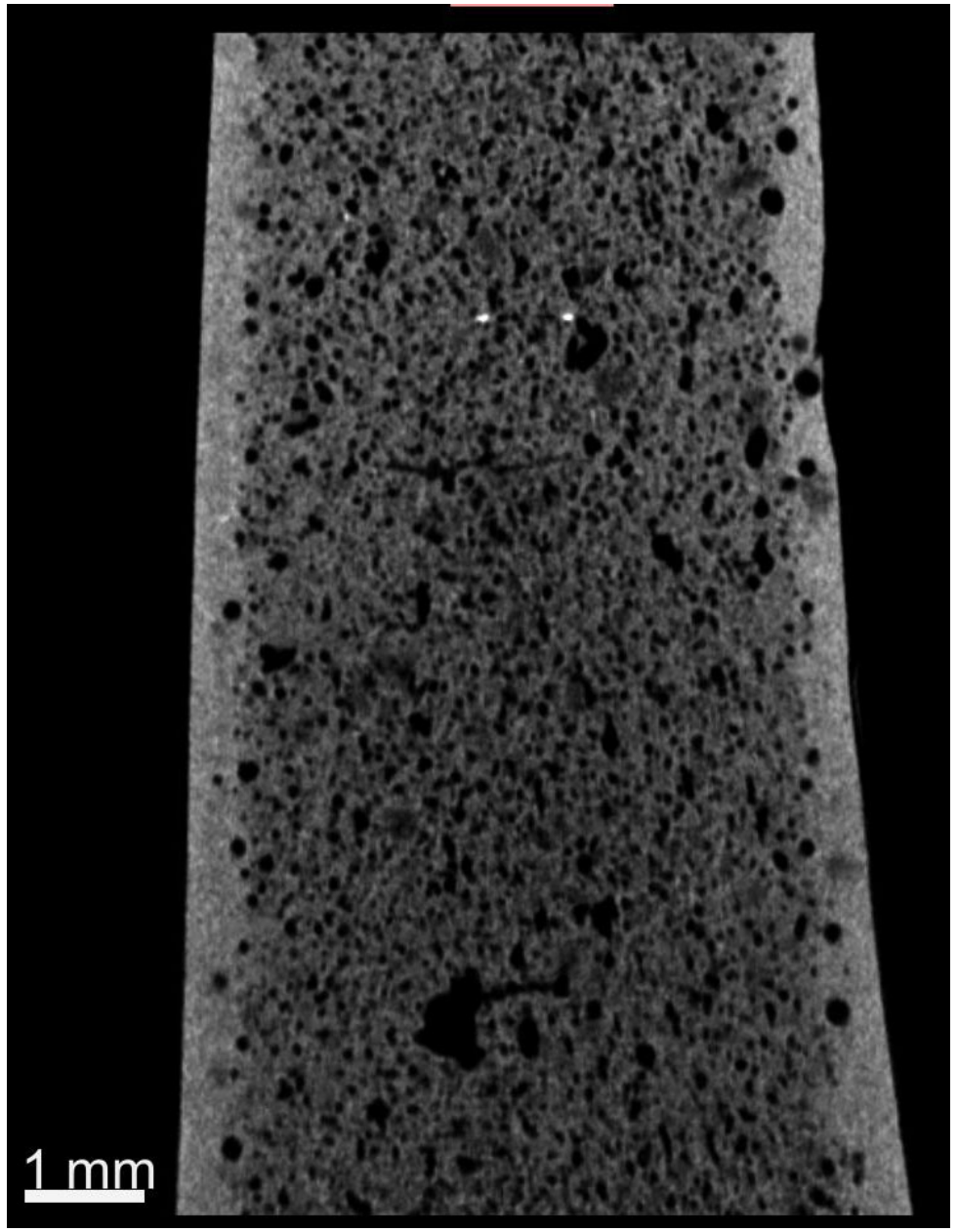

Open PNM Graph of Pores ROI - length (Micrometers)
3,568.52
3,097.24
2,625.96
2,154.69
1,683.41
1,212.13
740.85
269.57
Open PNM Graph of Pores ROI - inscribed_diameter (Micrometers)
10.96
154.93
298.89
442.86
586.82
730.79
874.75
1,018.72
1,162.68


Sparse graph of Pores ROI - Euclidean Length (Micrometers)
478.02
420.76
363.51
306.26
249.01
191.76
134.50
77.25
Sparse graph of Pores ROI - Connectivity (Generic continuous variable)
0.00
2.75
5.50
8.25
11.00
13.75
16.50
19.25
22.00

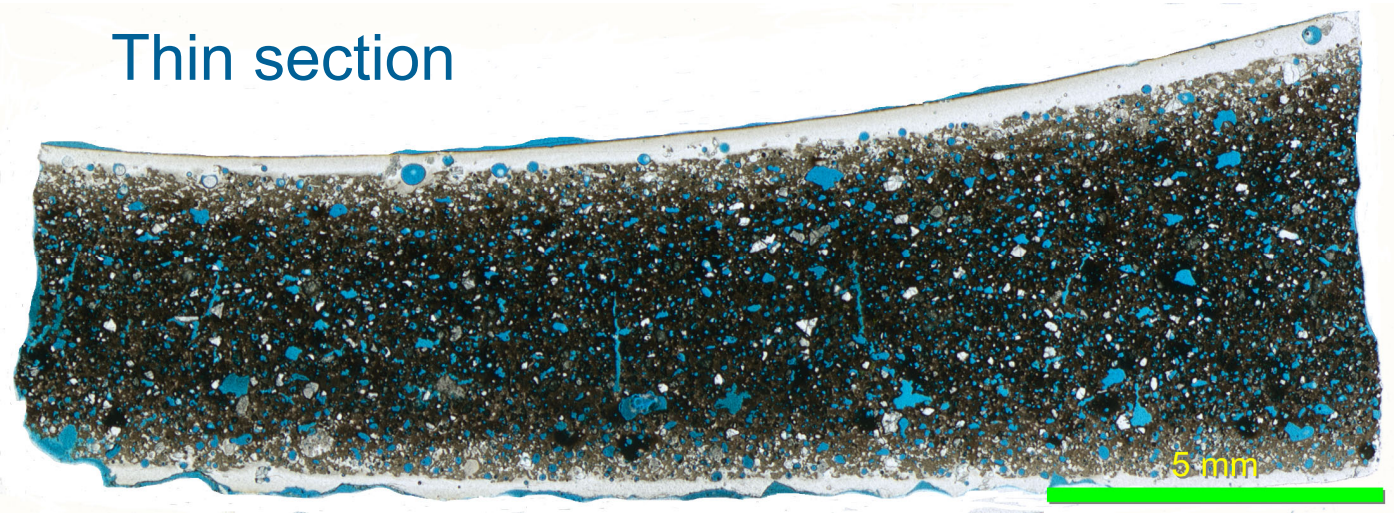


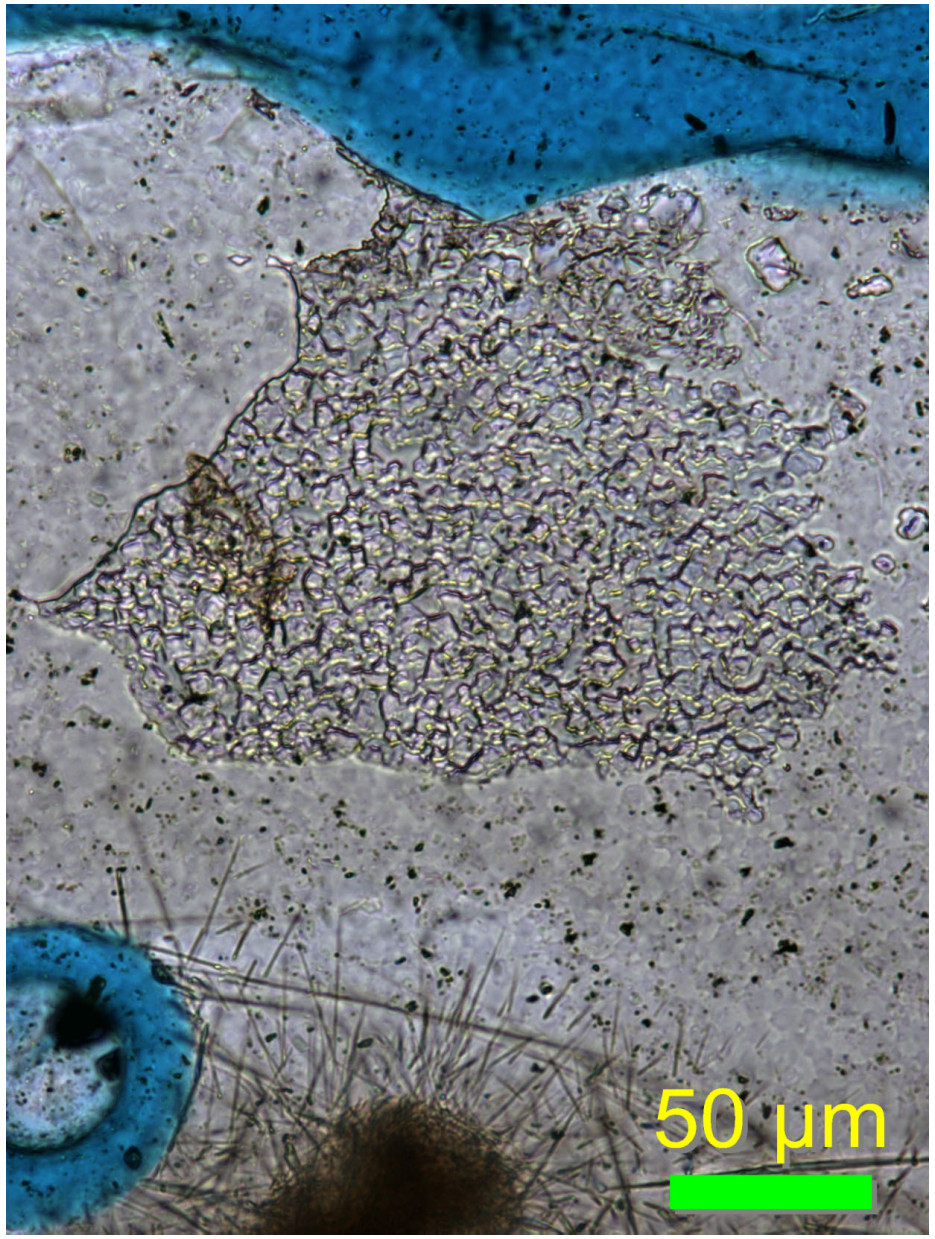


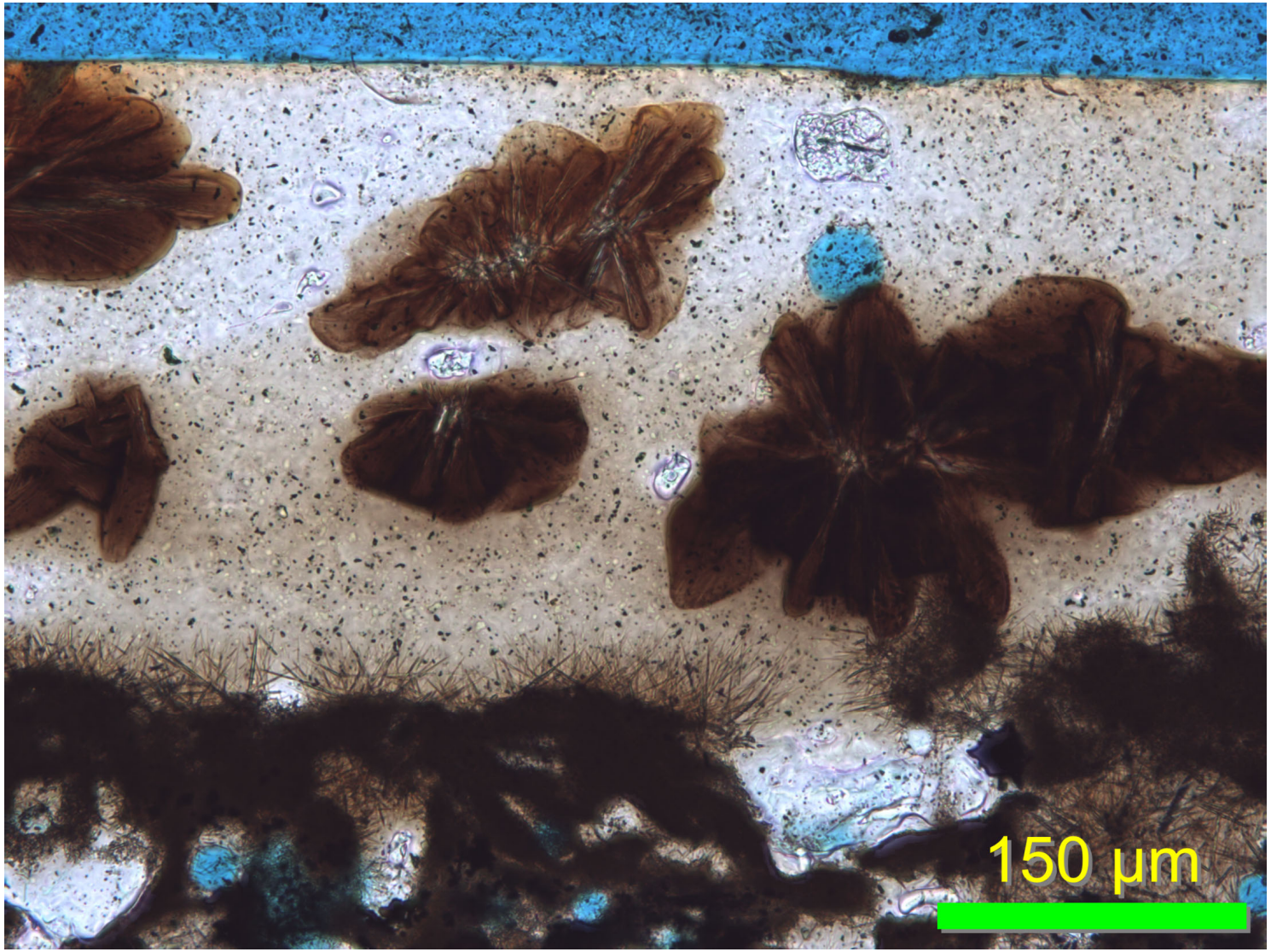
Micro-CT scan

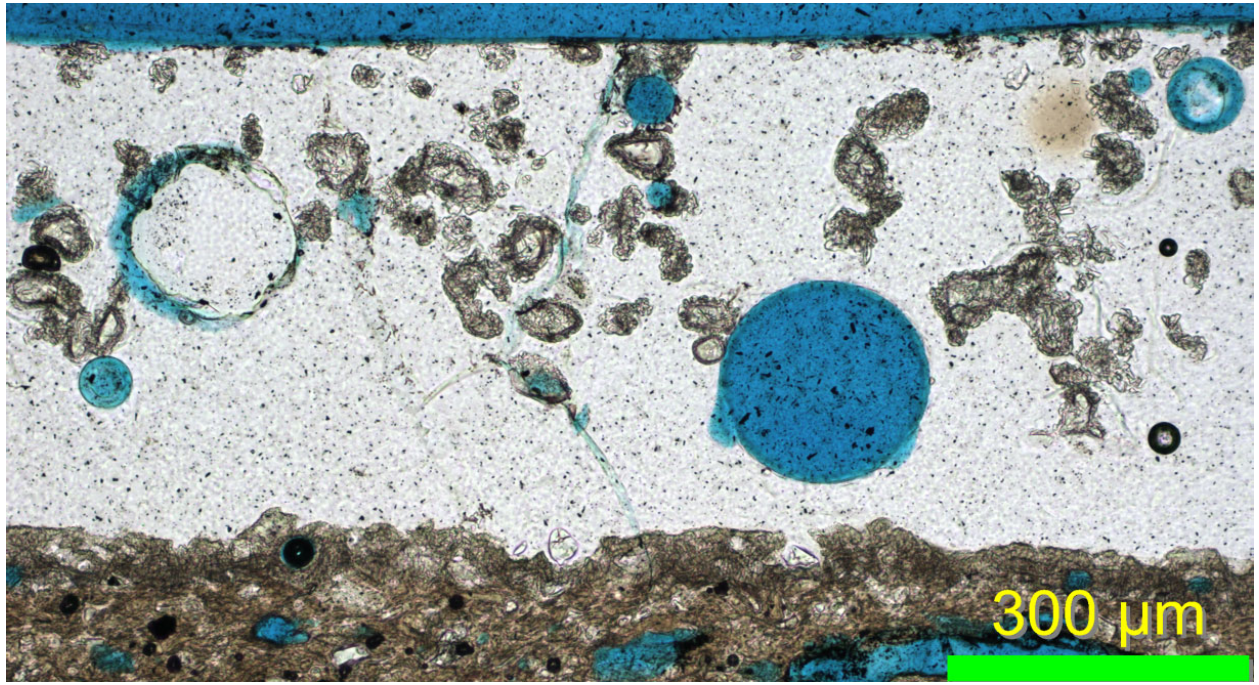


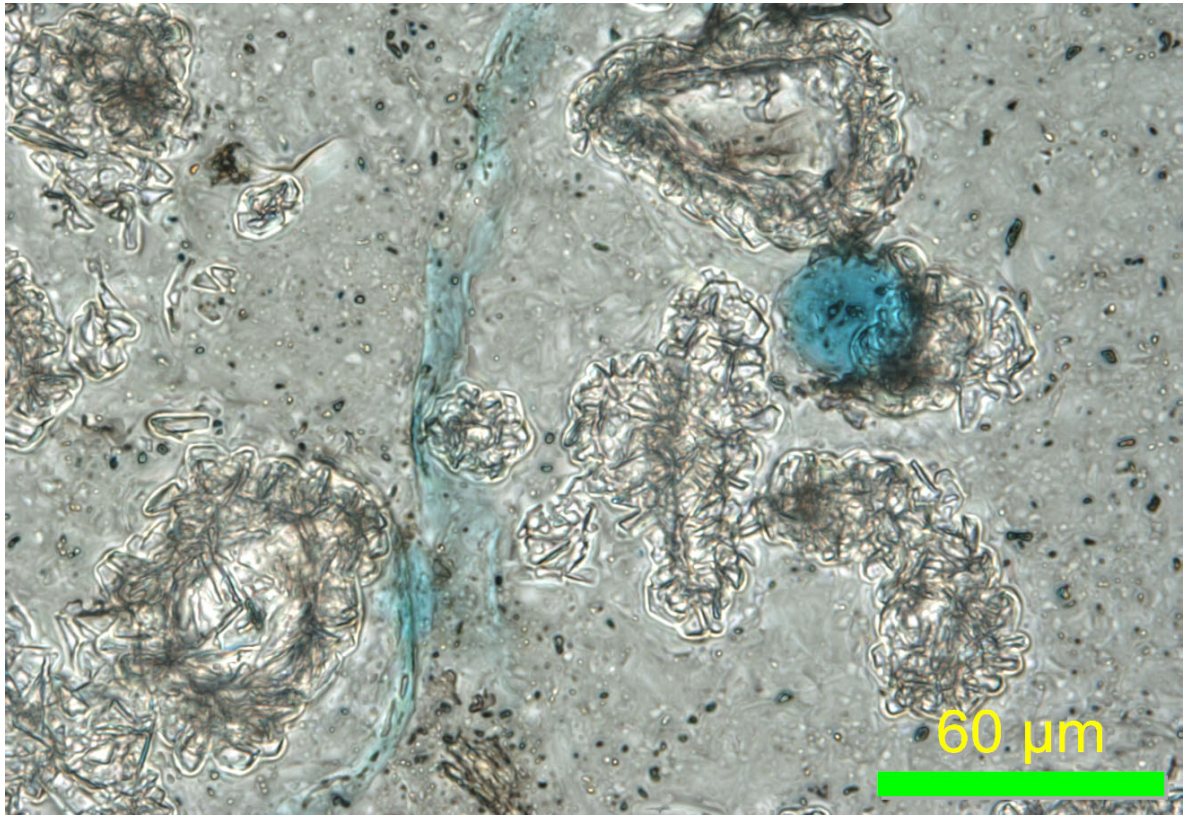
Thin section

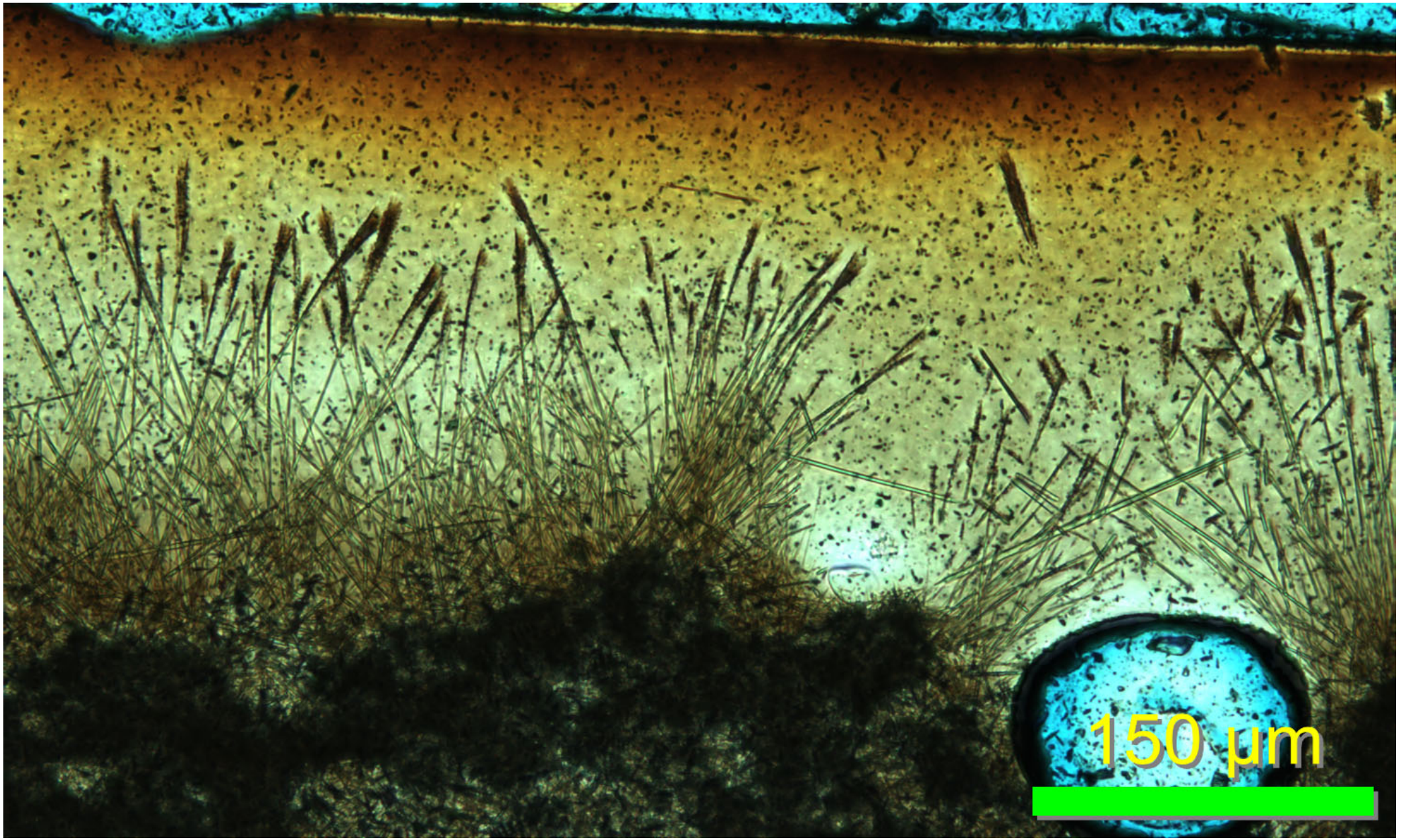


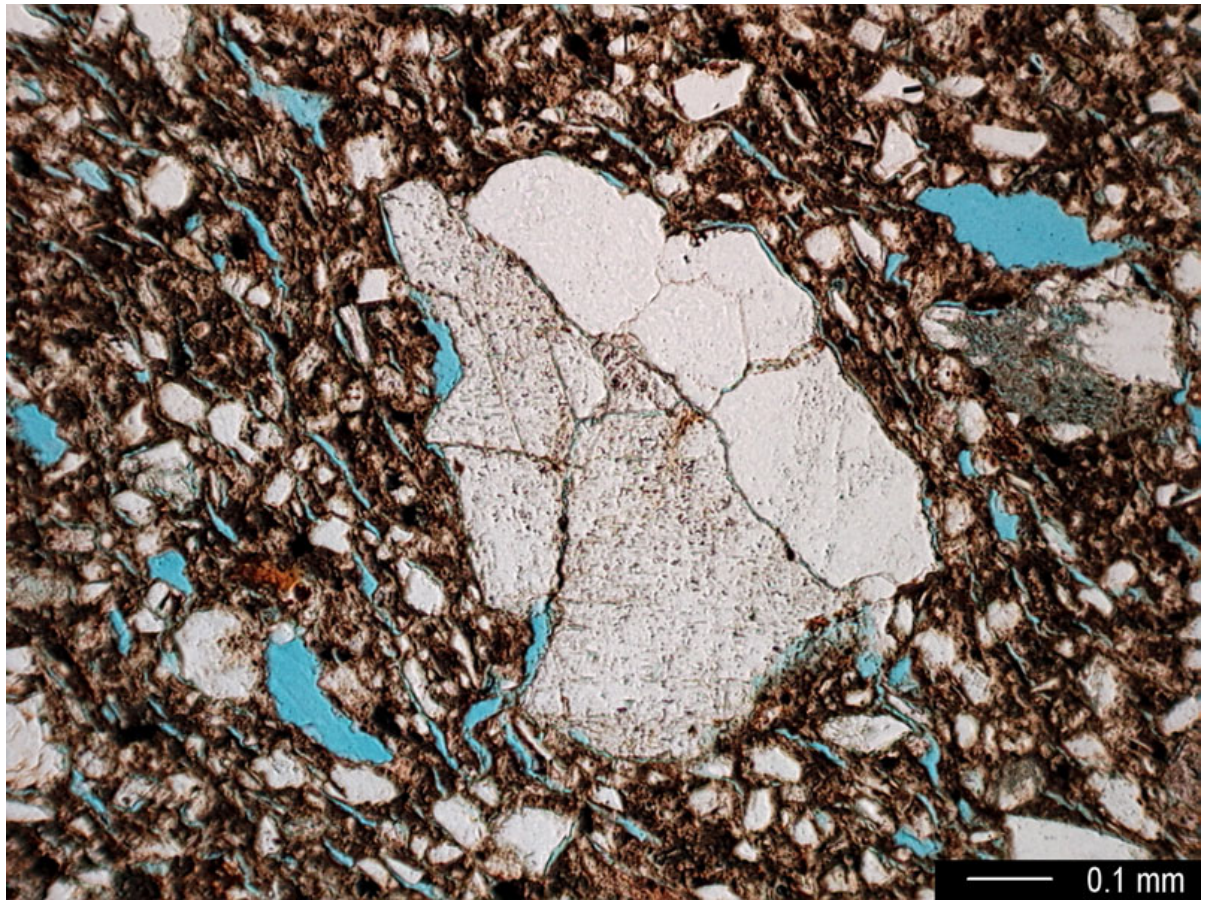

50 µm


150 µm

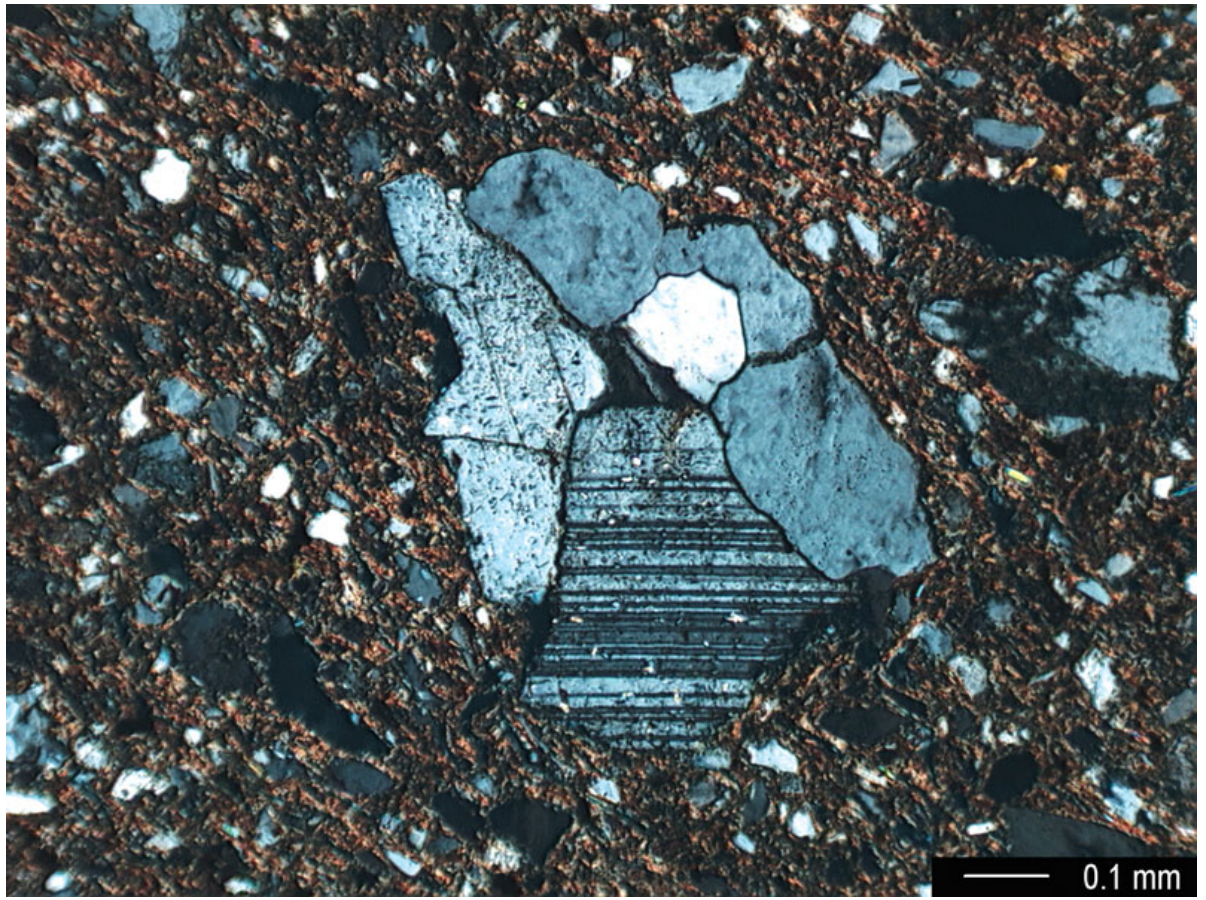

300 µm


60 µm


150 µm



Plane polarized light

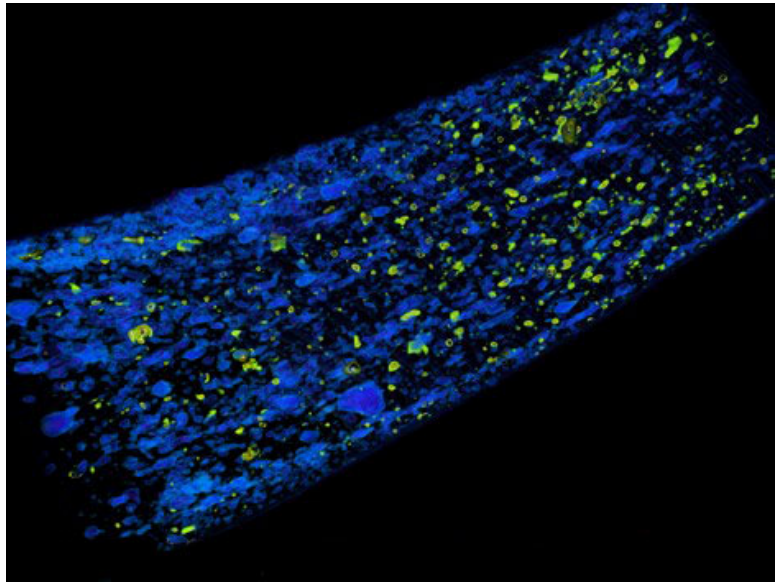


Crossed polarized light

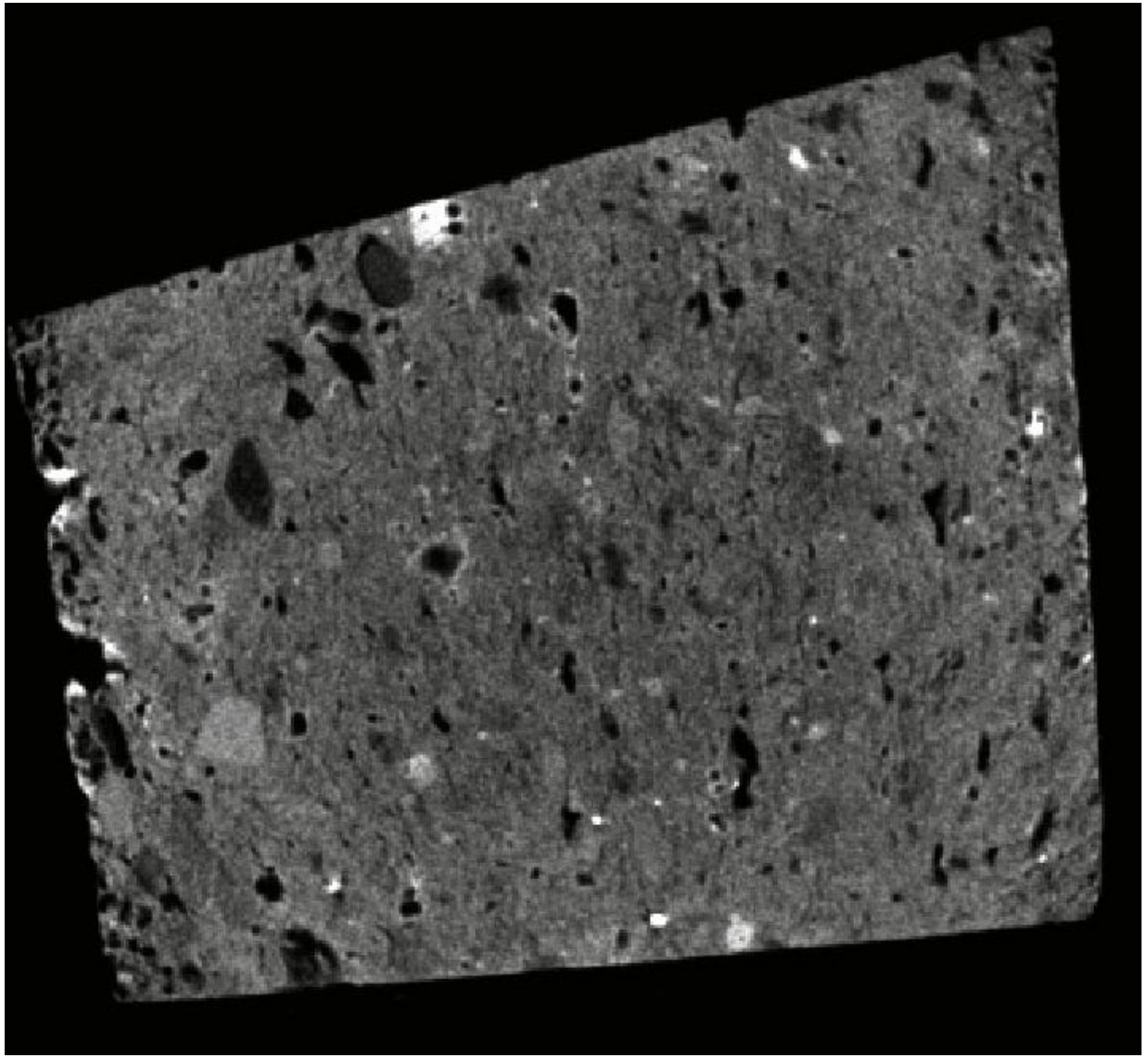
Yellow clay

Yingjing

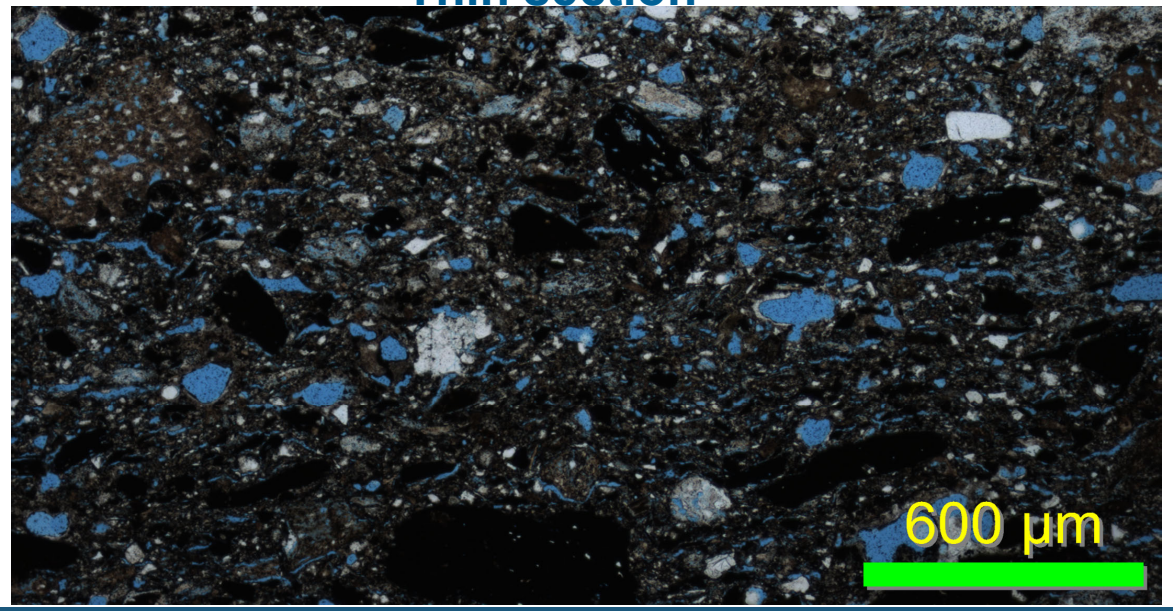
Burnt coal



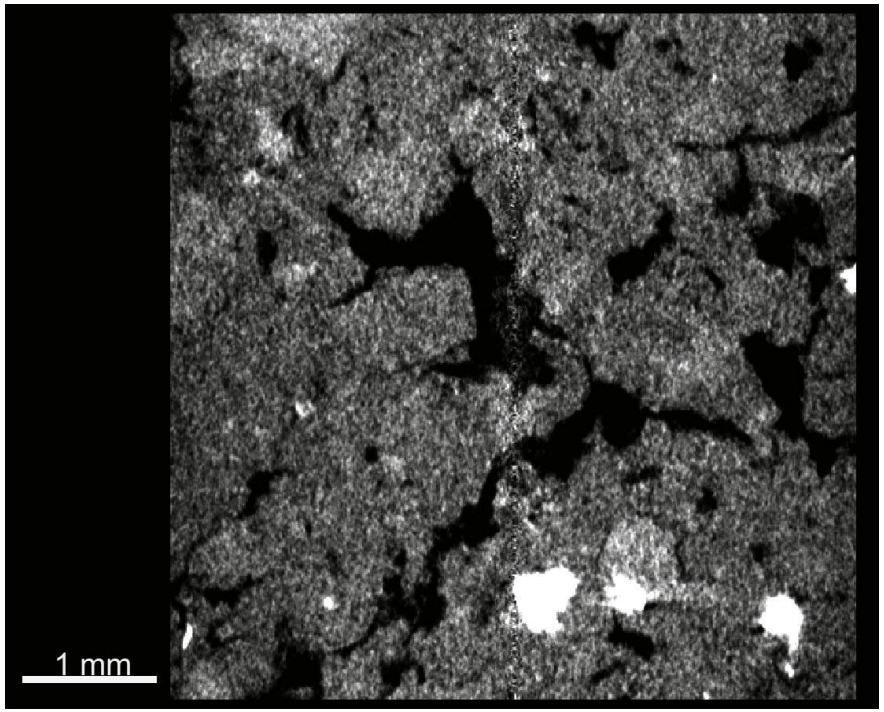
Micro-CT scan



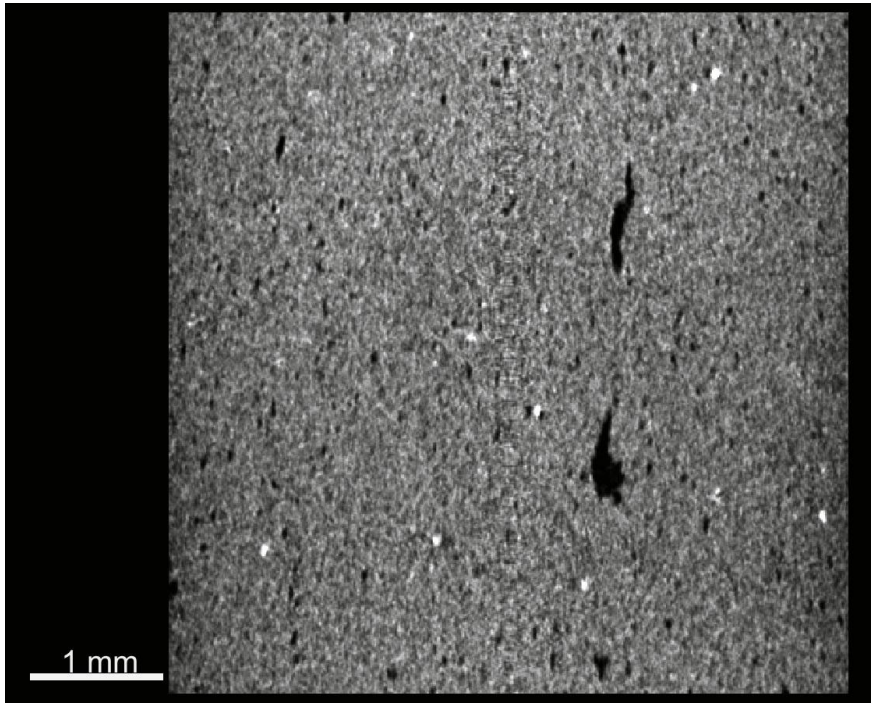
Thin section



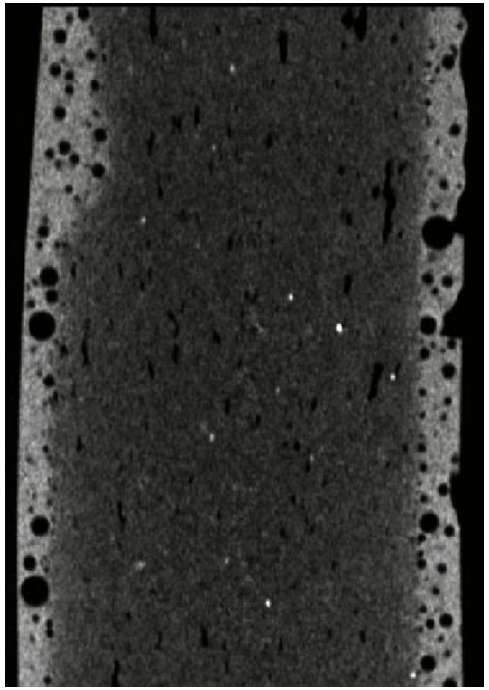
Micro-CT Scans



Low-fired ceramic

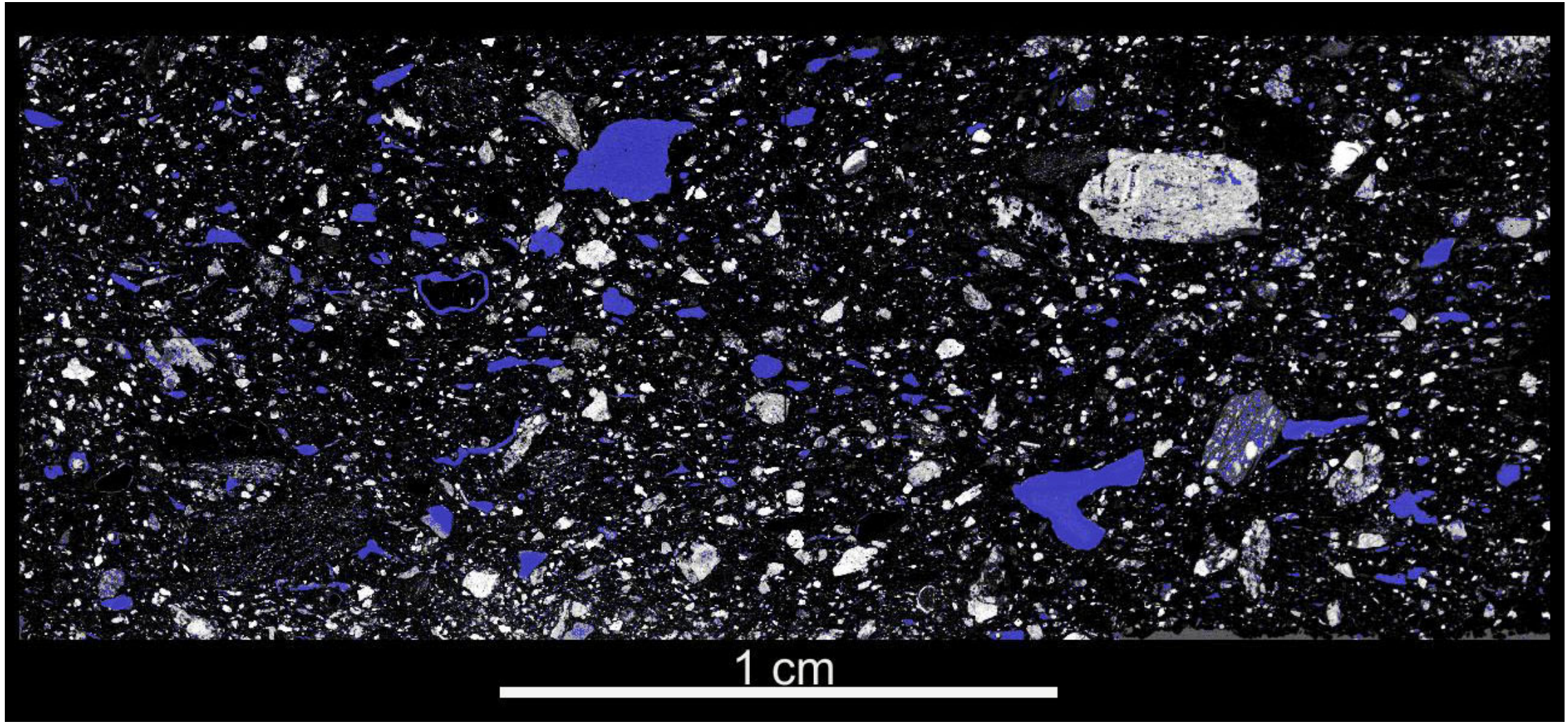


High-fired ceramic



Glazed ceramic

Using Dragonfly for image analysis of 2D thin sections



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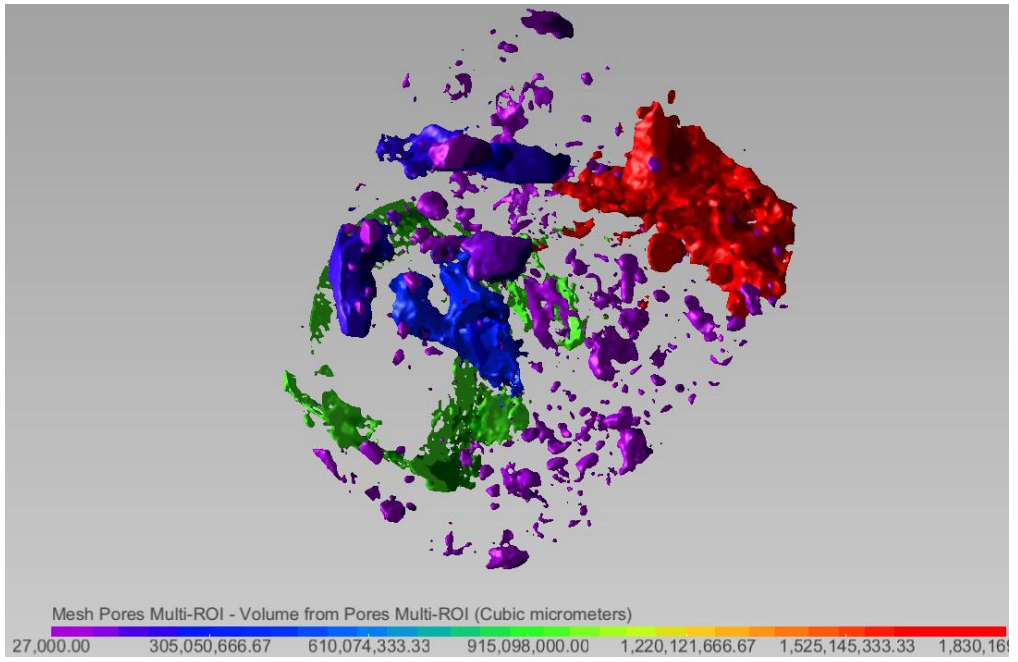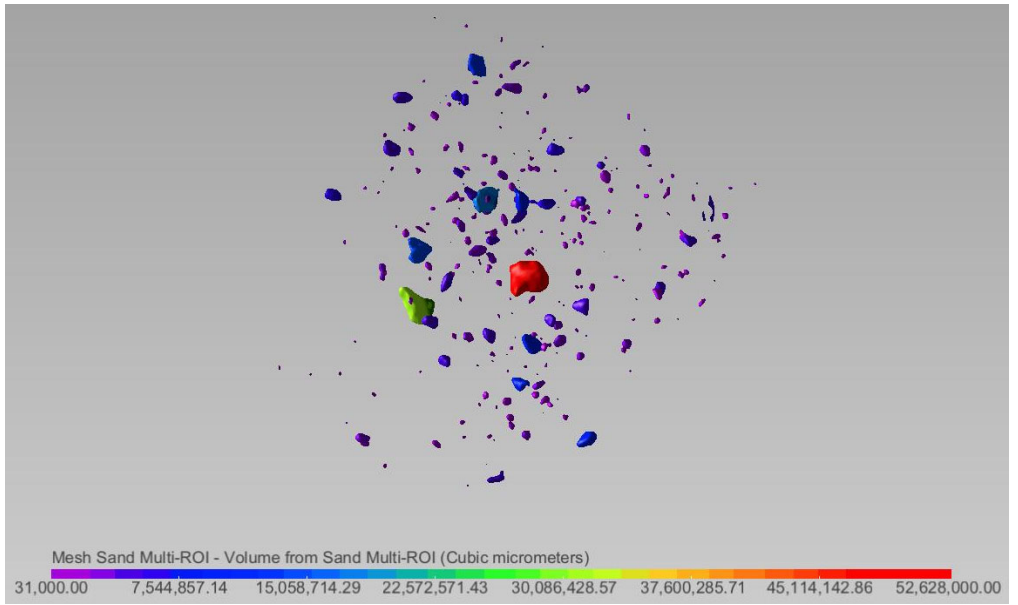
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