MONet Community Science Meeting – X-ray Computed Tomography (XCT) Hands-On Tutorial

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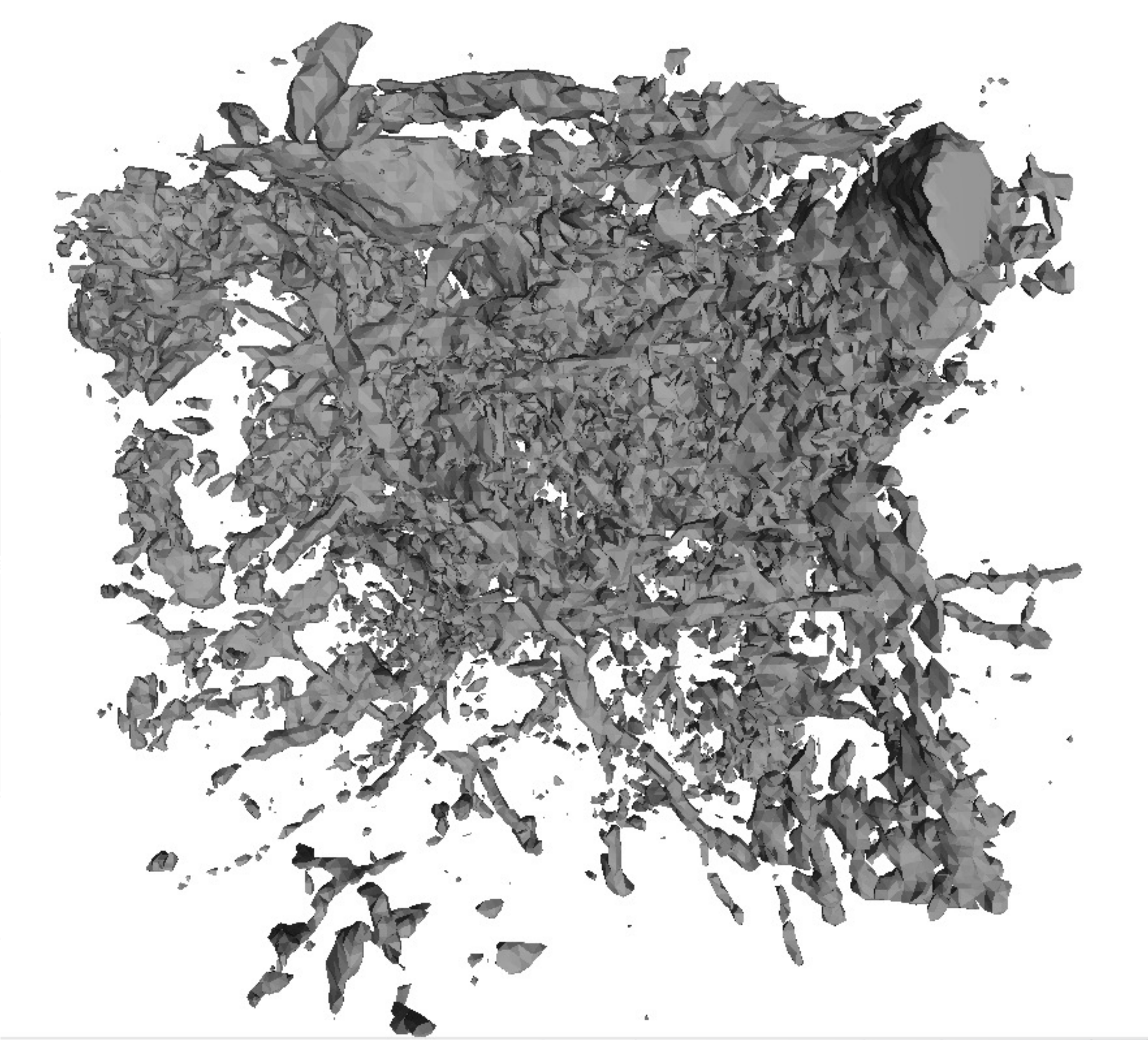


Things to do before the meeting

- Download and install Fiji (ImageJ), make sure it works: try opening “Soil core 2 top zoom_500x500x500_8b”, see slides 4-7 for help

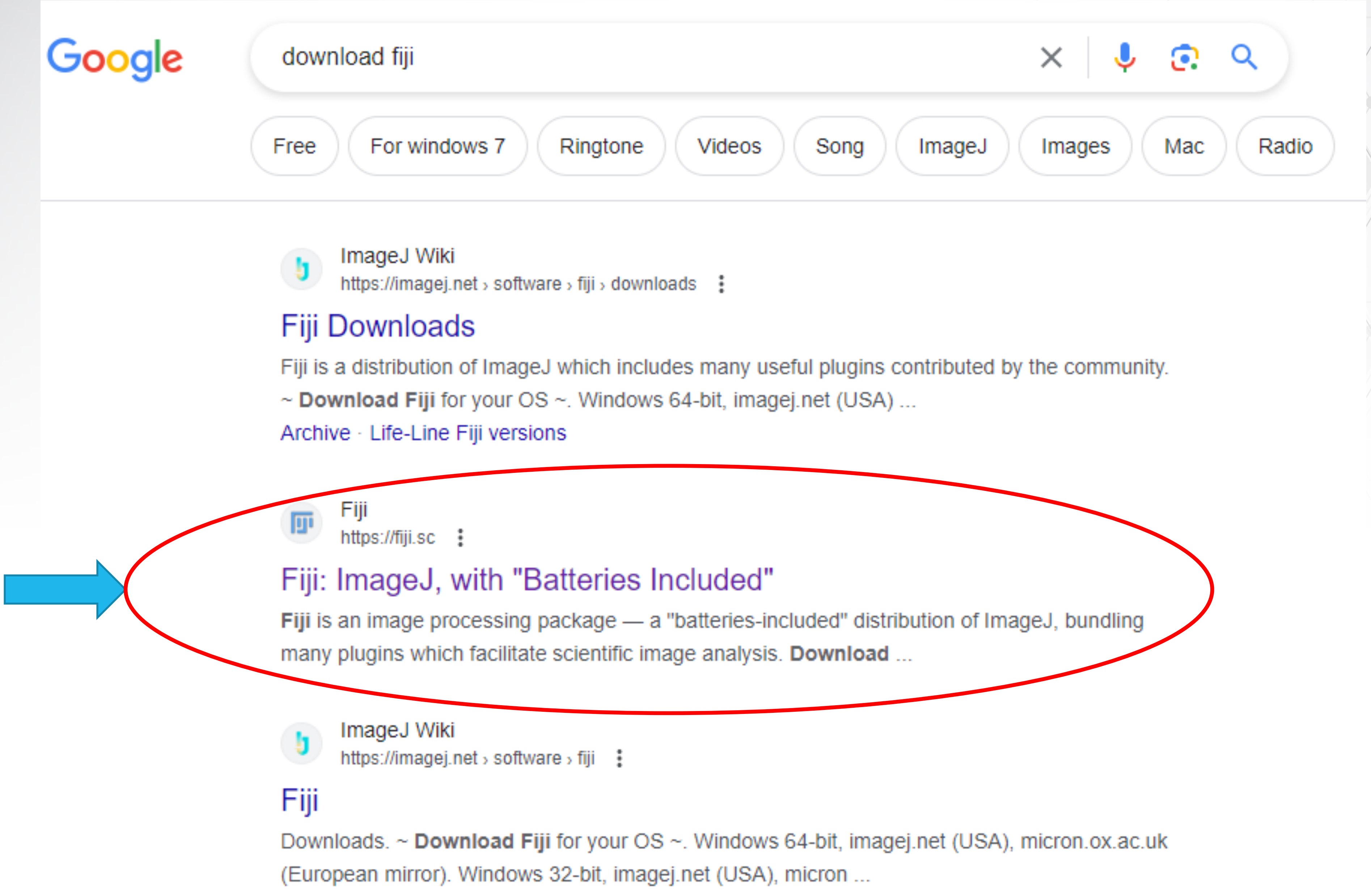
- Download files “Soil core 2 top zoom_500x500x500_8b”, “Binary image_500x500x500_8bit”, “Classified image_500x500x500_RGB”, “Pores.stl” and “Example soil porosity data.xlsx”

- Download ParaView: https://www.paraview.org/download/

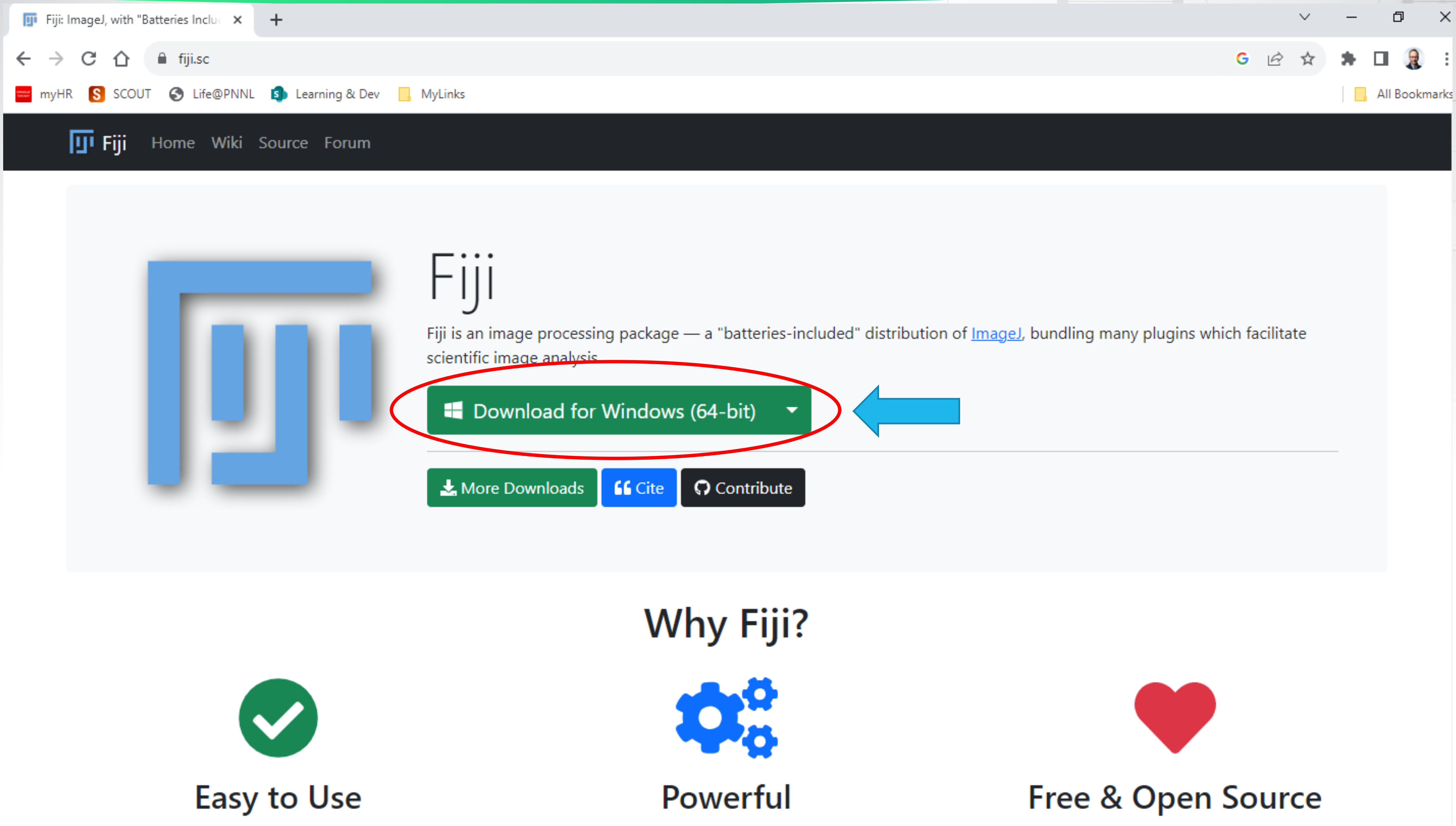
Outline

- Processing and segmentation of 3D data in Fiji (ImageJ)
- Basic porosity analysis: pore size distribution
- Example for easy visualization of 3D data
- XCT data analysis and visualization needed for PFLOTRAN modeling
    - Google Colab notebook
    - 3D visualization using ParaView

Download Fiji

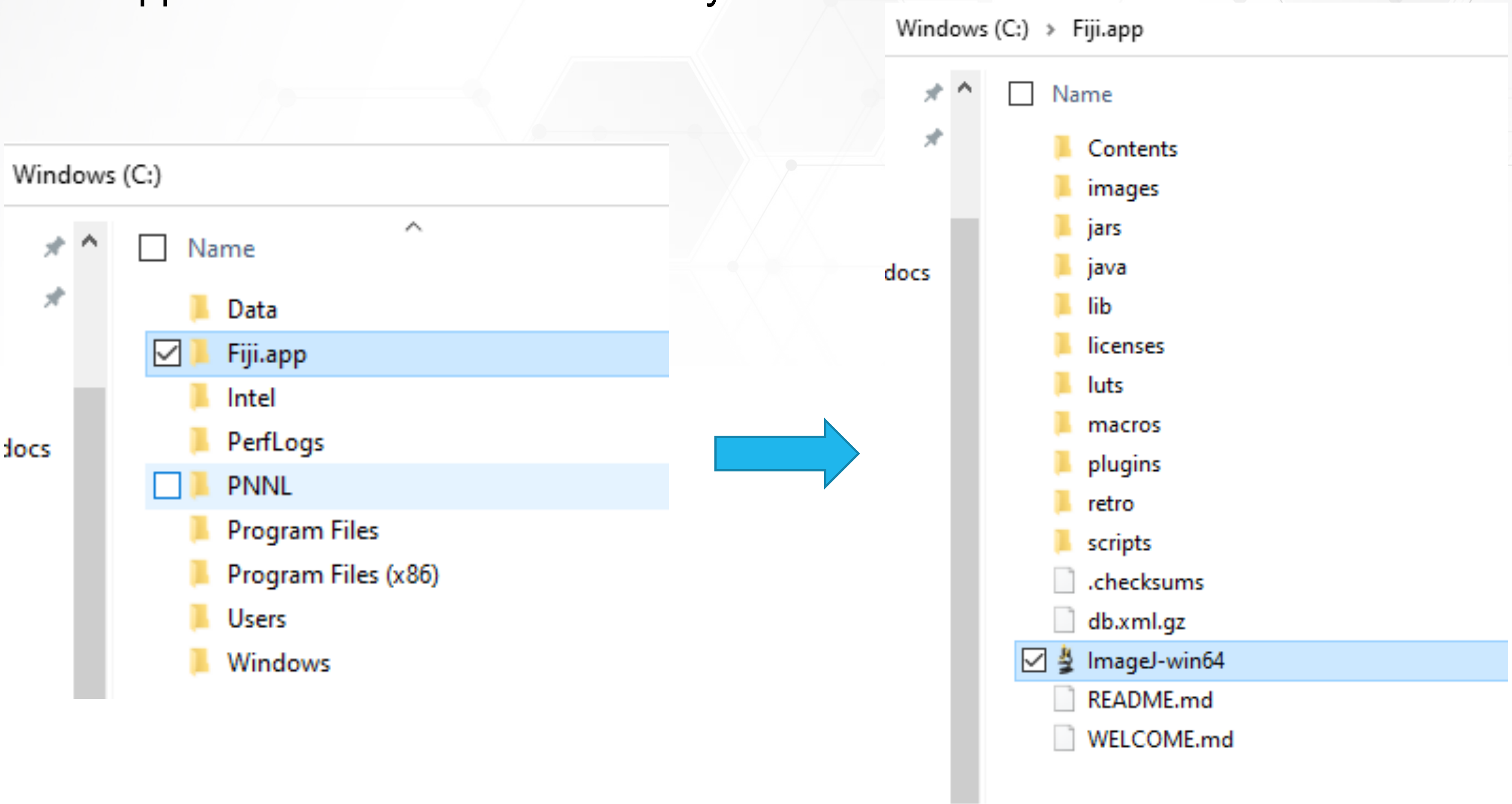


Install Fiji

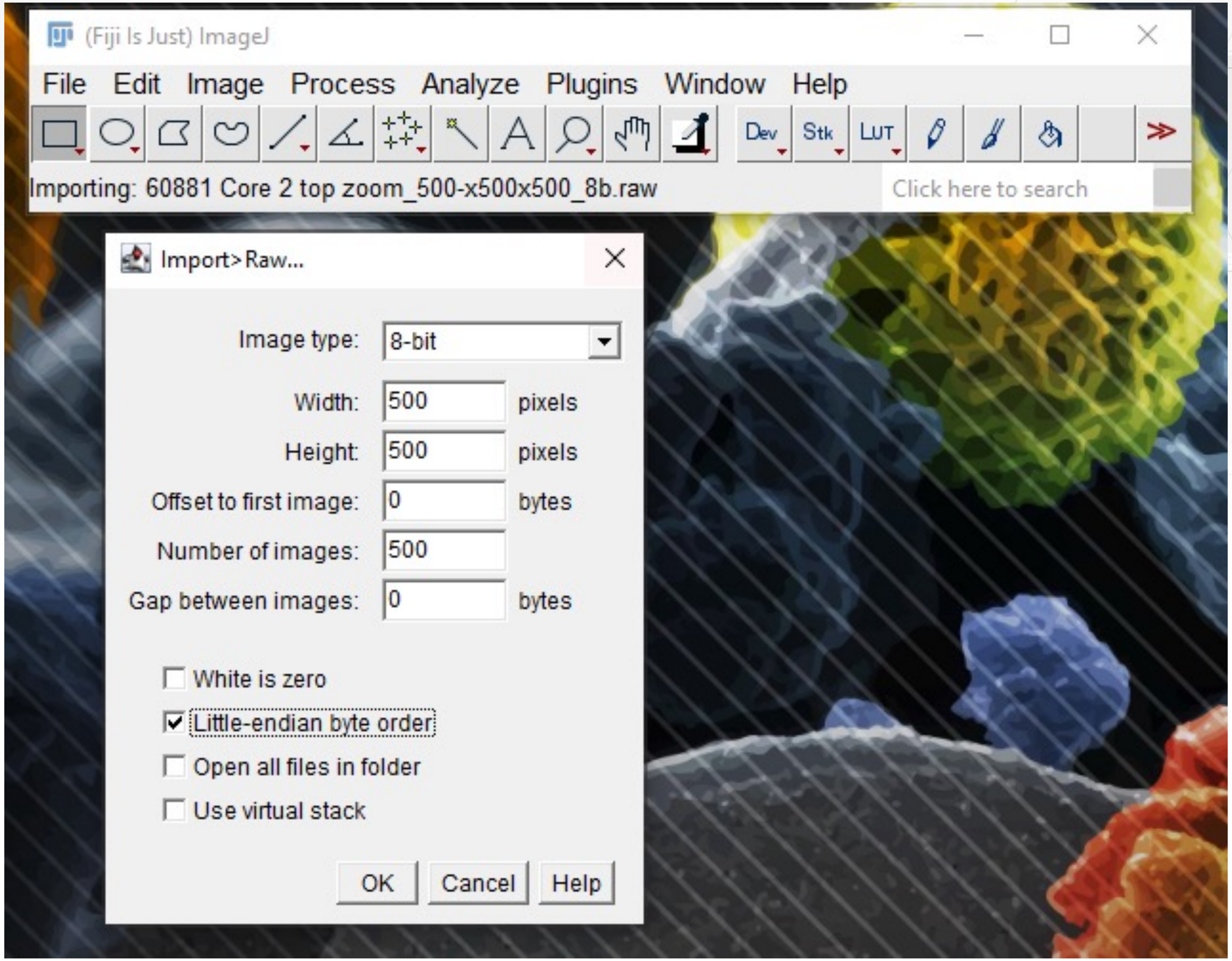


Install Fiji – cont.

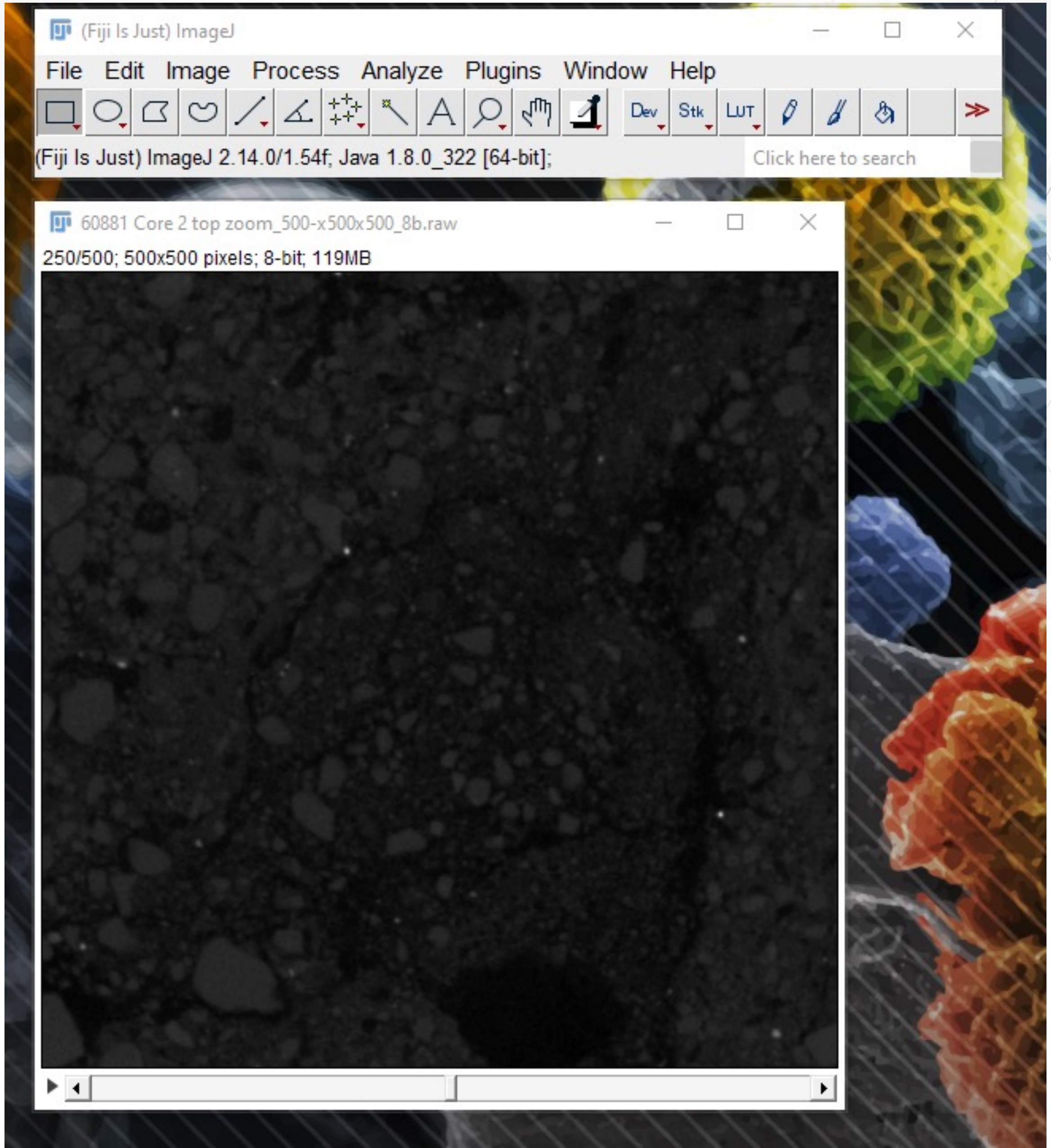
- Copy Fiji.app folder from zip file to C drive
- Run application file “ImageJ-win64”
- Allow for Java installation as offered (if you do not already run Java 1.8)
- Once app started, run updater
- You can pin this application file to taskbar for easy access



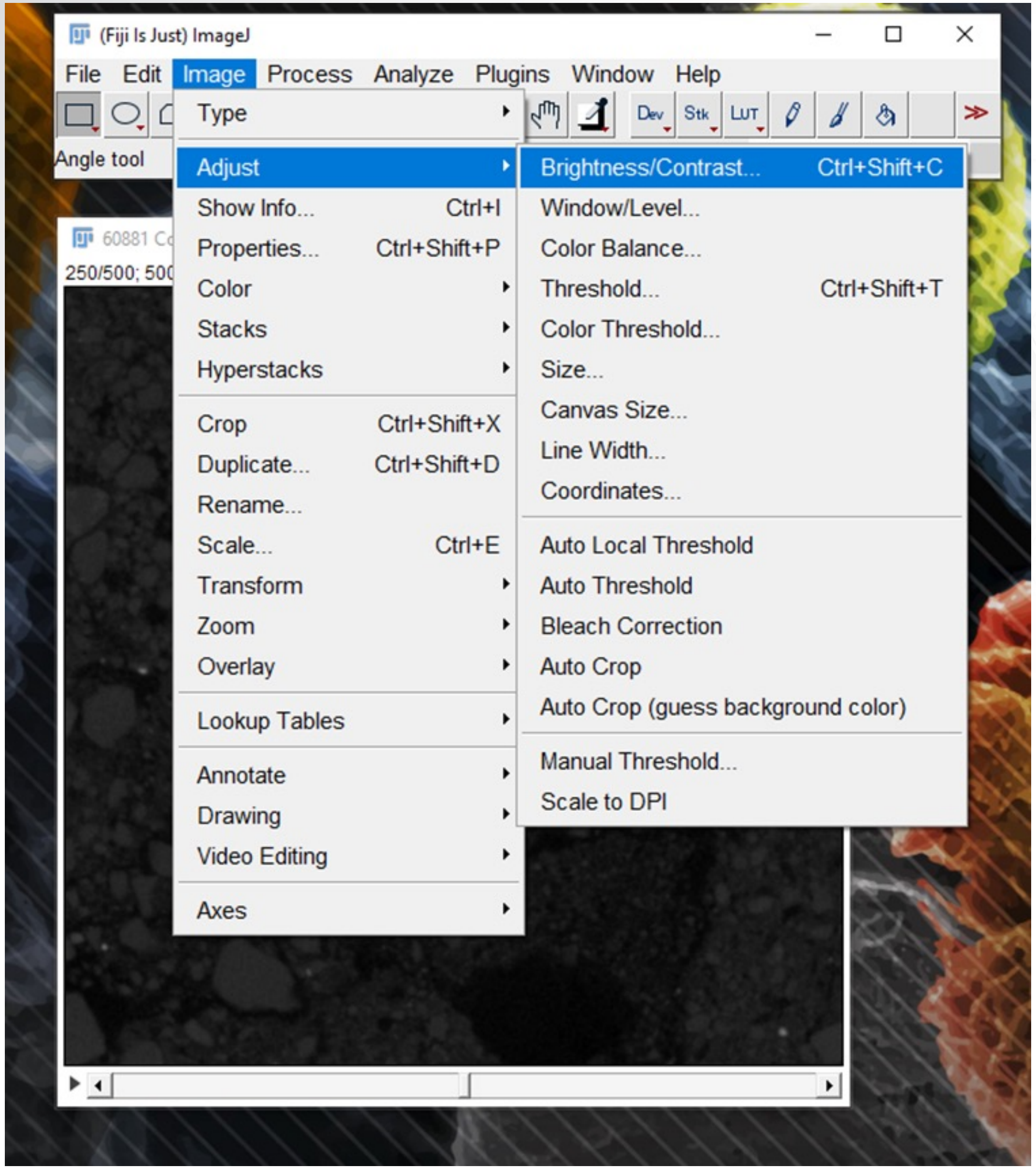
Import data: Soil core 2 top zoom_500x500x500_8b.raw

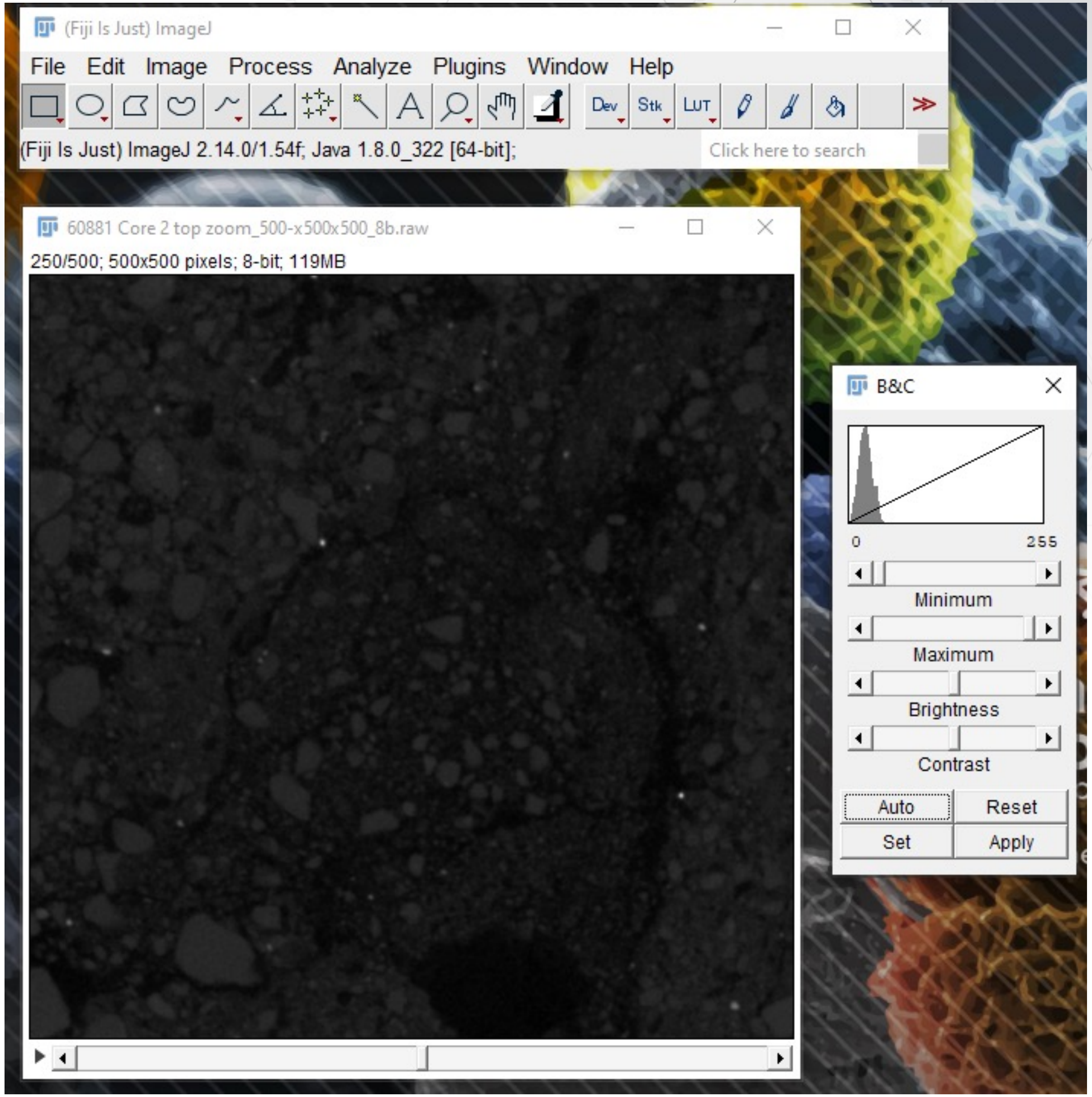


Import data – cont.

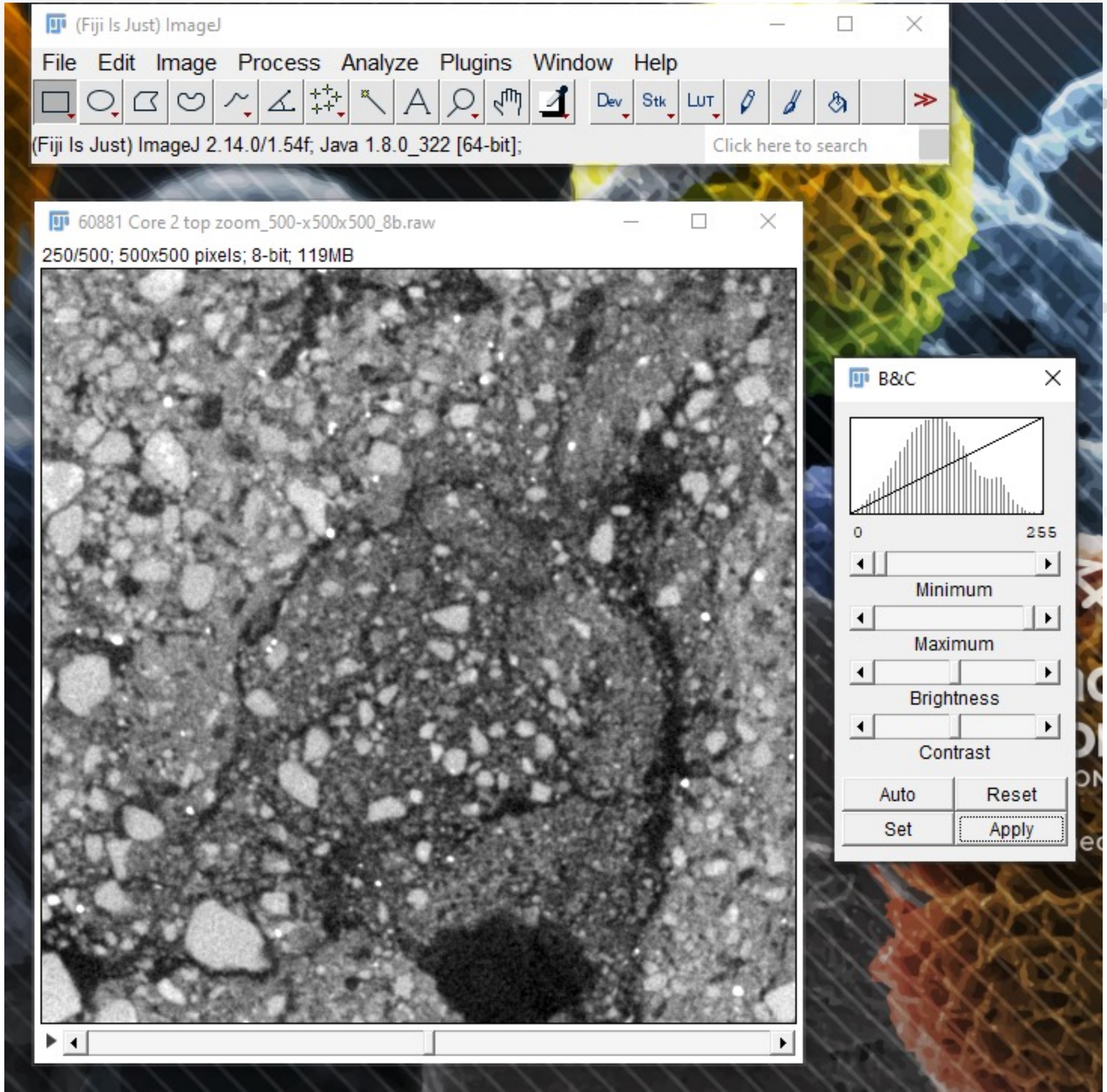


Enhance image contrast

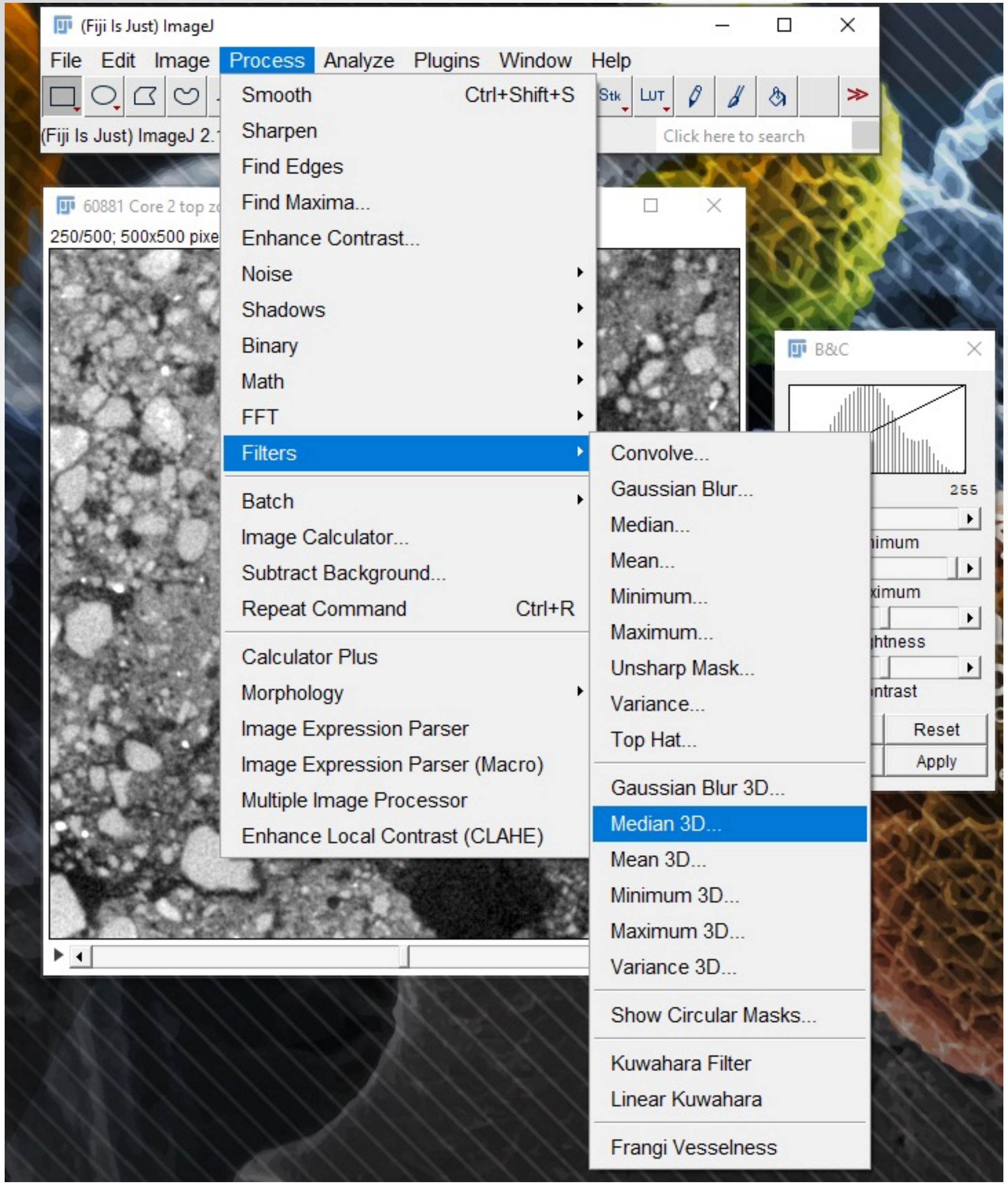




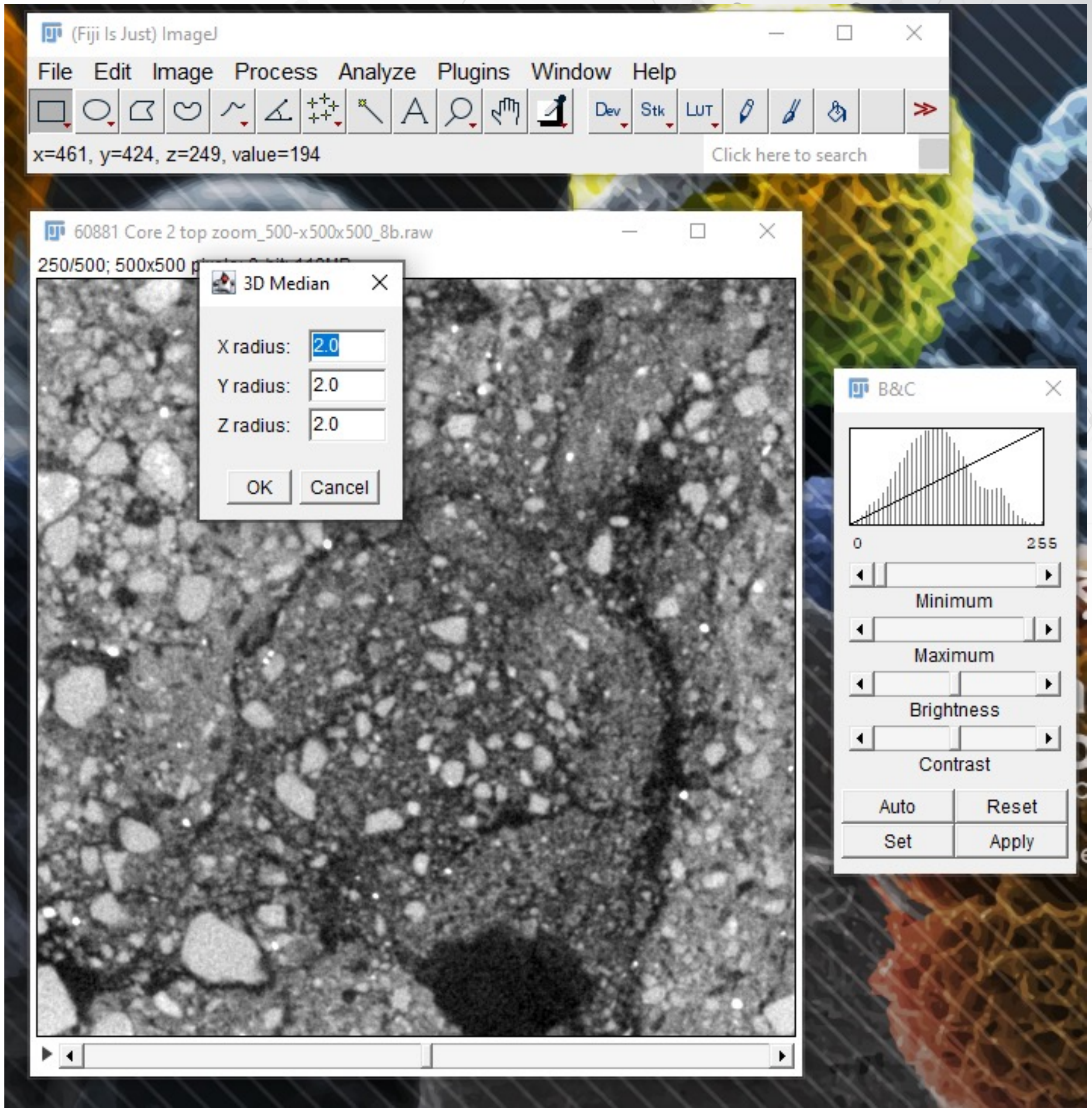
Enhance image contrast – cont.



Filtering

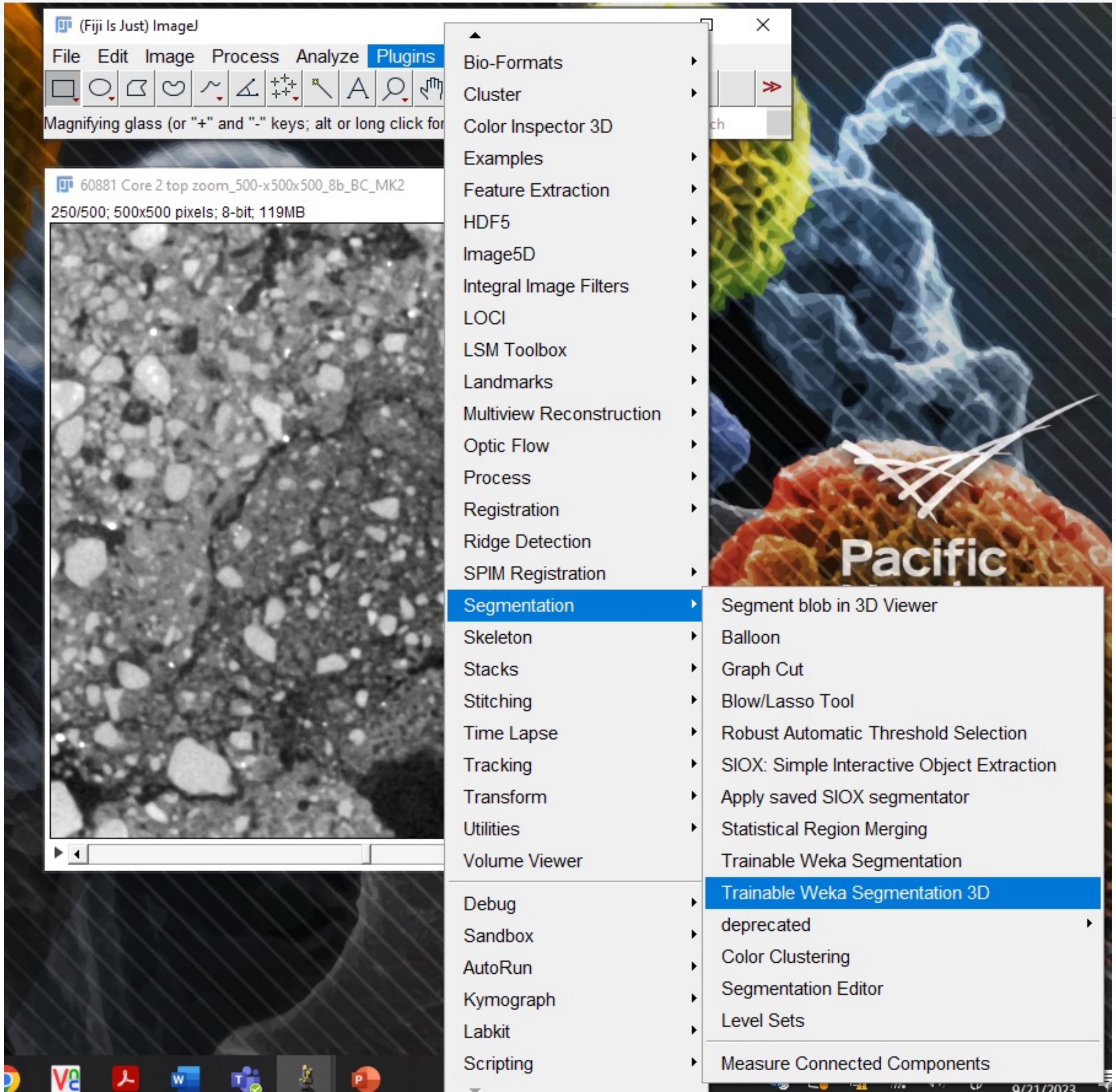


(Fiji Is Just) ImageJ
File Edit Image Process Analyze Plugins Window Help
Click here to search
Smooth Ctrl+Shift+S
Sharpen
Find Edges
Find Maxima...
Enhance Contrast...
Noise
Shadows
Binary
Math
FFT
Filters
Batch
Image Calculator...
Subtract Background...
Repeat Command Ctrl+R
Calculator Plus
Morphology
Image Expression Parser
Image Expression Parser (Macro)
Multiple Image Processor
Enhance Local Contrast (CLAHE)
Convolve...
Gaussian Blur...
Median...
Mean...
Minimum...
Maximum...
Unsharp Mask...
Variance...
Top Hat...
Gaussian Blur 3D...
Median 3D...
Mean 3D...
Minimum 3D...
Maximum 3D...
Variance 3D...
Show Circular Masks...
Kuwahara Filter
Linear Kuwahara
Frangi Vesselness
250/500; 500x500 pixe
B&C
Reset
Apply

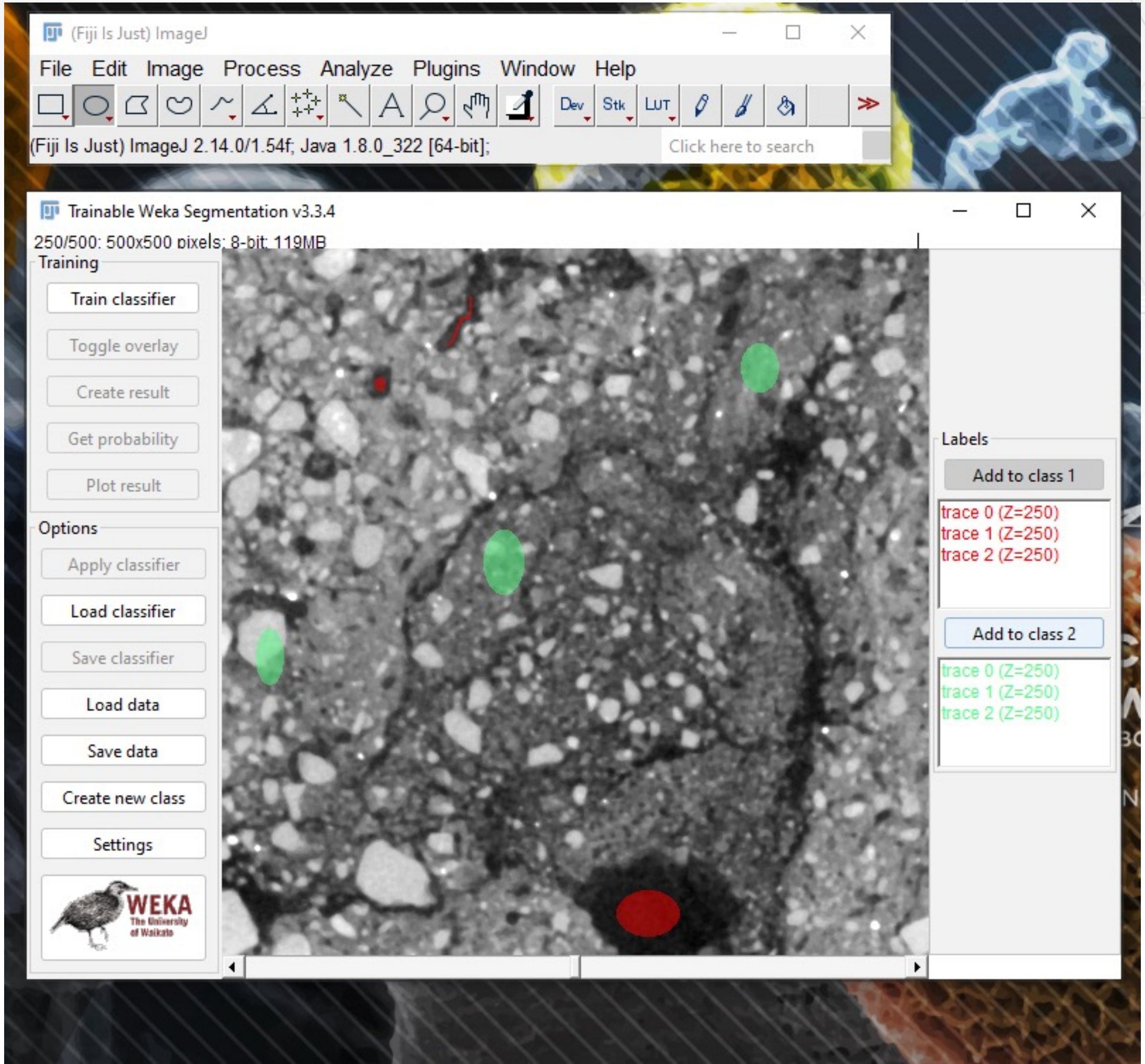


(Fiji Is Just) ImageJ
File Edit Image Process Analyze Plugins Window Help
x=461, y=424, z=249, value=194
Click here to search
60881 Core 2 top zoom_500-x500x500_8b.raw
3D Median
X radius: 2.0
Y radius: 2.0
Z radius: 2.0
OK Cancel
B&C
0 255
Minimum
Maximum
Brightness
Contrast
Auto Reset
Set Apply

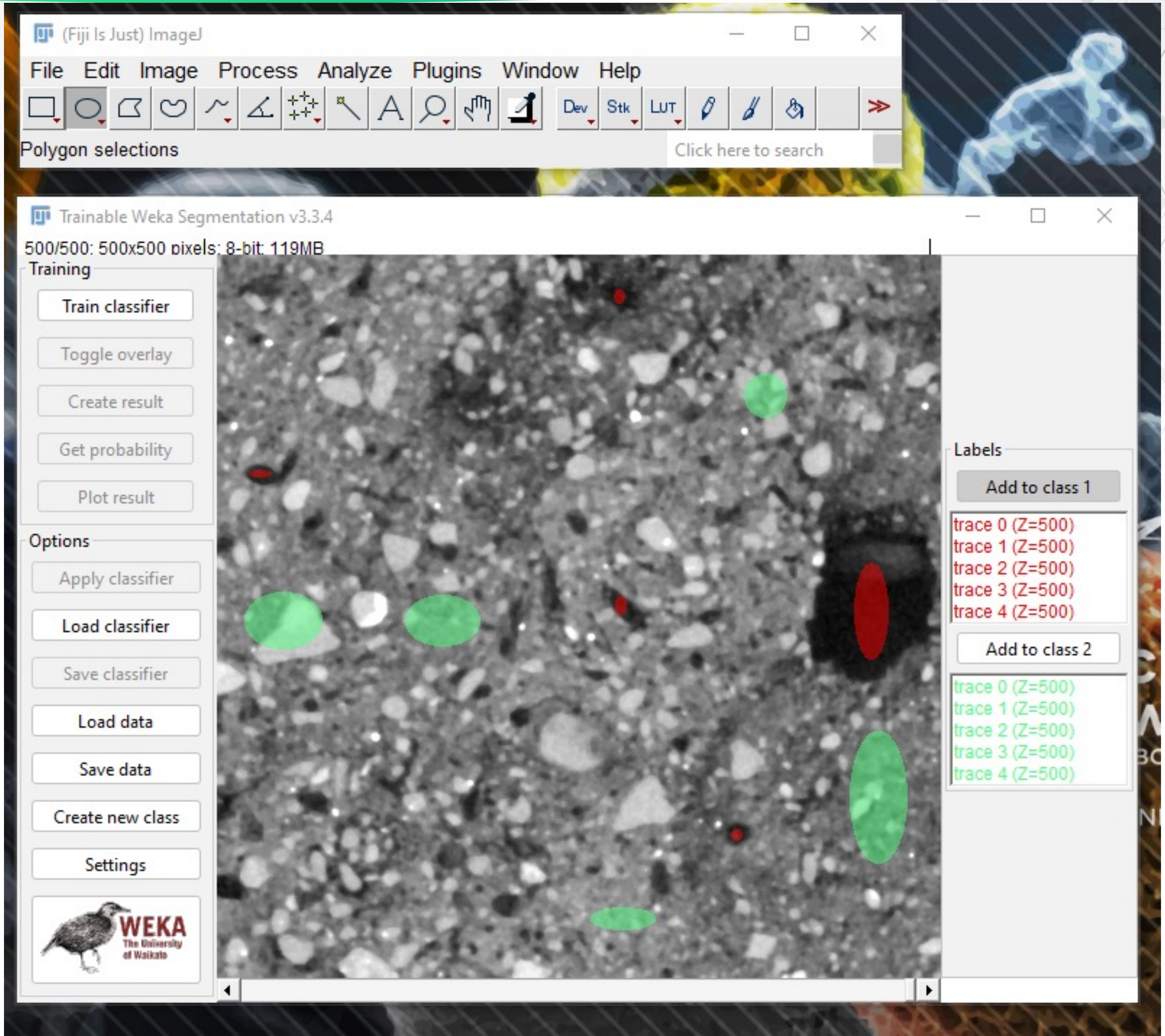
Segmentation – Trainable Weka Segmentation 3D plugin



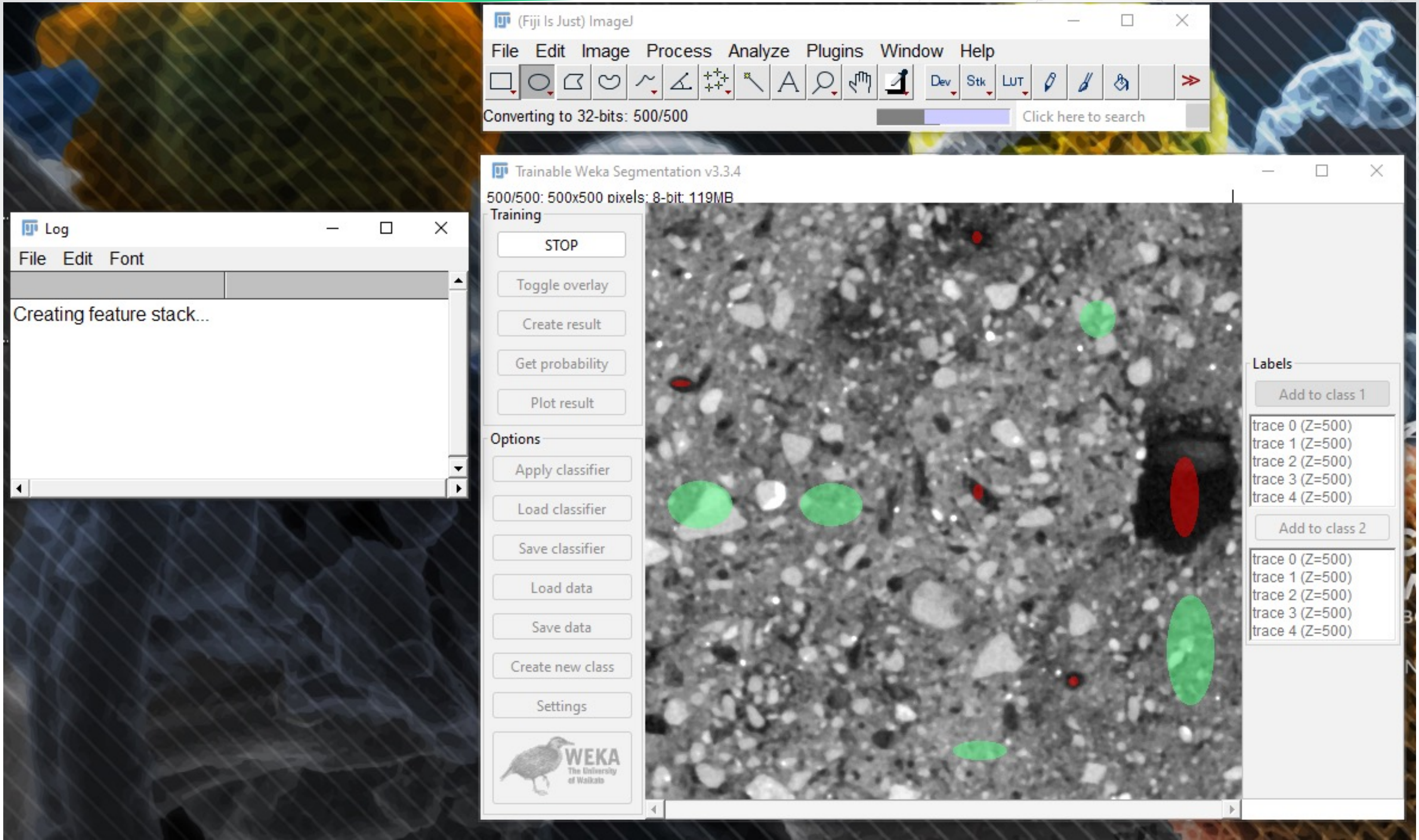
Segmentation – Annotate regions for pores (red) and soil matrix (green)



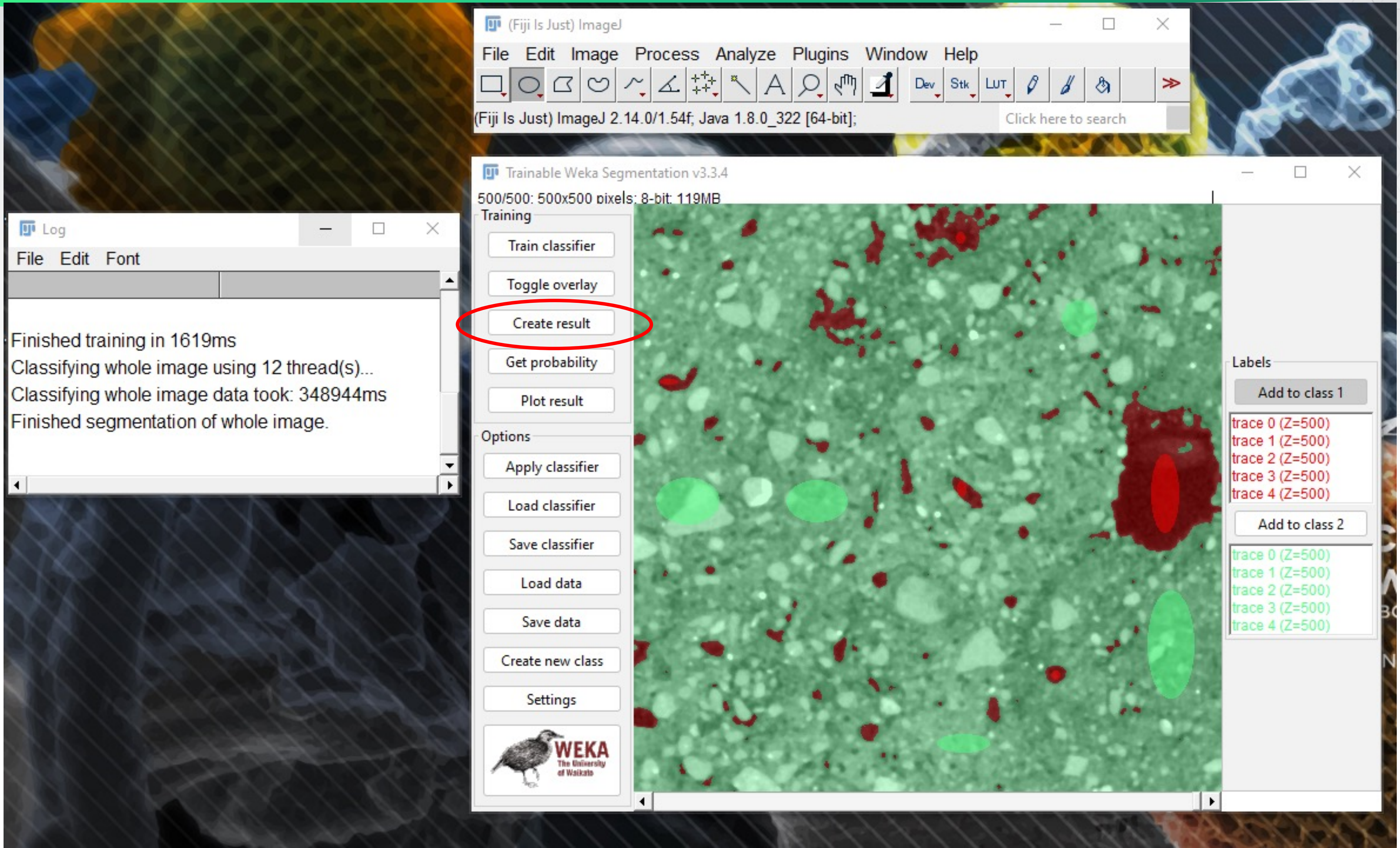
Segmentation – Do this classification for multiple slices (to create more training data)



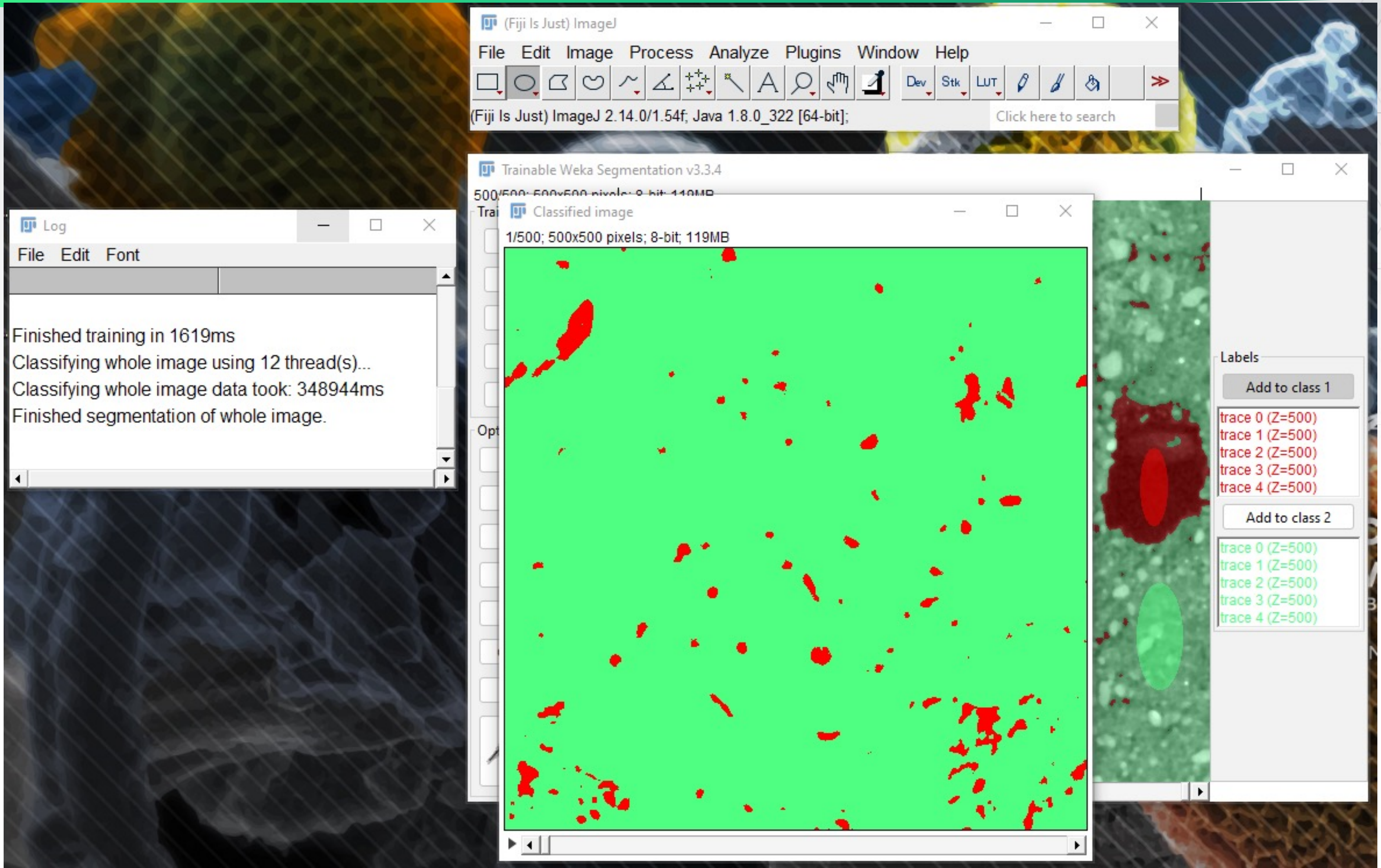
Segmentation – Train classifier (may take up to 30+ minutes)



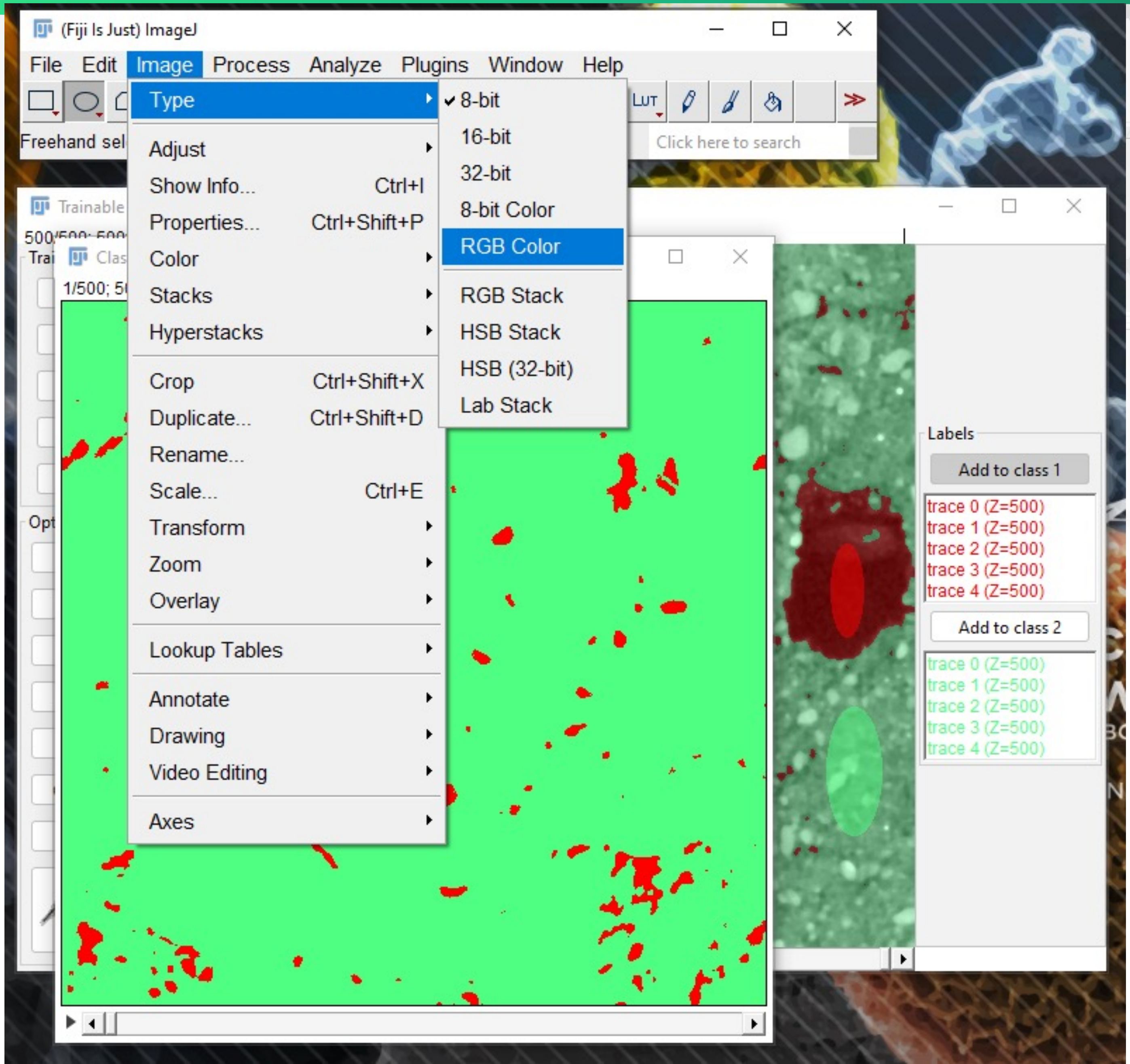
Segmentation – Create result from classified data (Classified image_500x500x500_RGB)



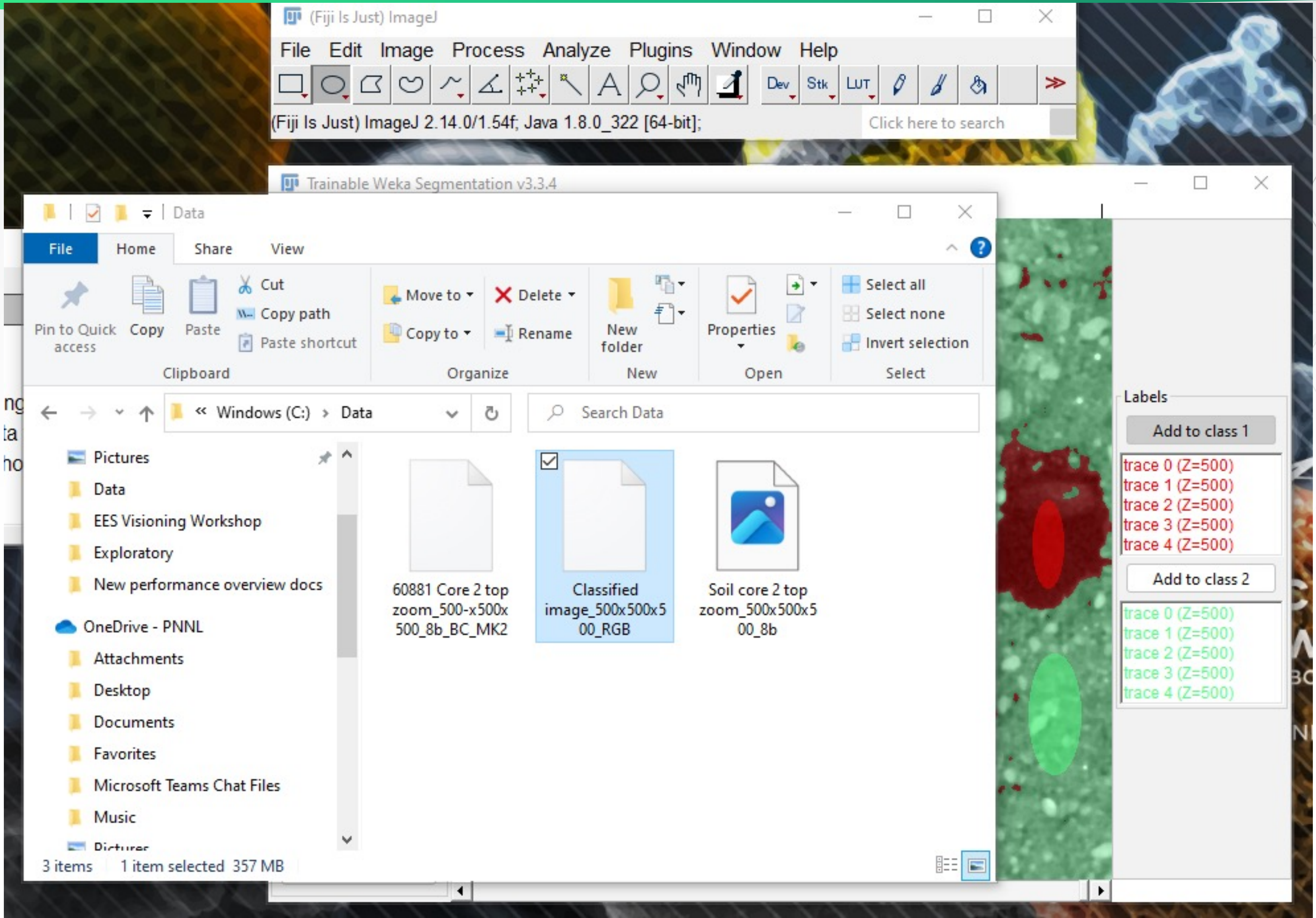
Segmentation – Create result from classified data – cont.



Segmentation – Convert segmentation result into RGB color data

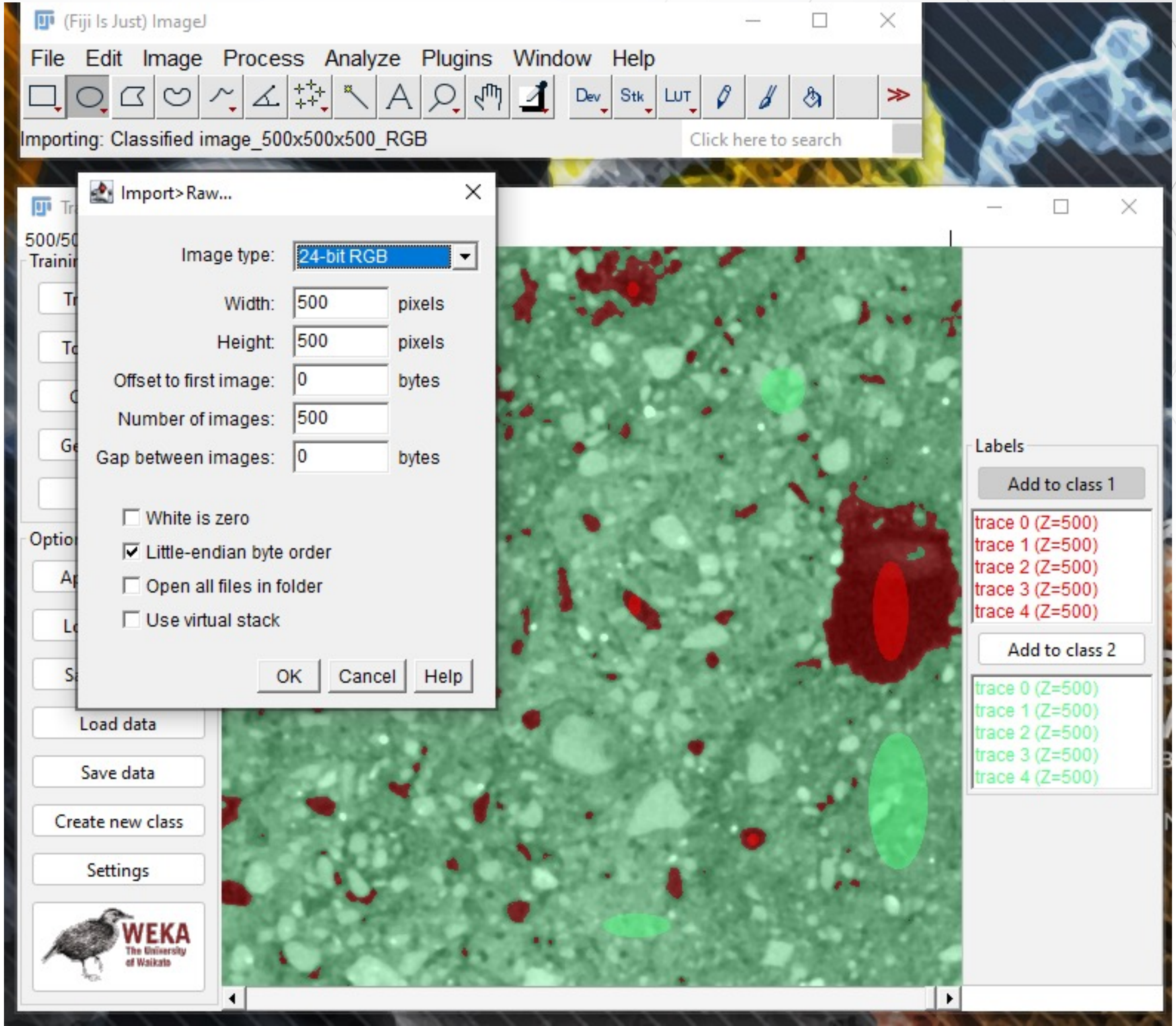


Segmentation – Save RGB color data as new raw file

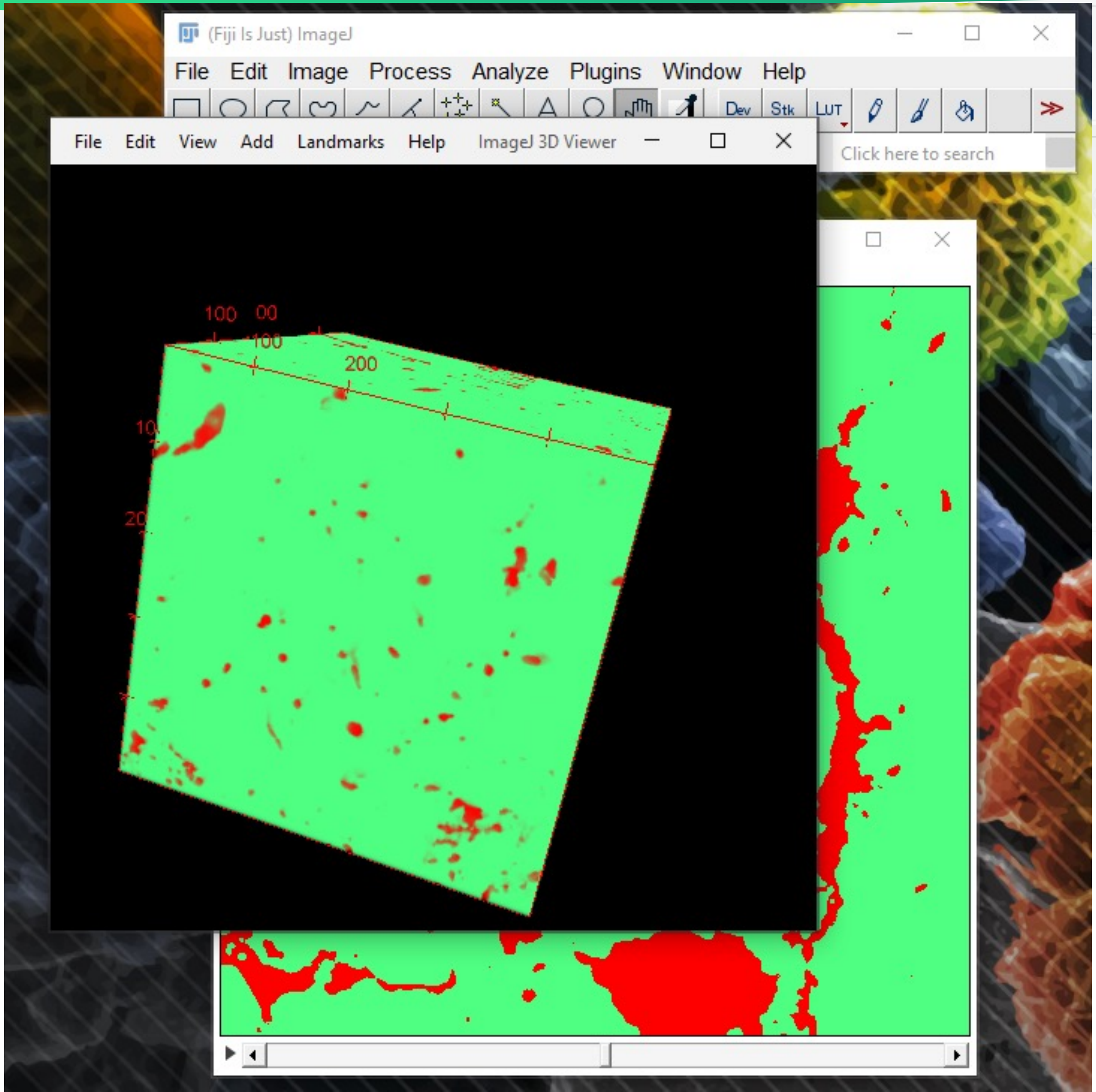


Segmentation – Open segmented (RGB) data as 24-bit RGB

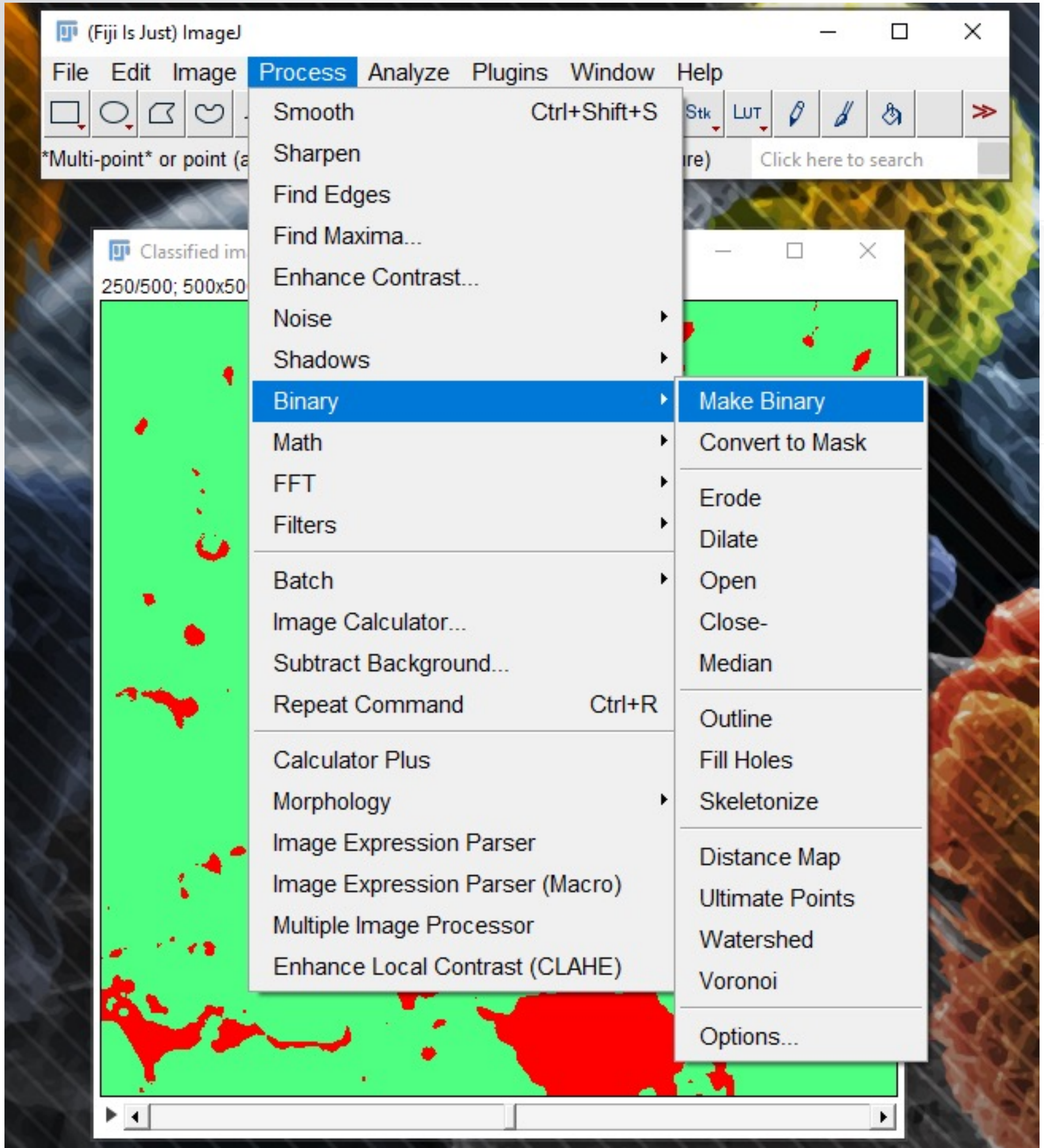
File-Import-Raw-Select 24-bit RGB

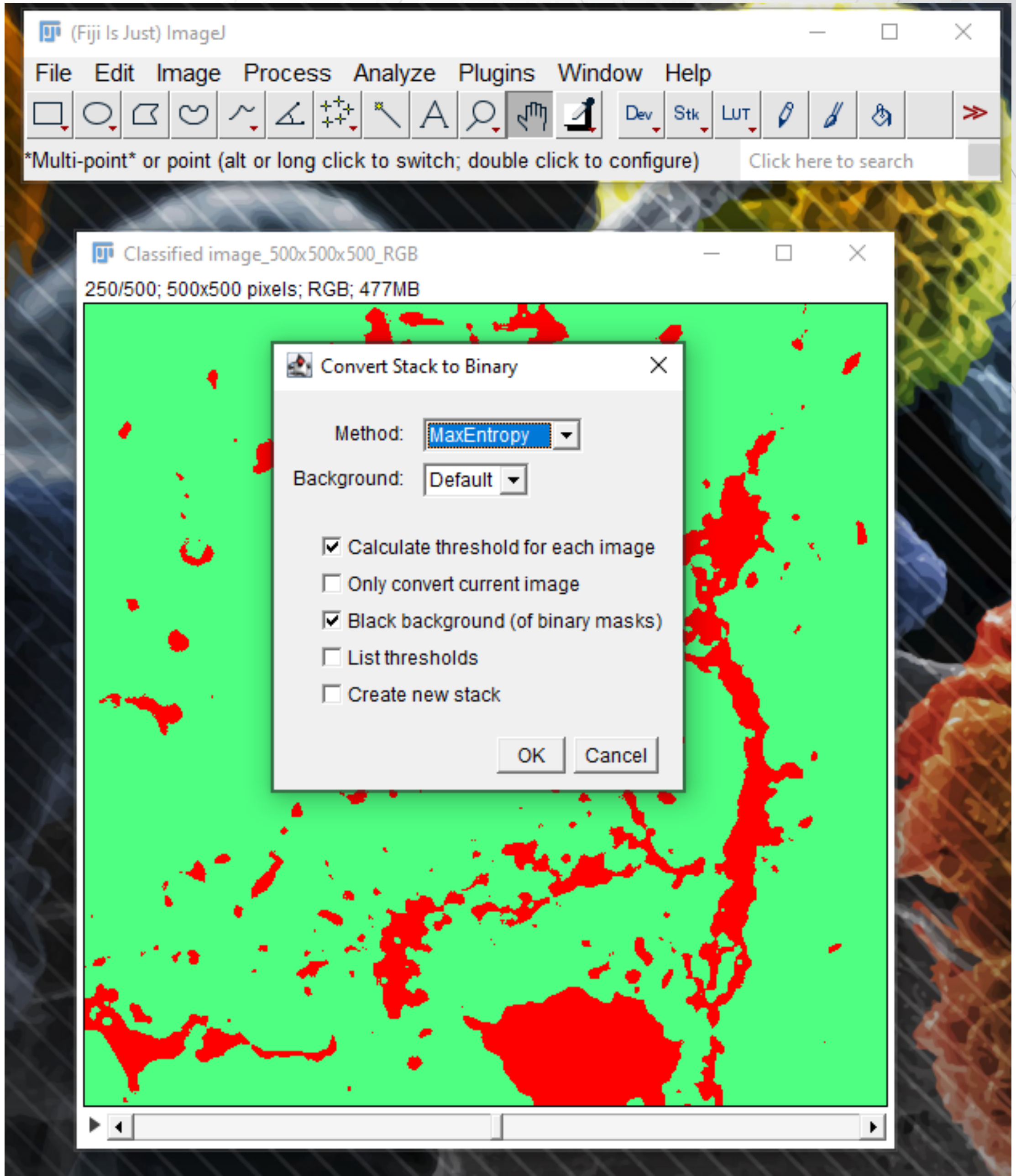


Visualization – The RGB data is not very useful for porosity visualization

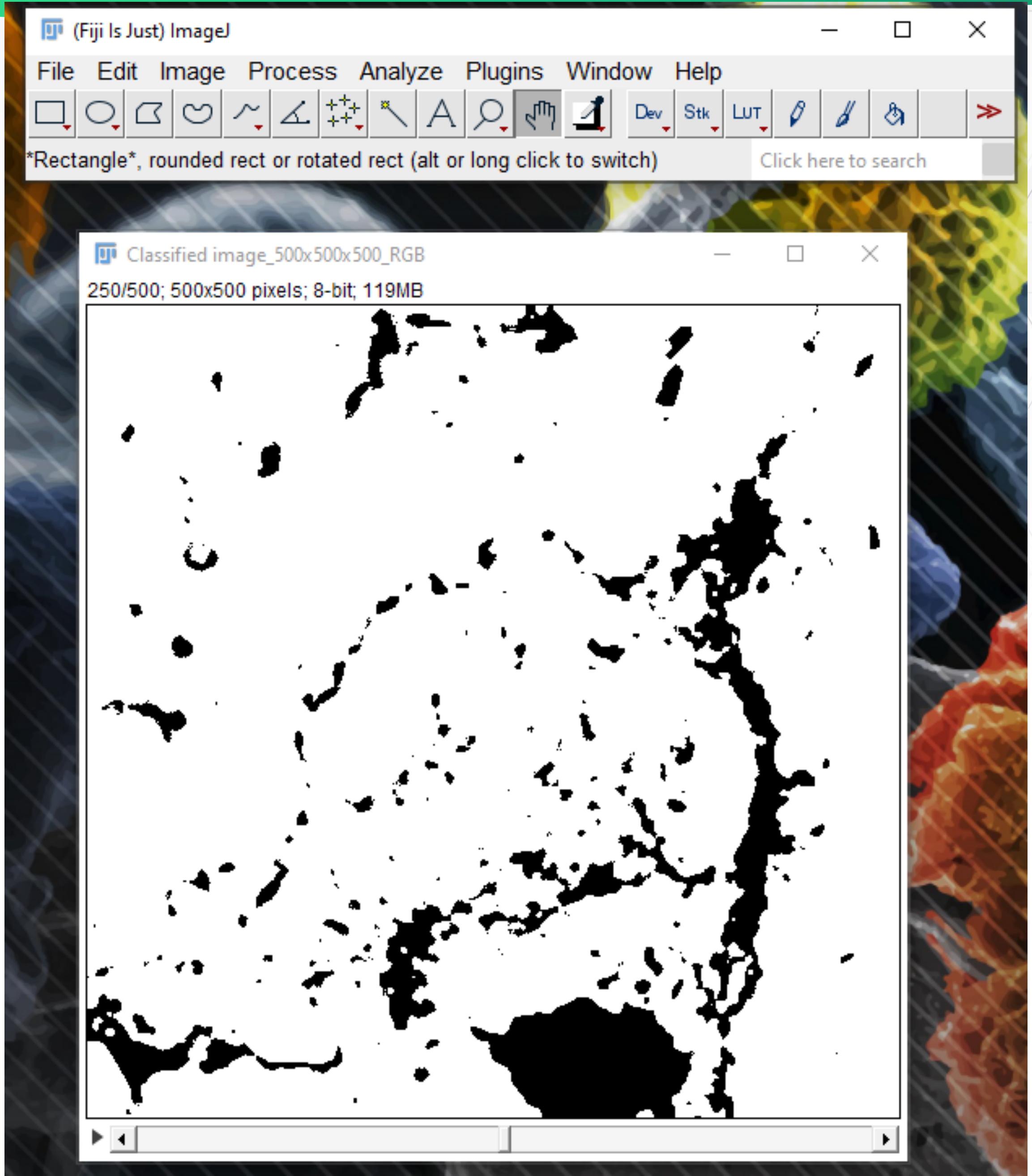


Visualization – Convert the RGB data into binary

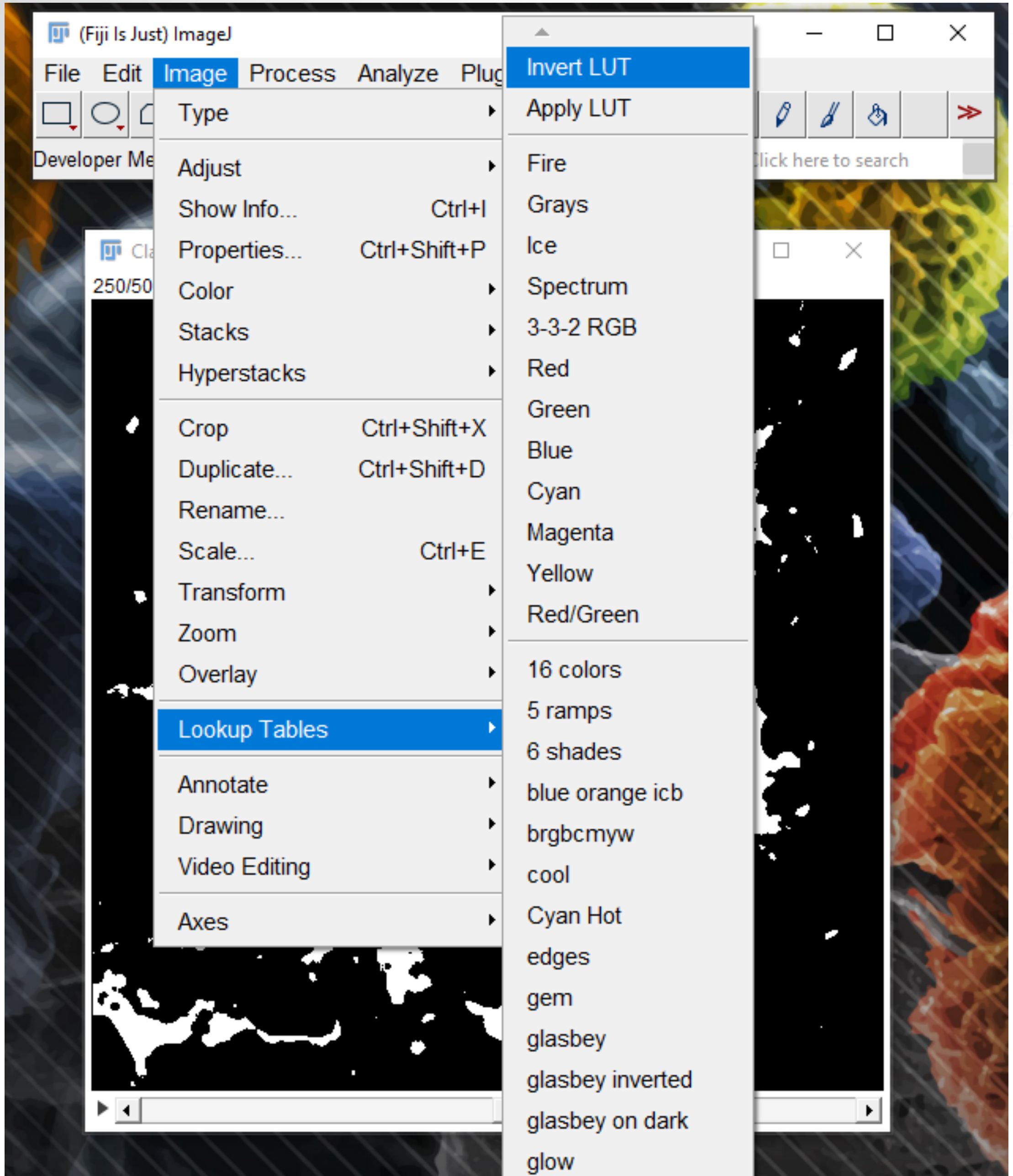




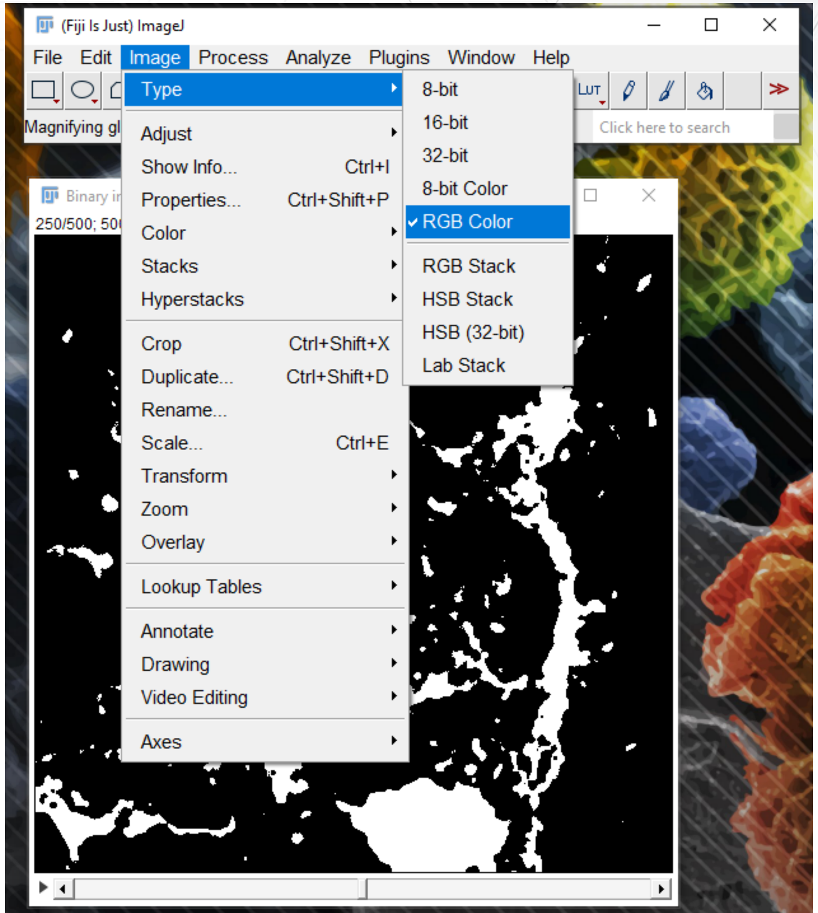
Visualization – Binarized data needs to be inverted (pores must be white)



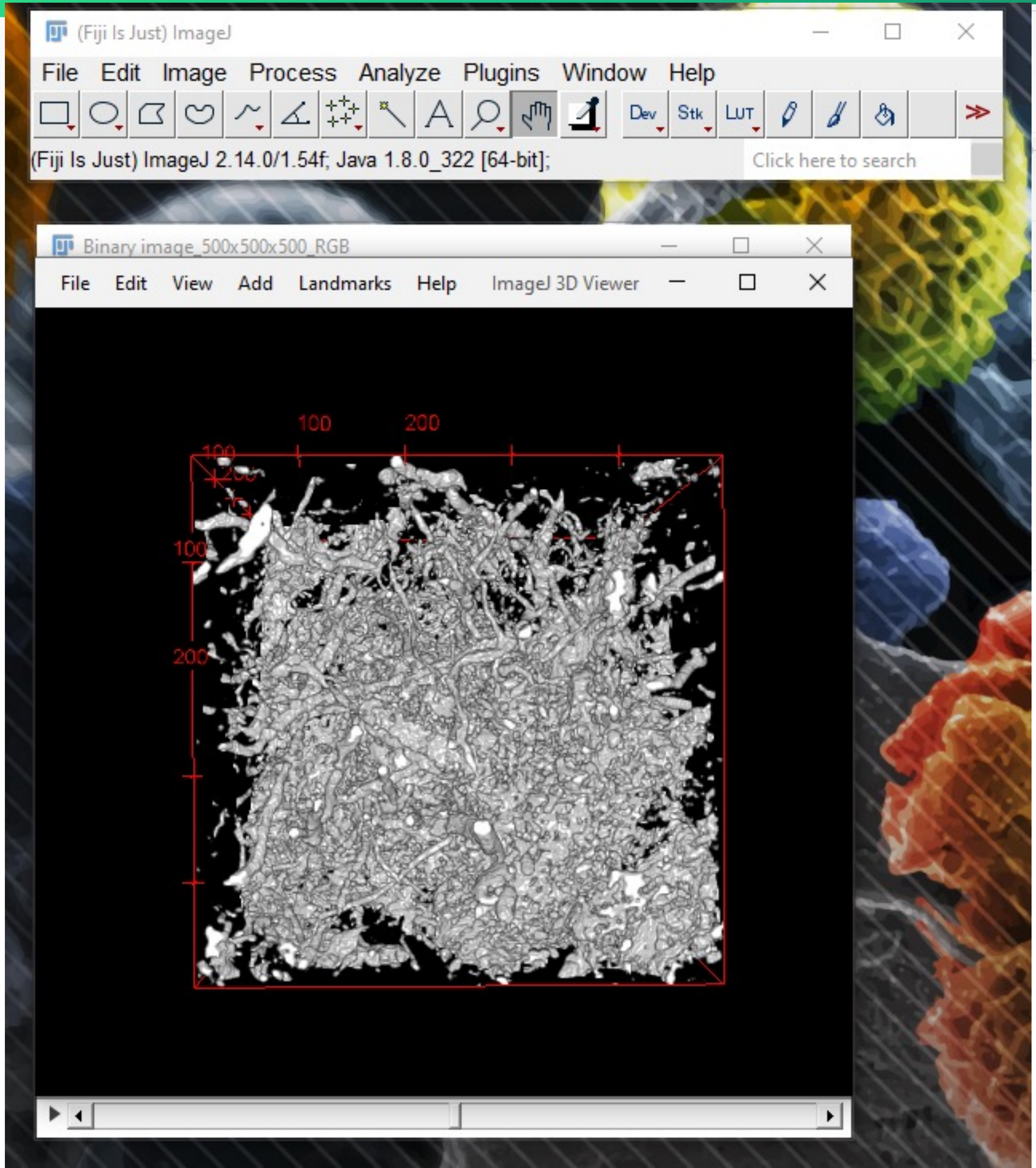
Visualization – Binarized data needs to be inverted (pores must be white)



Binarized data becomes 8-bit. It needs to be converted back to RGB so that it can be saved as inverted. The saved file can be opened again as 24-bit RGB and saved again as 8-bit.

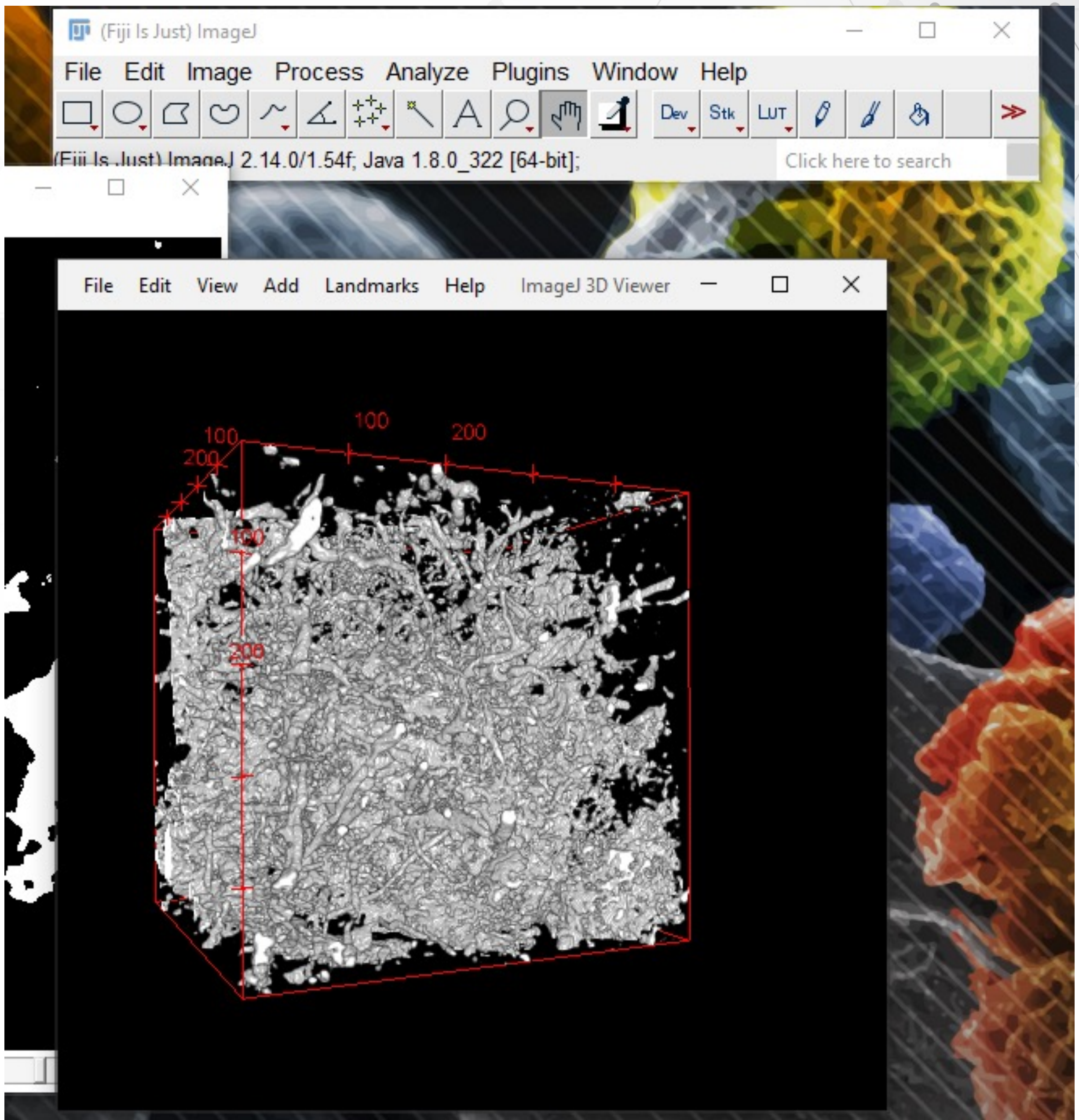


Visualization – Open 3D Viewer from Plugins to visualize the pore structure



Visualization – Create an animation

- Click "Start animation" under "View"
- You can record a movie by clicking on "Record 360 deg rotation"

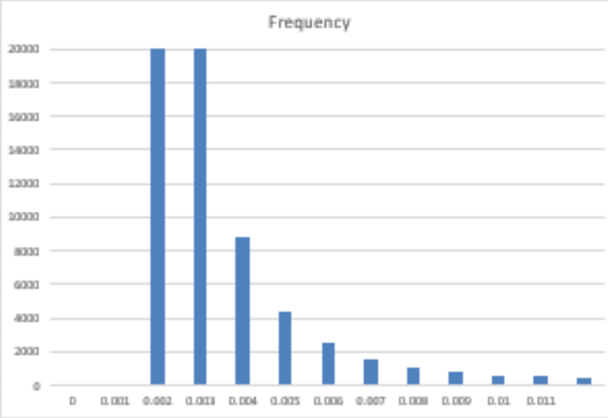


Analysis of porosity data in Excel

- Open file: Example soil porosity data.xlsx

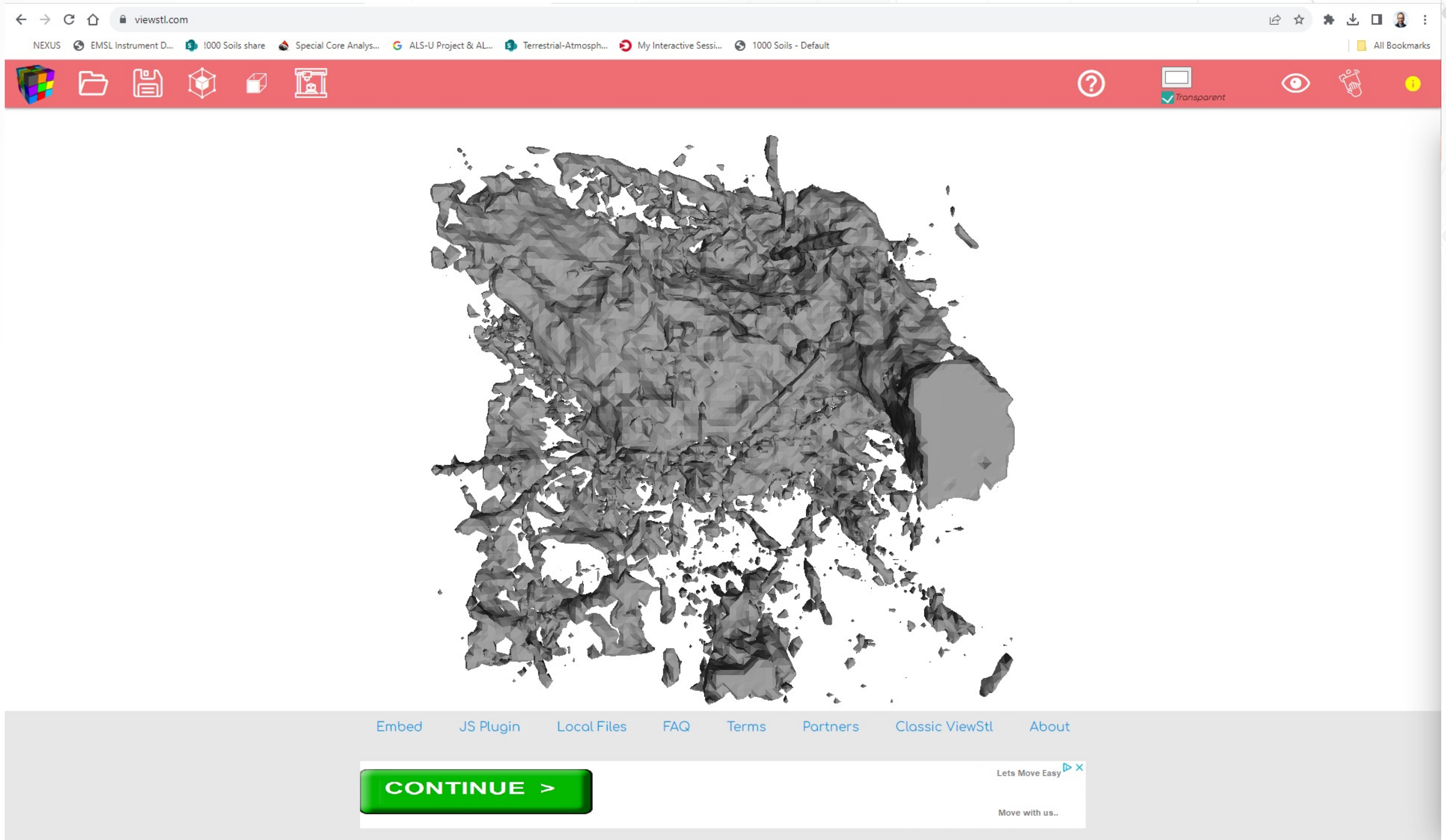
	A	B	C	D	G	H	I	J
1					volume (mm:	Area (mm2)	Area Fracti	Diameter (mm)
2								
3	Poros	0.08597			0.00055506	0.0311012	4.07E-09	0.101964
4					5.55E-05	0.00437138	4.07E-10	0.0473274
5					0.00022202	0.0152754	1.63E-09	0.0751276
6					0.00444046	0.187809	3.26E-08	0.203928
7	Poros.Ax	0.06784			0.00699372	0.320421	5.13E-08	0.237267
8			connect	0.78905	0.0501772	1.23785	3.68E-07	0.457617
9					0.00049955	0.031401	3.66E-09	0.0984451
10	PNM in Z				0.00011101	0.00820897	8.14E-10	0.0596288
11	k [µm^2]	k [d]	TotalFlo	Tortuosity	9249.34	190975.9	0.0678378	26.0438
12	14197.3	14385.4	141710	1.35323	0.00632765	0.2437	4.64E-08	0.229482
13					0.0251441	1.01731	1.84E-07	0.363479
14					0.00055506	0.0366056	4.07E-09	0.101964
15	PNM in Y				5.55E-05	0.00437138	4.07E-10	0.0473274
16	k [µm^2]	k [d]	TotalFlo	Tortuosity	0.00044405	0.0256504	3.26E-09	0.0946549
17	71.1757	72.1188	1257.68	1.80898	5.55E-05	0.00437138	4.07E-10	0.0473274
18					0.048179	1.67739	3.53E-07	0.45146
19					5.55E-05	0.00437138	4.07E-10	0.0473274
20	PNM in X				0.00049955	0.0300194	3.66E-09	0.0984451
21	k [µm^2]	k [d]	TotalFlo	Tortuosity	0.00022202	0.0150413	1.63E-09	0.0751276
22	368.357	373.238	5184.8	1.58235	0.00066607	0.0420517	4.89E-09	0.108353
23					0.00144315	0.080395	1.06E-08	0.140207
24					0.00011101	0.00843833	8.14E-10	0.0596288
25					5.55E-05	0.00437138	4.07E-10	0.0473274
26	wet bulk	2.06034			5.55E-05	0.00437138	4.07E-10	0.0473274
27					0.00049955	0.0296423	3.66E-09	0.0984451
28					5.55E-05	0.00437138	4.07E-10	0.0473274
29					0.00016652	0.0117422	1.22E-09	0.068258
30					0.00011101	0.00850627	8.14E-10	0.0596288
31					5.55E-05	0.00437138	4.07E-10	0.0473274
32					0.00011101	0.00843838	8.14E-10	0.0596288
33					5.55E-05	0.00437138	4.07E-10	0.0473274
34					5.55E-05	0.00437138	4.07E-10	0.0473274
35					0.00333034	0.171603	2.44E-08	0.185281
36					0.00210922	0.100285	1.55E-08	0.159114
37					0.00011101	0.00820897	8.14E-10	0.0596288
38					5.55E-05	0.00437138	4.07E-10	0.0473274
39					0.0268093	1.15696	1.97E-07	0.371332
40					5.55E-05	0.00437138	4.07E-10	0.0473274
41					0.00022202	0.0158842	1.63E-09	0.0751276
42					0.00022202	0.0158092	1.63E-09	0.0751276
43					0.00088809	0.0474681	6.51E-09	0.119258
44					5.55E-05	0.00437138	4.07E-10	0.0473274
45					0.00066607	0.040134	4.89E-09	0.108353
46					0.00027753	0.019113	2.04E-09	0.0809288
47					5.55E-05	0.00437138	4.07E-10	0.0473274
48					0.00011101	0.00850627	8.14E-10	0.0596288
49					5.55E-05	0.00437138	4.07E-10	0.0473274
50					5.55E-05	0.00437138	4.07E-10	0.0473274
51					5.55E-05	0.00437138	4.07E-10	0.0473274

	M	N	O	P	Q	R
1		volume (	Area (mn	Area Fra	Diameter (mm)	
2						
3	Mean	0.00199	0.05406	1.45E-08	0.069619	
4	Min	5.55E-05	0.00437	4.07E-10	0.047327	
5	Max	9249.34	190976	0.06784	26.04379	
6	Median	9.22E-05	0.00764	6.76E-10	0.059606	
7	Variance	15.1332	6446.43	8.14E-10	0.001437	
8	Kurtosis	5658180	5658176	5658182	69404.55	
9	Skewnes	2378.69	2378.69	2378.69	90.81248	
10						
11						
12						
13						
14		frequenc	count		Size rang	Frequency
15	(mm)				(mm3)	
16	0-0.1		945303		0	0
17	0.1-0.2	0.1	92624		0.001	997169
18	0.2-0.3	0.2	7860		0.002	27041
19	0.3-0.4	0.3	1727		0.003	8865
20	0.4-0.5	0.4	558		0.004	4370
21	0.5-0.75	0.5	370		0.005	2488
22	0.75-1	0.75	84		0.006	1580
23	1to5	1	47		0.007	1120
24	5to10	5	0		0.008	769
25	10to25	10	0		0.009	581
26	25to50	25	1		0.01	525
27	>50	50	0		0.011	430
28						3635



Using the porosity data: measurements, modeling

- Volume analysis tools for pore network characterization (Avizo, ImageJ, Excel)
- Conversion to STL format for visualization and modeling
- Free STL viewer: https://www.viewstl.com/



XCT data analysis – Google Colab Notebook

XCT_SubDataAnalysis.ipynb

File Edit View Insert Runtime Tools Help Last saved at 9:09 AM

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RAM Disk

[1]
```
!rm -Rf XCT_toy_data
!rm -Rf Img_Binarize_v3
```

[2]
```
# Import relevant modules needed for simple segmentation
# https://towardsdatascience.com/7-ways-to-load-external-data-into-google-colab-7ba73e7d5fc7
#
import cv2 as cv
import numpy as np
from matplotlib import pyplot as plt
import copy
import time
```

[3]
```
!git clone https://github.com/maruti-iitm/XCT_toy_data.git
```

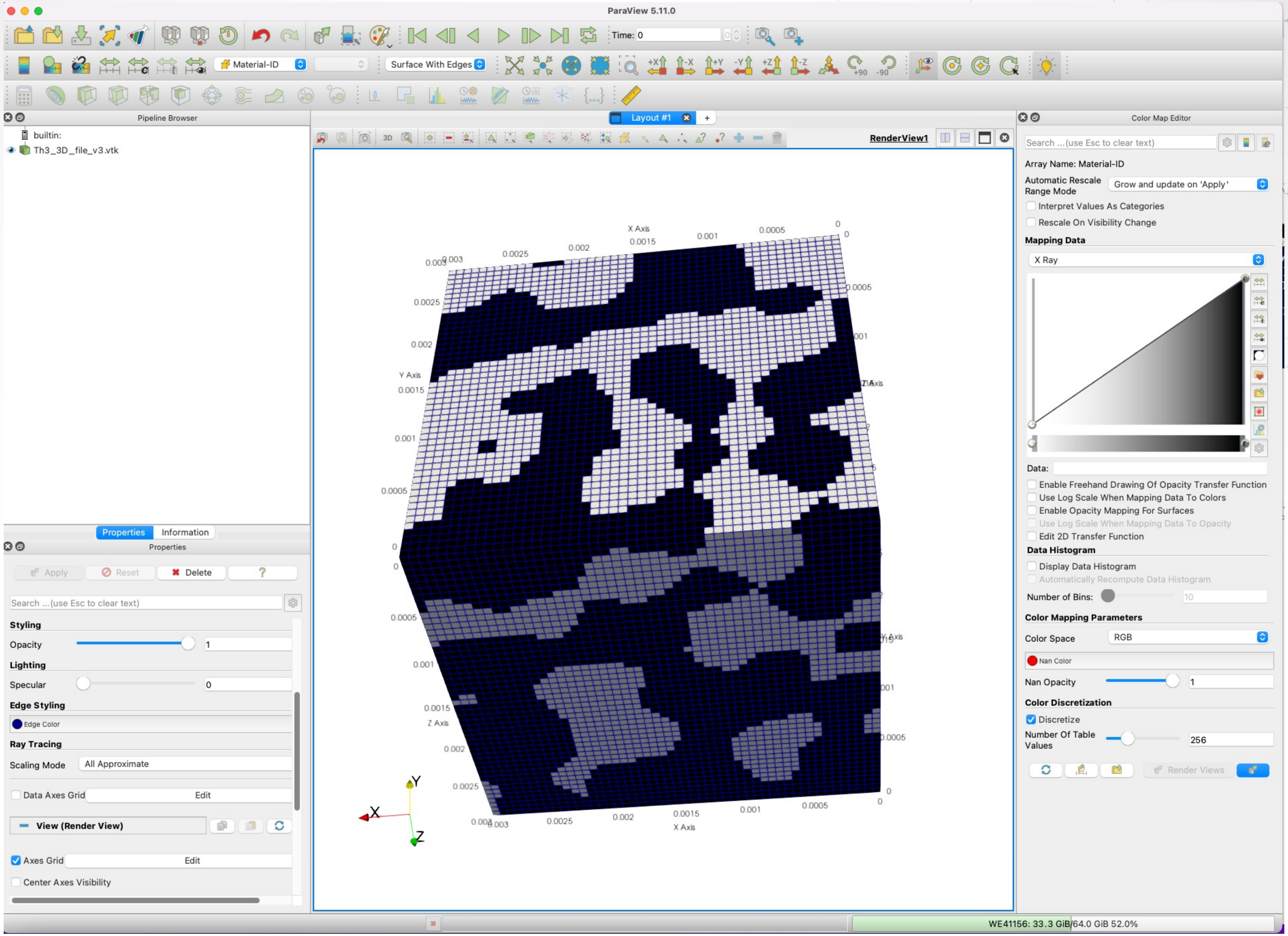
```
Cloning into 'XCT_toy_data'...
remote: Enumerating objects: 557, done.
remote: Counting objects: 100% (54/54), done.
remote: Compressing objects: 100% (48/48), done.
remote: Total 557 (delta 29), reused 15 (delta 4), pack-reused 503
Receiving objects: 100% (557/557), 56.24 MiB | 21.90 MiB/s, done.
Resolving deltas: 100% (60/60), done.
```

[4]
```
#===============================================================;
#  Function-1: Write VTK file to visualize part of the XCT data  ;
#===============================================================;
def write_VTK_file(vtk_fl_name, num_nodes, num_elements, nodes_per_element, \
                    coord_matrix, connectivity_matrix, mat_id_matrix):

    #----------------------------------------------;
    #  Write coord, connectivity, and scalar fields  ;
    #----------------------------------------------;
    fid = open(vtk_fl_name + '.vtk','w+')
    #
    fid.write('# vtk DataFile Version 2.0 \n') #Write the 'Header' for ASCII files; HEADER: Lines required in output file = '5'
    fid.write('Written using Python (TEST CASE) \n')
    fid.write('ASCII \n')
    fid.write('DATASET UNSTRUCTURED_GRID \n \n')
    #
    fid.write('POINTS ' + str(int(num_nodes)) + ' float \n') #Write the coordinate matrix -- Relative
    for i in range(0, num_nodes):
        fid.write(str(float(coord_matrix[i,0])) + ' ' + \
                    str(float(coord_matrix[i,1])) + ' ' + \
                    str(float(coord_matrix[i,2])) + '\n')
    fid.write('\n')
    #
    fid.write('CELLS ' + str(int(num_elements)) + ' ' + \
              str(int(num_elements*(nodes_per_element+1))) + ' \n') #Write the connectivity matrix
    for i in range(0, num_elements):
        fid.write(str(8) + ' ' + str(int(connectivity_matrix[i,0])) + \
                  ' ' + str(int(connectivity_matrix[i,1])) + \
```

Connected to Python 3 Google Compute Engine backend

XCT segmented data visualization – ParaView (VTK files)



Questions?