Understanding the Impact of Biochar Amendment on Macropores in Soil from 3D X-Ray CT Tomography

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UNIVERSITY OF DELAWARE

Overview

- Research background
- Experiment background and set-up
- X-ray CT
- Dragonfly analysis

Introduction

- Departments of Transportation (DOTs) must meet increasingly stringent stormwater runoff regulations
  - Maryland DOT
    - 75% reduction in nitrogen, phosphorous, and sediment loads

Capital Gazette Newspaper

Stormwater Runoff- Quality

- Pesticides, leaking fuel or motor oil and other chemical contaminants
- Nutrients from atmospheric deposition, roadway debris
- Stream restoration = $73k per impervious acre treated
- Tree plantings = $100k " " "
- Retrofits = $92k " " "

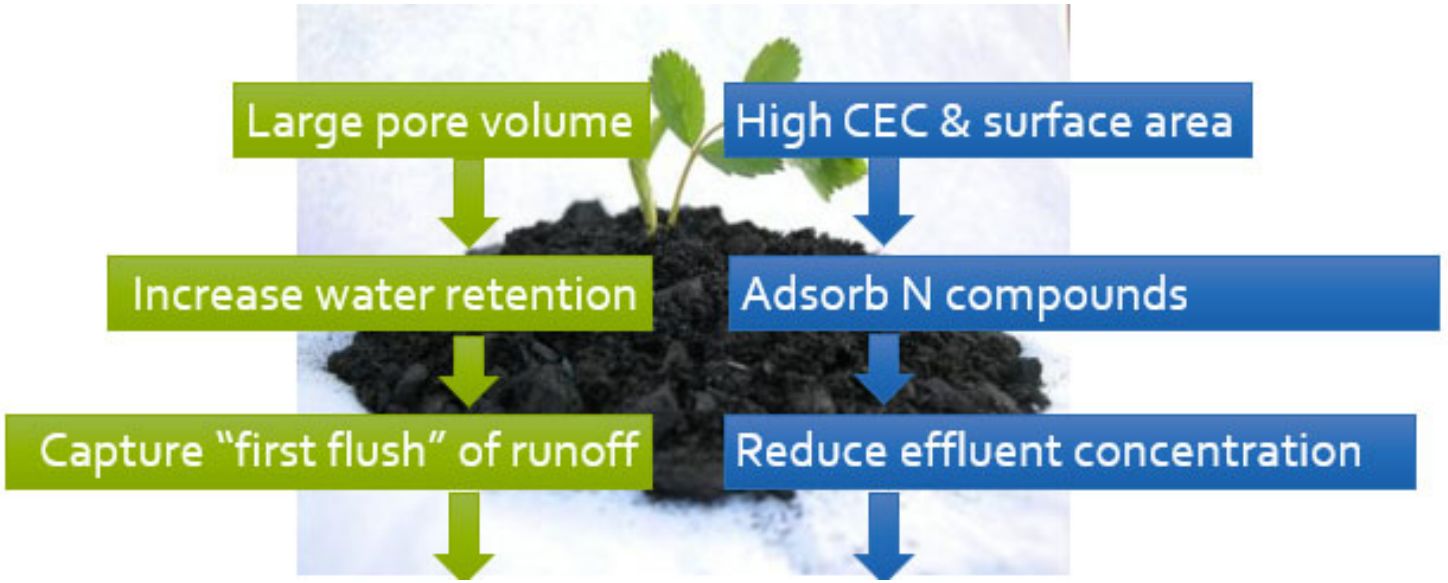
Overall Problem and Proposed Solution

- Use existing highway greenway – usually not counted for treatment
  - Highly compacted with steep slopes
    - Little no stormwater infiltration
- Modify existing space with biochar
  - Increase water infiltration and water holding capacity
    - Biological pollutant removal

Transportation Research Board 2018

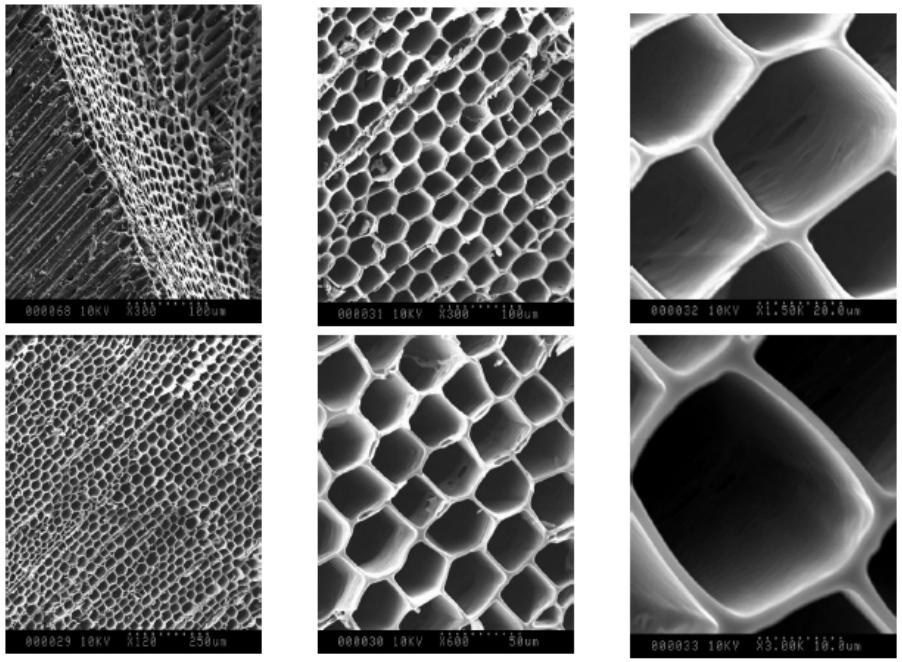
Biochar

- Enhance retention of N and water in the soil zone
- Increase rates of infiltration and chemical transformations



Biochar

- Pine wood biochar
- Envelope density (g/cm^3)= 0.44



IBI biochar report

Particle Size Distribution

	Results	Units
< 0.5mm	1.4	percent
0.5-1mm	3.2	percent
1-2mm	49.8	percent
2-4mm	43.9	percent
4-8mm	1.8	percent
8-16mm	0.0	percent
16-25mm	0.0	percent
25-50mm	0.0	percent
>50mm	0.0	percent

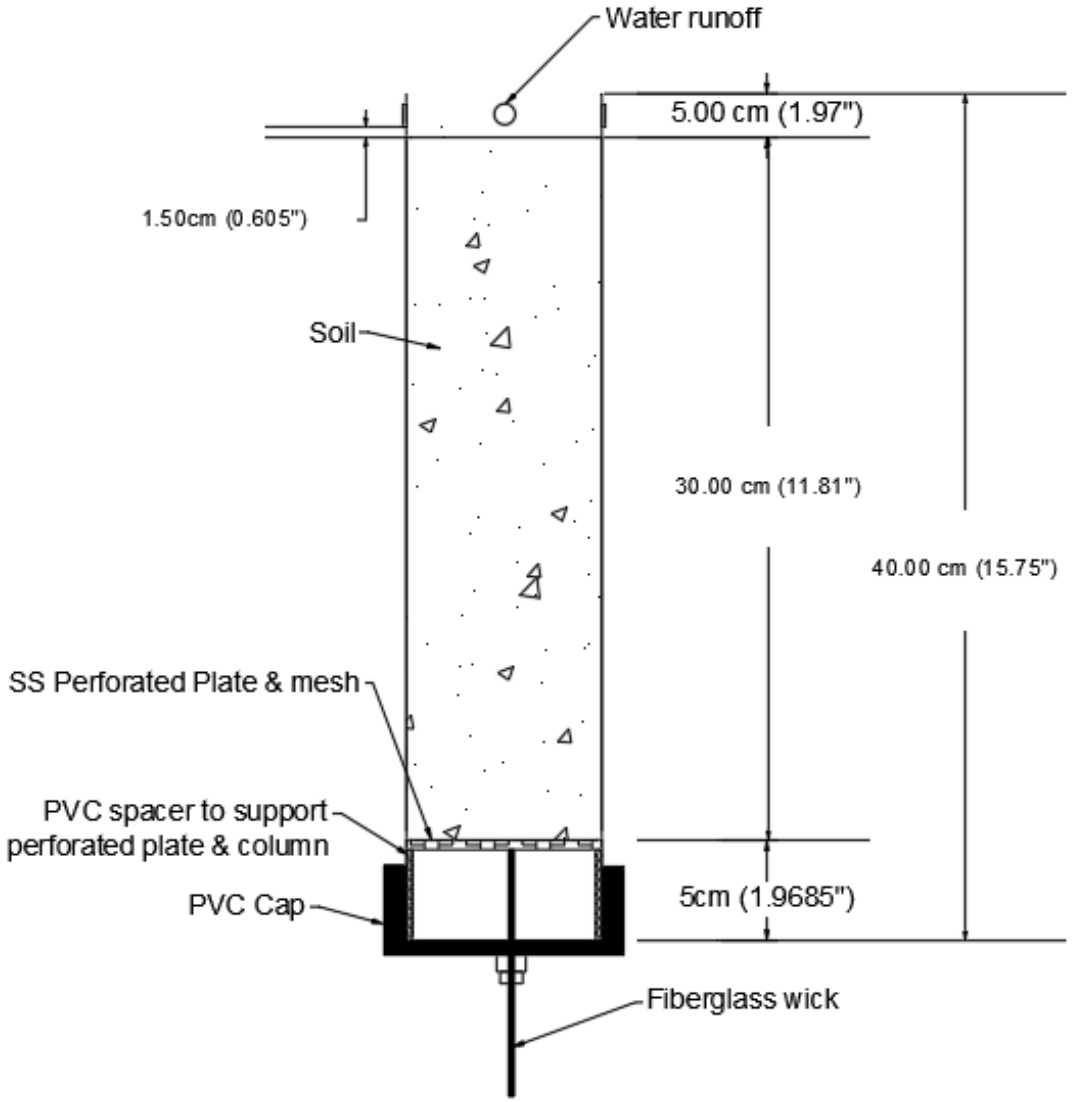
Big Picture Questions

- How does biochar impact soil hydrology and soil properties?
- Does biochar have a significant impact on the growth and root structure of typical roadside turfgrass (Tall Fescue)?

Experiment Measurements

- Soil hydrology and soil properties
  - Wet aggregate size distribution, water retention, and water infiltration
- Grass chlorophyll content, shoot dry biomass and shoot height
- Grass root biomass and morphology
- Experiment consists of 72 columns with 6 replicates of the following combinations:
  - “Normally” compacted vs. highly compacted
  - Grass vs. bare soil
  - 0%, 2% and 4% Biochar (w/w) amended soil

Experimental Setup



X-Ray Analysis

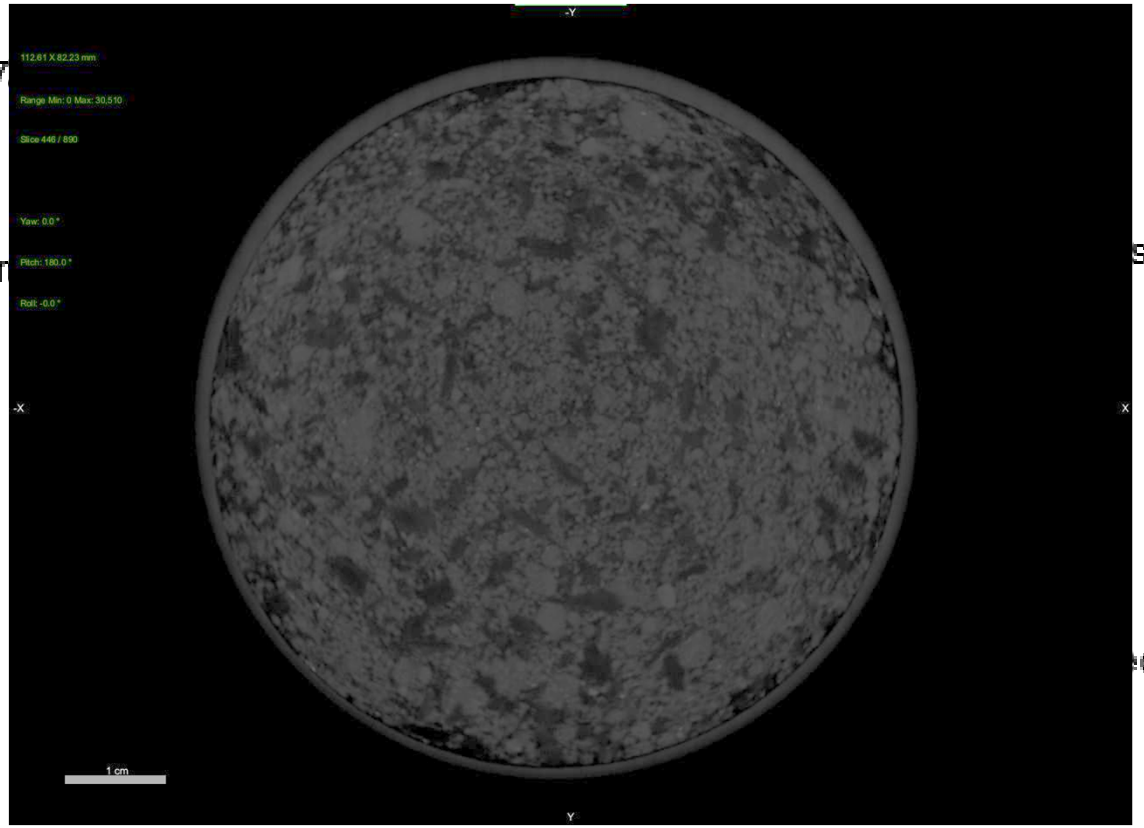
- Use x-ray imaging to scan undisturbed soil columns
- How does macropore structure change between treatments?
  - Total volume of air-filled pores
  - Pore connectivity via pore-network modeling
  - Pore size distribution

X-Ray CT

- Used the Rigaku GX 130 CT Scanner to scan columns
  - High resolution with 57-minute scan time

Outside Diameter= 2.86" (7

Inside Diameter= 2.70" (68.56 m

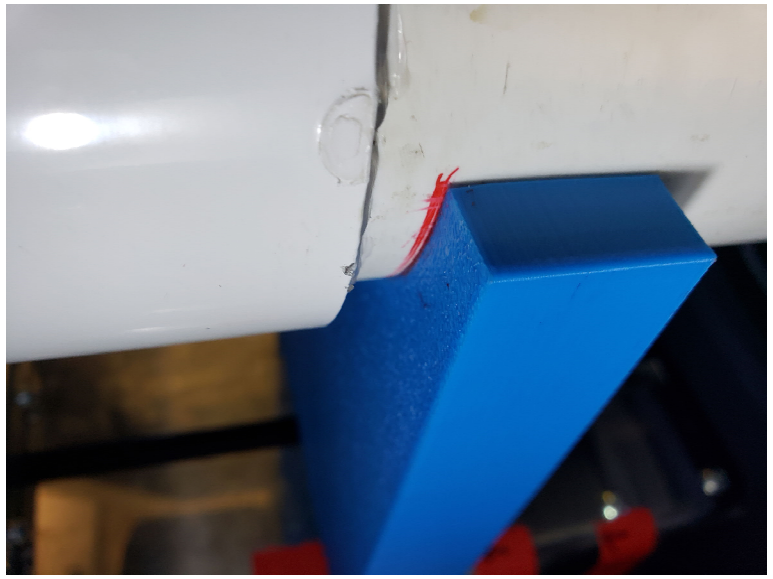


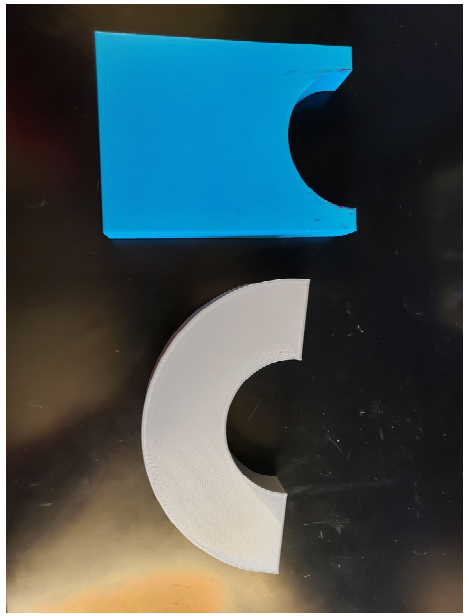
ss= 0.088" (2.24 mm)

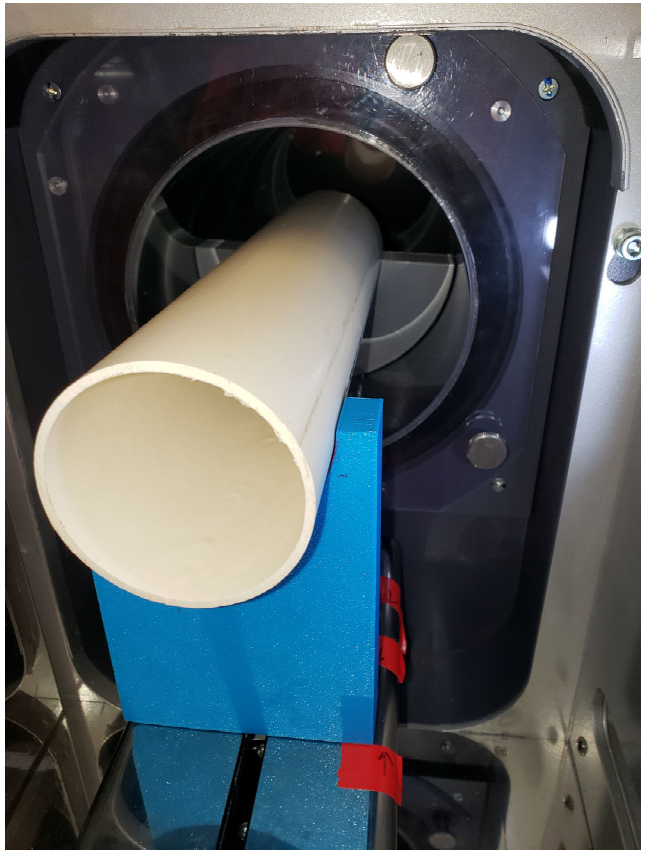
ction

X-Ray CT

- Scanned one representative replicate for each of the 0% and 4% biochar columns
  - 8 columns in total
- Scanned the top 12cm of each column

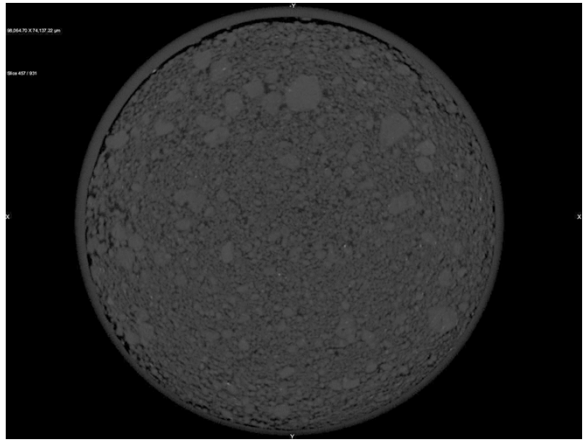


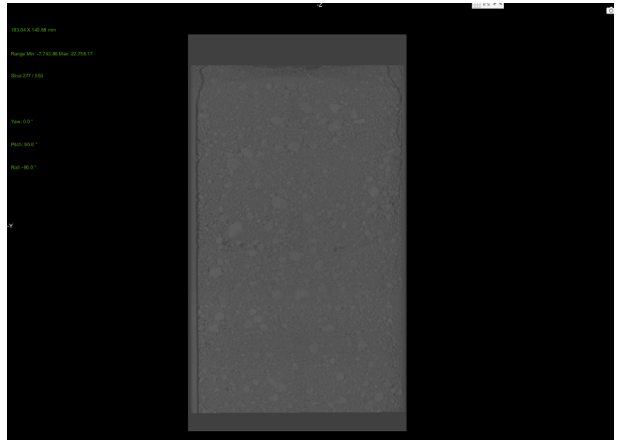




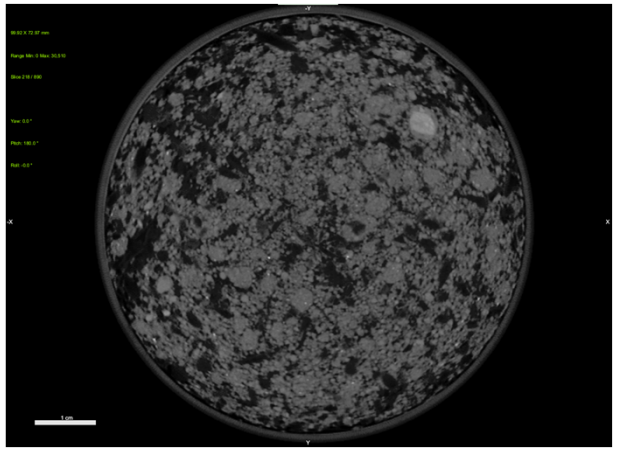
Dragonfly Analysis

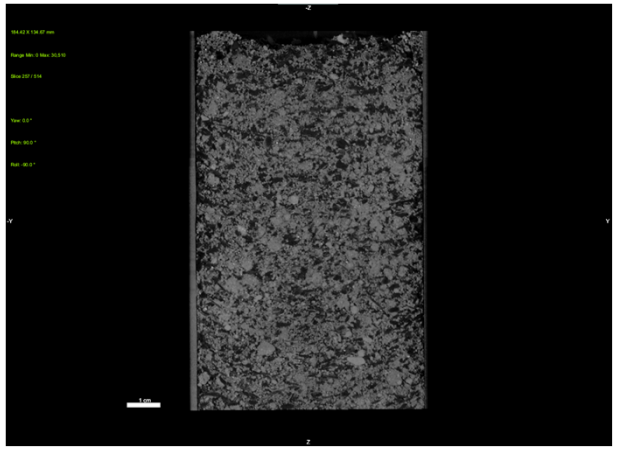
- Use Dragonfly to model & analyze column scans
- 144-micron resolution





0% biochar, uncompacted, no grass



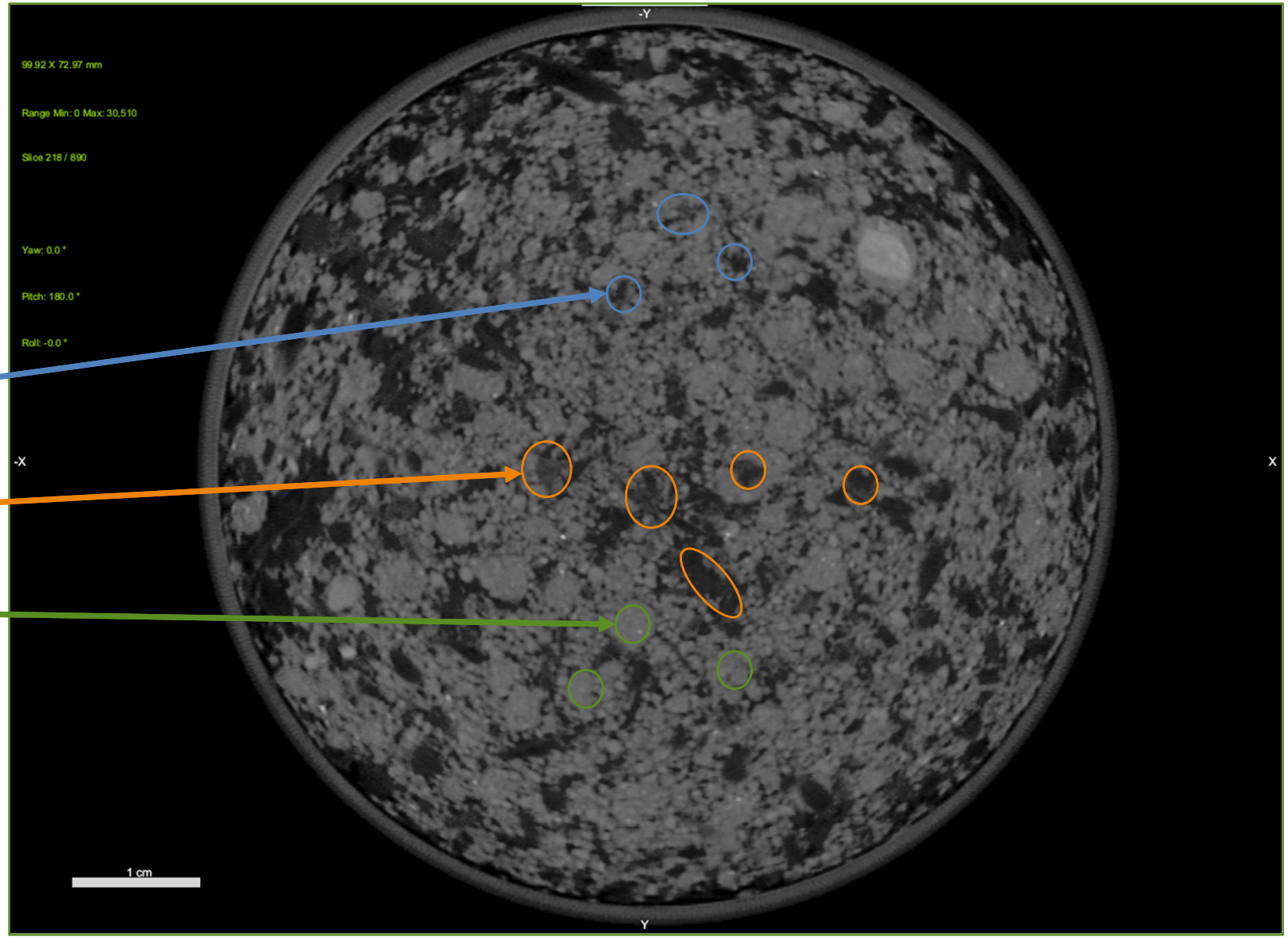


4% biochar, compacted, no grass

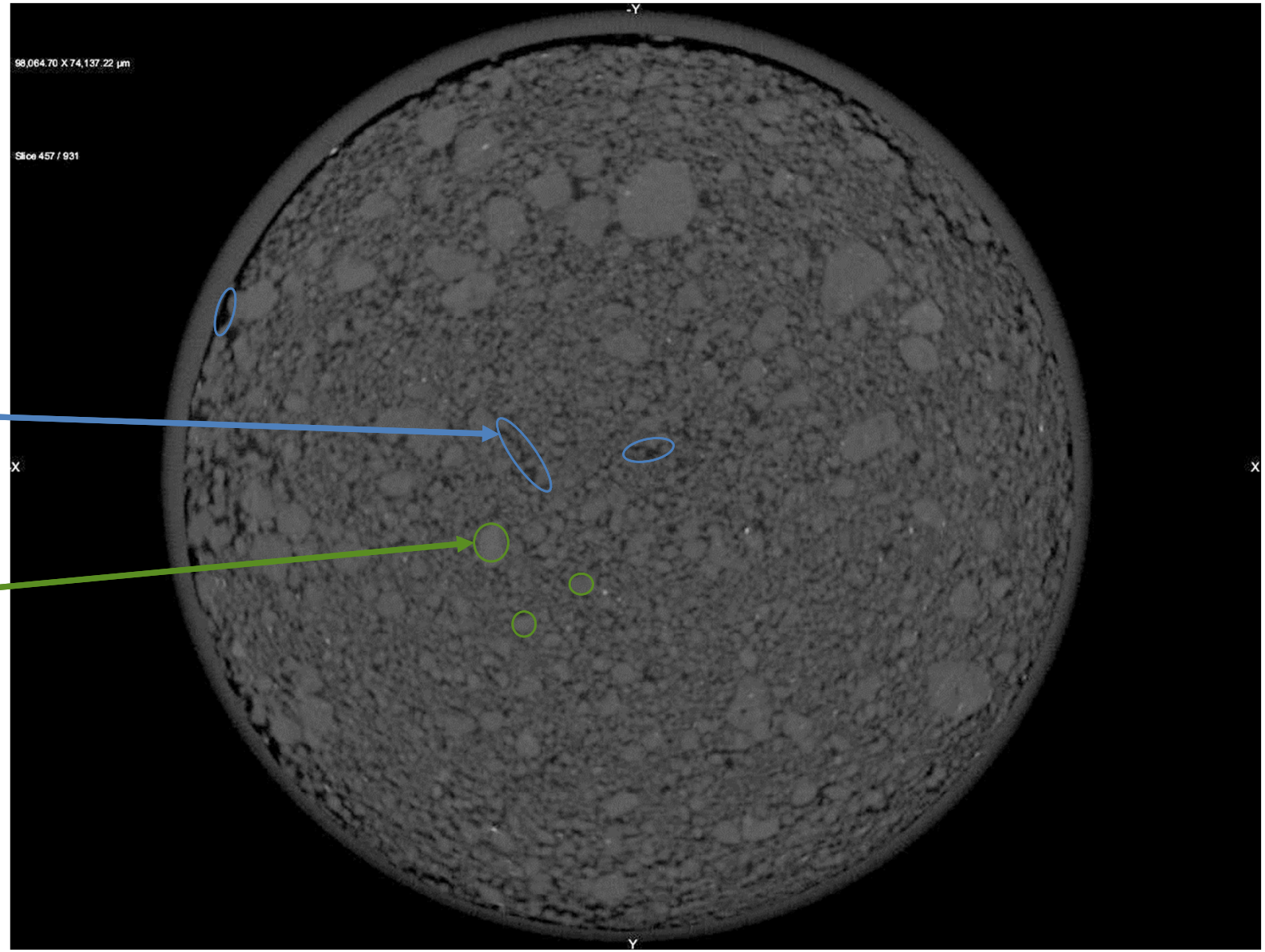
Air

Biochar

Solids



4% biochar, compacted, no grass



0% biochar, uncompacted, no grass

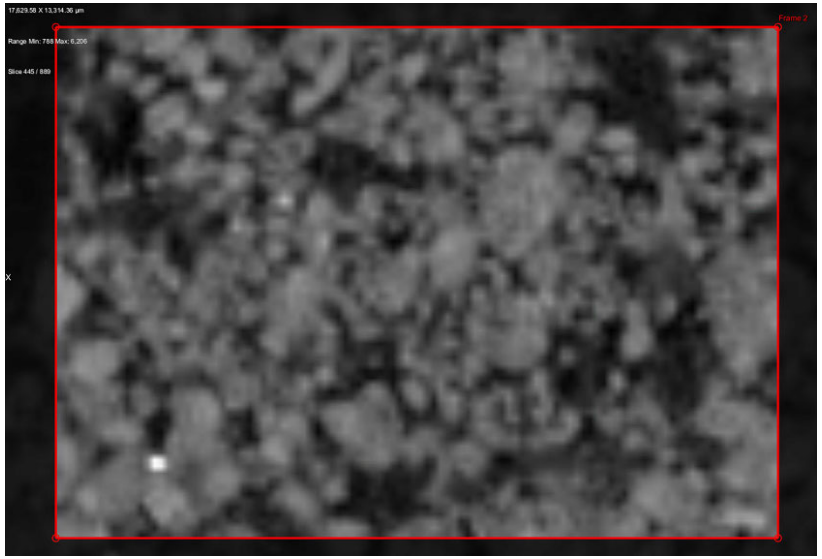
Segmentation Wizard – General Procedure

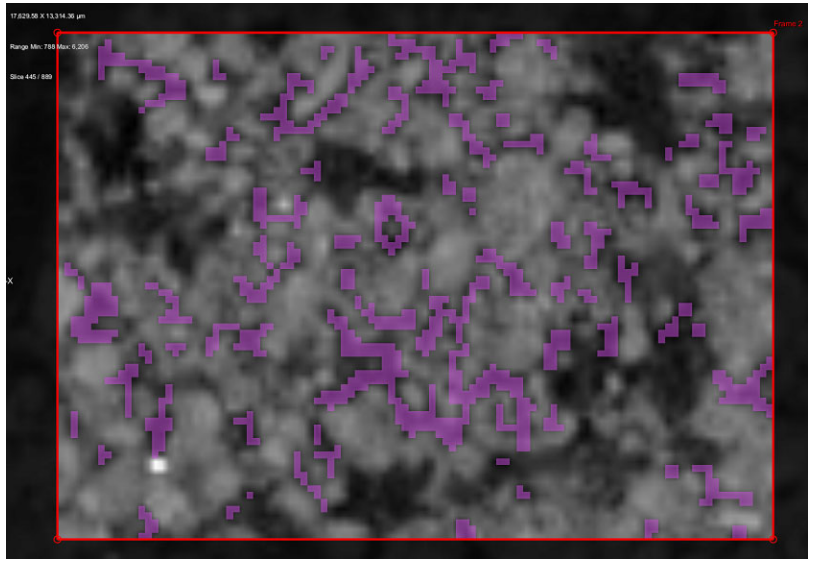
1. Begin by separating high and low threshold ranges
   - Upper and lower Otsu
2. Paint everything
   - Upper Otsu= Solids
   - Lower Otsu= Biochar/air
3. Manually adjust paintings
4. Train model
   - “Quick Start” option
5. Make a new frame and apply best model
6. Manually adjust segmentation with painting
7. Train model
8. Repeat steps 5-7 until 5 frames have been trained
9. Apply model

Segmentation Wizard- Procedure Information

- Gradually increase each frame size for training
  - Frame 1 labeled ~4,500 voxels
  - Frame 5 labeled ~12,500 voxels
- Adjust manually painted frames as needed
- Not all new frames needed manual adjustment with painting after applying model to them
- Applied the “Quick Start” models to train
  - SegWiz_U-Net_dl-3_ifc-64
  - SegWiz_R-Forest_A-M-2
  - SegWiz_R-Forest_Morphological_GaussianMS_Neighbors
- Deep Learning models seemed best

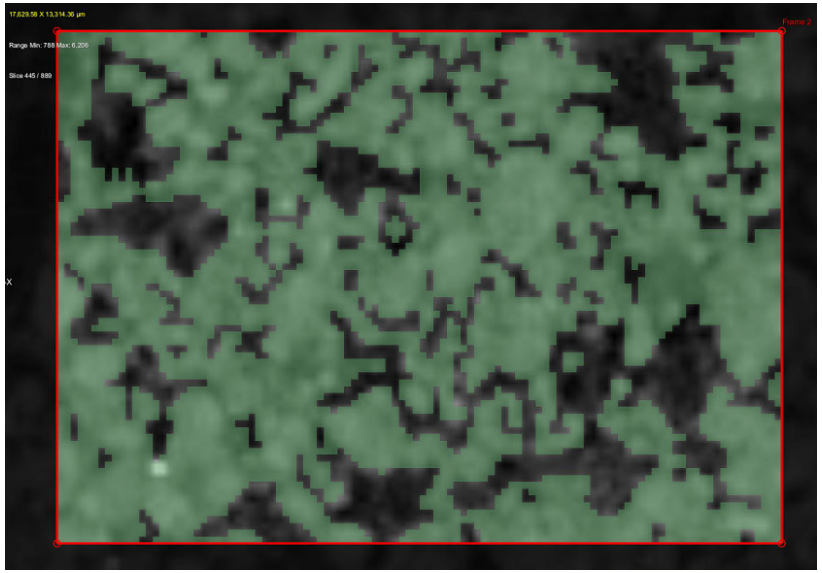
Segmentation Wizard

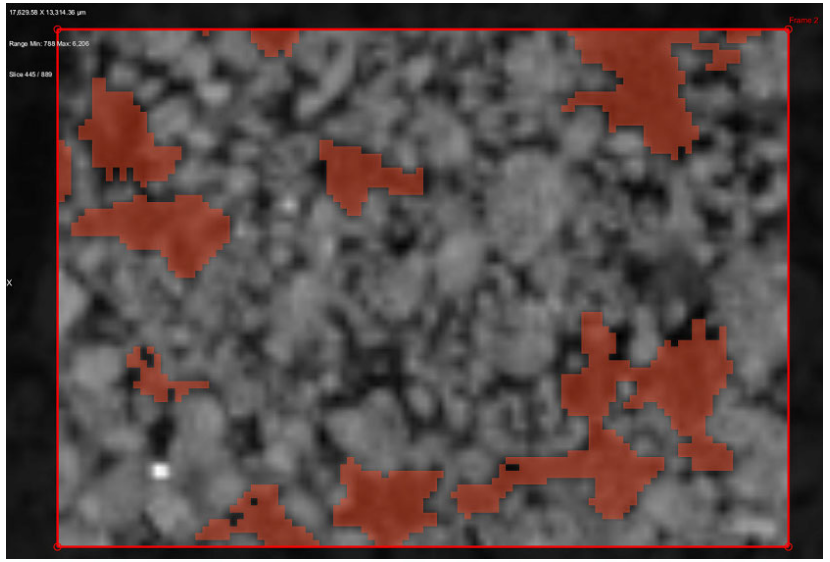




Air

Soil

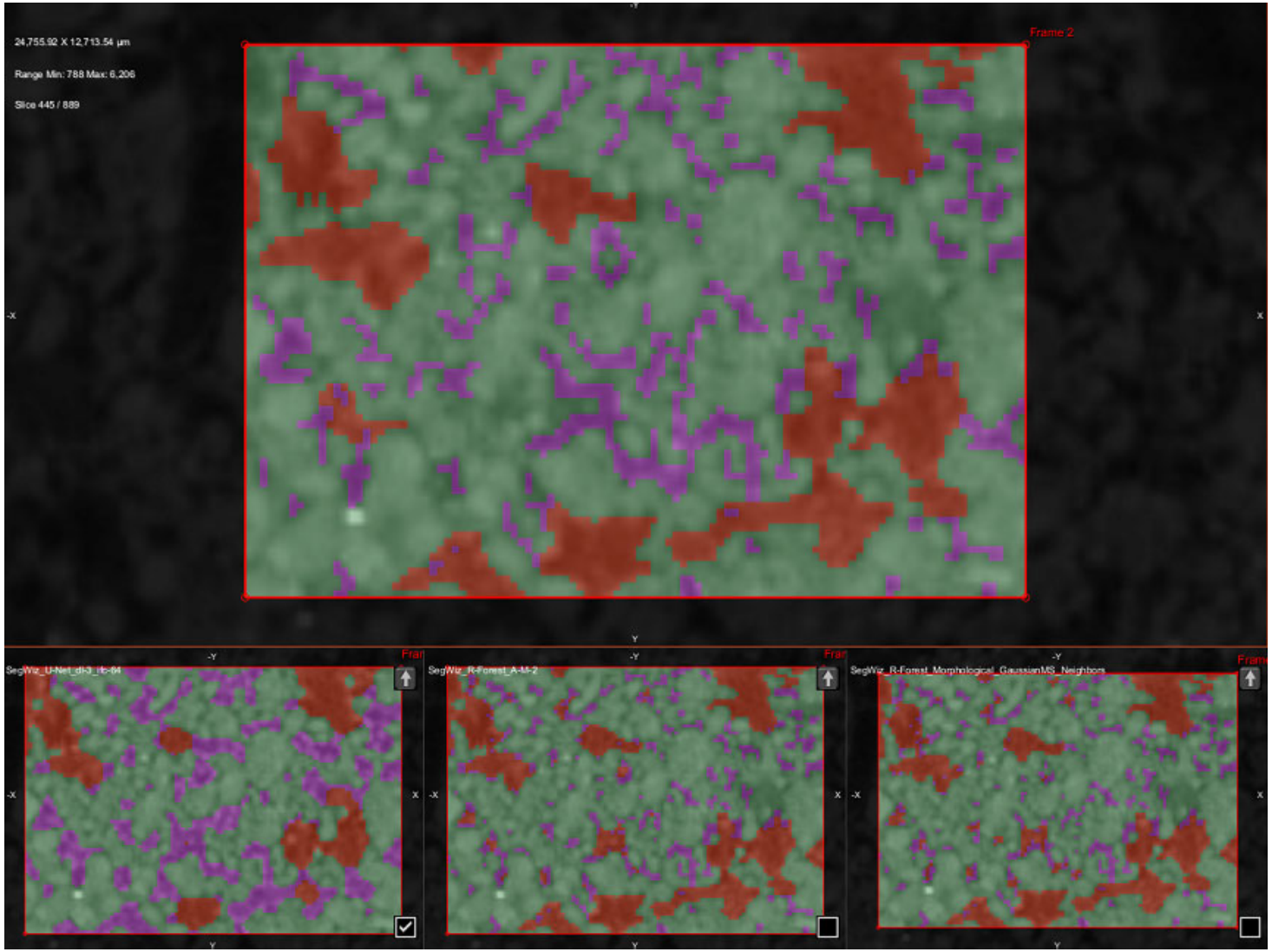




Biochar

4% biochar, compacted, no grass

Segmentation Wizard



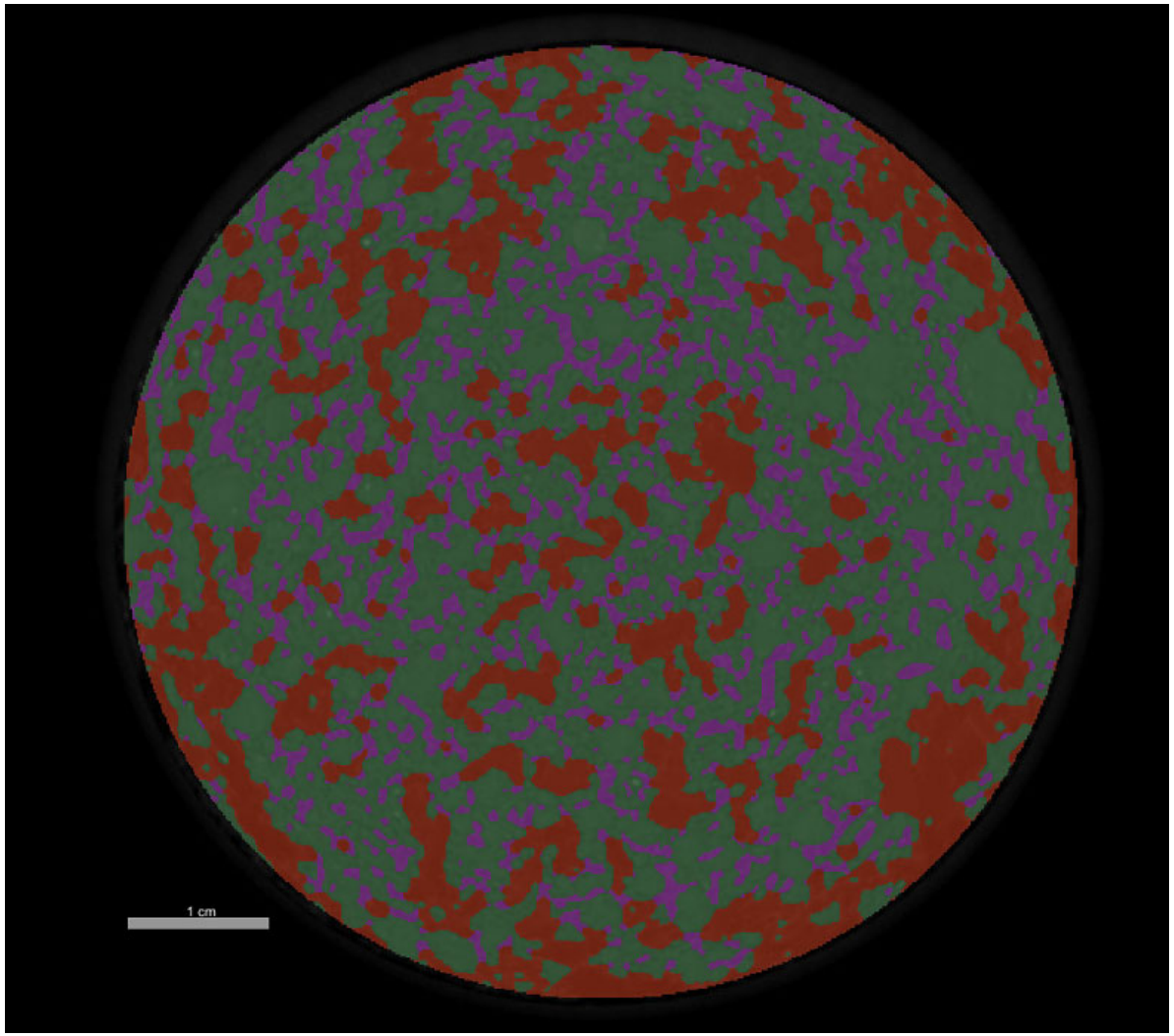
Soil = green
Air = Purple
Biochar= Orange

4% biochar, compacted, no grass

Segmentation with a Mask- 4% Biochar Column

- Segmentation with a mask over original data set
- Going to lose some data along the PVC wall

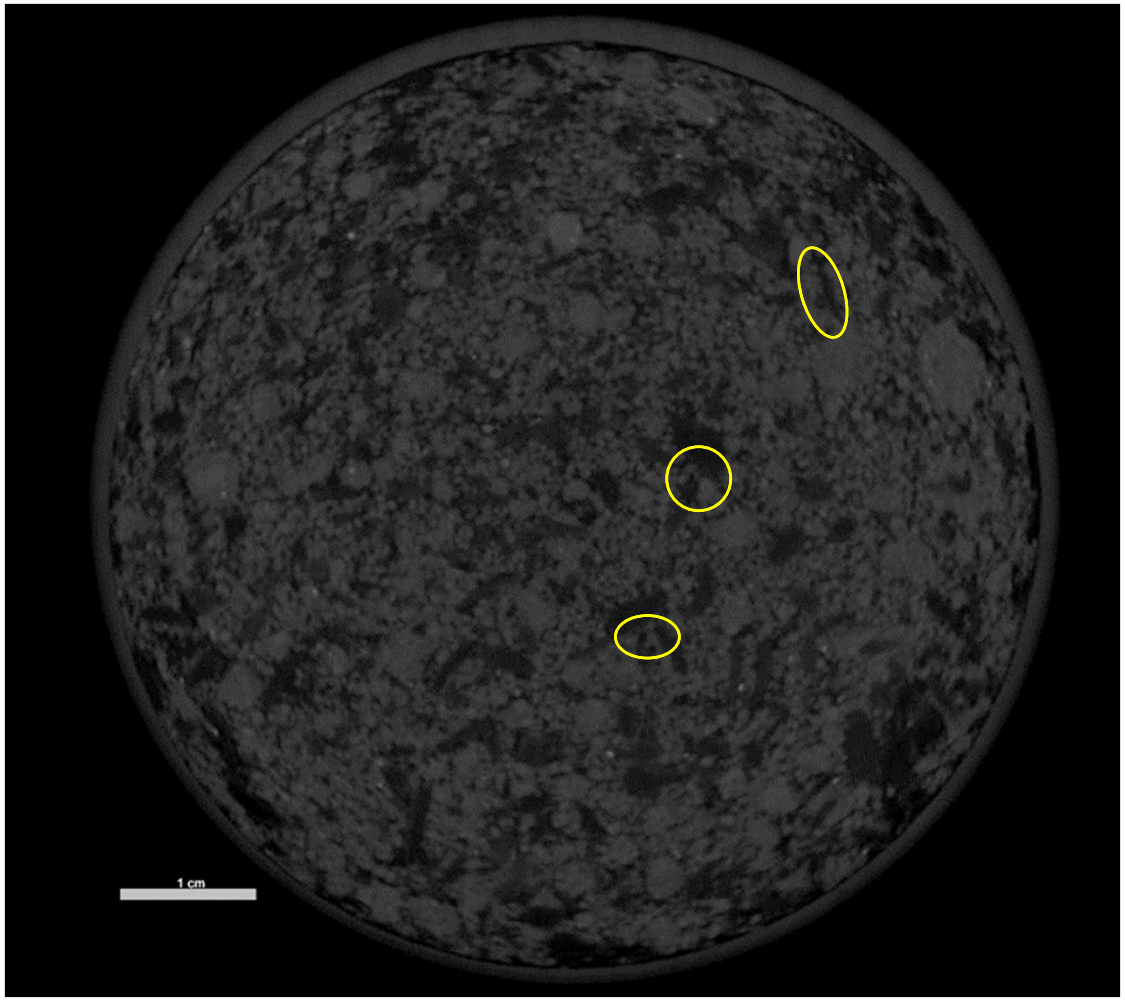
Soil = green
Air = Purple
Biochar= Orange

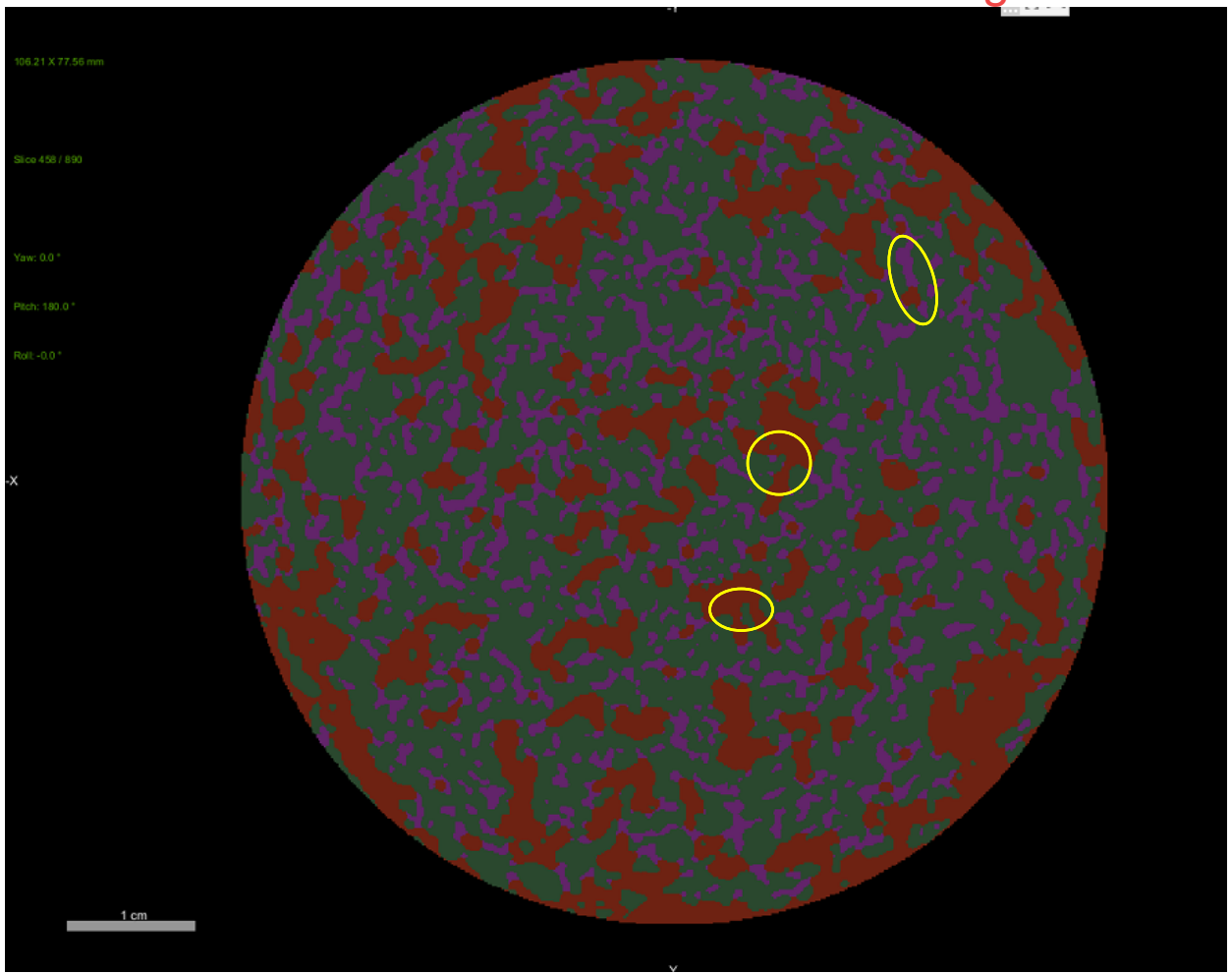


4% biochar, compacted, no grass

Segmentation Results- 4% Biochar Column

Soil = green
Air = Purple
Biochar= Orange



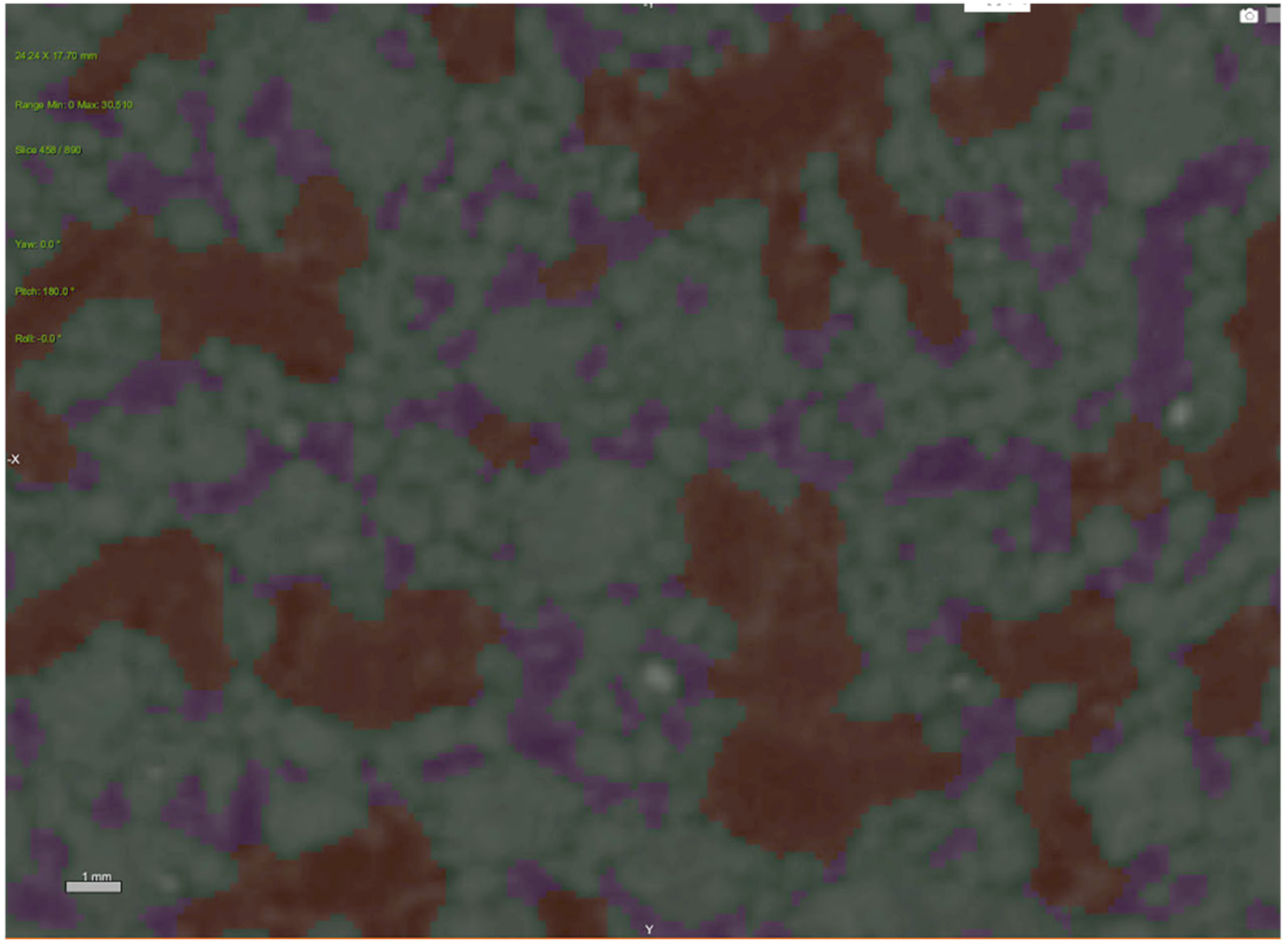


4% biochar, compacted, no grass

Segmentation Results- 4% Biochar Column

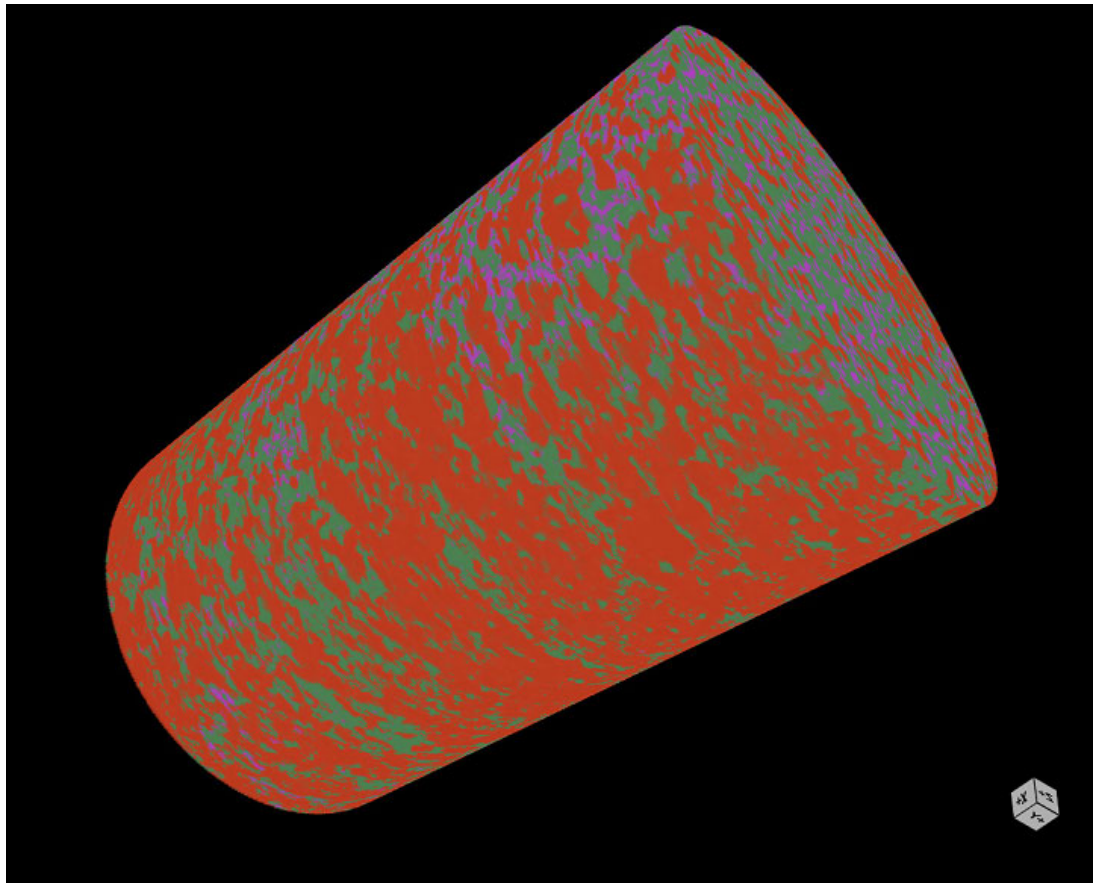
- Some solids getting mixed in with pores
- Air space being counted as a solid is typically ~200-300 microns in width by ruler
  - 1 to 2 voxels

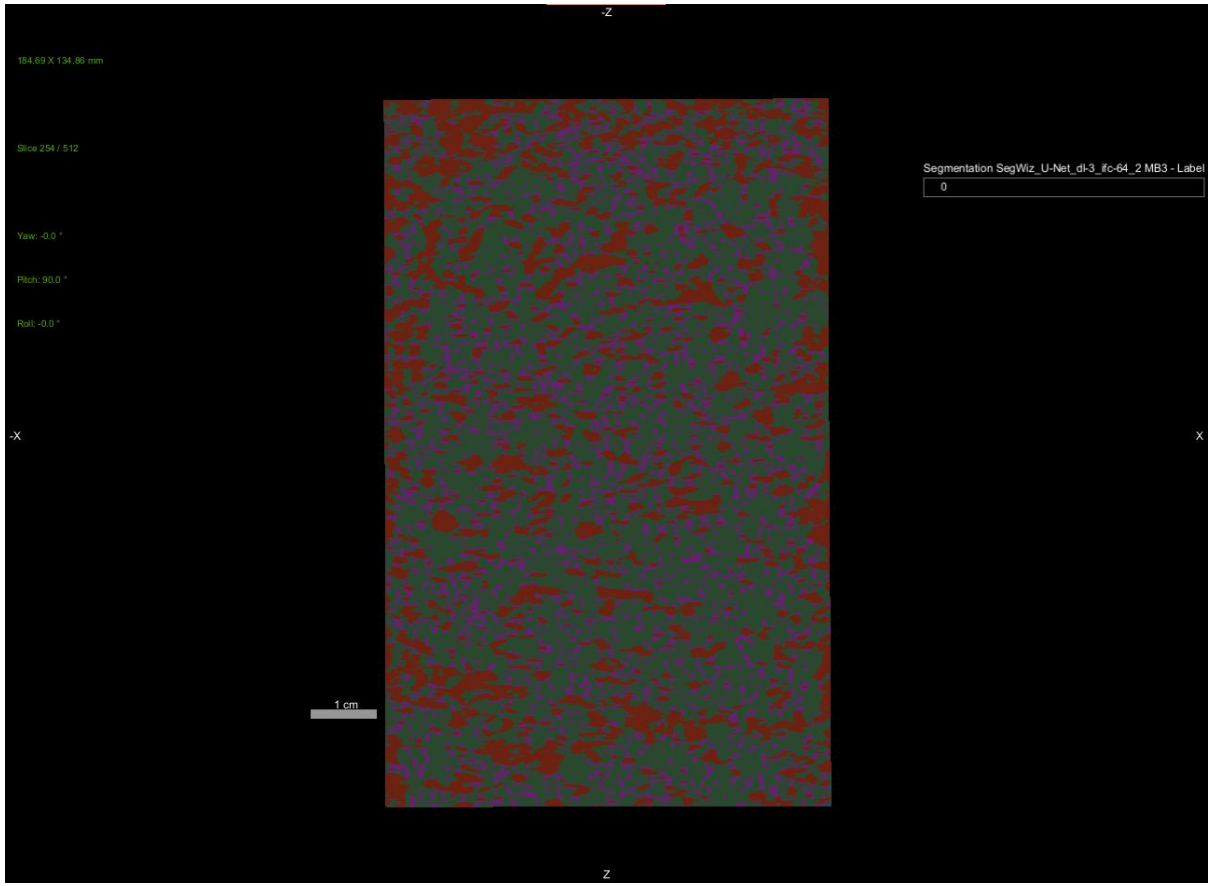
Soil = green
Air = Purple
Biochar= Orange



4% biochar, compacted, no grass

Segmentation Results- 4% Biochar Column





Soil = green
Air = Purple
Biochar= Orange

Segmentation Results- 4% Biochar Column

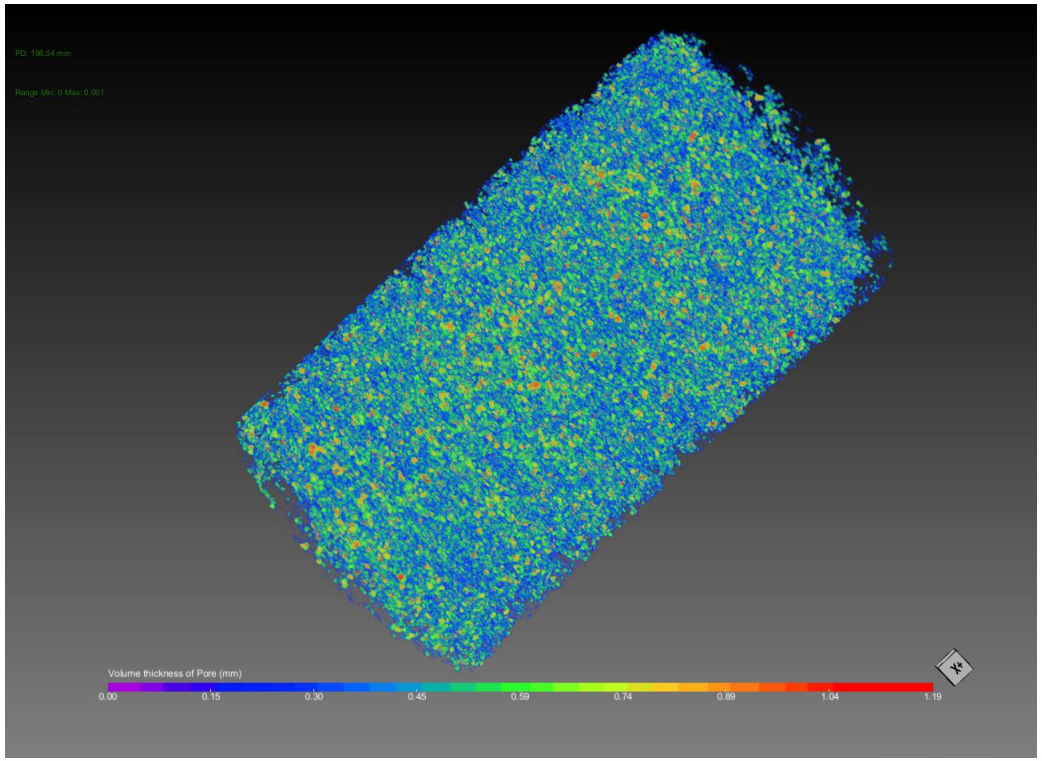
- Biochar volume from model= 27.5%
  - Actual volume= 9.7%
- Air space volume from model= 16.0%
  - Calculated total pore volume= 51.7%
    - Scans did not pick up air space below 144-µm
- Solids volume from model= 56.3%
  - Actual volume= 38.6%
- Significant water in pore space being counted as a solid or biochar?

<u>Possible conclusions thus far:</u>

- Solids getting mixed in with smaller air space
- Air space getting labeled as biochar?

Air Space Volume Thickness Distance Map- 4% Biochar Column

- Smaller air spaces directly adjacent to biochar appear to be getting labeled as air space
  - Similar densities of biochar and air makes it difficult to decipher

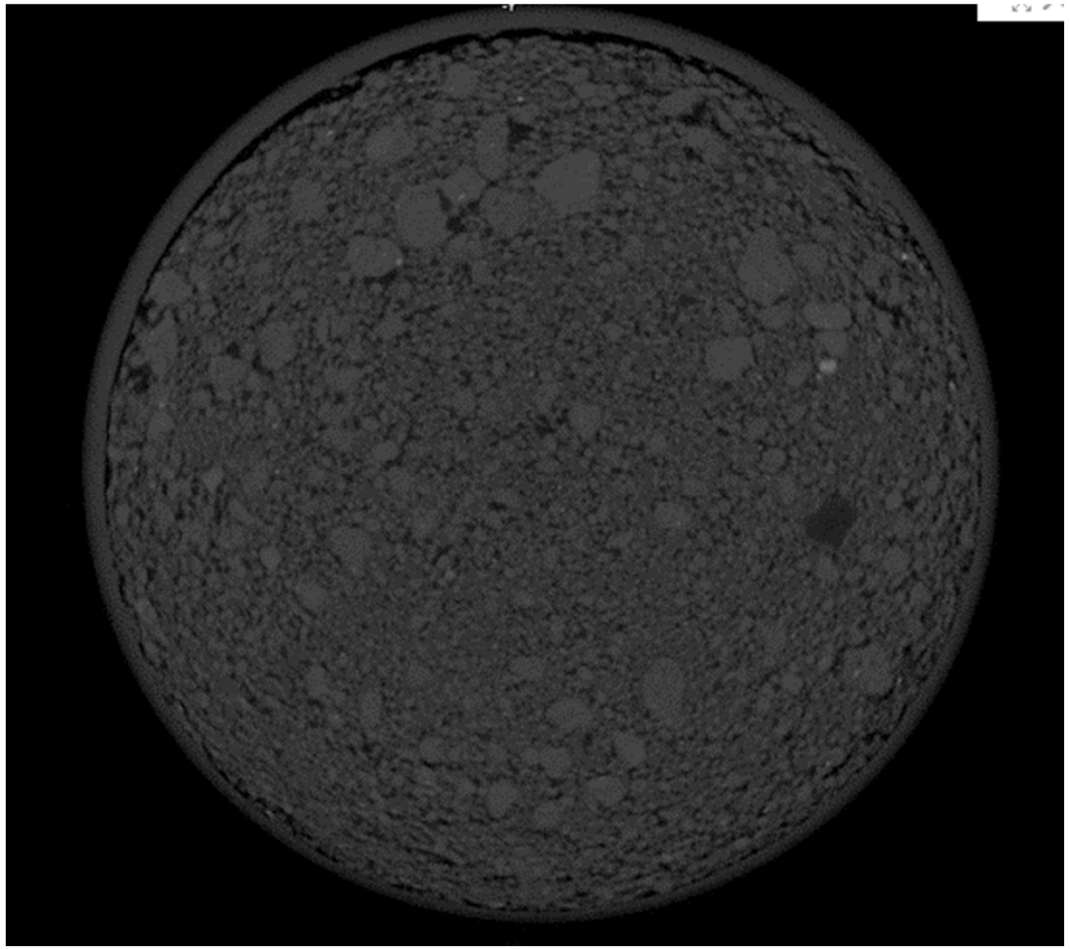


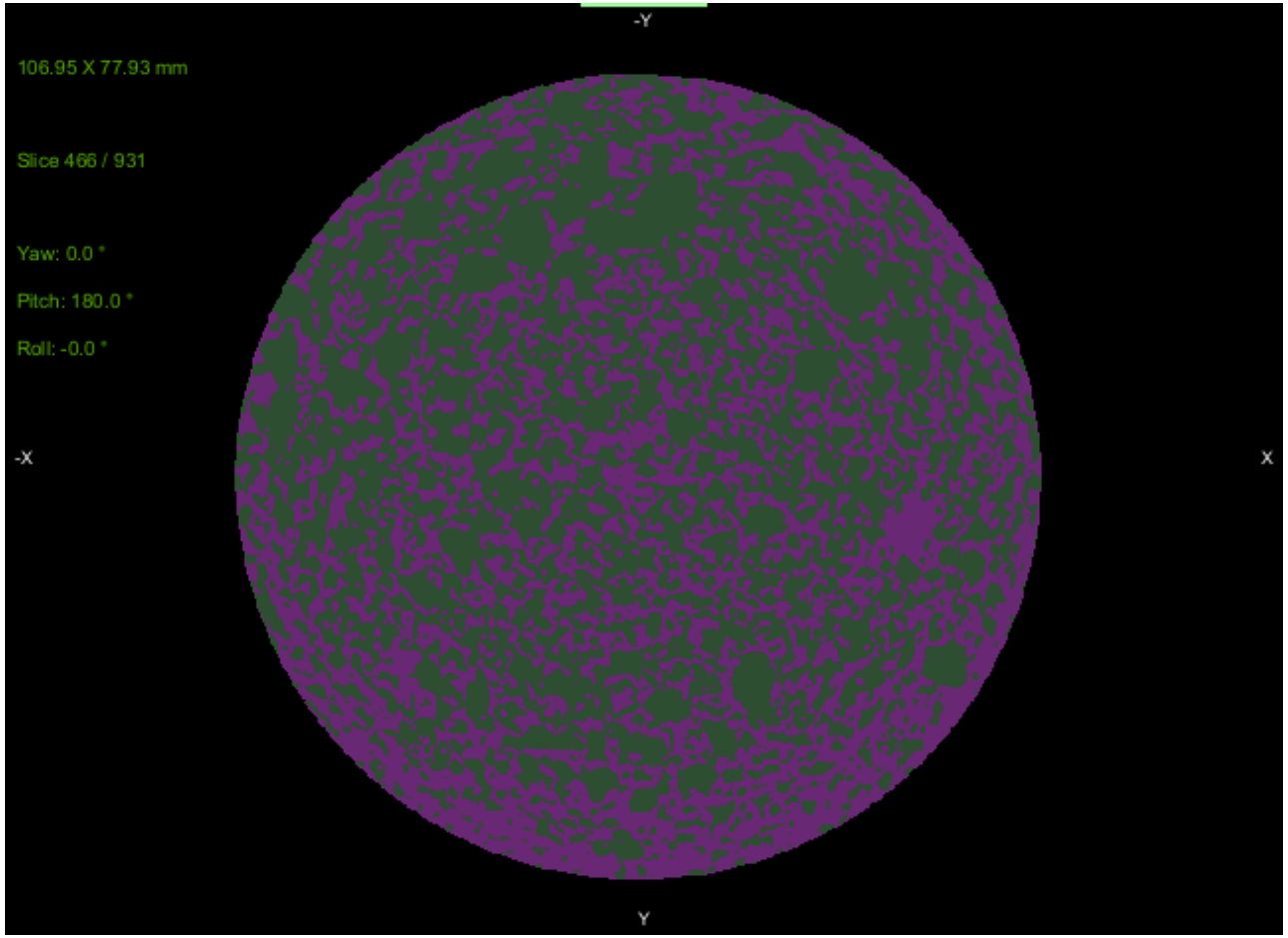
4% Biochar Modeling Issues Summary

1. Air space smaller than 144-microns not getting picked up
2. Significant water still being held?
3. Adjacent air space to biochar getting included with biochar
4. Smaller air spaces being counted as solids

Segmentation Results- 0% Biochar Column

Soil = green
Air = Purple

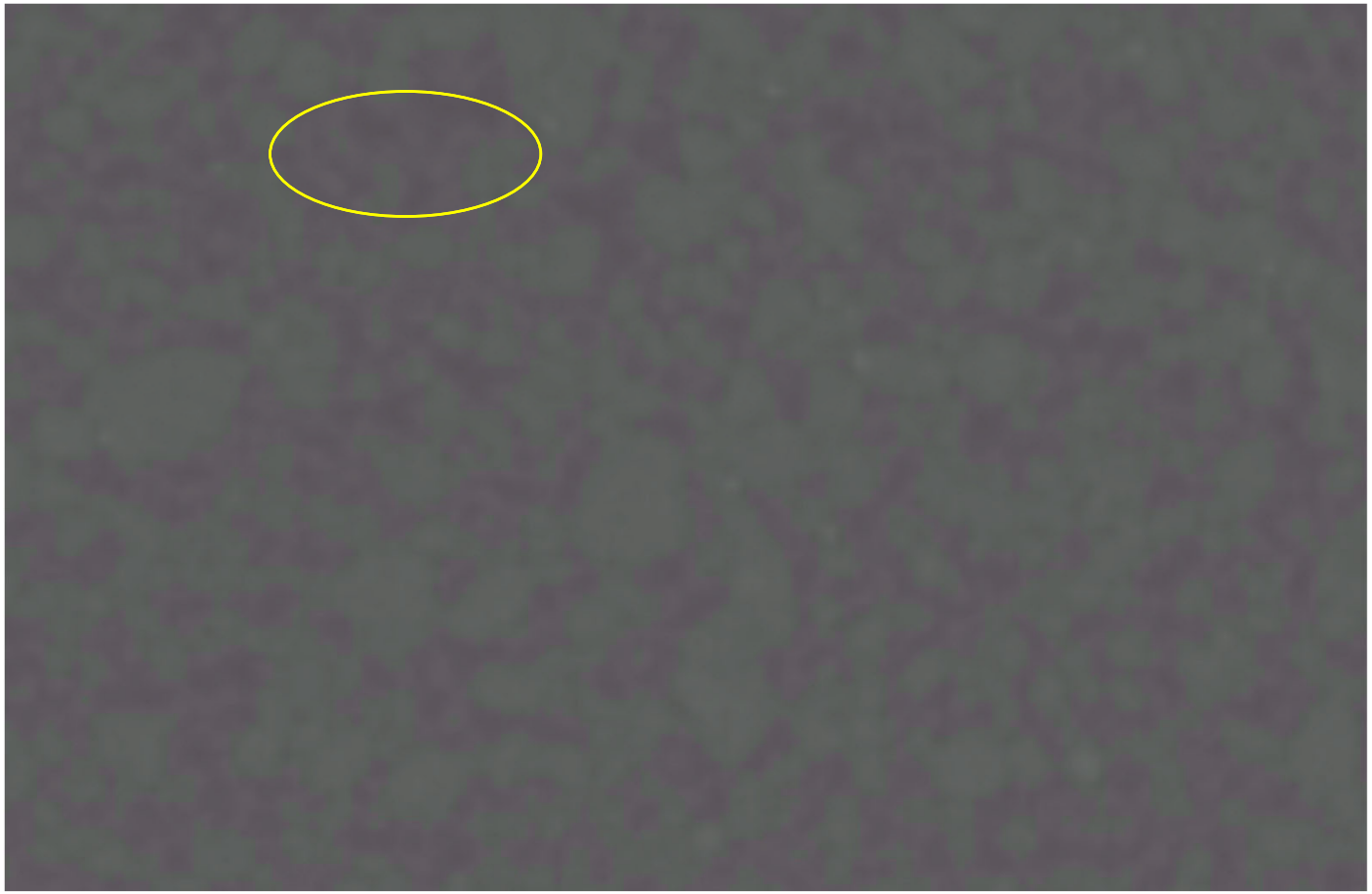




0% biochar, uncompacted, no grass

Segmentation Results- 0% Biochar Column

- A lot of overlap between air space and solids
- Similar issue of smaller air spaces being counted as solid
- Not much information could be gathered from this model

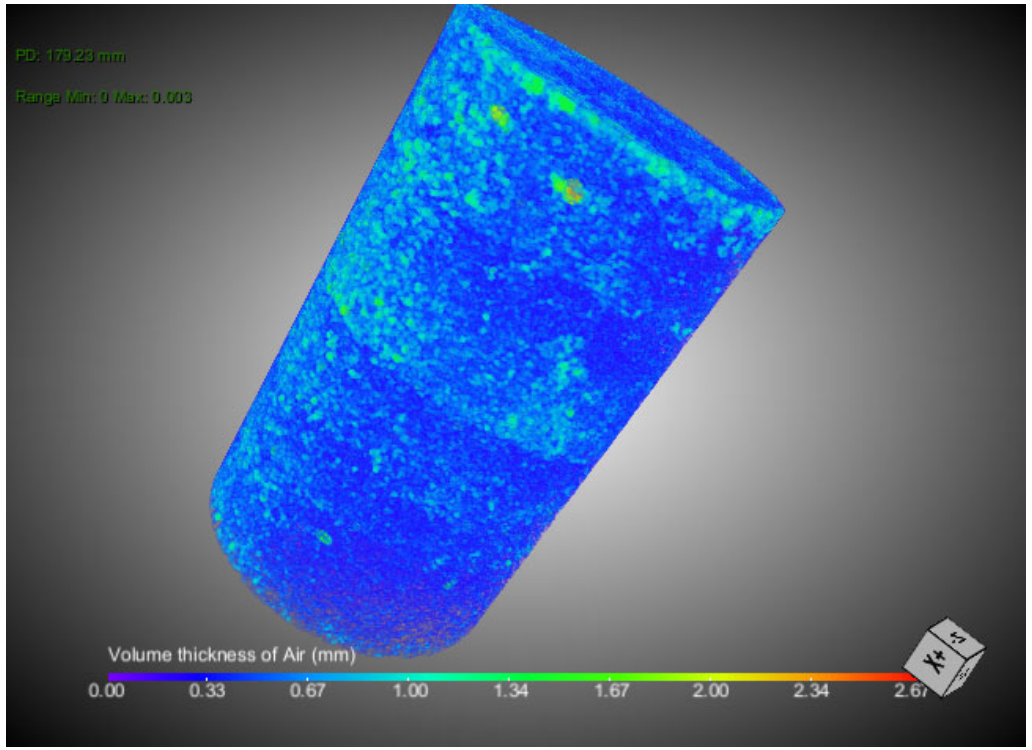


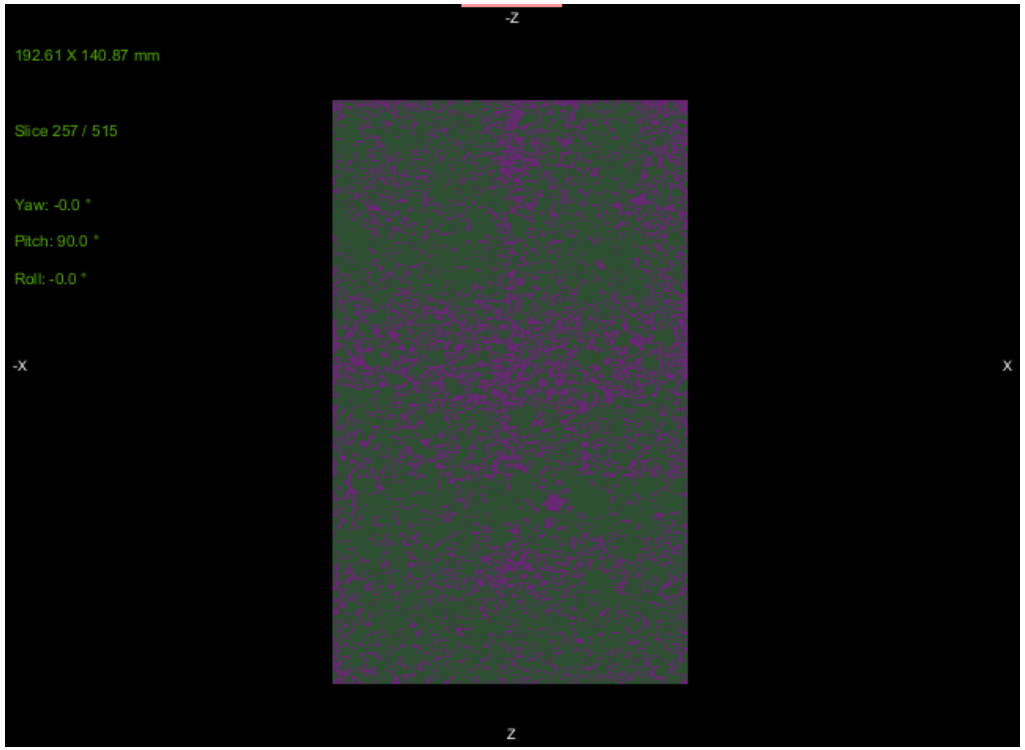
Soil = green
Air = Purple

4% biochar, compacted, no grass

Air Space Volume Thickness Distance Map- 0% Biochar Column

- Appears striation is occurring in this column
  - Column wasn't packed well

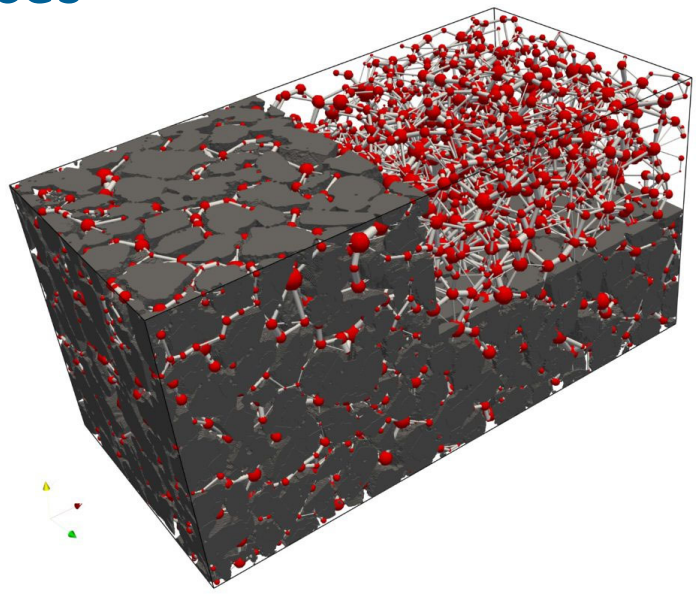




Next Steps

- See if better models can be trained
  - Include smaller air spaces in-between solids
  - Distinguish biochar from adjacent pore spaces
- Rescan columns at a smaller resolution?
- Make a pore-network model
- Get air space size distribution
- Compare results between treatments

Pore-Network Model Example



Project CPGs Nubian- ETH Zurich

The Big Questions

- Can the deep learning tool accurately segment air space, biochar, and solids?
- Will I have to train a new model for each column set scanned?
- Is there significant user error during the model training process?

Acknowledgments

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