Enhanced Feature Segmentation of X-ray Micro-CT Scans of Geomaterials using Contrastive Learning and UNet-based Architecture

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Background → The Global Carbon Problem

Heat increase

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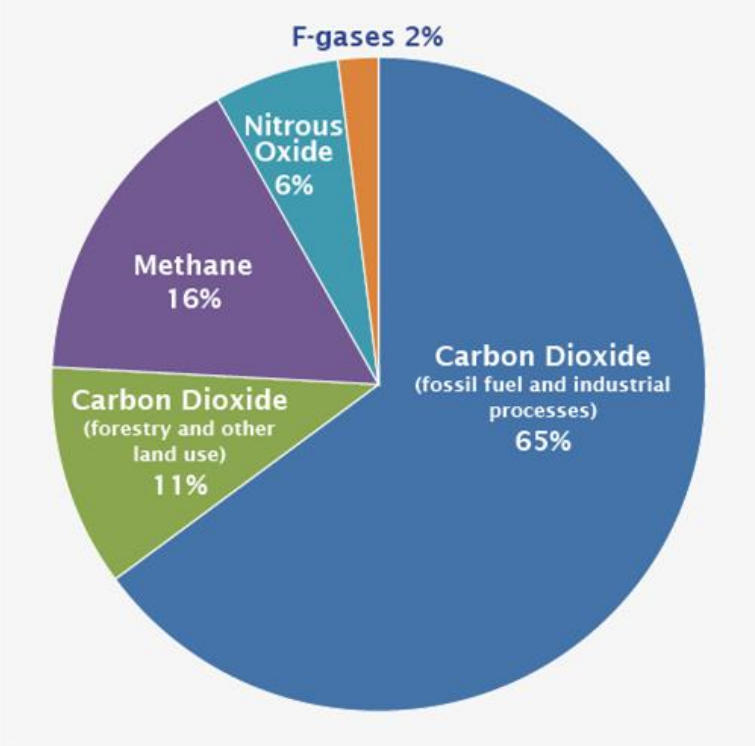
Glaciers melting

↓

Higher sea level

↓

Strain on coastal infrastructure



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Intergovernmental Panel on Climate Change (IPCC). (2014).

Engineering Solution

Carbon Capture, Utilization, and Storage (CCUS)

→ captures carbon dioxide (CO_2) emissions → reuses or stores it

Core analysis

→ examines the physical properties of rock samples

→ porosity, permeability, and mineral composition assessments

The research aims to develop **a deep learning model** for pore segmentation to minimize human bias in the analysis process.

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X-ray micro-computed (micro-CT)

A robust method to quantify various features in porous geomaterials

- portland cement-based materials
- geological materials

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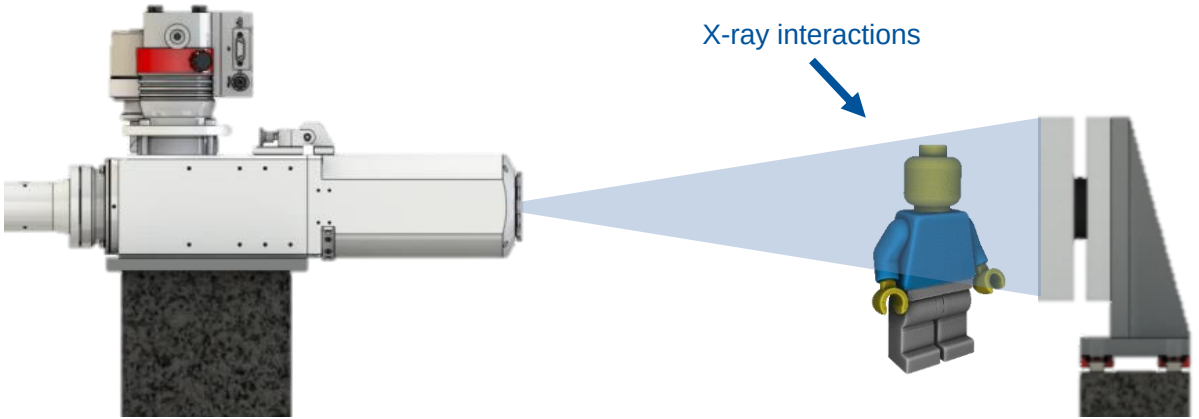
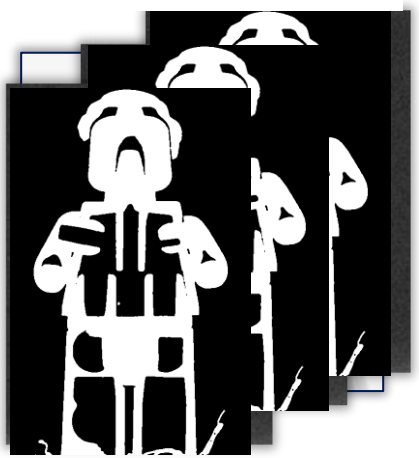
Basic Configuration of X-ray CT



Segmentation



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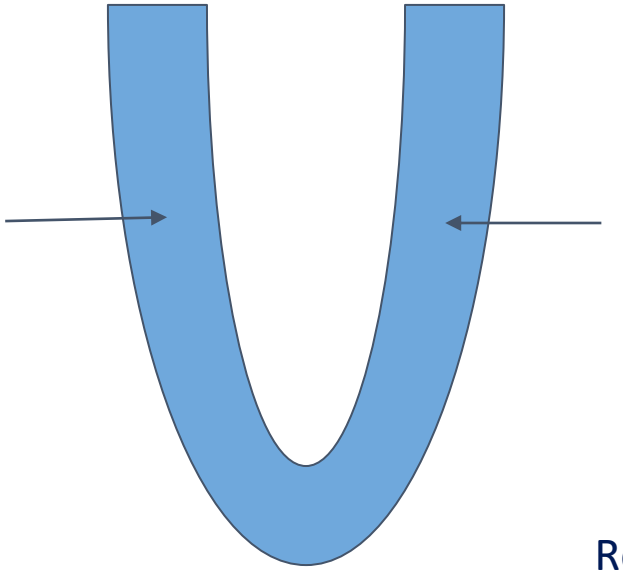
Original slides from TESCAN

UNet

What is UNet?

A convolutional neural network (CNN) specifically designed for image segmentation.

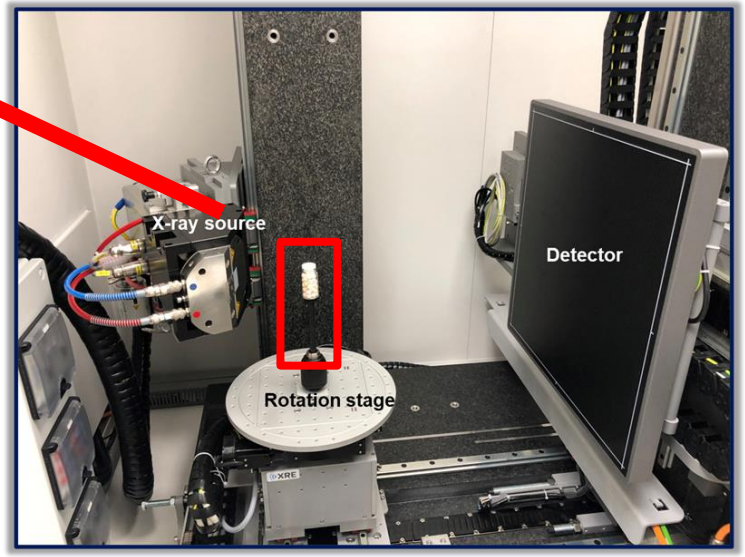
a contracting path (encoder) to capture context



an expansive path (decoder) for precise localization

Ronneberger et al, 2015

Data e Central Campus Geo ct



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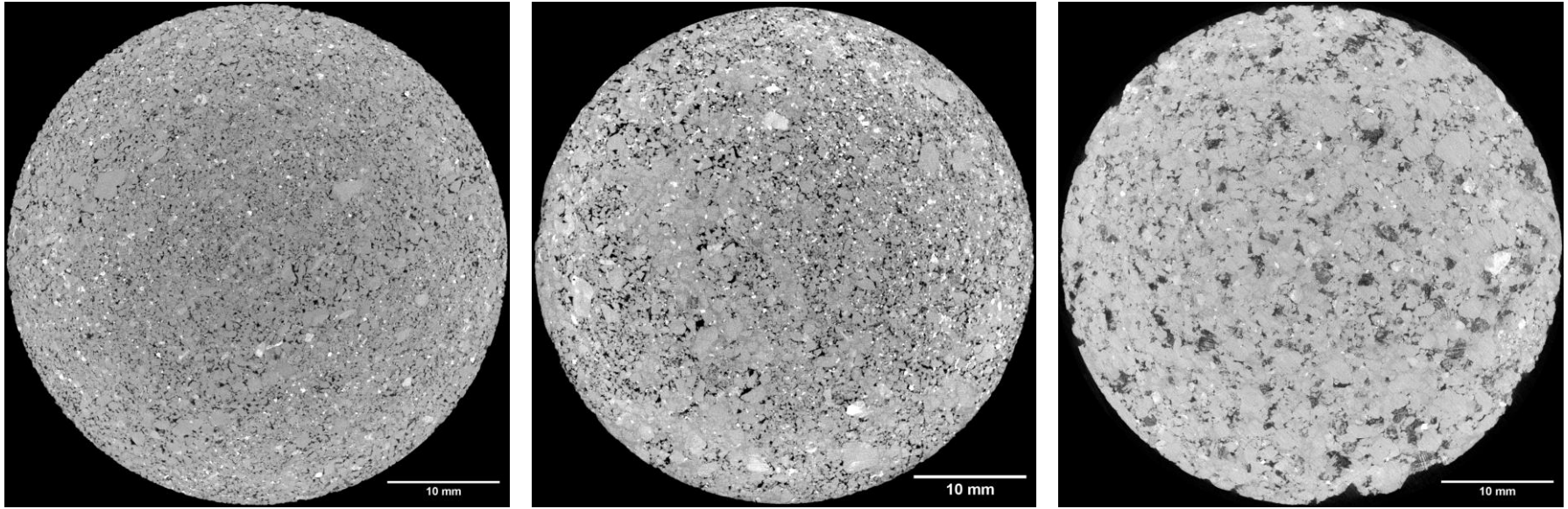
Data



These are micro-CT scan slices from different sections of a 10ft tall cylinder core.

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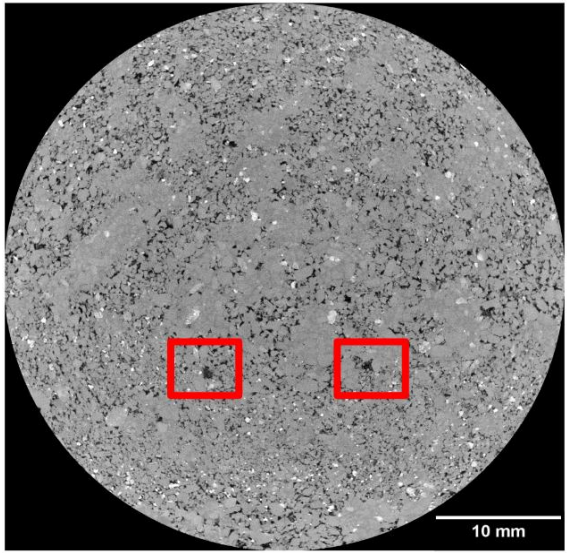
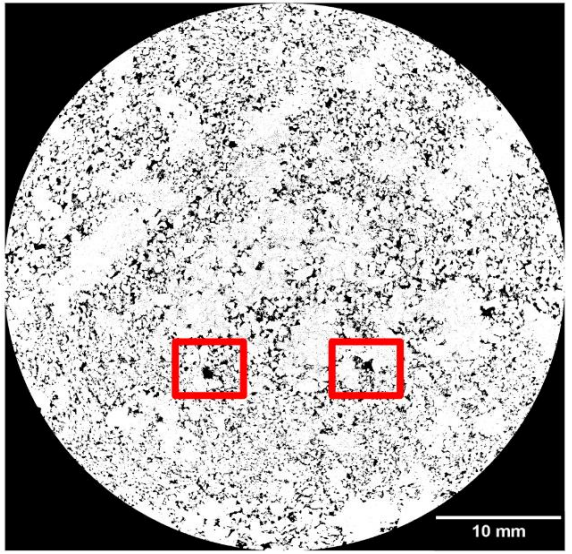
Generate labels for deep learning model

A **mask** can be used to **isolate** a specific area or object within an image. For instance, in image segmentation tasks, a mask might be a binary image.



original image

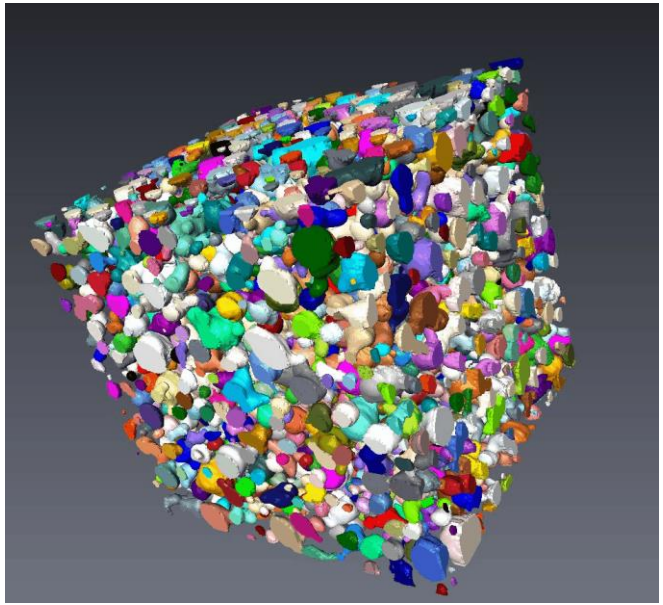


corresponding mask

Foamed cement

Foamed cement, also known as cellular concrete

- Lightweight construction material
- Made by mixing cement slurry with a foam agent
- Oil and gas industry
- Nitrogen bubbles



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Proposed model

Input: micro-CT images of core samples

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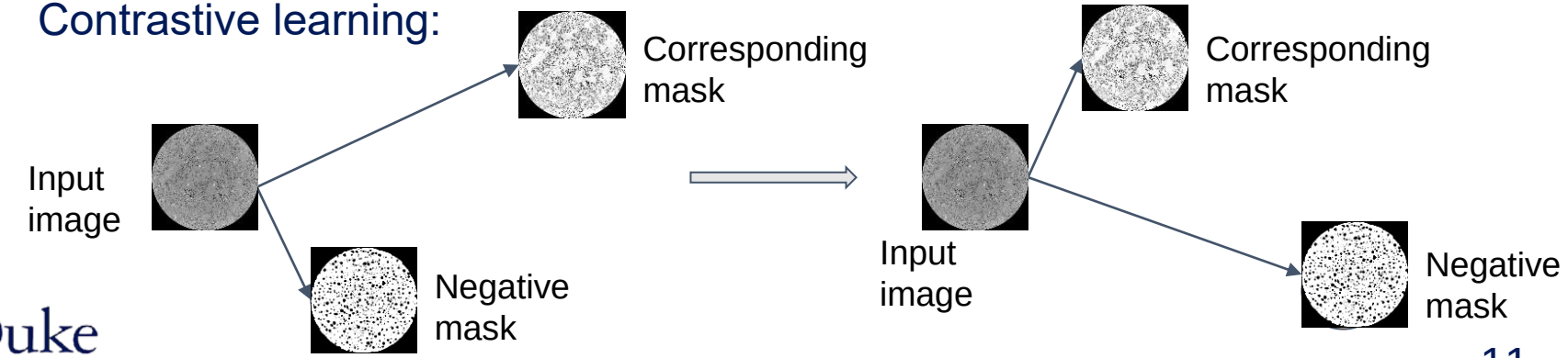
Phase 1: Convolutional Neural Network (CNN)

→ contrastive learning

Phase 2: UNet → segmentation

Contrastive learning:



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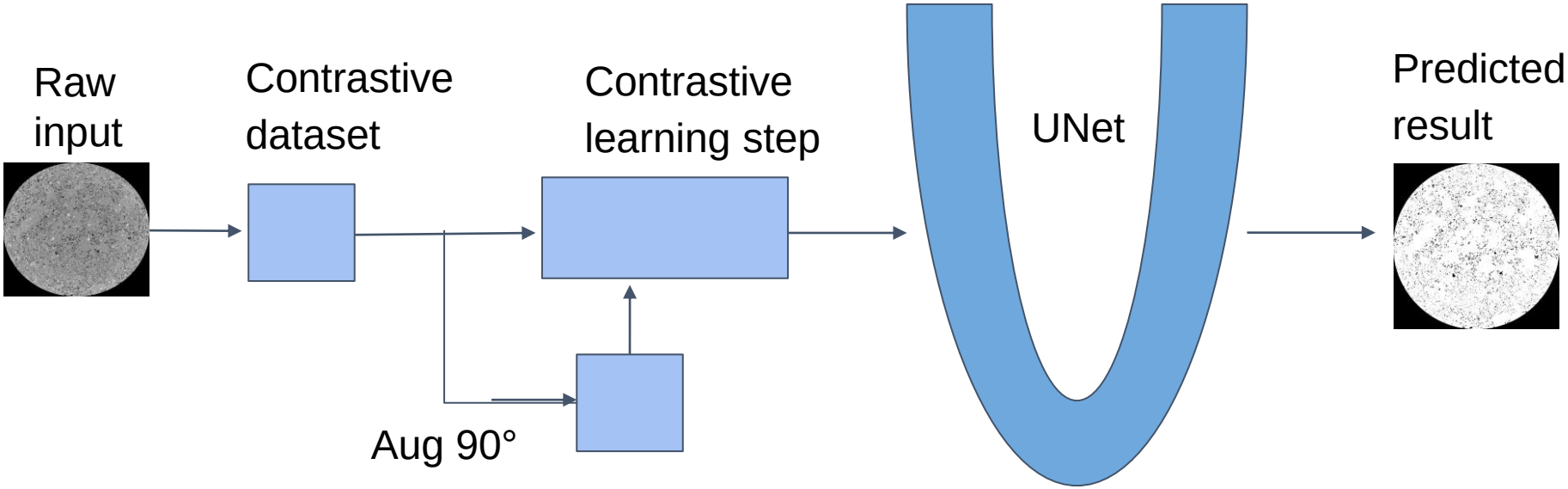
Proposed network architecture



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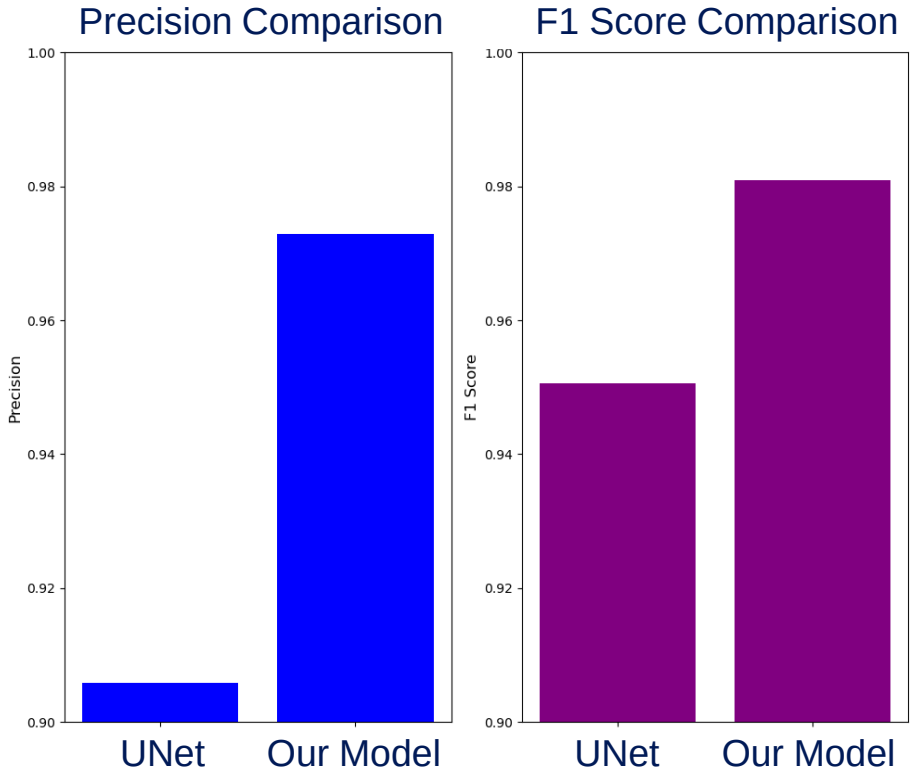
Evaluation

Precision: High precision means most **pixels classified as pores** are correctly identified.

F1 Score: A high F1 score signifies a reliable model, **accurately capturing pore spaces** without missing or falsely identifying them.



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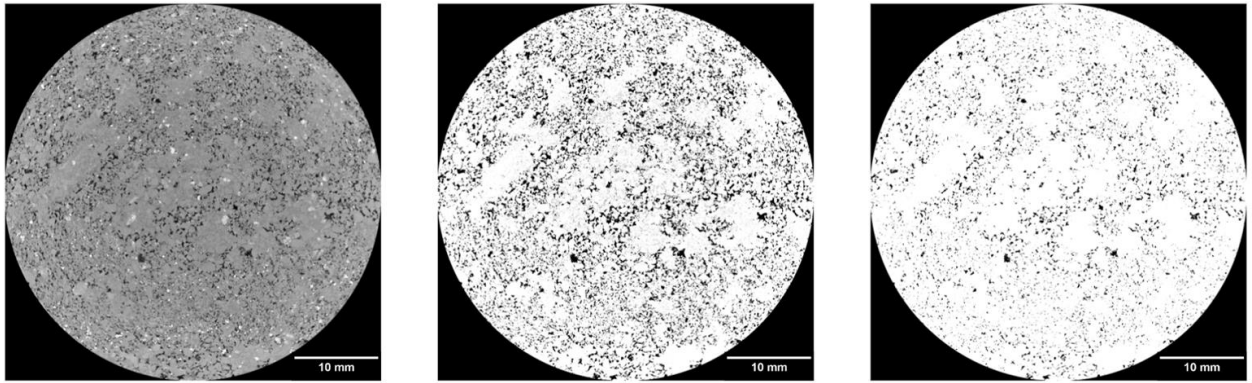
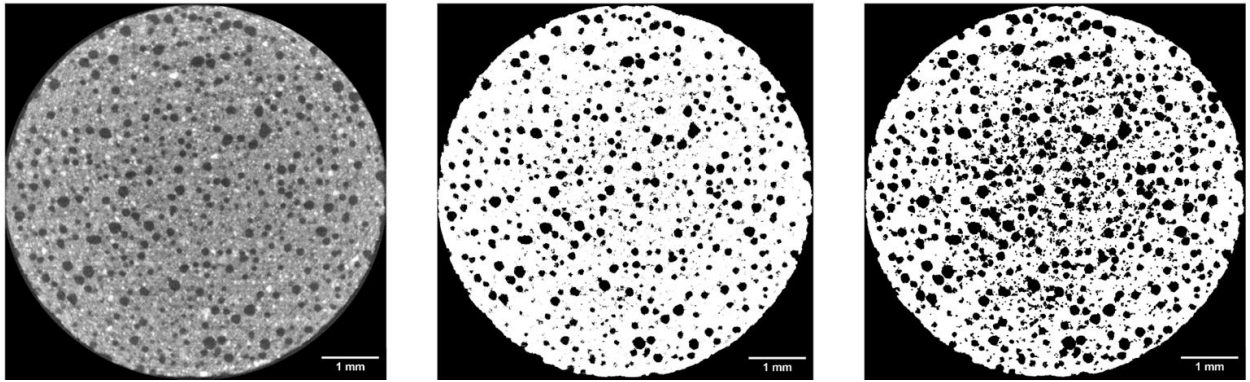
Results

Core data



Foamed cement



Input | Mask | Predicted Result

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Crandall et al, Digital Rocks Portal, 2018

Conclusion

- Enhanced Performance
  - contrastive learning has **improved** the segmentation results of original UNet model
- Promising Potential
- Bias Reduction
  - helped in **removing human bias**
  - leading to more accurate and reliable data interpretation.

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Next step

- 3D Visualization
  - get a **better understanding** of the spatial relationships
- Porosity Calculation
  - calculate the **porosity** of the core sample using the enhanced segmentation data
  - gain insights into its **permeability** and **potential** for carbon storage and geothermal use.
- Multiphase segmentation

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Acknowledgment

Duke | CIVIL & ENVIRONMENTAL ENGINEERING

Duke | NICHOLAS SCHOOL of the ENVIRONMENT

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Duke University Central Campus Geothermal Test

Thank you for your attention!

Questions?

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