Fractured Reservoir Rock Modelling:
AI-driven Segmentation, Multiscale Pore Network Modelling and Experimental Investigation

C. T. Panaitescu, M. E. Kartal, Y. Tanino, A. Starkey, N. S. Japperi, K. Wu

OUTLINE

- Introduction and challenges in modelling fractured reservoirs
- Geomechanics-flow fracturing experiments
- Digital Rock Technology
- Semantic Segmentation: Applications of AI
- Fracture-Matrix modelling

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School of Engineering
Fraser Noble Building
King's College
Aberdeen
AB24 3UE
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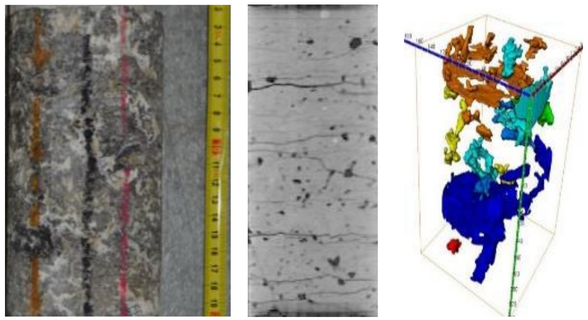
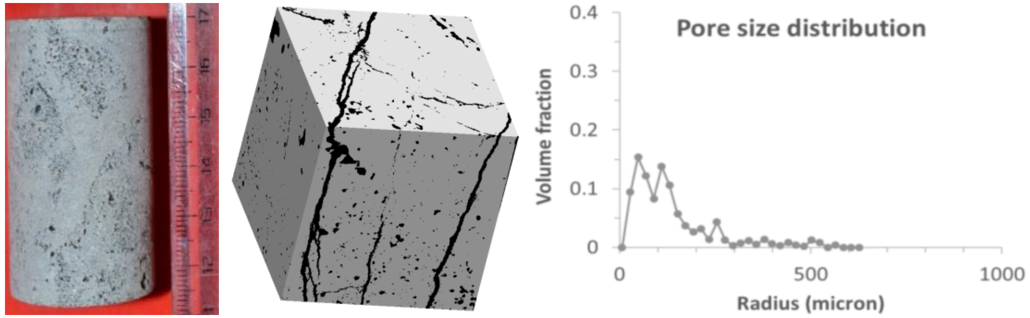
FRACTURED GEOLOGIC MEDIA

- Fracture has a controlling impact on reservoir flow systems, and there is high uncertainty of fracture systems in reservoirs.
- There is a gap in the flow simulation in the Fracture-matrix system.

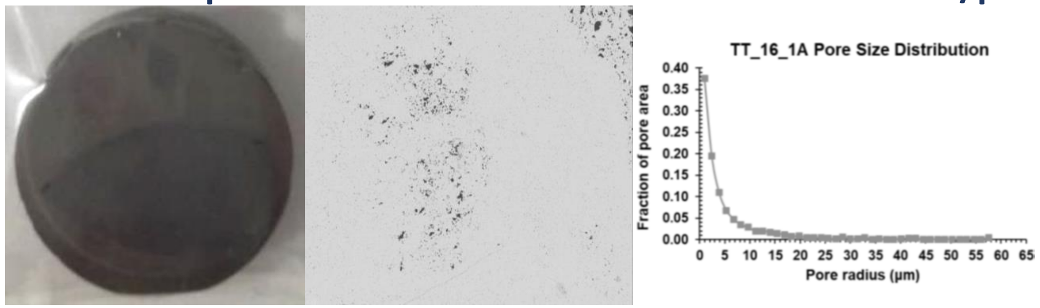
Full core: 5 inches in diameter resolution 200 microns/voxel



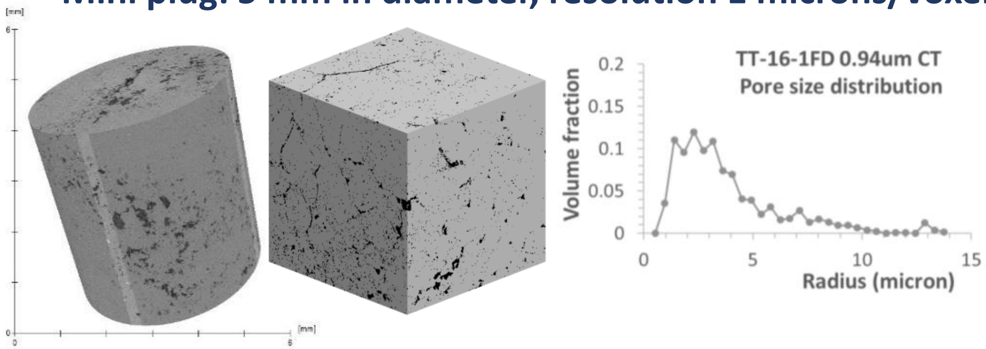
Plug: 1.5 inches in diameter, resolution 20 microns/voxel



Small SEM chip: 25 mm in diameter resolution 0.25 microns/pixel



Mini plug: 5 mm in diameter, resolution 1 microns/voxel



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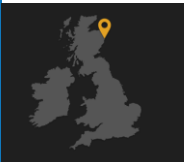

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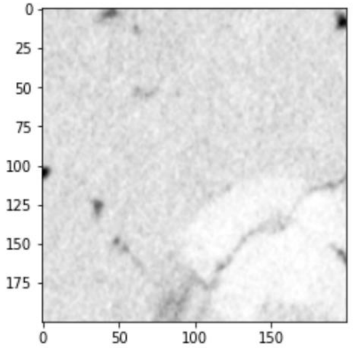

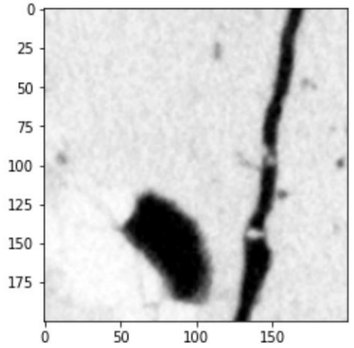

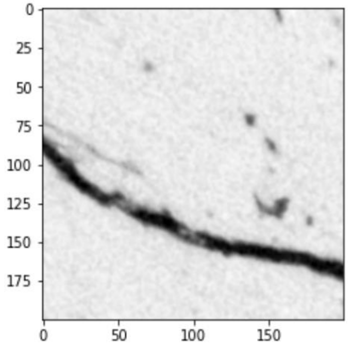

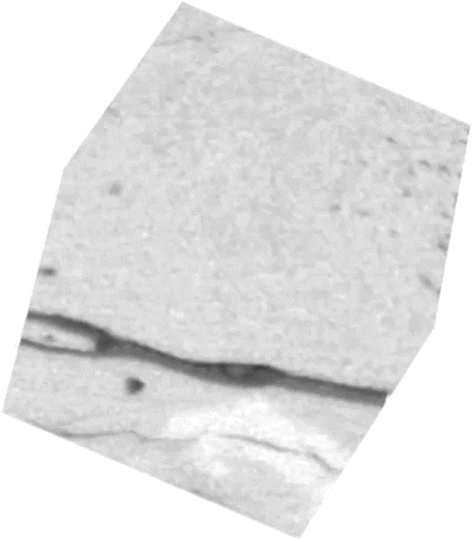

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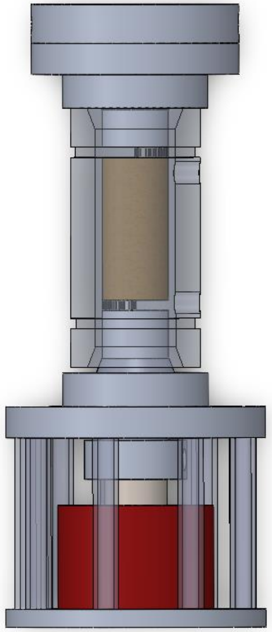
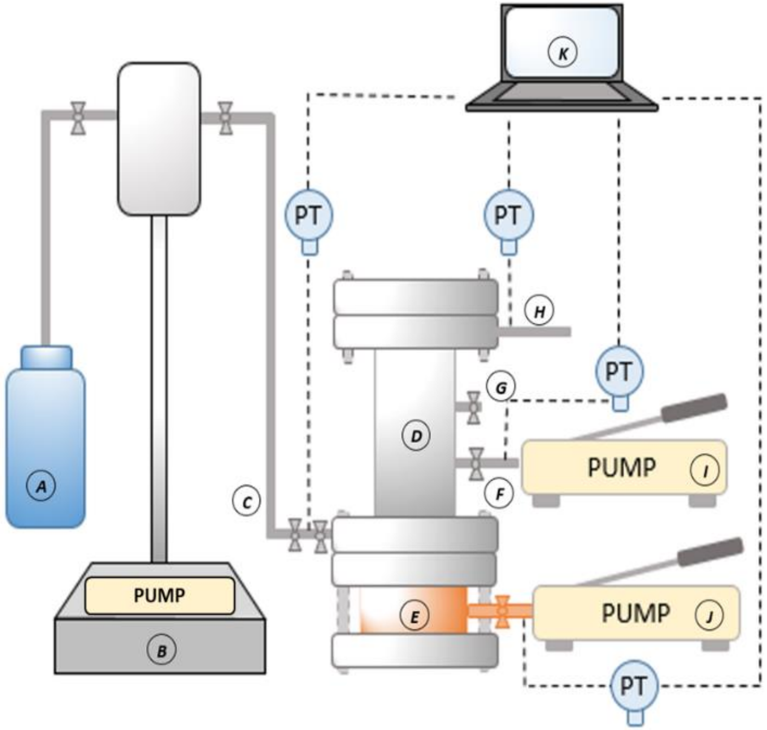
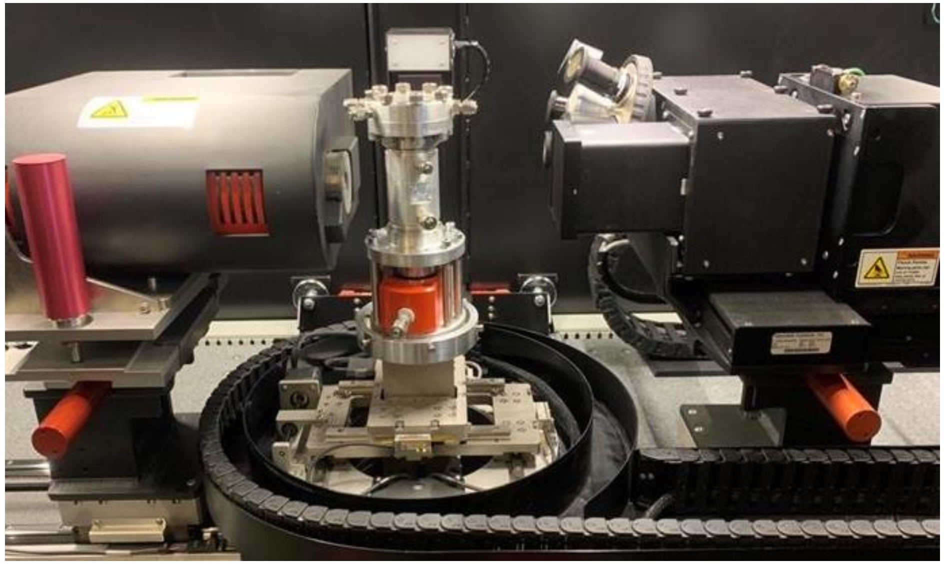
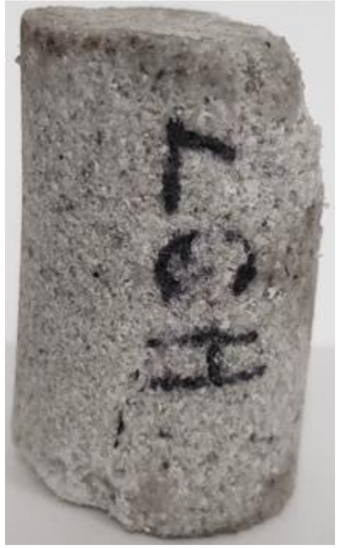
EXPERIMENTAL SETUP









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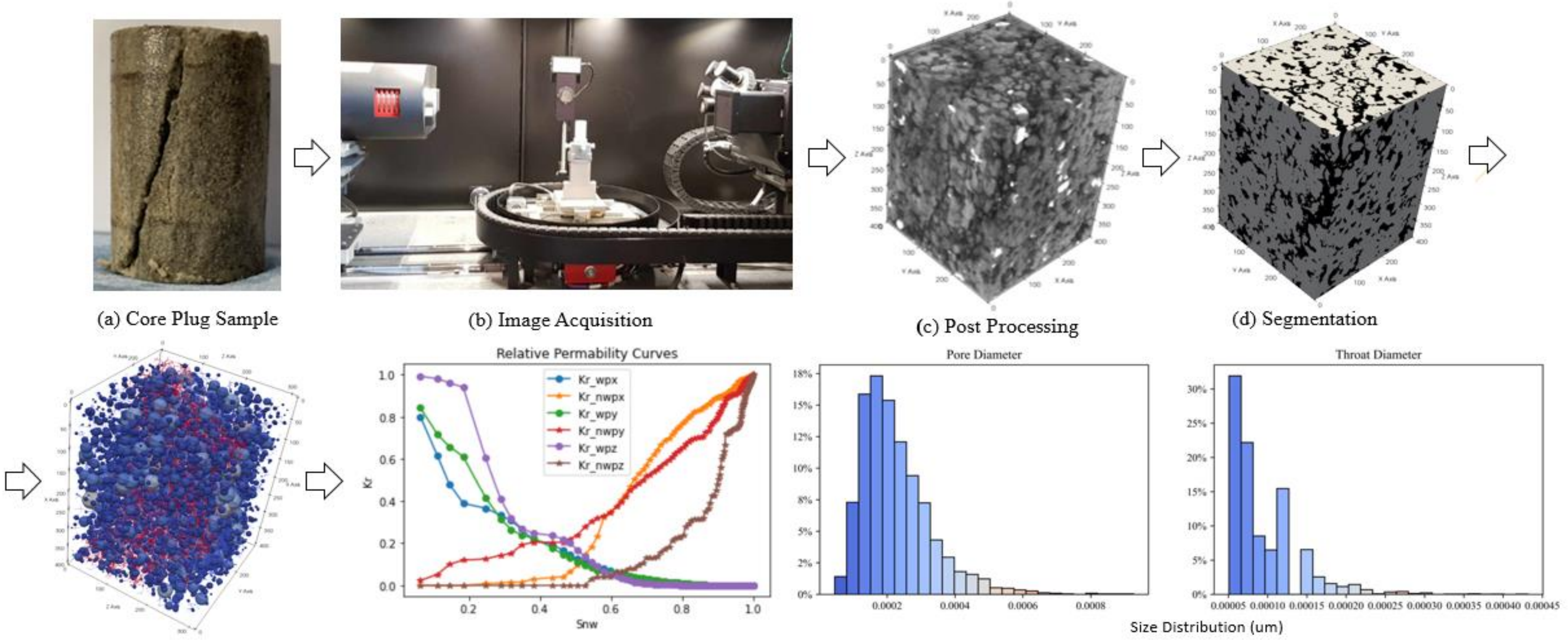
DIGITAL ROCK TECHNOLOGY



(a) Core Plug Sample

(b) Image Acquisition

(c) Post Processing

(d) Segmentation

(e) Simulation Setup

(f) Flow Properties and Statistical Analysis

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PORE SCALE FLUID SIMULATION TECHNIQUES

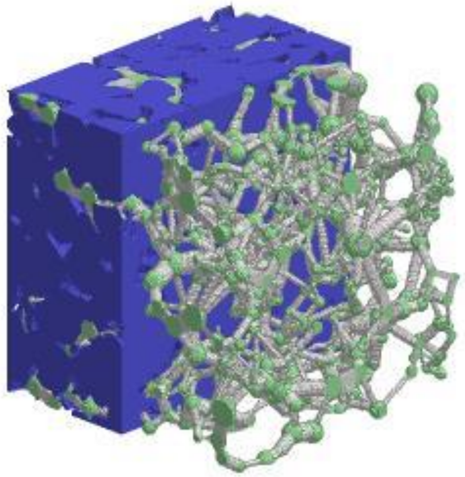
Digital Rock Technology techniques include:

(A) ***Direct simulation*** using **Finite Difference**, **Finite Volume**, or **Lattice Boltzmann**:

- The method is **very accurate** but **resource-intensive** and not **easily generalised**

(B) ***Pore network models (PNM):***

- Can quantify the **macroscale flow** of the **matrix** for the reservoir rock (**pore size distribution** and **connectivity**)
- **Computationally efficient** single and multiphase flow



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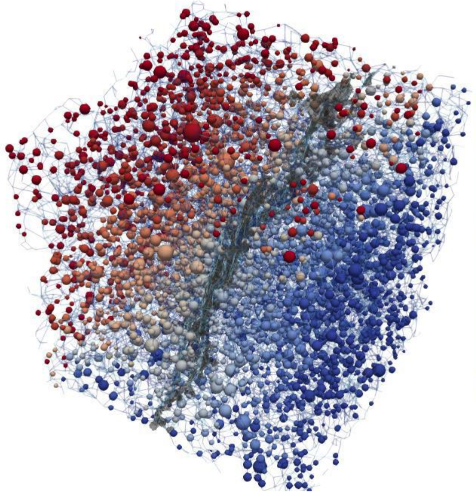
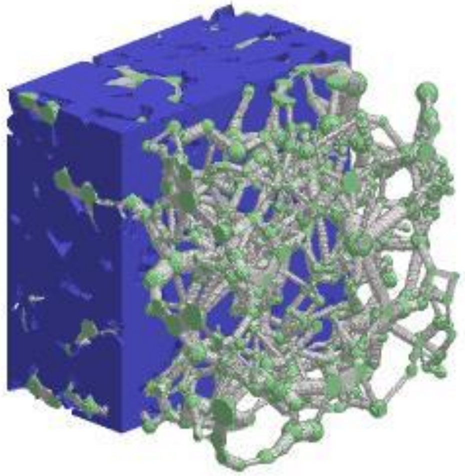
(B) ***Pore network models (PNM):***

- Can quantify the **macroscale flow** of the **matrix** for the reservoir rock (**pore size distribution** and **connectivity**)
- **Computationally efficient** single and multiphase flow

(C) **Improved DRT technique - *Fracture-Matrix Pore network model (FPNM):***

- Quantify the multiscale **fracture and matrix** (Fracture and pore distribution and their connection)
- Computationally efficient **multiscale** and **single/multiphase** flow





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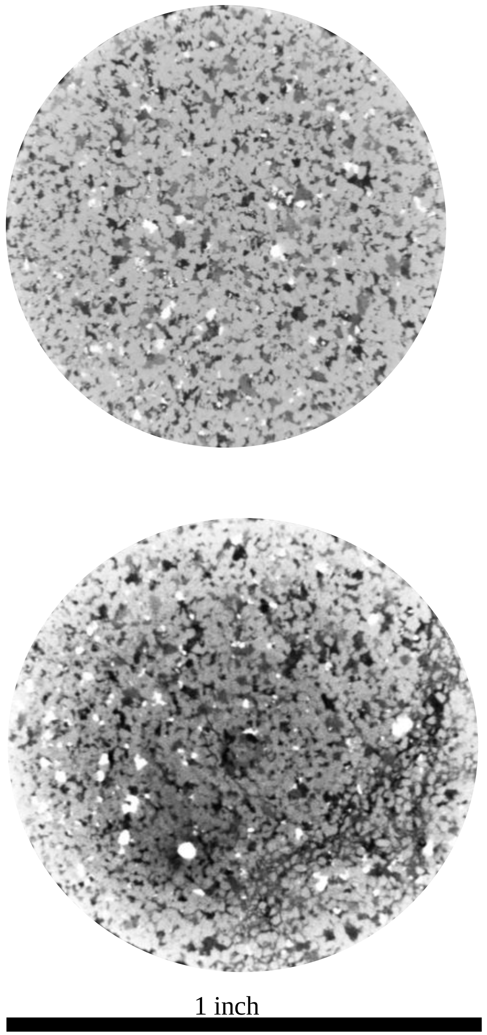
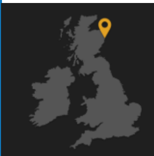
UNFRACTURED SAMPLE ANALYSIS





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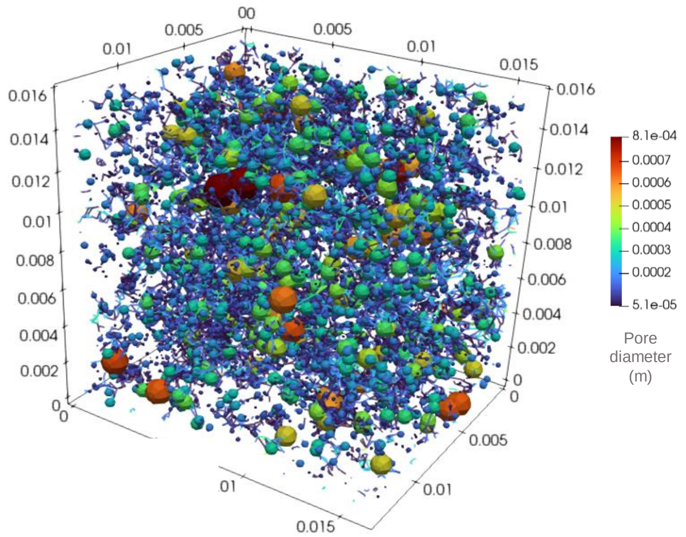

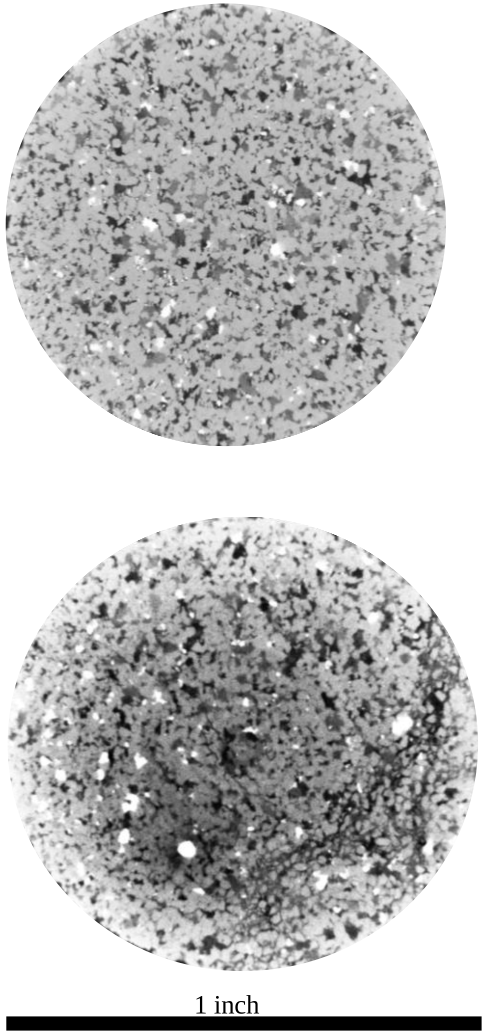

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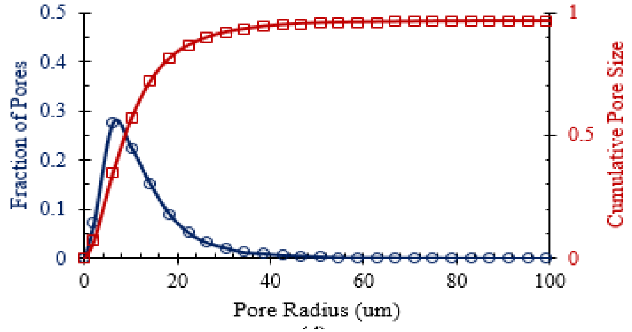

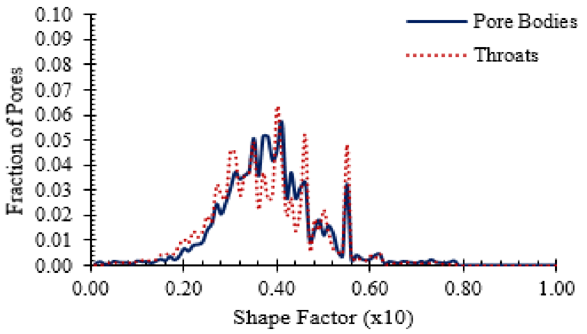

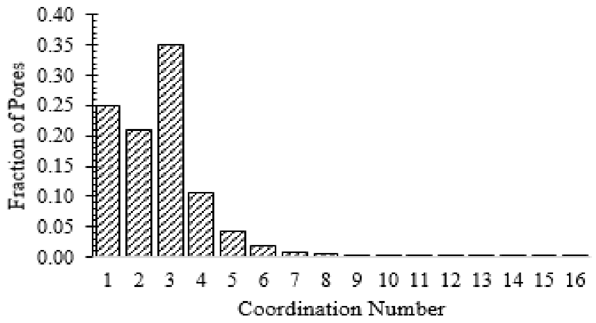

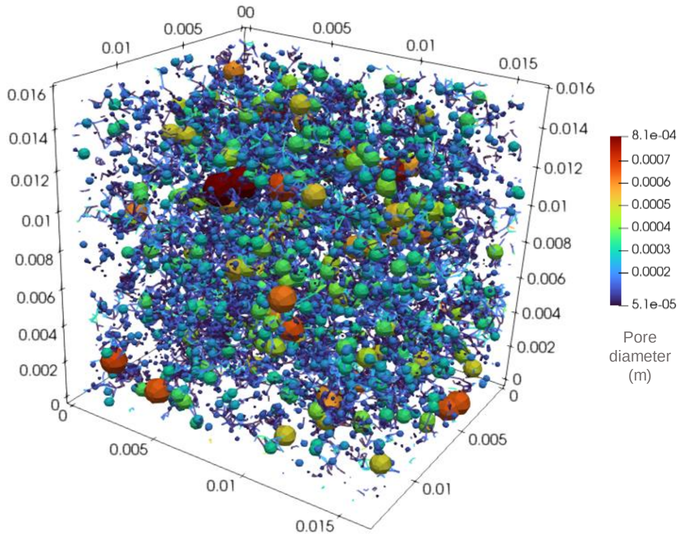

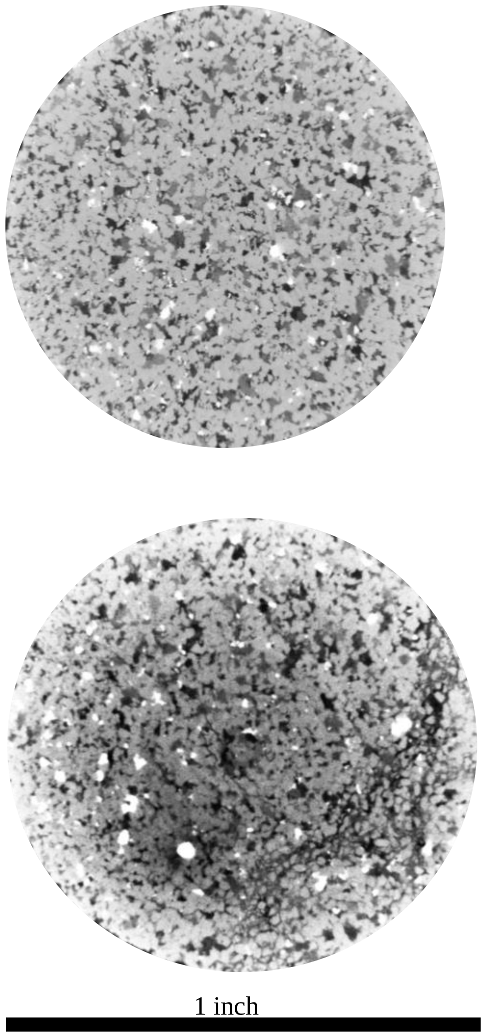

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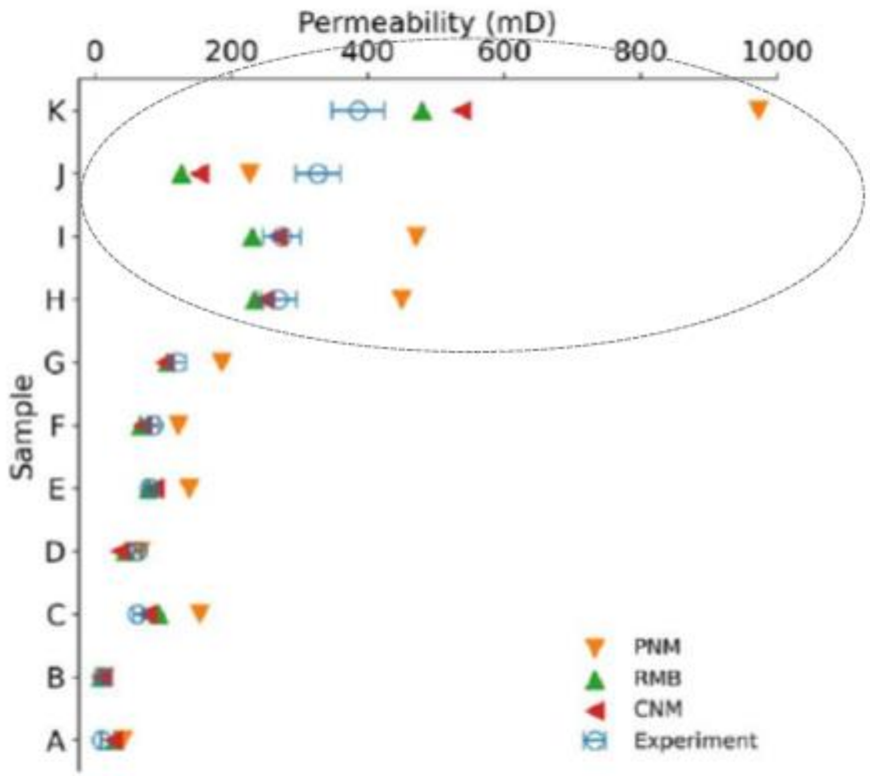
ADVANCED MATRIX-FRACTURE MODELLING



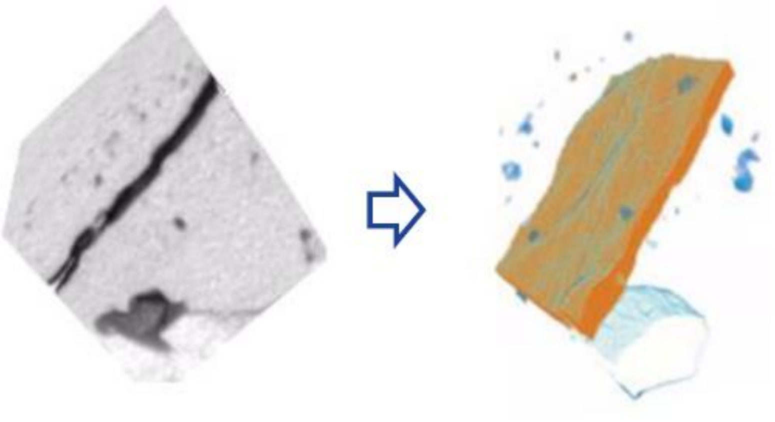
(Neumann et al., 2021)

ADVANCED MATRIX-FRACTURE MODELLING

Main-stream codes do not treat multiscale features differently

(3 steps)

Step 1: Multi-class segmentation



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ADVANCED MATRIX-FRACTURE MODELLING

Main-stream codes do not treat multiscale features differently (3 steps)

Step 1: Multi-class segmentation

Step 2: Additional Fracture-Matrix Pore network extraction

Step 3: Fracture-fracture and Fracture-pore physics

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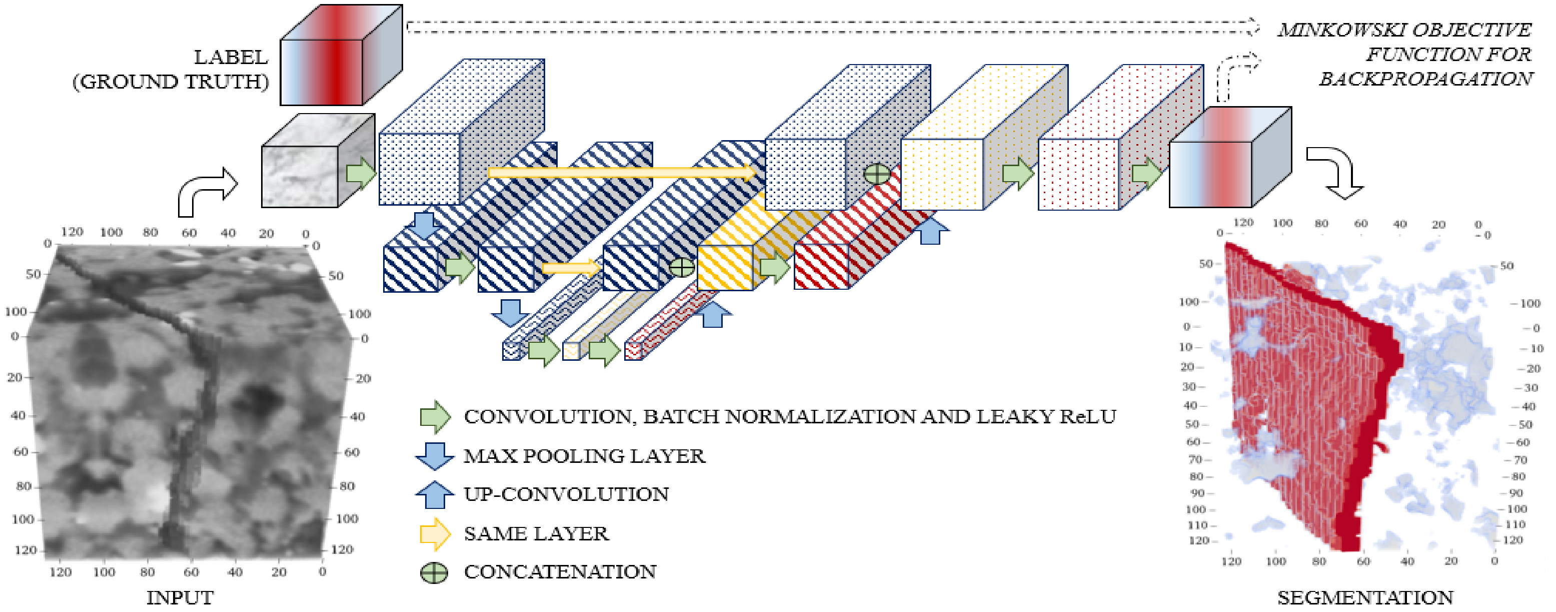
DEEP LEARNING SEMANTIC SEGMENTATION



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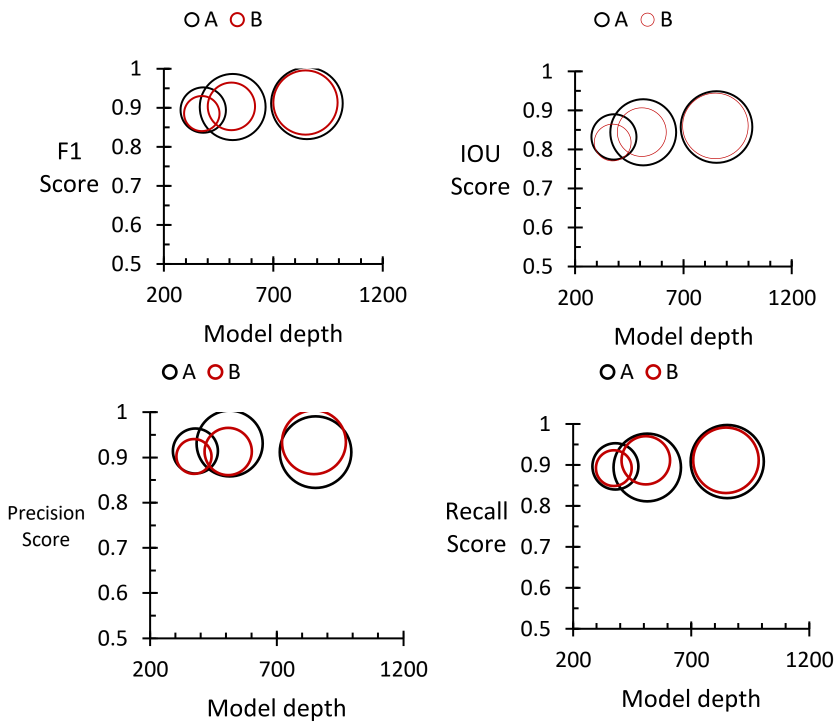
DEEP LEARNING SEMANTIC SEGMENTATION

- Factorial Analysis performed on the relative importance of: ***backbone, architecture, objective function, model size, and transfer learning***



The bubble area is directly proportional to FLOP usage or energy consumption per 100 epochs.

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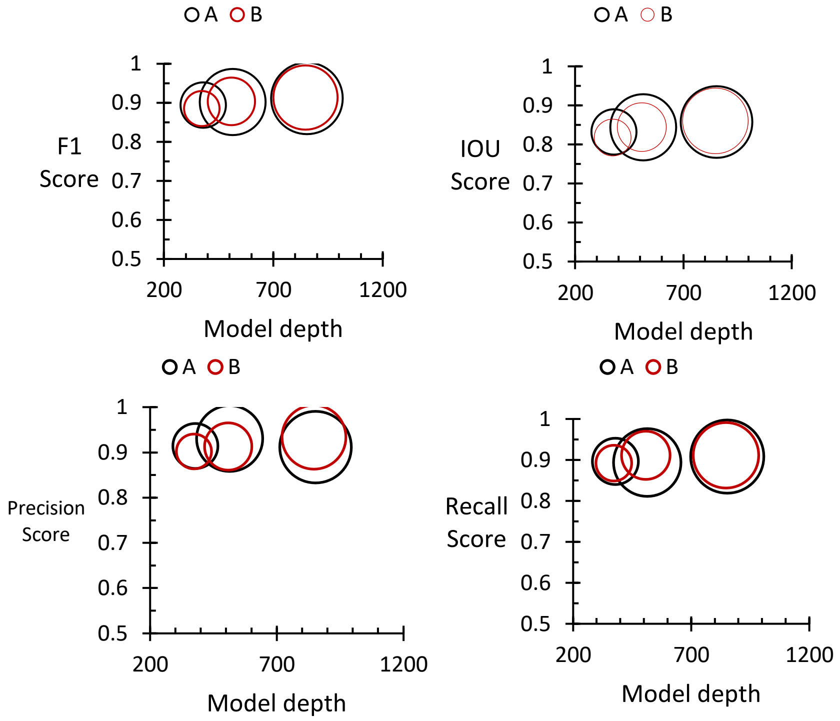
DEEP LEARNING SEMANTIC SEGMENTATION

- Factorial Analysis performed on the relative importance of: ***backbone, architecture, objective function, model size, and transfer learning***
- Dominant 2nd order effects for both performance and resource use.
- Using the new Minkowski Objective Function combined with pre-training improves performance by 4% even when considering area-based and pixel-based metrics (F1, IOU) but only when using transfer learning
- Model size and depth are less important than optimizing the match between factors
- Top performing model achieves F1 of 0.9 and IOU of 0.85
- Ballanced model achieves F1 of 0.9 and IOU of 0.84, but used 40% lower resources



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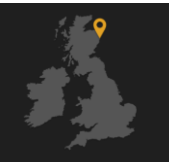

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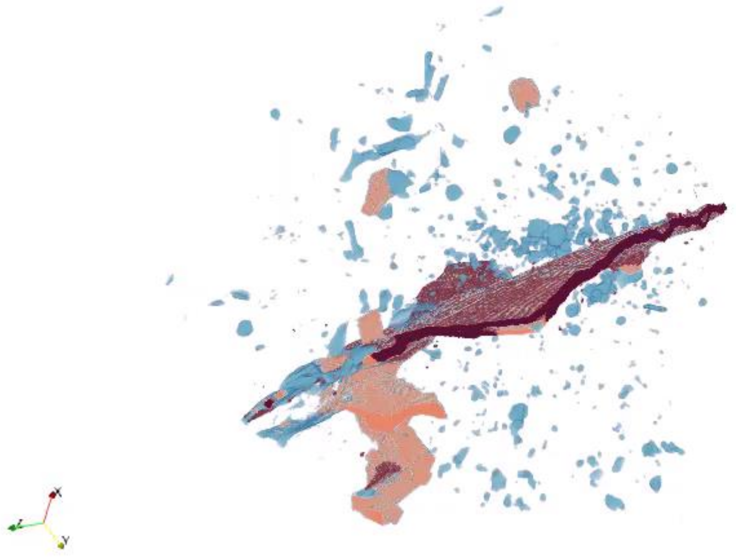
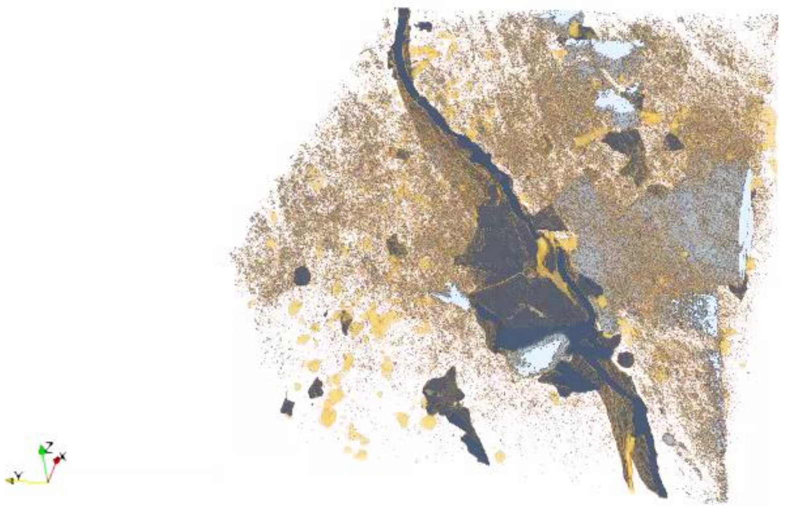
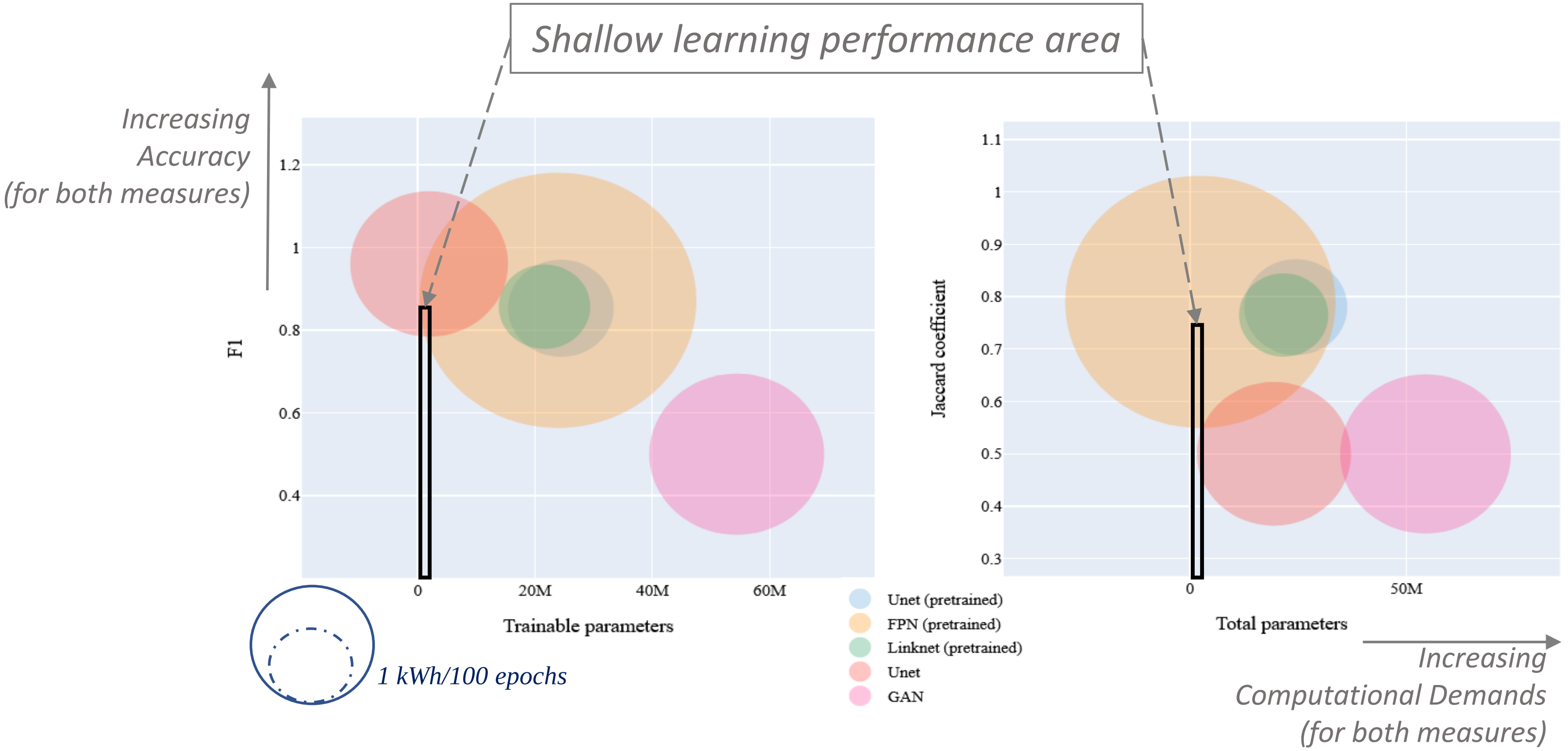
PORE-FRACTURE-VUG SEGMENTATION RESULTS





COMPARISON OF DEEP AND SHALLOW LEARNING



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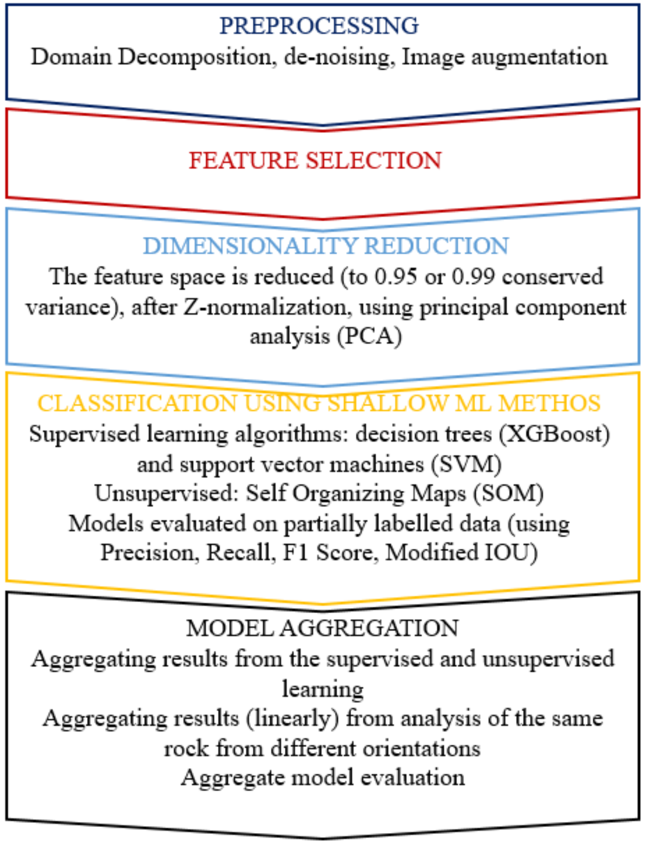
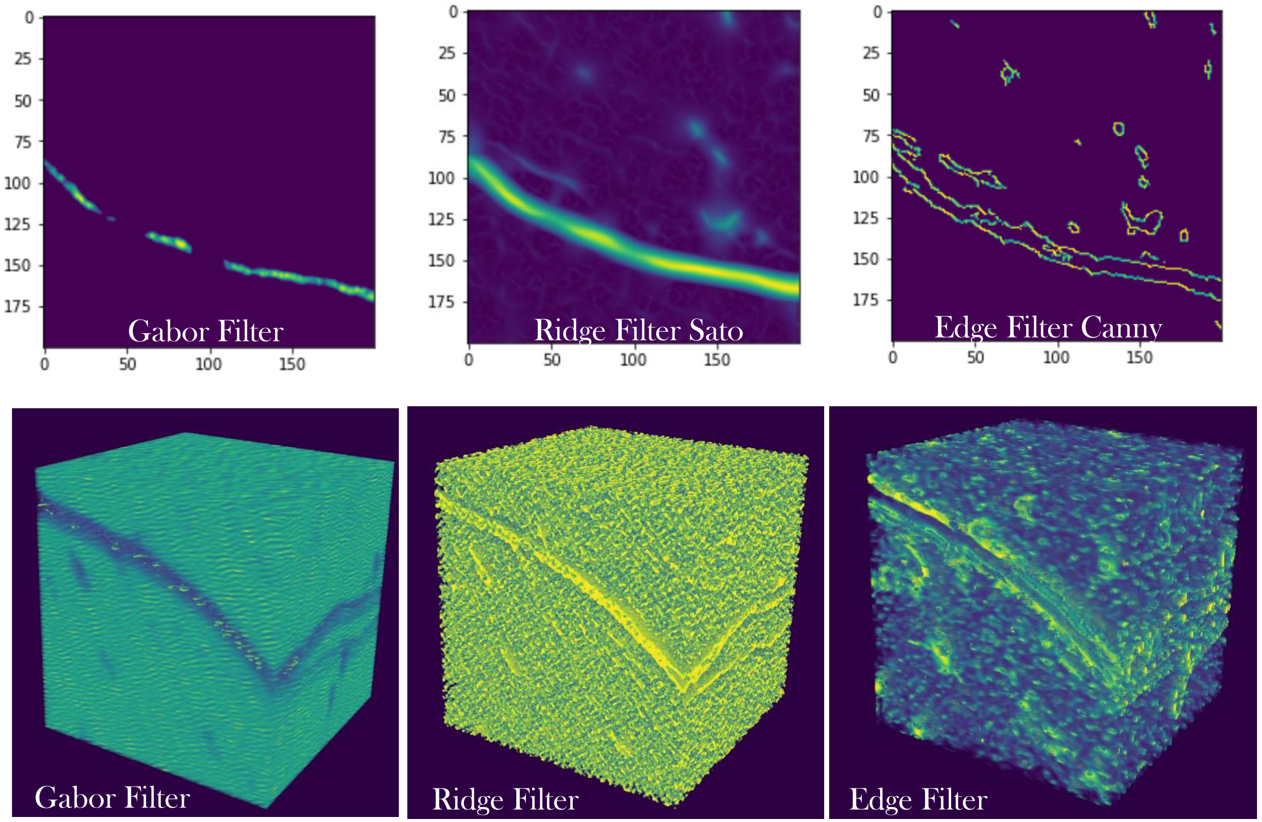
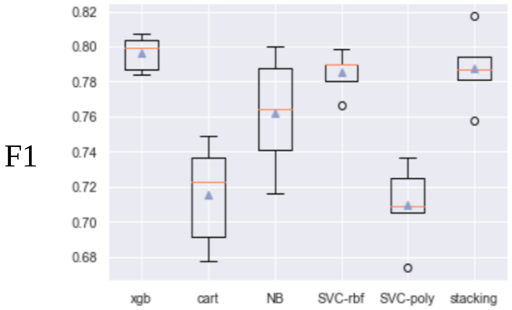
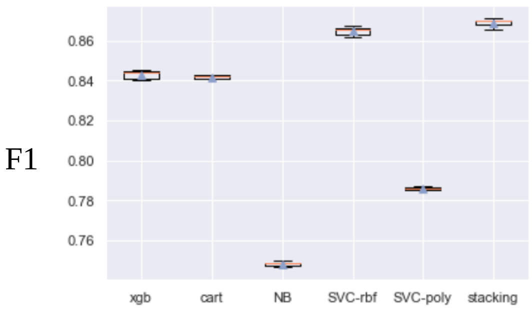






0.2% of full volume data used



0.5% of full volume data used

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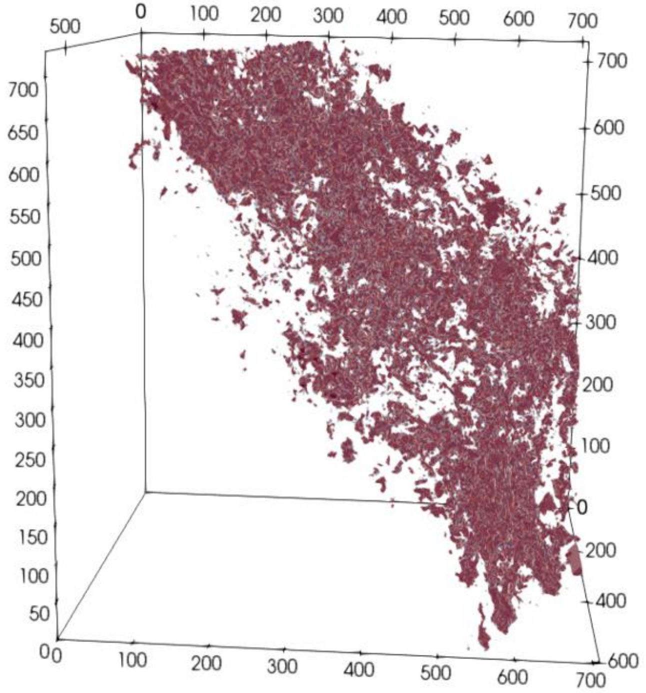
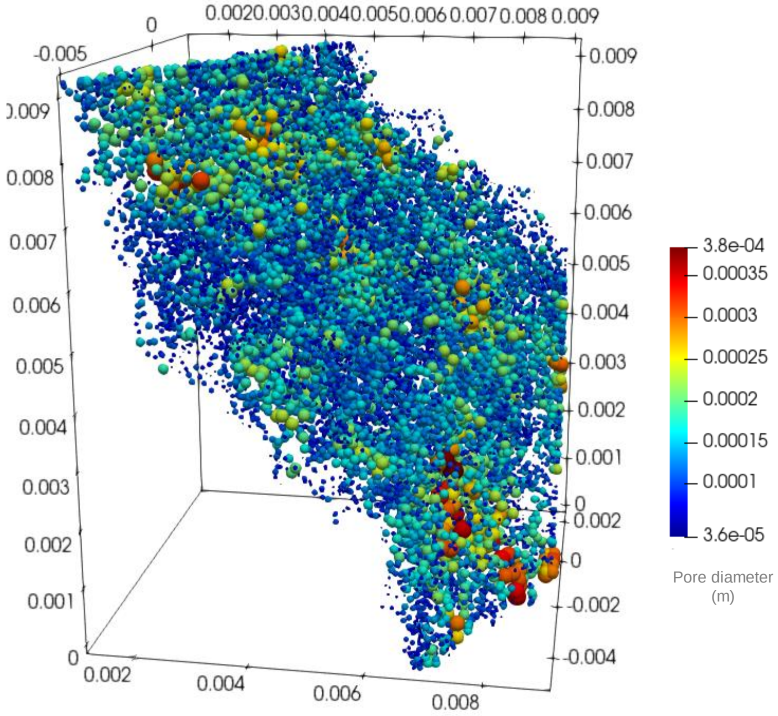
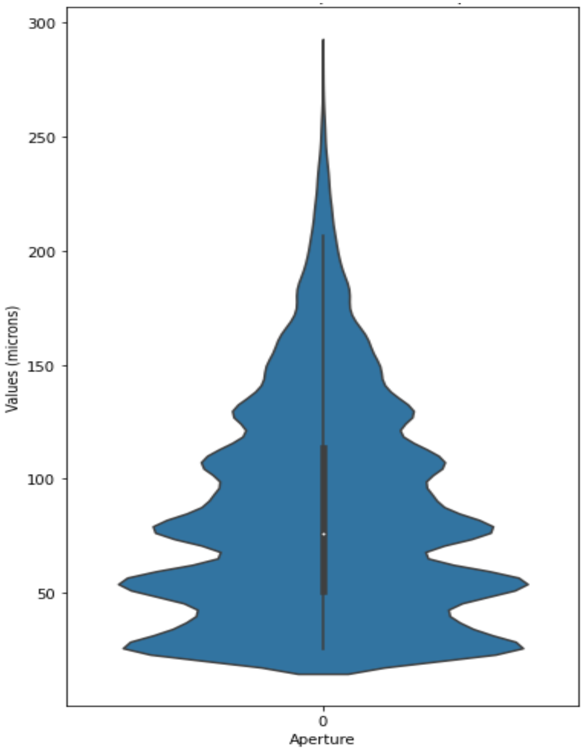
FRACTURE ANALYSIS

Fracture permeability contribution: 21.5 mD (86.7%)
Experimental post-fracture permeability: 24.8 mD







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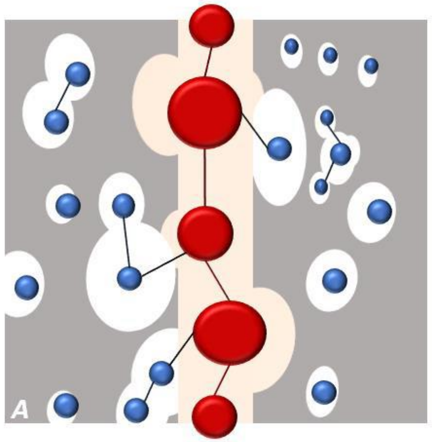
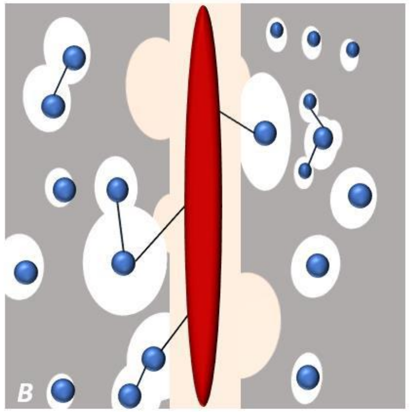
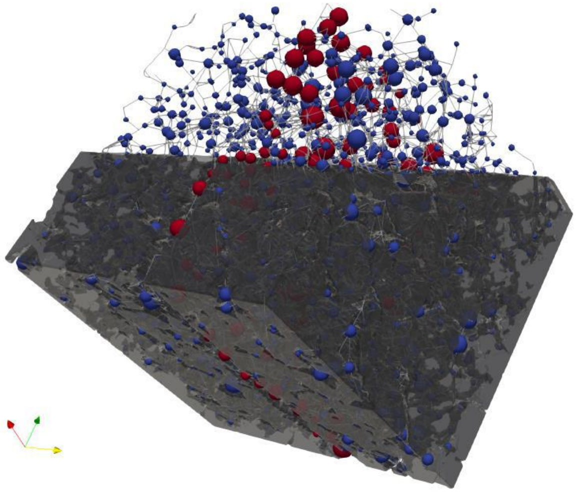
LIMITED DOMAIN FRACTURE-MATRIX SYSTEM

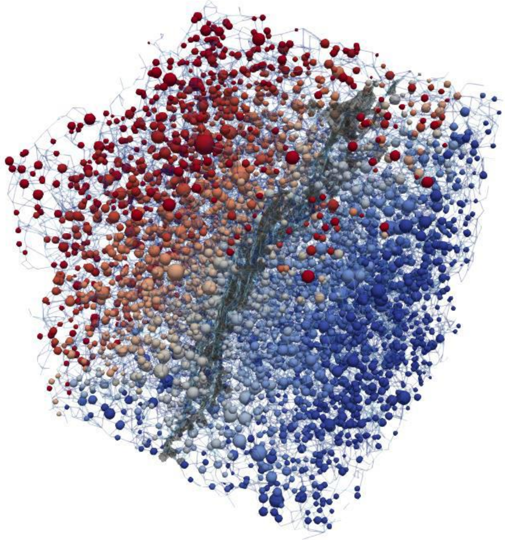




A: MULTI-PORE CUBIC LAW

Kz= 813.99 mD
Kx= 747.75 mD
Ky= 412.12 mD





B: SINGLE FRACTURE ELEMENT

Kz= 1986.46 mD
Kx=1281.89 mD
Ky= 417.58 mD

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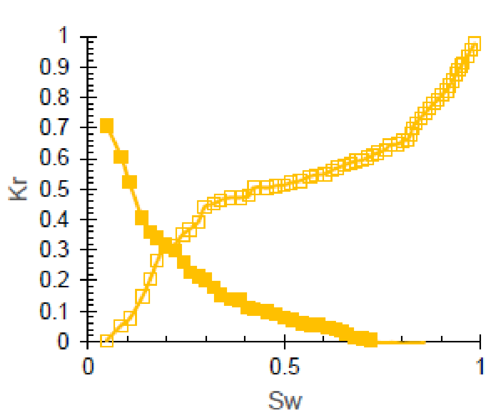
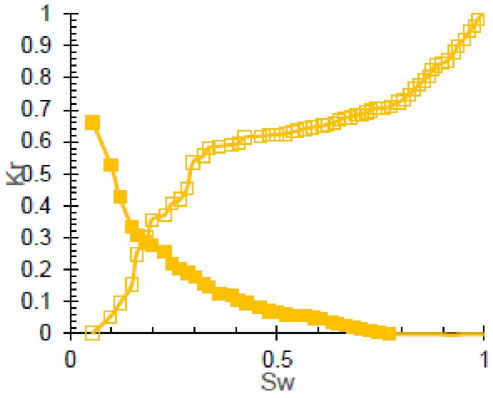
FRACTURE-MATRIX SYSTEM

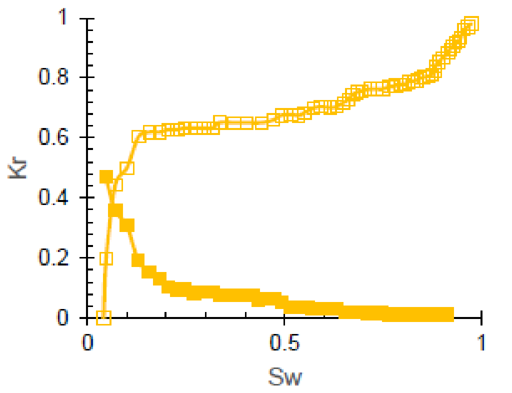
CLASSIC PNM

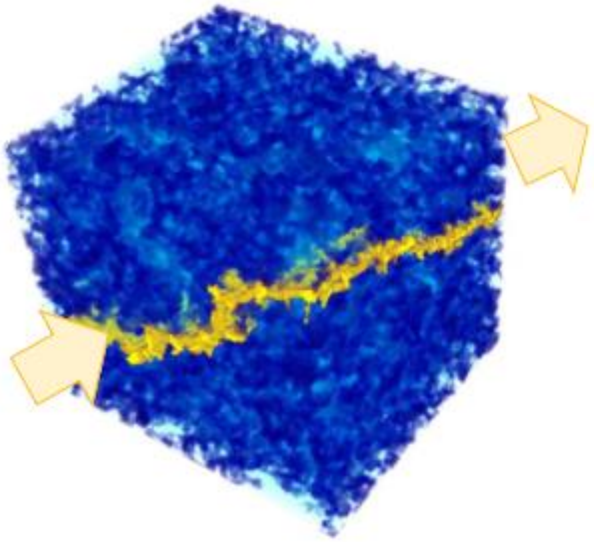


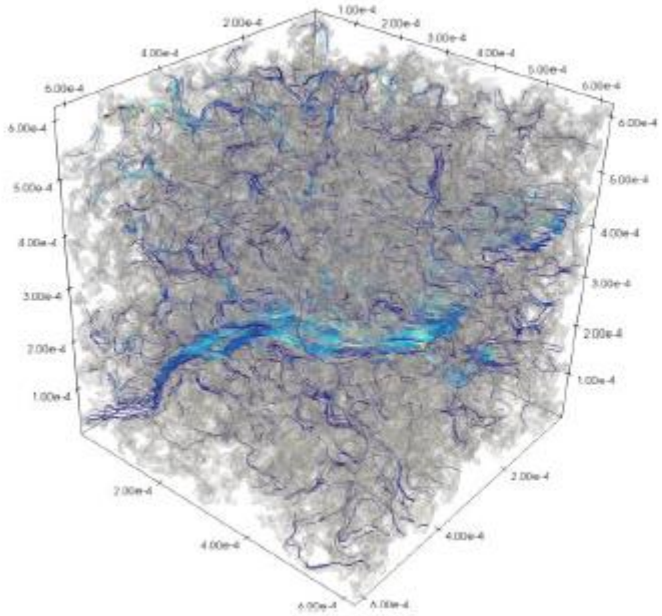
MULTI-PORE CUBIC LAW



SINGLE FRACTURE ELEMENT







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CONCLUSIONS

• Flow properties of rock samples are obtained through the modified triaxial test experimental procedure, which is used to validate flow simulations.

• AI tools are used to identify and segment pore and fracture features at different scales and prepare for combined multiscale simulations.

• New approaches and results were presented for the quantification and modelling of flow in the complex multiscale fracture-matrix system.

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THANK YOU

Q&A