

3-D Printing Artificial Reservoir Rocks to Test Their Petrophysical Properties*

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Abstract

At present, pore-scale imaging and modeling are becoming routine geoscience techniques of reservoir simulation in the oil and gas industry. The foundation of these techniques is the development of sophisticated three-dimensional models that can represent both the multiphase flow dynamics and the geometry of the rock's pore system. Three-dimensional printing may facilitate the transformation of pore-space imaging into rock models, which can be tested using traditional laboratory methods to provide data that is easily comparable to literature data. Although current methodologies for rapid rock modeling and printing obscure many details of rock geometry, computed tomography data is one route to refine pore networks and experimentally test hypotheses related to rock properties, such as porosity and permeability.

This study uses three-dimensional printing as a novel way of interacting with (a) x-ray computed tomography data from reservoir rocks, and (b) mathematical models of pore systems in coarse-grained sandstones and limestones. These artificial rocks will be used as a proxy to better understand the contributions of various pore system characteristics at various scales to petrophysical properties in oil and gas reservoirs. Pore sizes of typical reservoir sandstone range from 0.1 to 100s of microns. The resolution of three-dimensional digital printing used in the study varied from 16 to 300 microns, therefore, the three-dimensional imaging and especially printing might have lost information on pore geometry. The increase in scale of the pore systems (e.g. from 1 micron in reality to 50 microns in a three-dimensional model) will be a key factor for a precise determination of porosity-permeability relationships as they can be verified against core-scale measurements. The long-term

goal of this study is to focus on testing of petrophysical hypotheses by manipulating digital rock models to determine the resulting changes in artificial rock properties that affect fluid flow. If the pore system models could include tools for adequate measurements of petrophysical properties in “manufactured” rocks in the laboratory conditions, the accuracy of reservoir flow simulations would be increased. Three-dimensional printing offers a great potential to improve our approach to reservoir simulation, facilitating more efficient oil and gas recovery.

The Use of Computed Tomography and 3D Printing Technology to Replicate Reservoir Pore Systems

Sergey Ishutov, PhD student

Advisor: Dr. Franek Hasiuk

Collaborators: Dr. Chris Harding and Dr. Joe Gray



April 7, 2014

AGENDA

Introduction

- Definition of Pores in Reservoir Rocks

Importance

- Challenges of Pore Network Modeling

Hypothesis and objectives

CT scanning

- Complexities in Porosity-Permeability Scanning

Modeling

- Reconstruction of CT volume
- Network Extraction

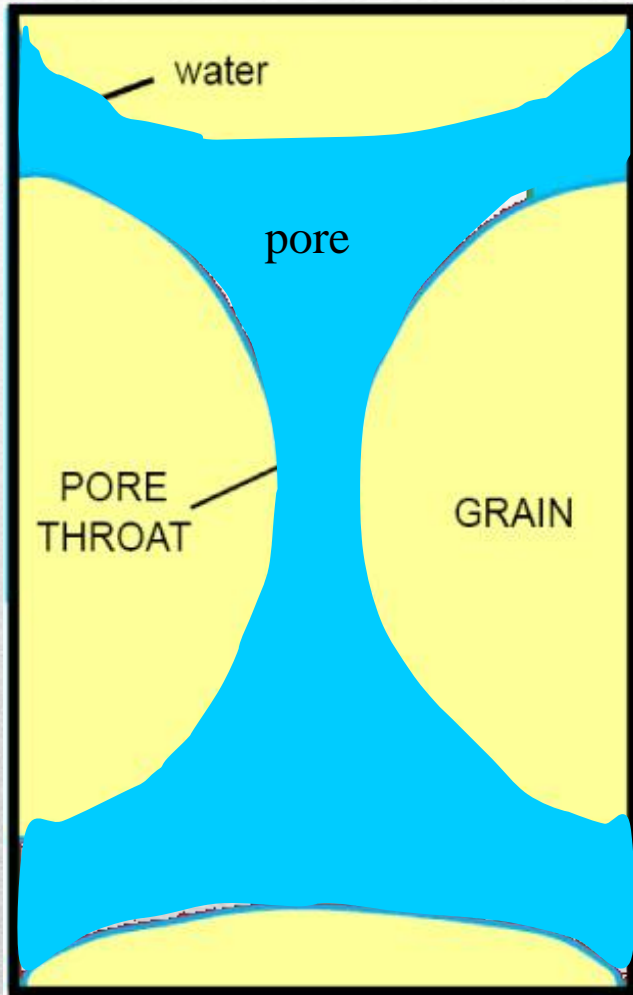
3D printing

- Resolution and positioning accuracy
- Artificial core plugs

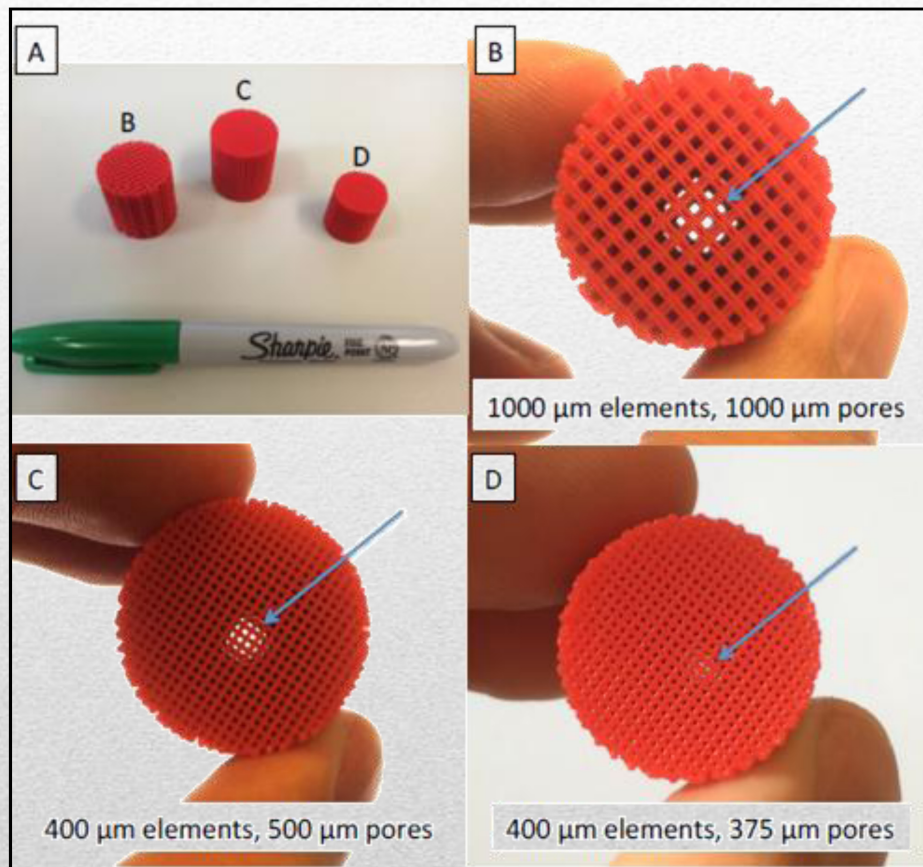
Petrophysical Measurements

- Porosity-permeability of natural and artificial rocks
-

PORES?



IMPORTANCE



- Reservoir core plugs
- Replication of solid materials and pore systems
- Slicing - scale matters!
- Demonstration \rightarrow research



GeoFabLab, Iowa State University

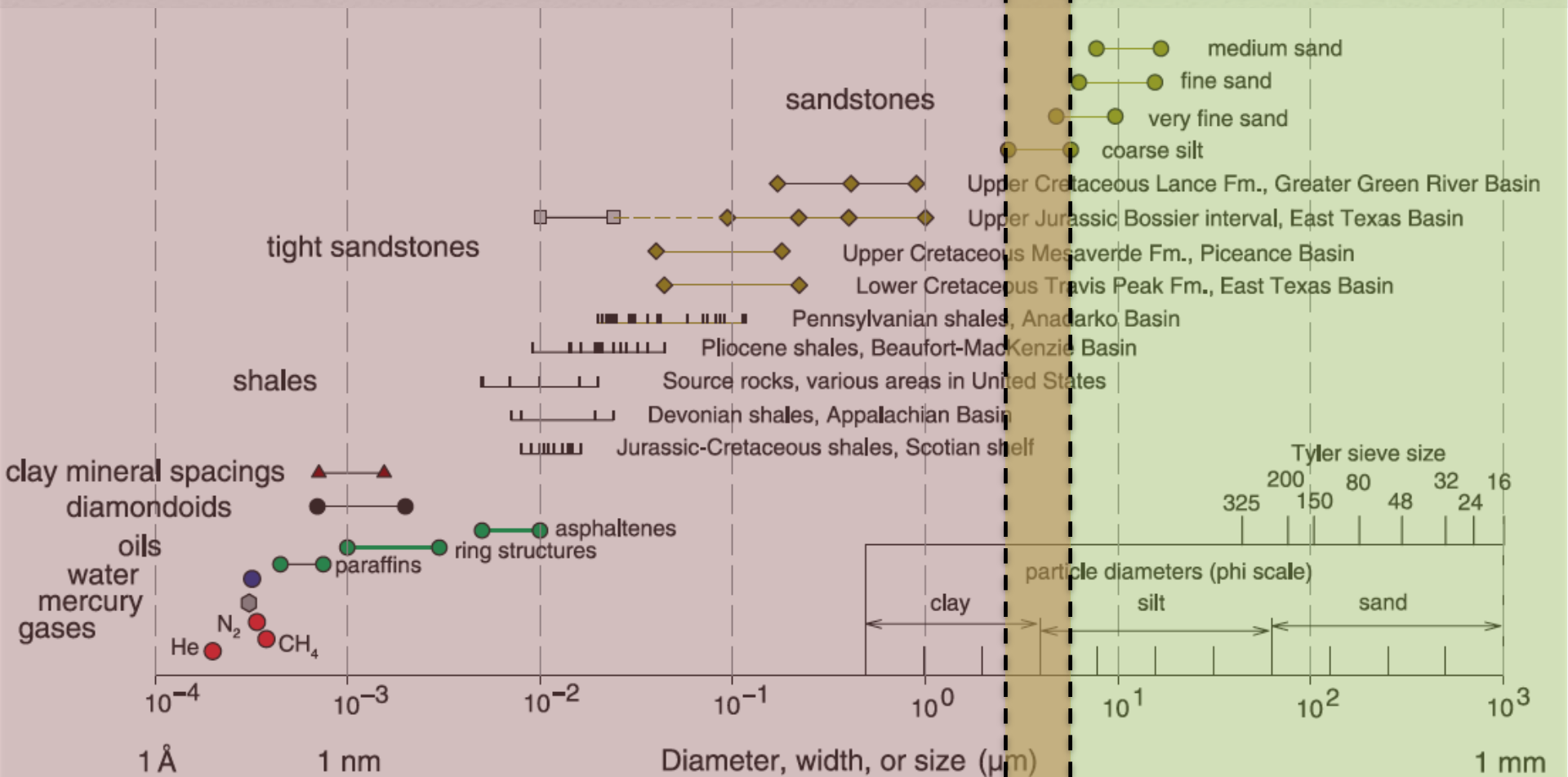
International Petroleum Technology Conference,
Qatar, January 2014

Printing Limit
(Positioning Precision)
2.5 μm

Scanning Limit
(Voxel Dimension)
6 μm

Not Scanable
Not Printable

Scanable
Printable



WHAT and WHY?

Hypothesis: Textural and petrophysical properties of porous reservoir rocks can be replicated with computed tomography (CT) and three-dimensional (3D) printing technology.

Objectives:

1. Test the extent to which CT and 3D printing technologies can reproduce pore geometries and connectivity of natural porous rocks;
2. Conduct experiments on pore systems of natural and artificial rocks to identify what matters to flow at various scales.

Samples: core plugs

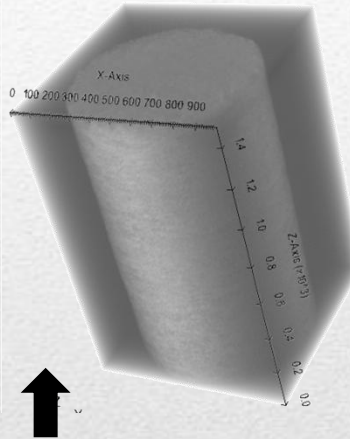
Type	Sample	Formation	Porosity, %	Permeability, md
Sandstone	Idaho gray	Idaho	29	2200
	Castlegate	Mesaverde	28	750
	Berea	Kipton	19	60
Carbonates	Racine Dolomite	Racine	11	2
	Edwards Brown	Edwards Plateau	40	90
	Guelph Dolomite	Niagara	17	10
	Indiana Limestone	Bedford	14	9
	Austin Chalk	Edwards Plateau	25	3

WORKFLOW

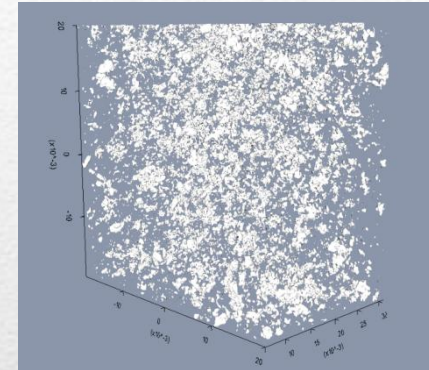
1) CT Imaging



2) Modeling



3) Network Extraction

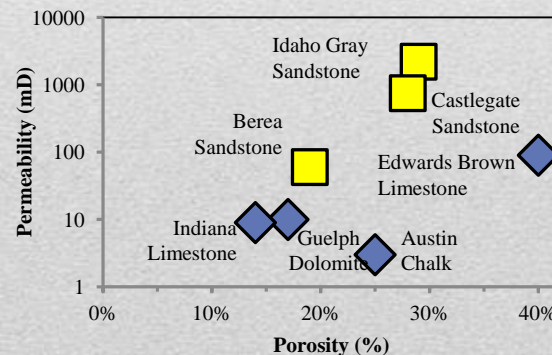


PERMEABILITY PREDICTION

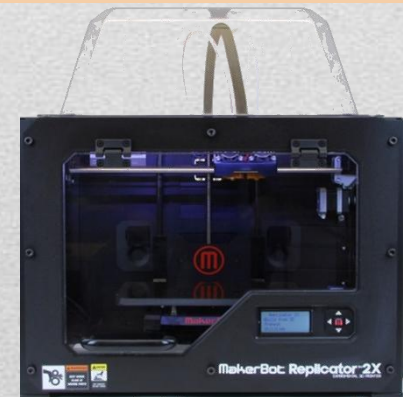


5) Rock properties

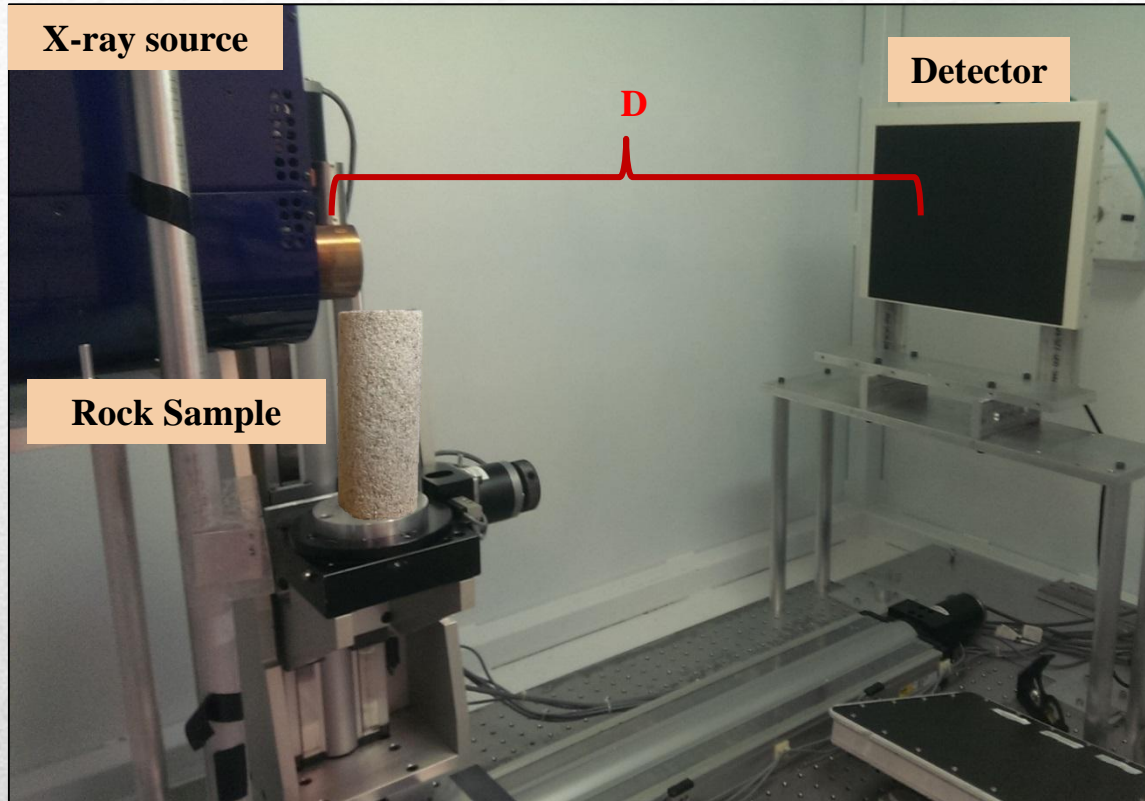
Artificial vs. Natural Rocks



4) Production



CT Scanning



Specifications:

- Resolution of CT system - 6 μm
- Magnification = D/a
a=distance between source and sample
- Samples: core plugs
- Size of sample: 1x2"
- Exposures: 2°, 5 sec.

Source:

KeveX PSX10-16W

- Set energy: 130 keV
- Set current: 100 micro-Amps
- Spot size: approx. 16 μm

Detector:

Varian PaxScan 3024I

- Resolution: 2816x3584 pixels
- Pixel Pitch: 83 μm

1) Imaging

Racine Dolomite



Porosity: 11%
Permeability: 2 md
Diameter: 1.75 inches

Idaho Gray Sandstone



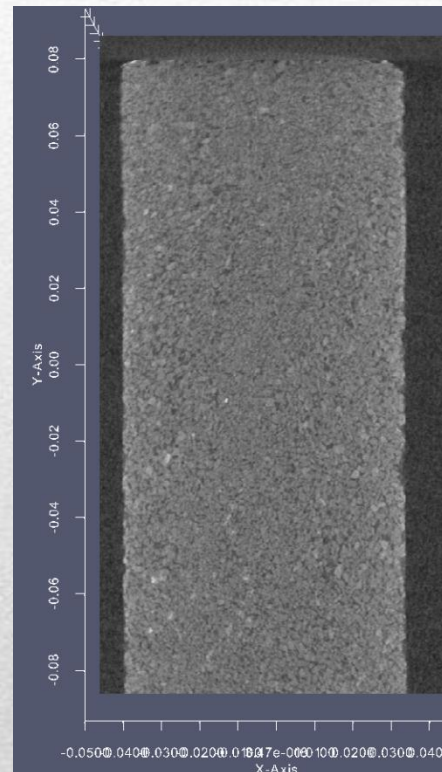
Porosity: 22%
Permeability: 2200 md
Diameter: 1 inch

Reconstruction of Idaho Gray Sandstone

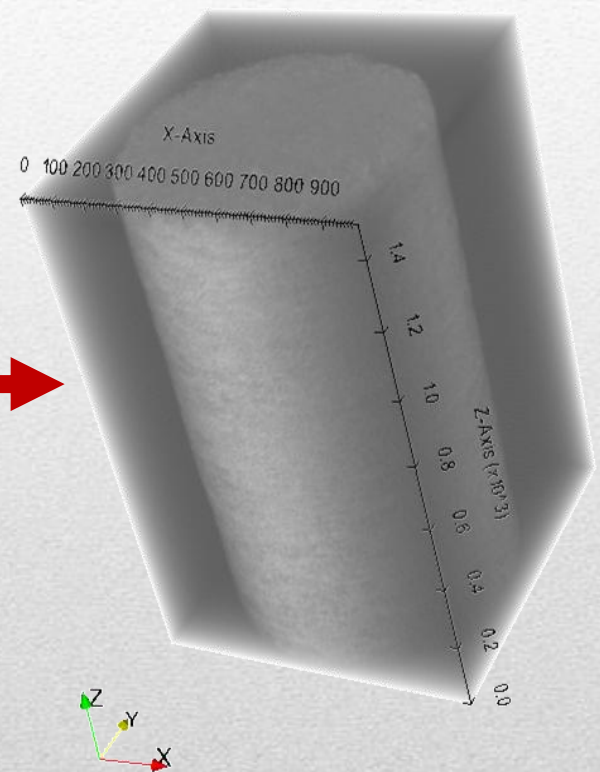
Dimensions: pixels, microns, voxels



Core plug

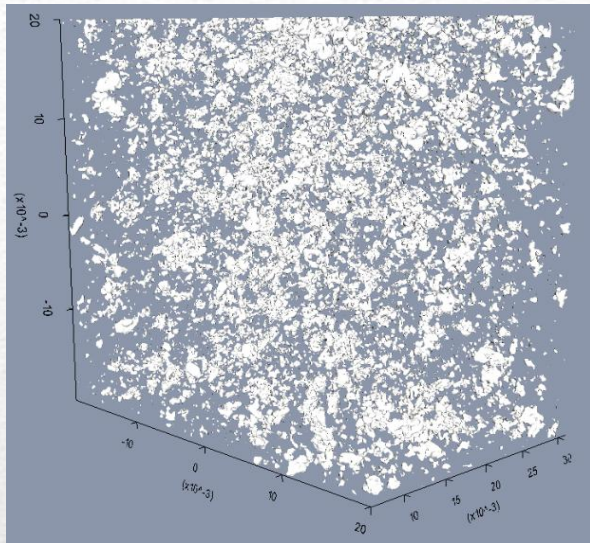


2D image of CT Slice

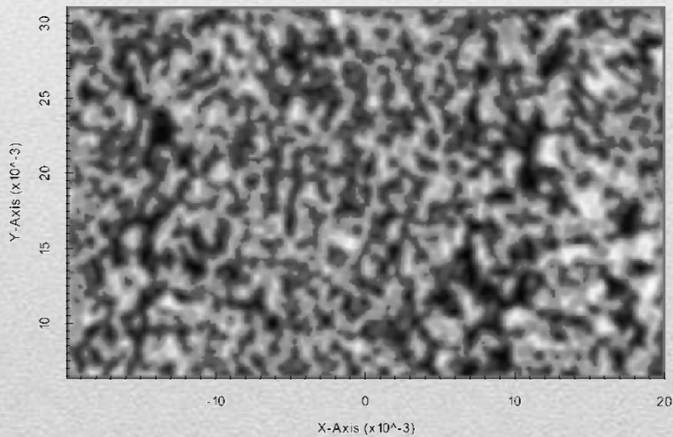


3D volume

1) Imaging → 2) Modeling → 3) Network Extraction !!!



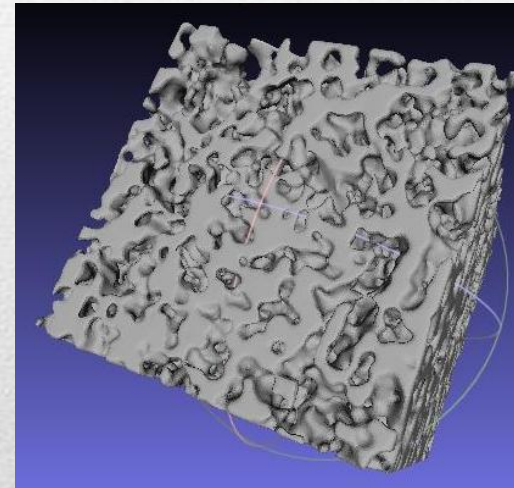
Porosity Extraction Isosurface



Porosity Threshold

Upscaling?

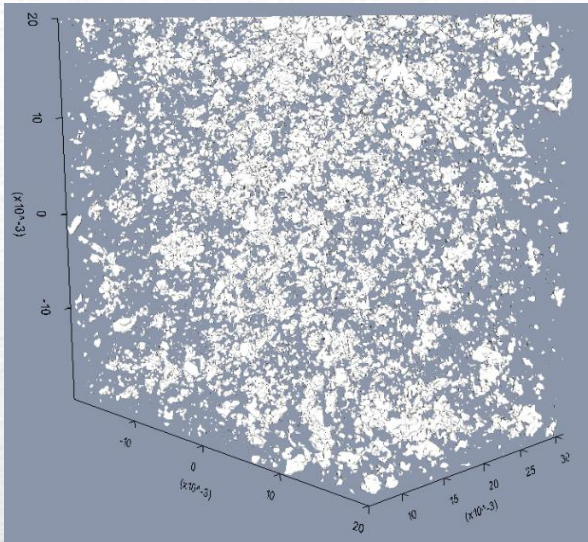
Original size of 3D model:
51x63x52 (mm)



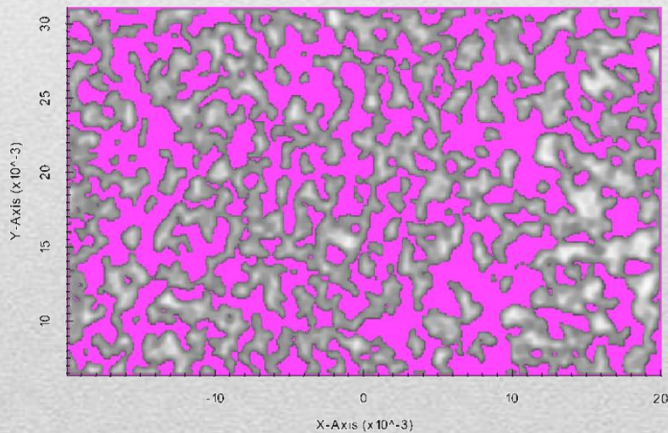
Connected Pores within
Idaho Gray Sandstone
10x magnification

1) Imaging → 2) Modeling → 3) Network Extraction !!!

Upscaling?

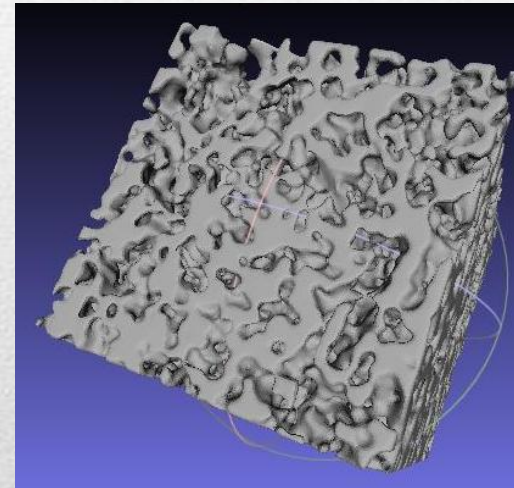


Porosity Extraction Isosurface



Porosity Threshold

Original size of 3D model:
51x63x52 (mm)

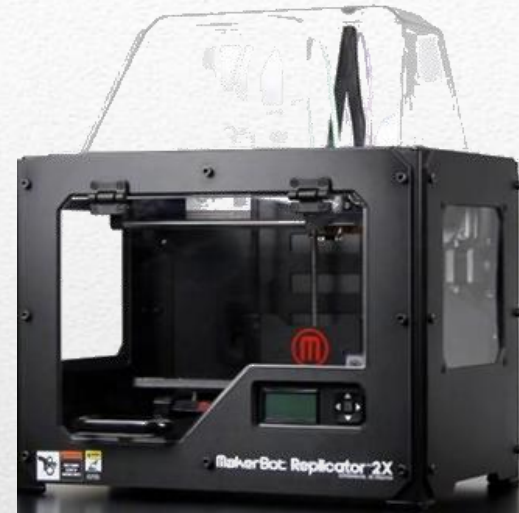


Connected Pores within
Idaho Gray Sandstone
10x magnification

3D PRINTING

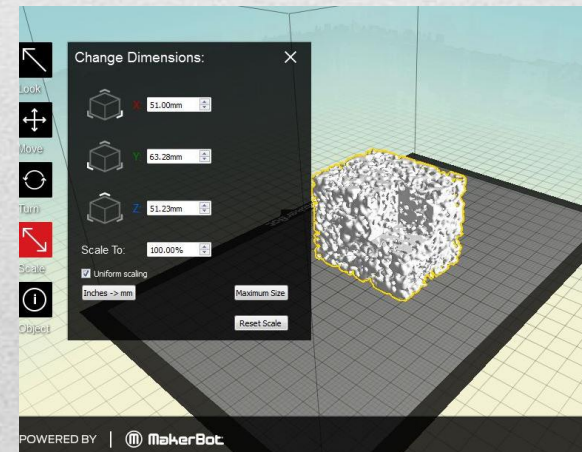
Makerbot Replicator 2X

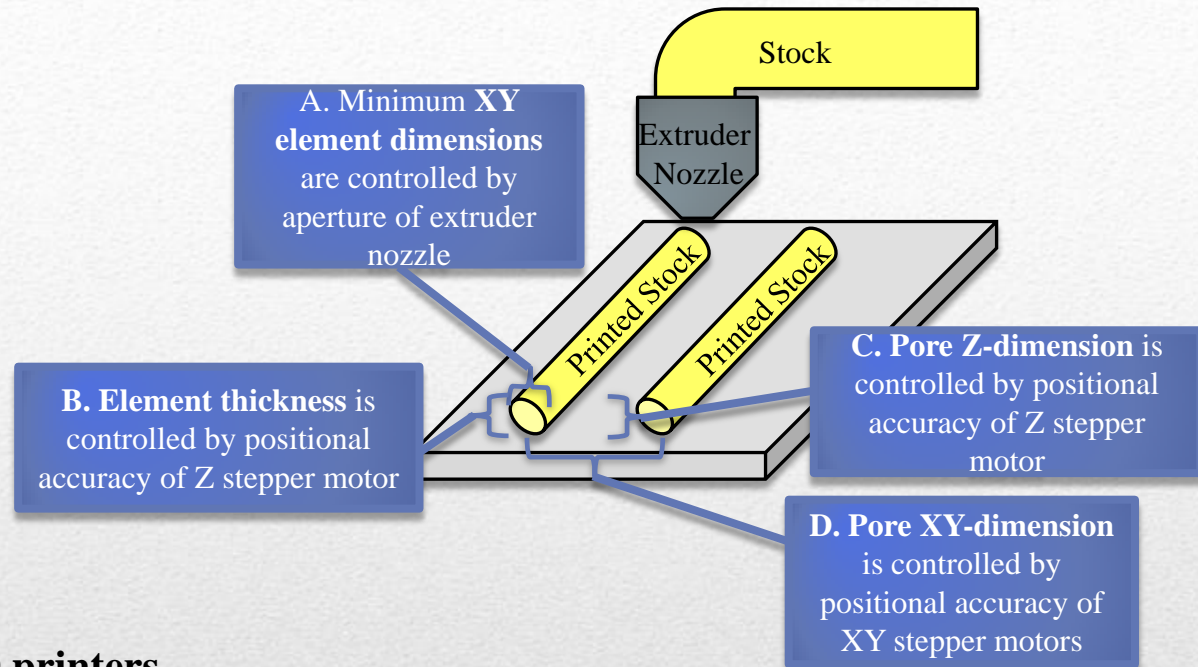
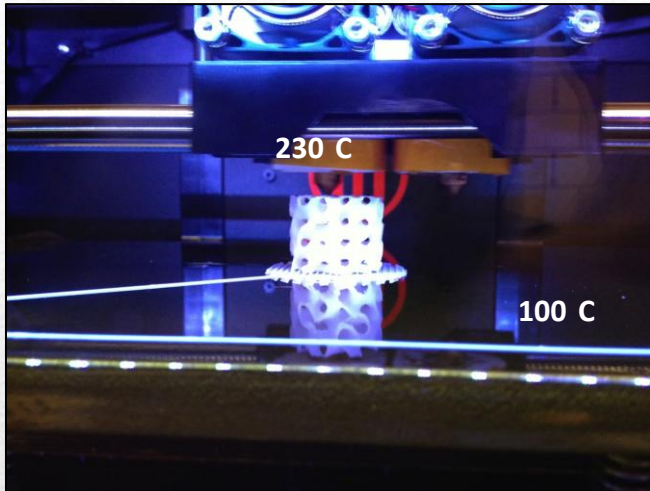
- 2 Print heads
- Fused Deposition Modeling
- Filament: *Acrylonitrile butadiene styrene (ABS)*



10x magnification

5x magnification





Important parameters of 3D printers

Printer	A. XY Resolution (Nozzle diameter)	B/C. Z Resolution (Layer Thickness)	D. XY Positioning Accuracy
	μm	μm	μm
Replicator 2X	400	100	2.5
Objet30 Pro	42	28	30
Objet260 Connex	42	16	30

Petrophysical Measurements

Pore size distribution

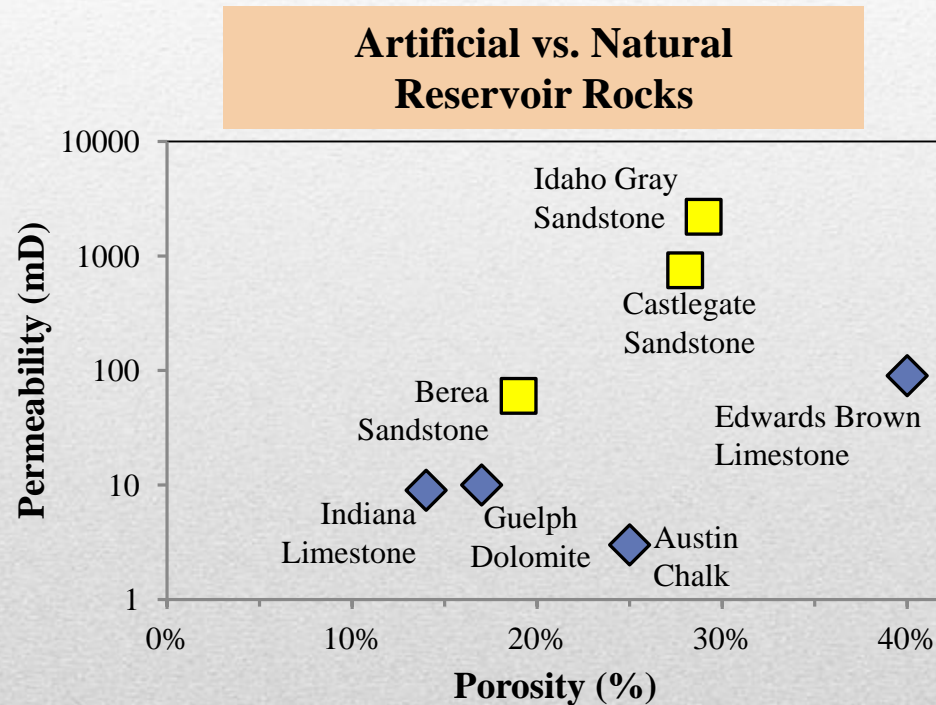
- Nuclear Magnetic Resonance
- Petrography
- SEM mosaic

Porosity, permeability, and pore throat size

- Helium Porosimetry
- High-Pressure Mercury Injection

Comparison of petrophysical properties between data collected from artificial and natural rocks.

Manipulation of properties in 3D models?



Acknowledgements

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Dr. C. Harding, GE-AT / Human-Computer Interaction, Iowa State University

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