GEODICT
The Digital Material Laboratory

IMPACT OF DIFFERENT SEGMENTATION METHODS ON DIGITAL ROCK ANALYSIS RESULTS

INCLUDING TRAINABLE DEEP LEARNING-BASED SEGMENTATION

iRIS virtual conference, Nov. 19th, 2020

1st international Rock Imaging Summit

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MATH 2 MARKET

Agenda

01 **Introduction**

Importance of Segmentation

02 **Methods**

Segmentation methods

03 **Berea Sandstone**

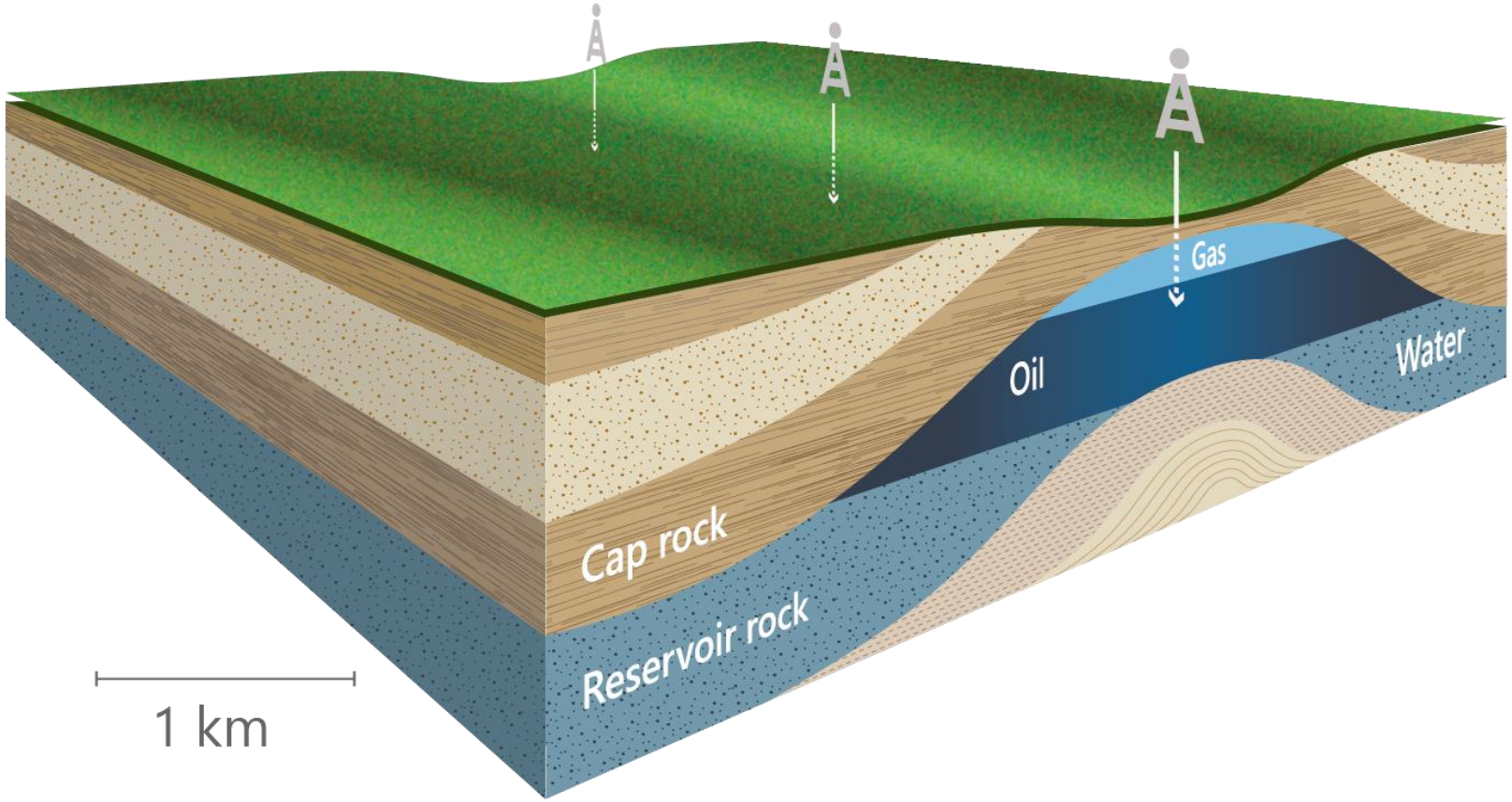
Segmentation and Permeability Analysis

04 **Discussion and Outlook**

Digital Rock Analysis with GeoDict 2021

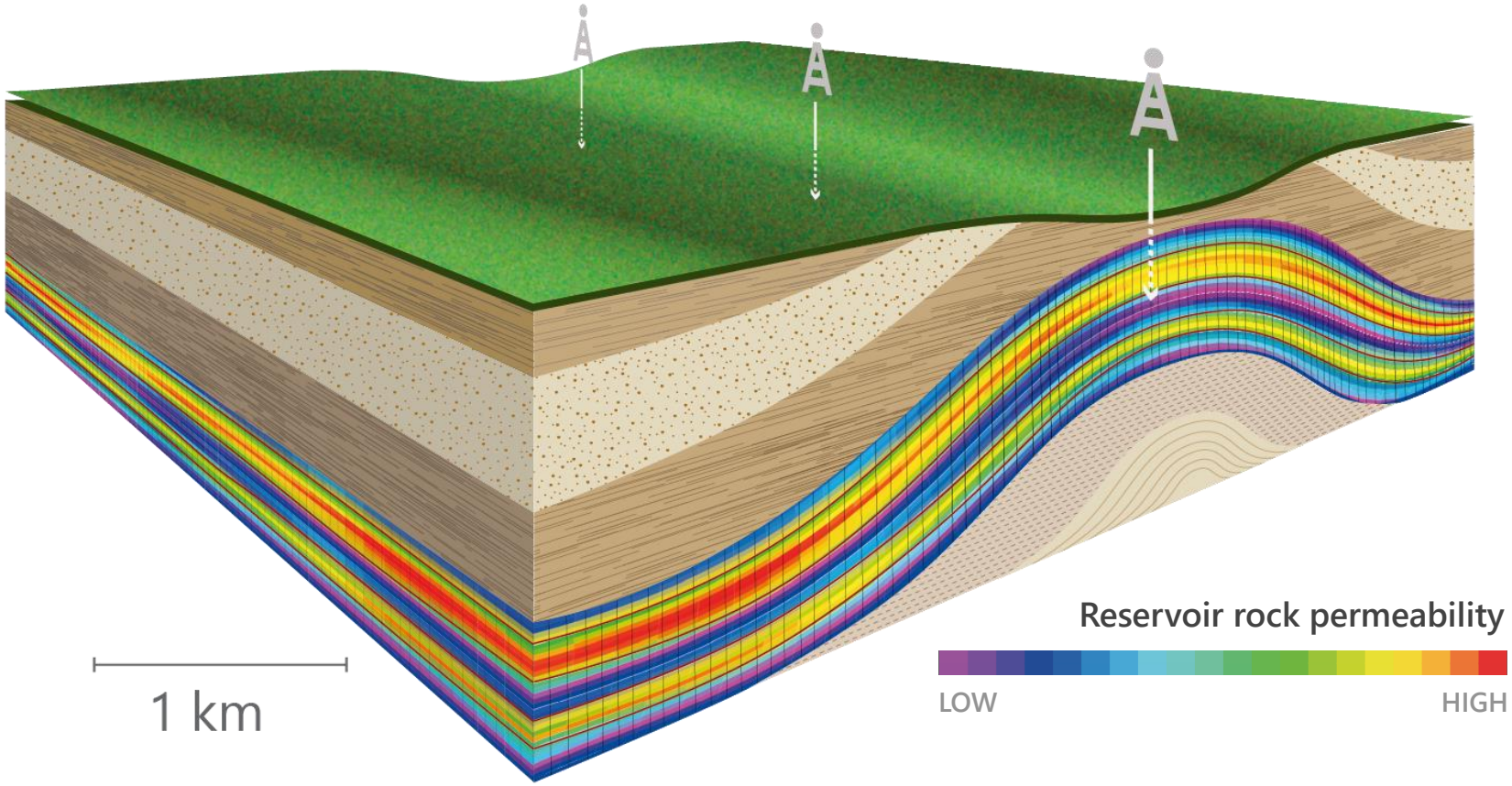
MAXIMIZATION OF OIL PRODUCTION

Oil reservoir - anticlinal trap



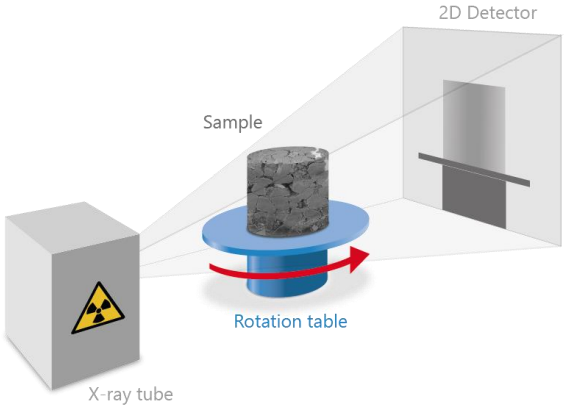
DIGITAL ROCK PHYSICS (DRP)

Oil reservoir - anticlinal trap



DIGITAL ROCK ANALYSIS WORKFLOW

The Digital Rock Analysis (DRA) workflow consists of three basics steps which depend on each other and are influenced by all preceding steps:



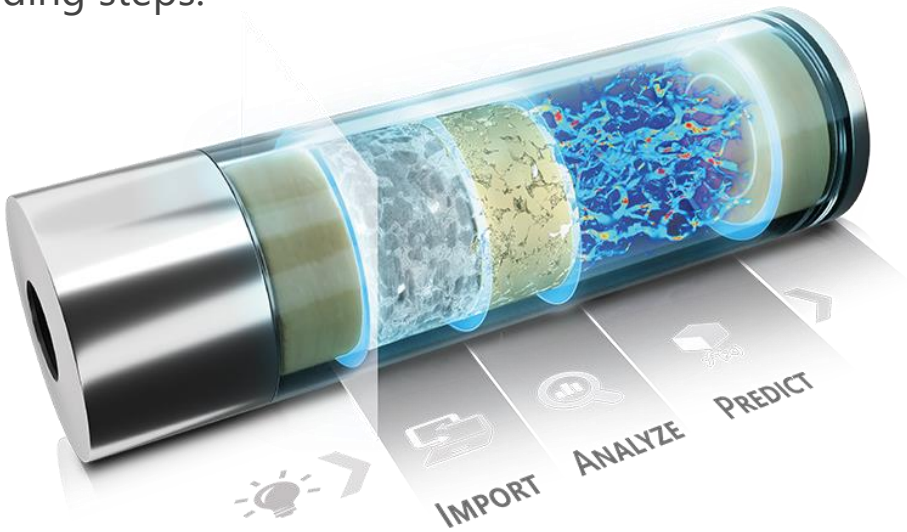


Image Acquisition

- *Sample preparation*
- *Scanning of rock cores or core plugs to obtain 3D gray value images*
- *Measurements via micro-CT device, nano-CT, FIB-SEM, …*

Image Processing & Segmentation

- *Application of image filters*
- *Segmentation*
- *Material labeling*

Rock property prediction

- *Pore space characterization*
- *Digital Rock Physics (DRP):*
  Flow properties,
  Electrical properties,
  Mechanical properties, …

MOTIVATION

Image (voxel) resolution significantly affects sample porosity and digital rock properties.

- Errors resulting from image acquisition have to be understood and reduced to increase the accuracy of physical rock properties obtained during Digital Rock Analysis

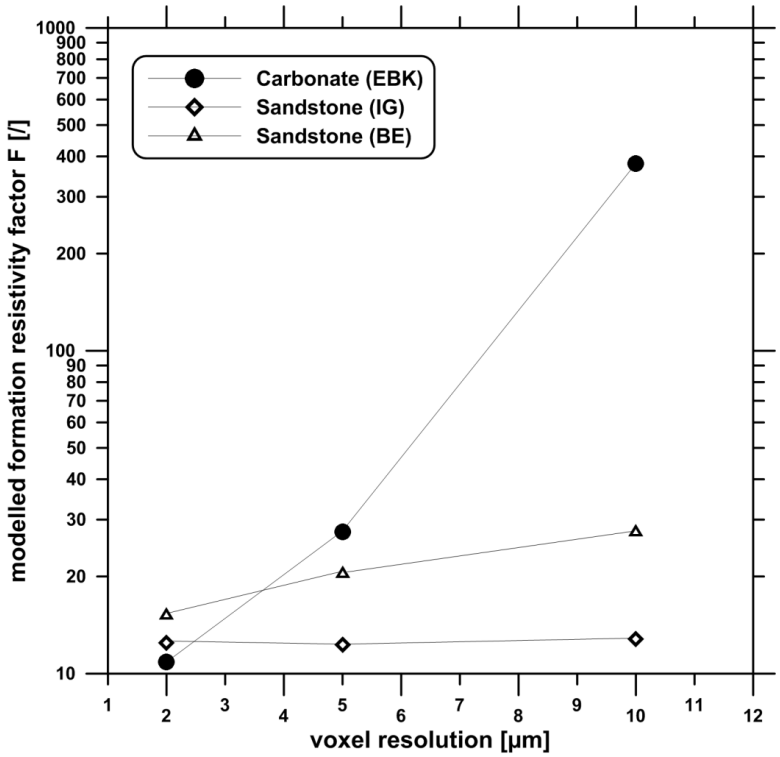


Image resolution vs. Rock properties

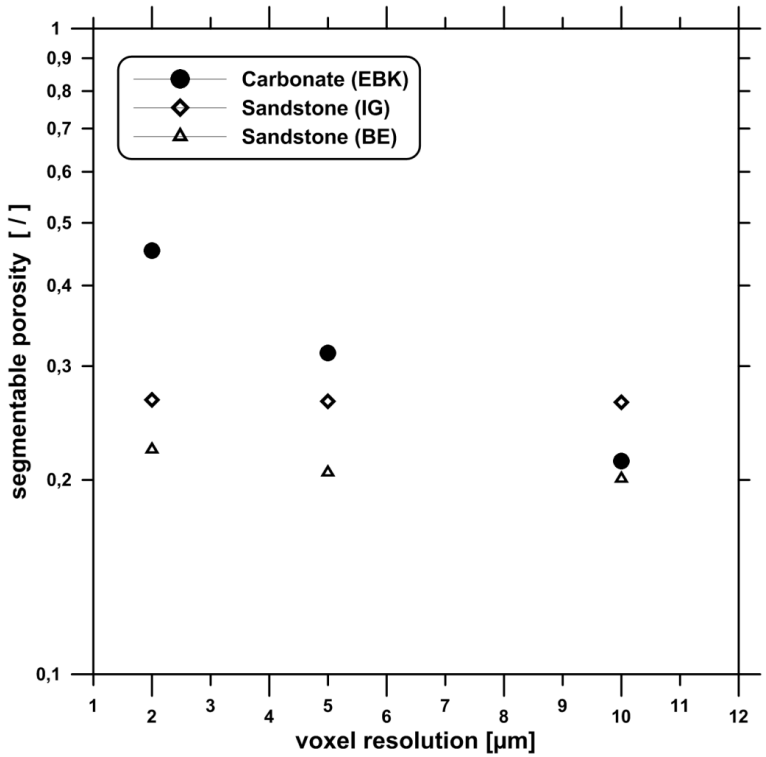


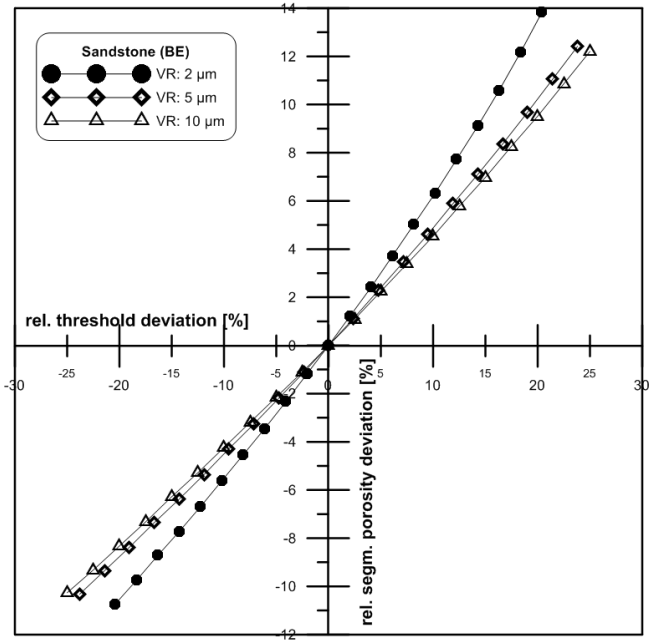
Image Resolution vs. Segmentation

Halisch et al. 2015. Systematic Parameter Study for Formation Factor Modeling at the Pore Scale.

MOTIVATION

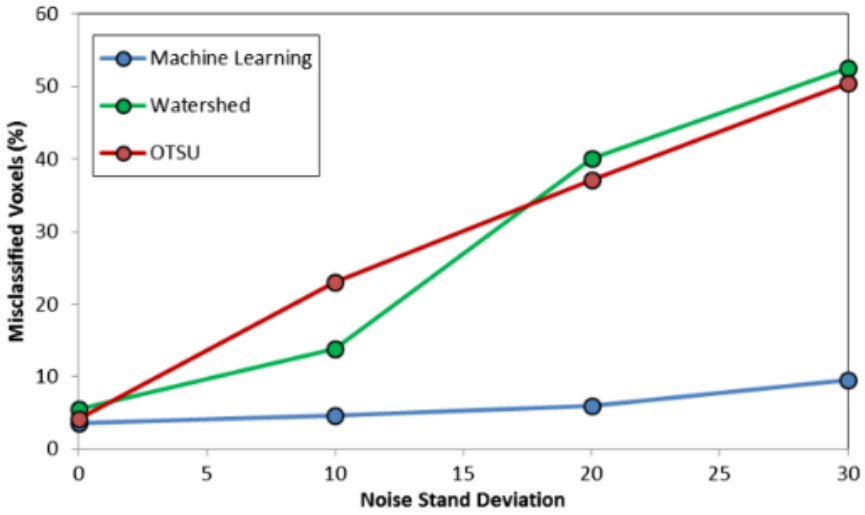
The image segmentation may significantly affect the resulting digital rock geometry and the physical properties computed.

- In dependence of chosen method, parameters, and noise in the gray value image:



Gray value threshold variation vs. resulting porosity deviation

Halisch et al. 2015. Systematic Parameter Study for Formation Factor Modeling at the Pore Scale.



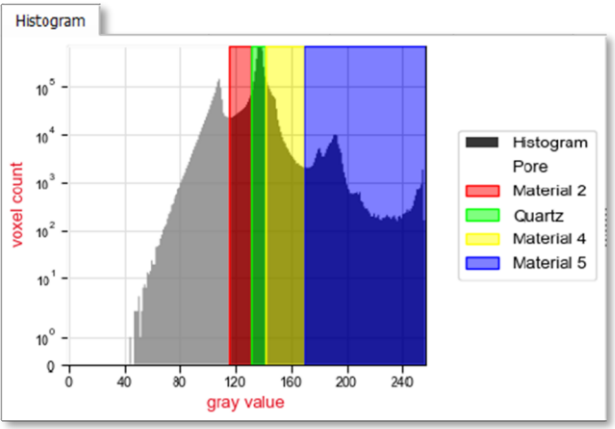
Segmentation quality with varying noise and segmentation methods

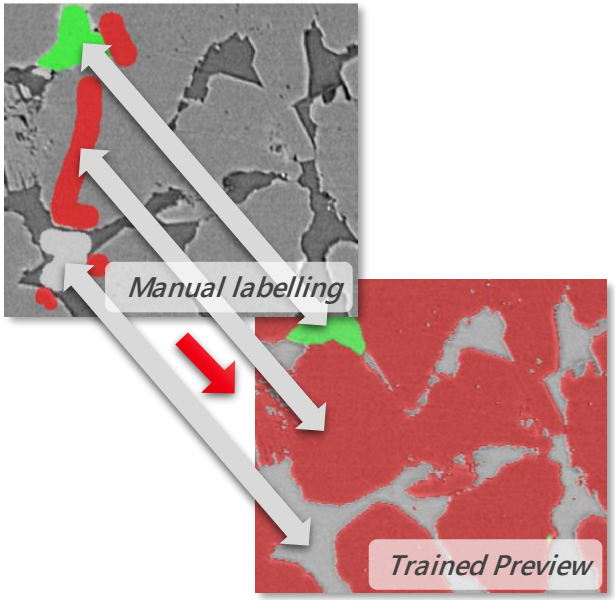
Applied on a FIB-SEM image scan of a Vacamuerta shale rock sample.

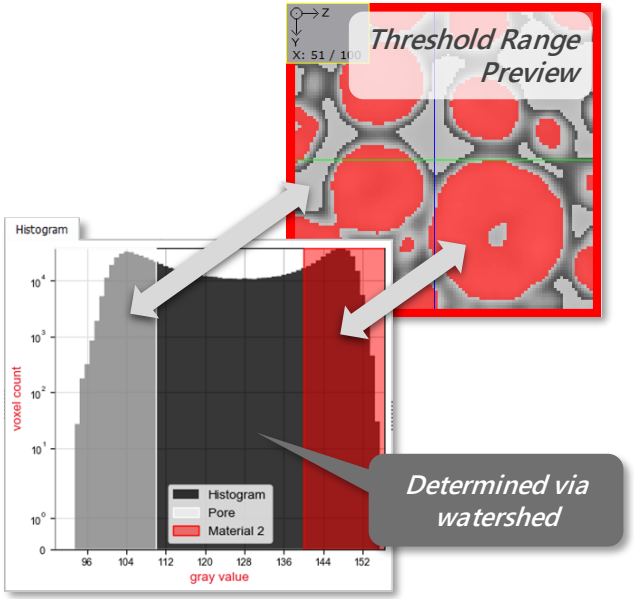
Andrew, M. 2018. A quantified study of segmentation techniques on synthetic geological XRM and FIB-SEM images.
https://doi.org/10.1007/s10596-018-9780-2

IMAGE SEGMENTATION

GeoDict 2021 offers multiple features to segment 3D Images:







Global Thresholding

- *Single-multiple gray value thresholds*
- *Automatic thresholding based on gray value histogram (OTSU)*

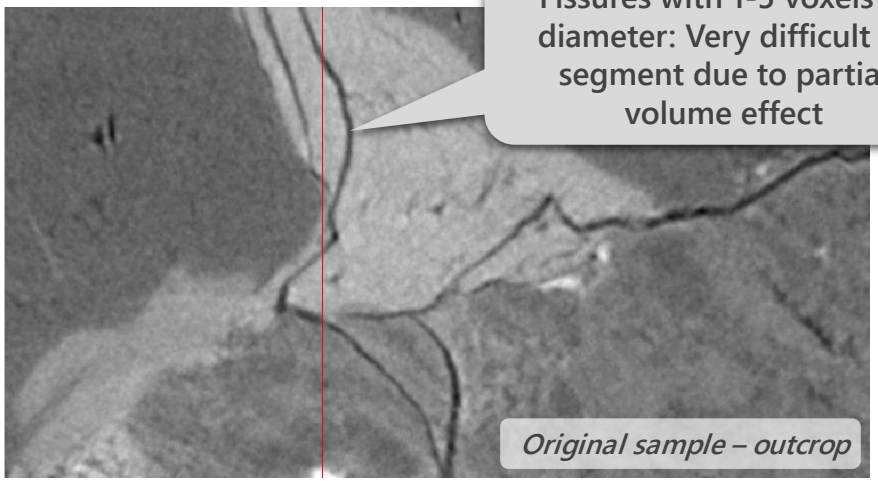
AI Segmentation

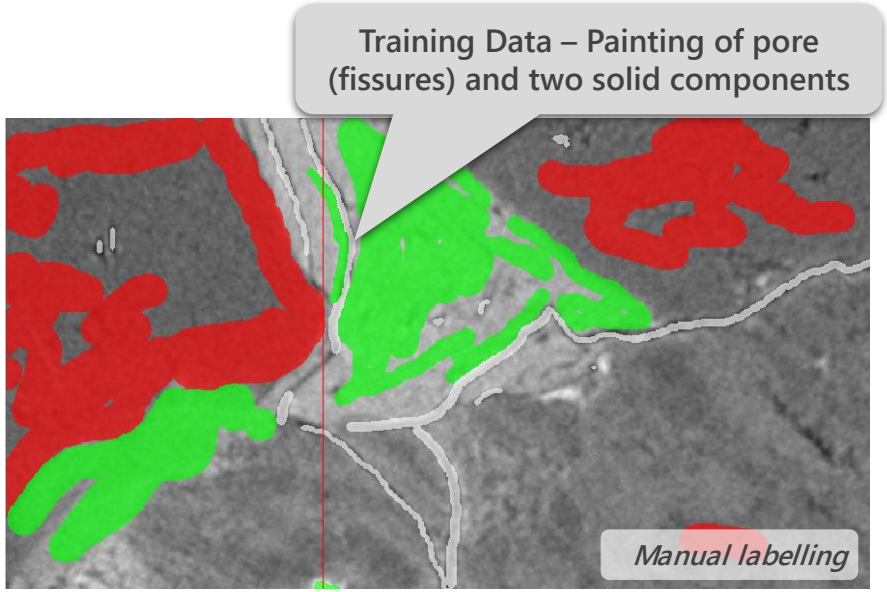
- *Label multiple materials manually*
- *Fast Machine Learning-based Training algorithm*
- *Deep learning-based Training algorithm (UNet2D, UNet3D)*

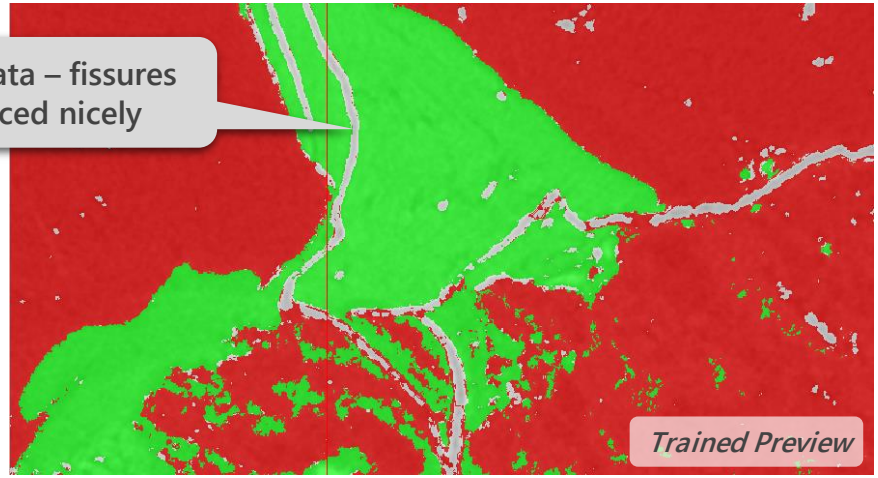
Multi-Phase Segmentation

- *Define gray value ranges for phases*
- *Any remaining "uncertain" areas are automatically segmented via **Watershed***

AI SEGMENTATION







Nano-CT image scan of a rock sample

The AI Segmentation approach succeeds to segment areas with significant partial volume effect.

→ *Recommended for segmentation of (thin) fractures*

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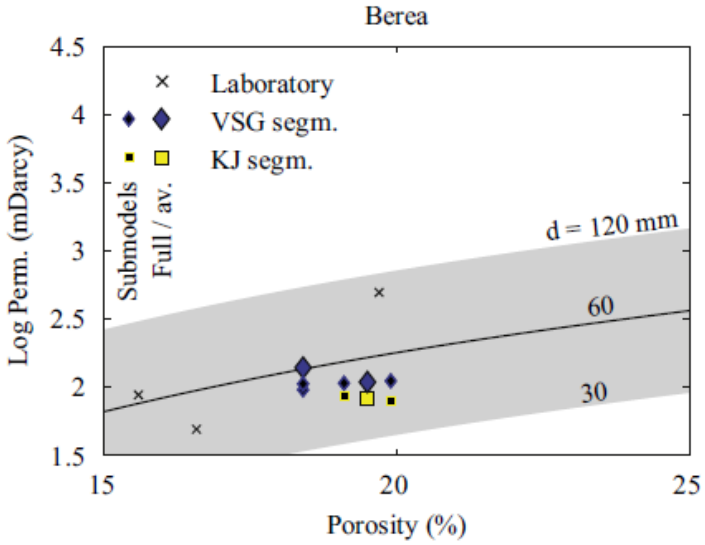
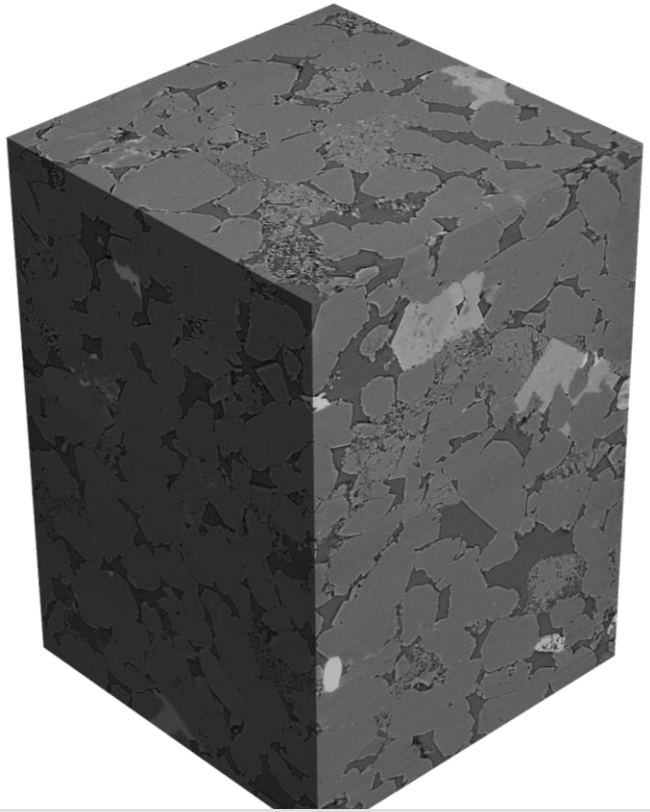
BEREA SANDSTONE

Berea Sandstone

Andrae et al. (2013a;b)

- Dimensions: 720x720x1024 voxels
- Resolution: 0.74 µm
- Components: Quartz, Feldspar, Calcite, Zircon
- Porosity: 18.4 %
- Permeability: approx. 109 mD



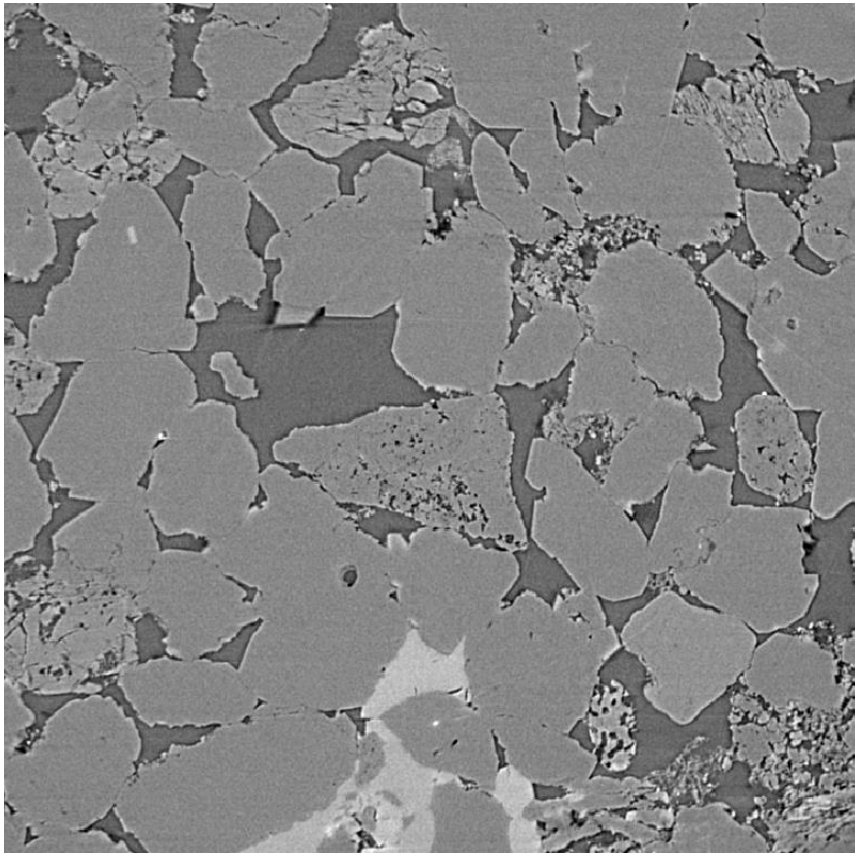


Berea gray value image

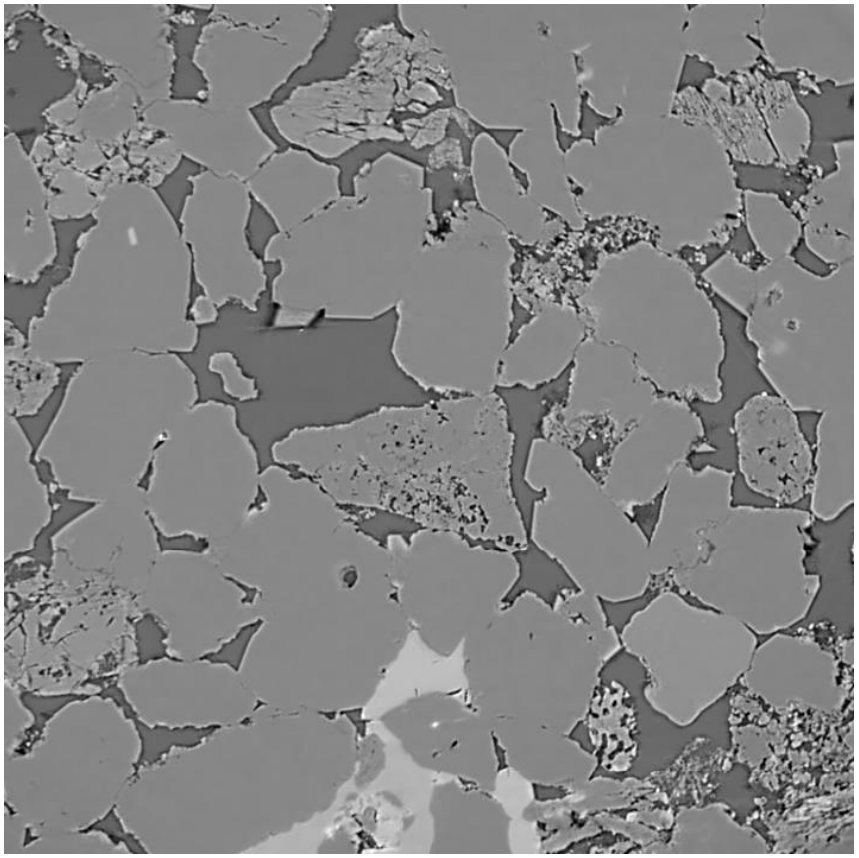
Andrae et al. (2013a). Digital rock physics benchmarks—Part I: Imaging and segmentation.
http://dx.doi.org/10.1016/j.cageo.2012.09.005

Andrae et al. (2013b). Digital rock physics benchmarks—Part II: Computing effective properties.
http://dx.doi.org/10.1016/j.cageo.2012.09.008

Non-Local Means filter



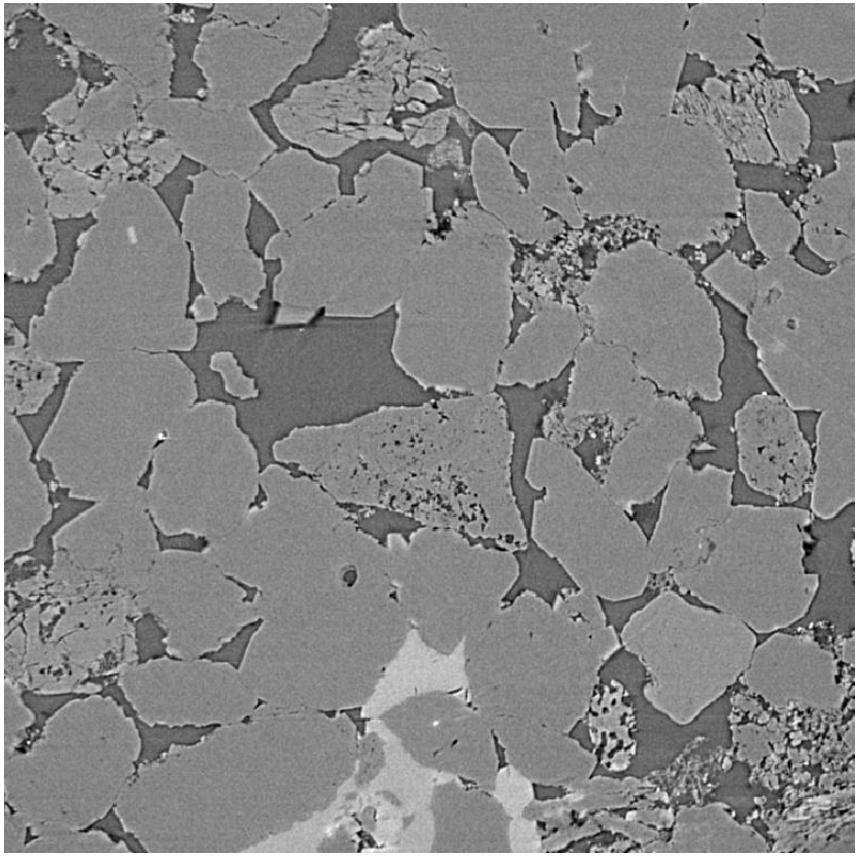
Original gray values



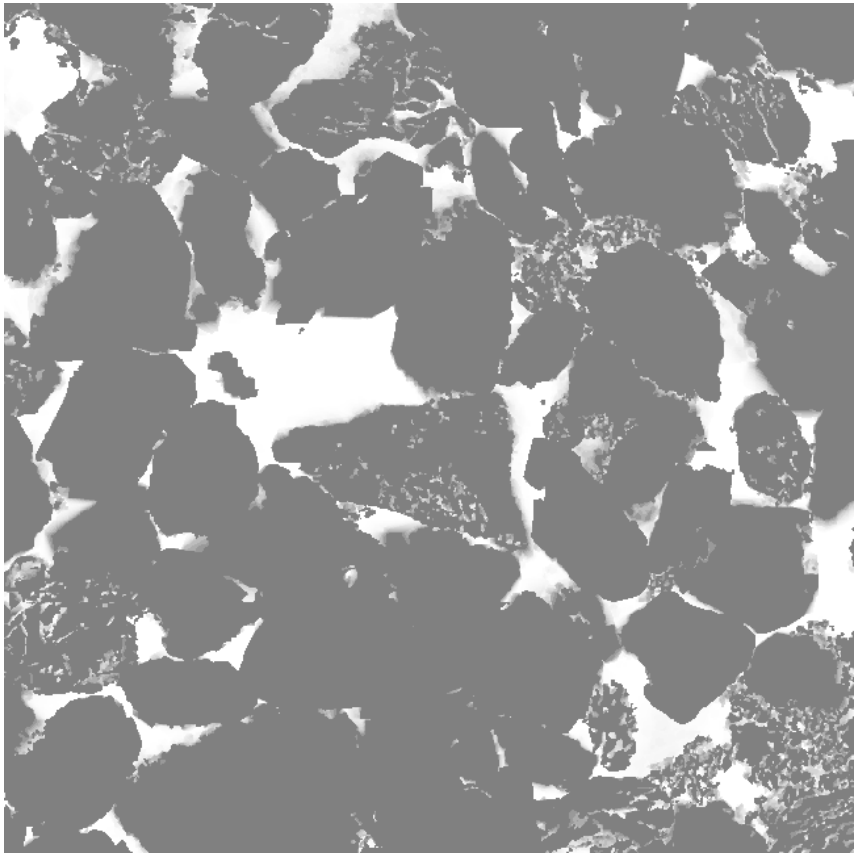
Non-Local Means (NLM) Filter

Smoothed noise, sharp edges

Global OTSU Segmentation



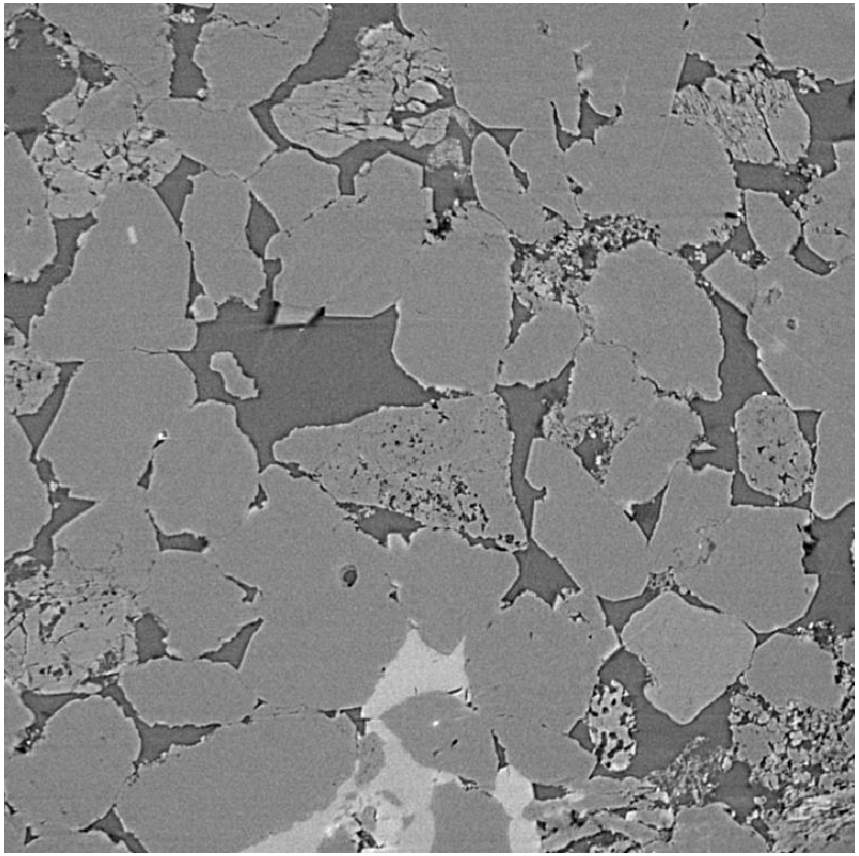
Original gray values



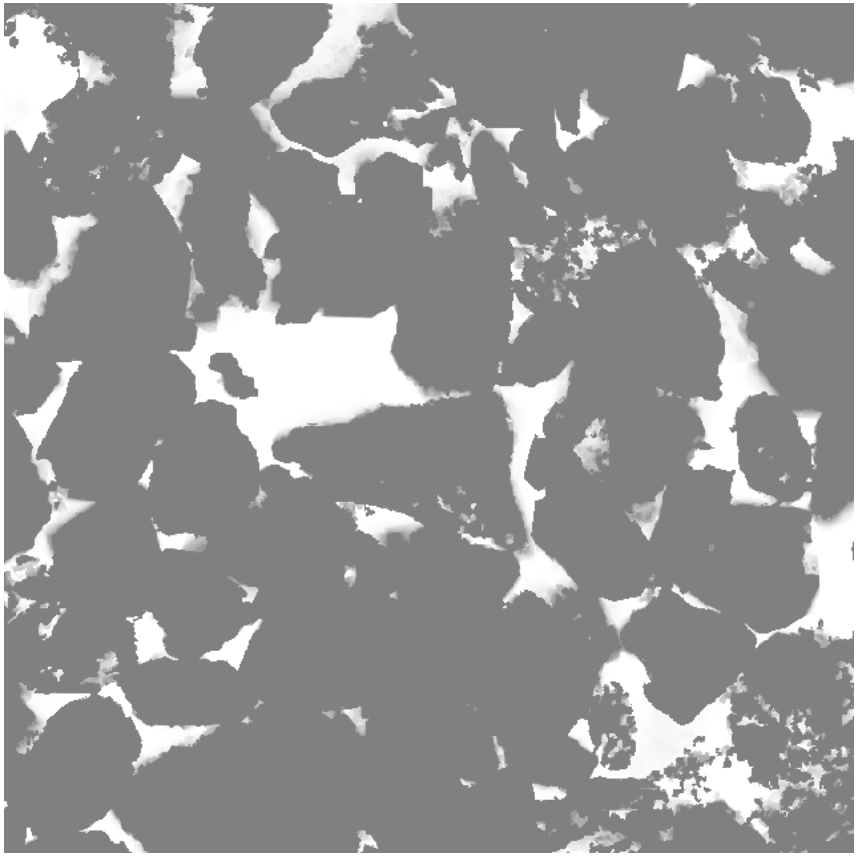
NLM + OTSU Segmentation

Global thresholding

Watershed Segmentation



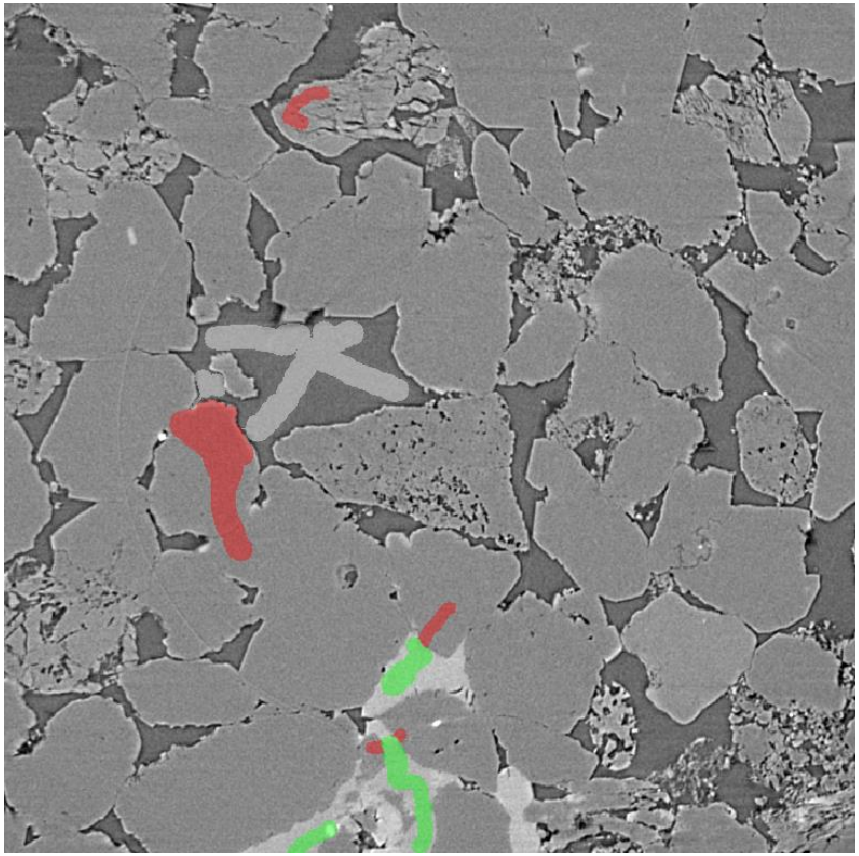
Original gray values



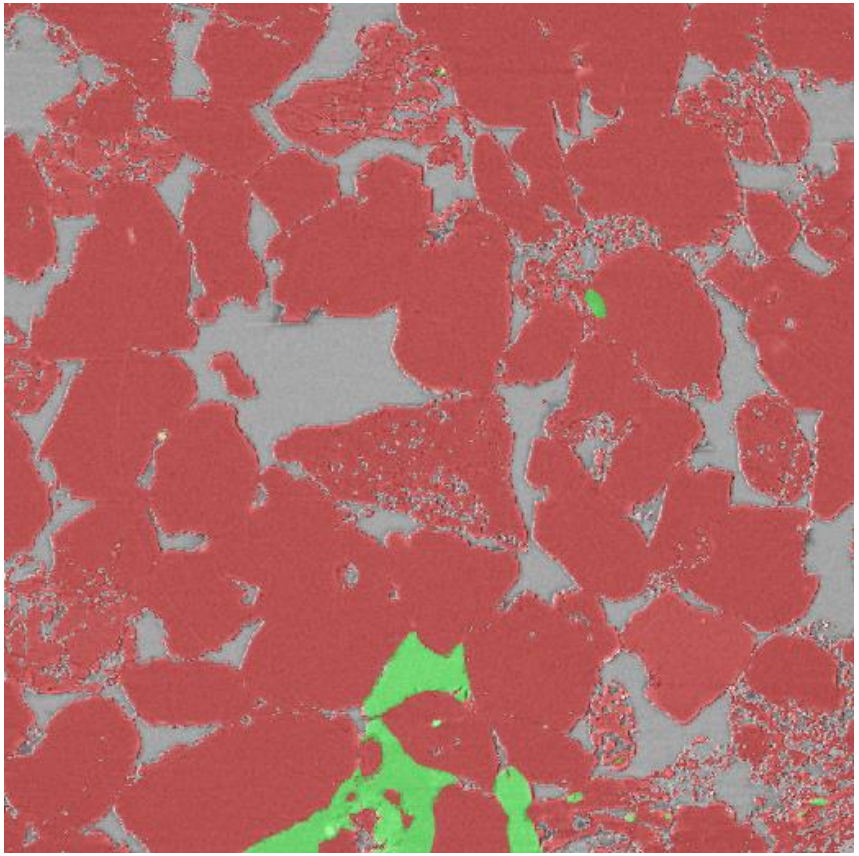
NLM + Watershed Segmentation

Reduced intragranular porosity

AI-labelling and segmentation preview



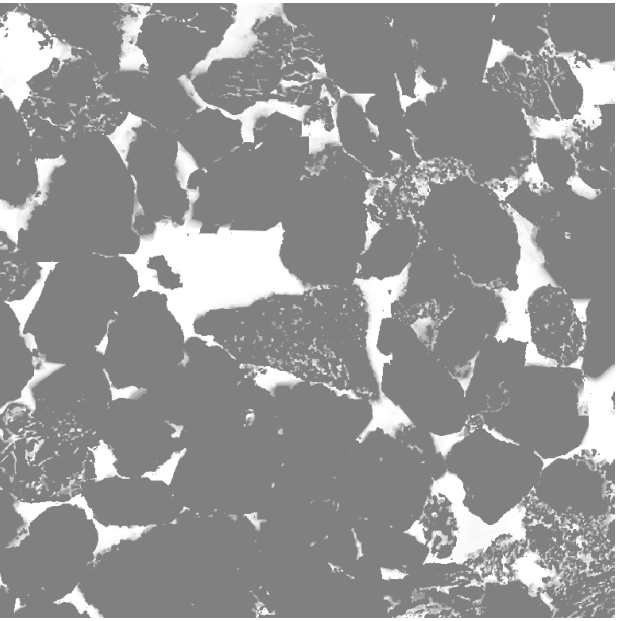
AI-Segmentation – Manual Labels



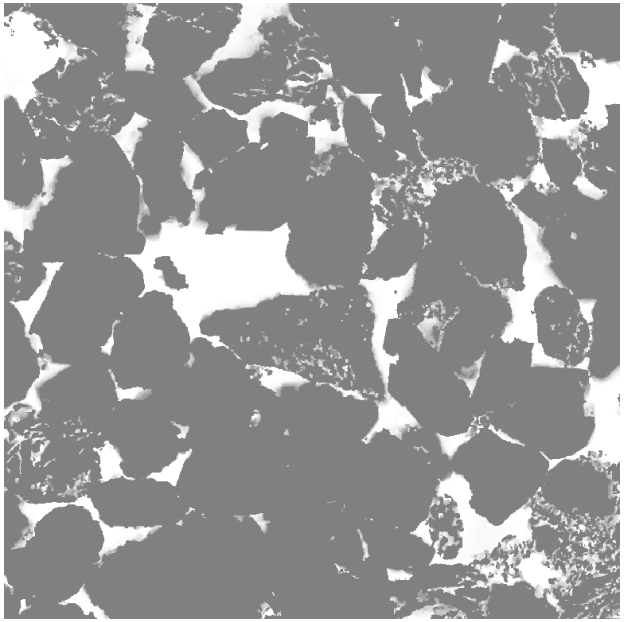
AI-Segmentation – Preview result

Comparison of Segmentations

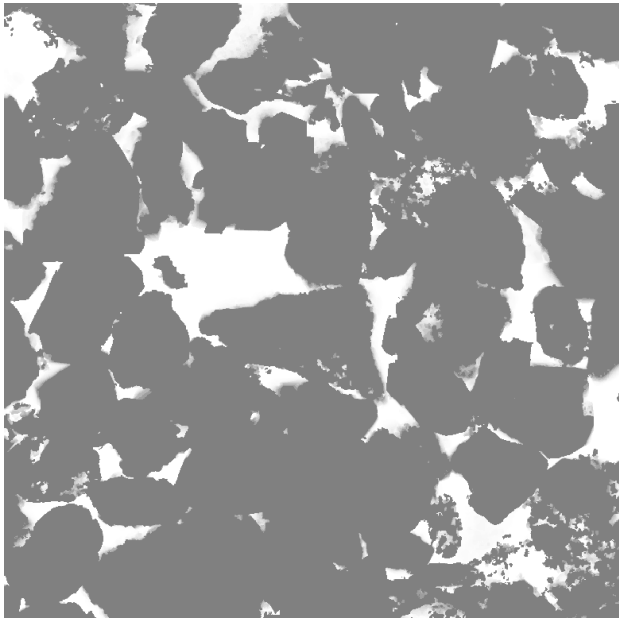
- Very similar: global OTSU segmentation on NLM-filtered image & AI-segmentation
- Watershed segmentation results in reduced amount of small grains and intragranular porosity



NLM + OTSU-thresholding



AI-segmentation + “Cleanse”



Watershed-based segmentation

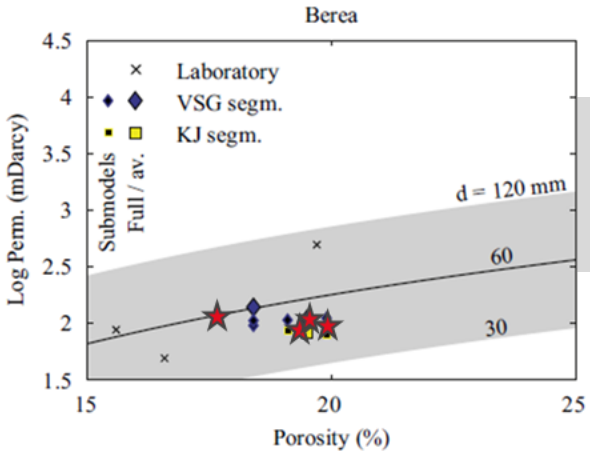
Cleanse: Re-labeled small-scale features

Segmentation Comparison

The segmentation methods we applied have similar results from Digital Rock Analysis.

For permeability computation, we applied the GeoDict LIR Stokes solver published by Linden et al. (2014).

Processing & Segmentation	Porosity	Percolation Path *(widest through-path diameter)*	Permeability *(absolute)*	Processing effort
Andrae et al. (2013)	18.4 %	8 voxels	109 mD	*Image processing & Watershed*
NLM-OTSU	19.3 %	8 voxels	80 mD	*Image processing & Cleanse*
AI	19.5 %	8 voxels	97 mD	AI-labeling & Cleanse
NLM-Watershed	17.3 %	9 voxels	110 mD	*Image processing* & Watershed threshold ranges
NLM-AI	19.9 %	7 voxels	82 mD	Image processing & AI-labeling



All results are within the range of lab data

published by Andrae et al. (2013b)

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DISCUSSION

Global OTSU segmentation

- Highest deviation from the result, but still within the range of published data
- Least suitable for the image scan under investigation

Watershed-based segmentation

- Best matches the absolute permeability with 99 % accuracy
- The algorithm applied removes small-scale features

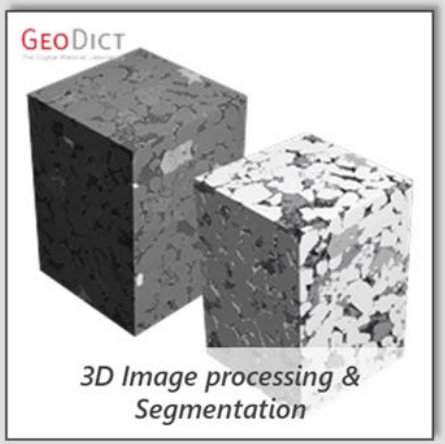
AI-segmentation

- Good agreement with a slight underestimation and 90 % accuracy
- The least efforts → didn't require Image Processing

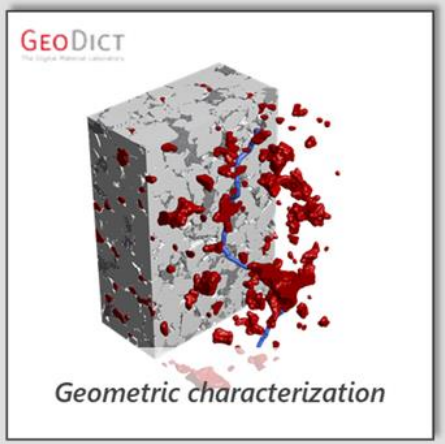
For this well-measured synchrotron-CT scan,
The Digital Rock Analysis Quality with GeoDict is just a matter of segmentation.

DIGITAL CORE ANALYSIS

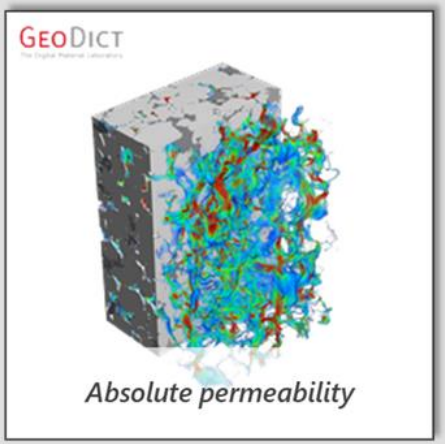
The GeoDict® Standard for Digital Core Analysis



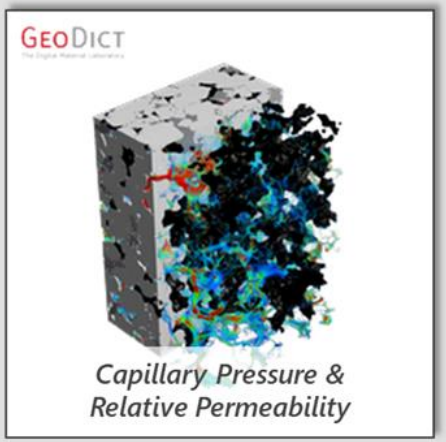
3D Image processing & Segmentation



Geometric characterization

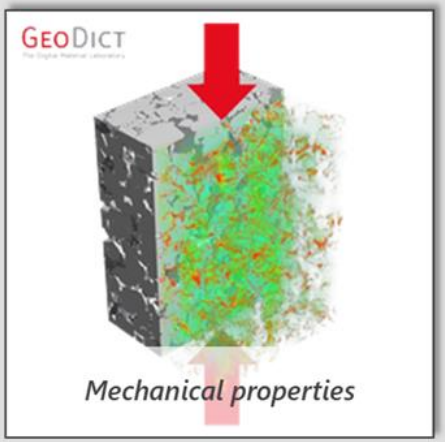


Absolute permeability

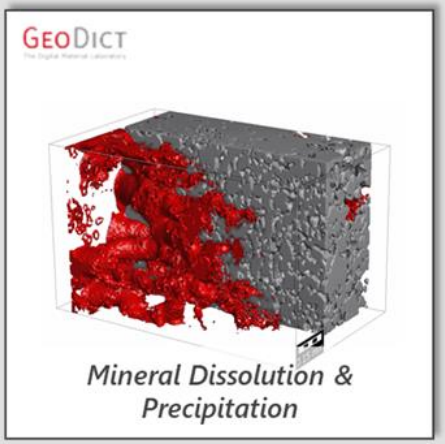


Capillary Pressure & Relative Permeability

Resistivity Index



Mechanical properties



Mineral Dissolution & Precipitation

Thank you for your attention!

Questions?

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