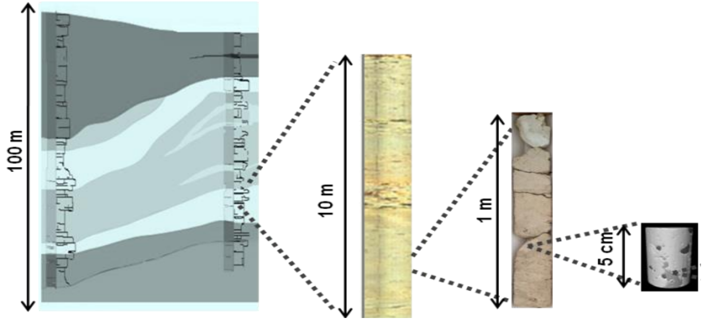
Challenging Laboratory Measurements – Contribution of Numerical Petrophysics

Vanessa HEBERT

SPWLA France - Technical session
Paris, SGF, 2019 octobre 8th

Still challenging

Multiscale reservoir analysis

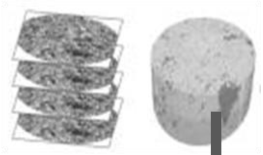


Reservoir Hole Core Plug

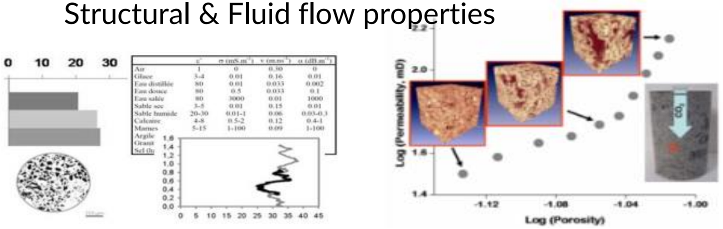
3D imaging

Faster analysis & Representativity

3D plug image



Structural & Fluid flow properties

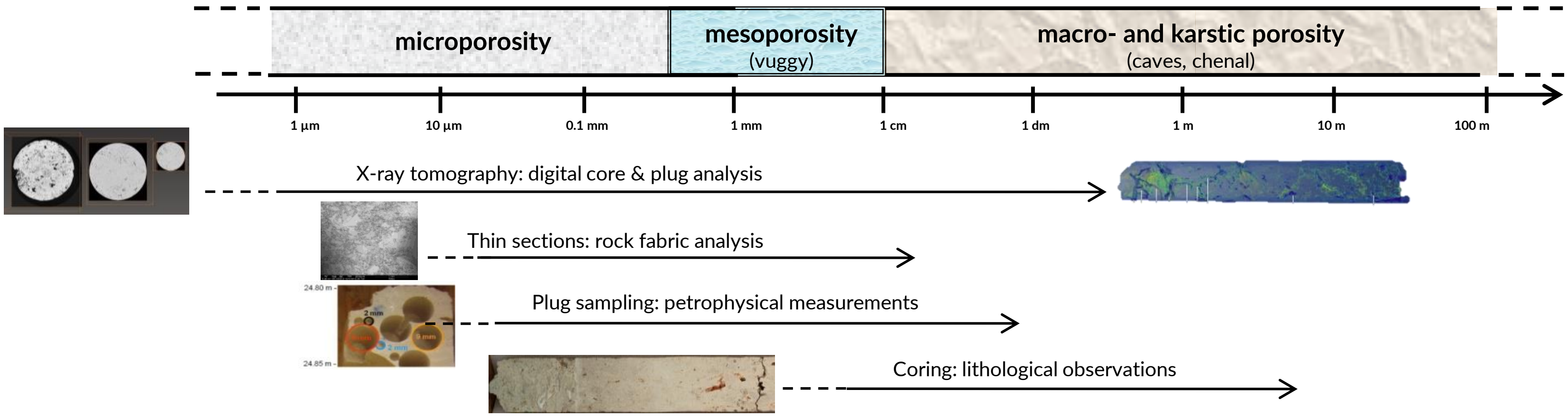


Imaging vs Sample size

4 scales of investigations: multiscale reservoir structures

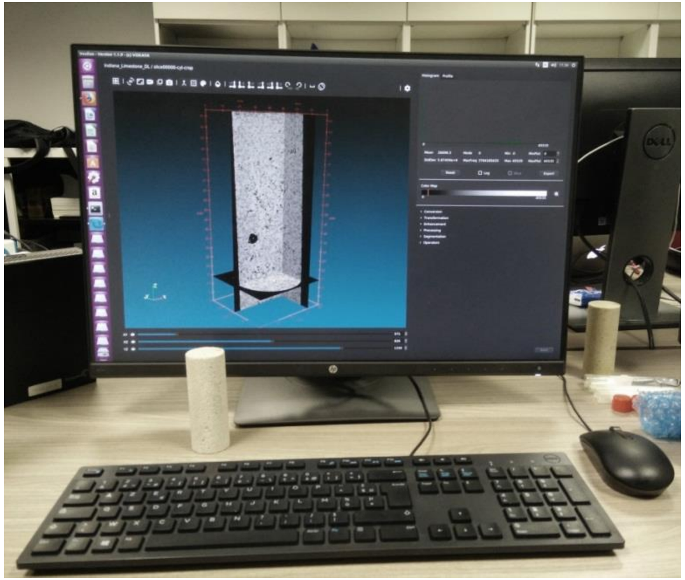
→ **Representative micro- to macro-scale properties**

→ **Fluid flow pathways**



Approch & Software solution

Database screening by 3D imaging: cores, plugs, cuttings, unstructured zones → Voxilon, workflow-oriented software

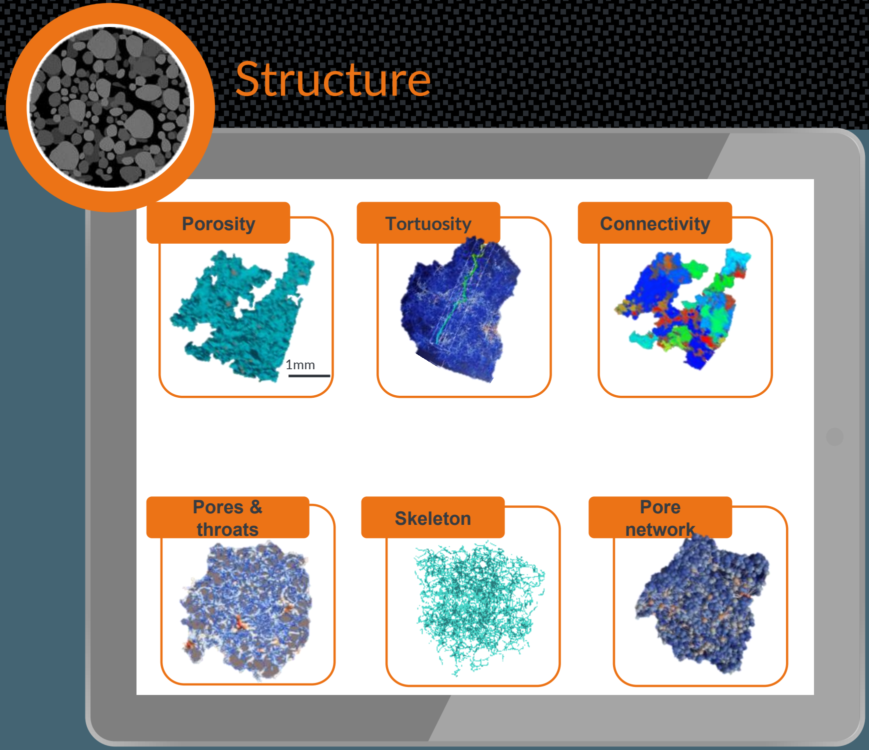


Voxilon

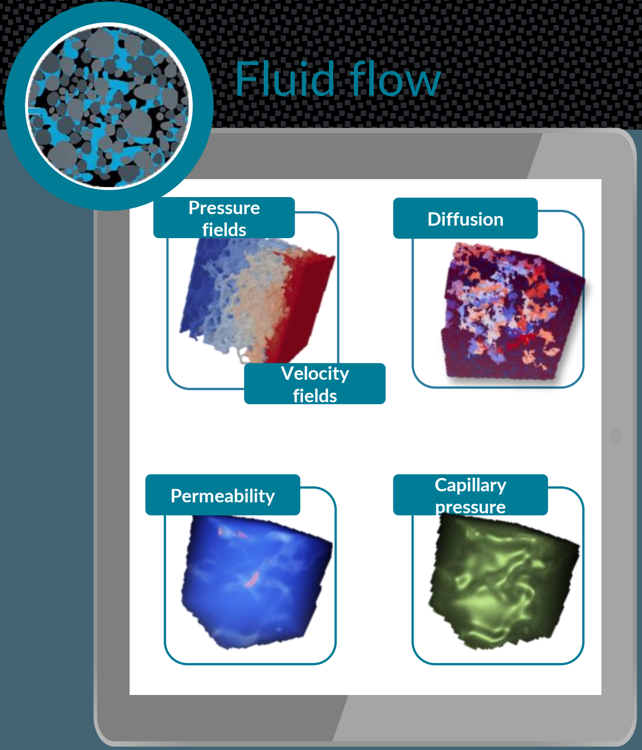
Numerical rock analysis software
Recipes & computation times

Voxilon Analysis

Structure



Fluid flow



Voxilon analyses list

Morphological characteristics

- Effective, Accessible porosities
- Chord-length distribution
- Sphere diameter distribution
- Geometrical tortuosity
- Formation factor

Dynamical properties

- Effective diffusion
- Diffusive tortuosity
- Absolute permeability (Kx, Ky, Kz)
- Capillary pressure

DRP measurements	Results	Computation time
Effective porosity	24.5%	3 sec
Max pore diameter (chord-length)	144 µm	1 sec
Main pore diameter (maximum-balls)	43 µm	1 sec
Geometrical tortuosity	1.5	181 sec
Connected pore components	519 components	2 sec
Diffusivity-tortuosity	5.2	90 sec
Absolute permeability	3130 mD	31 sec
Pore entry radius from Pc curve	23 µm	37 sec

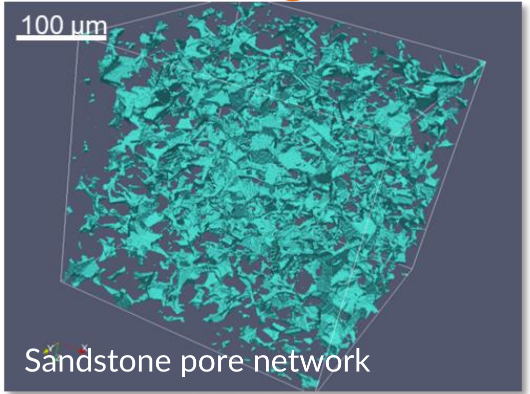
Total time: 6 min

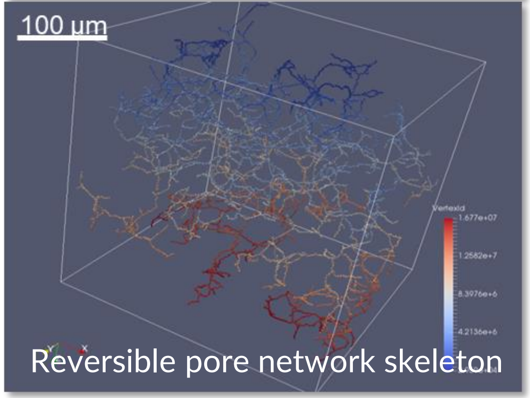
Computations made on a Fontainebleau sandstone image - 480^3 voxels (110 Mo)
Hardware setup: Dell XP 13 laptop 4 cores/8 GB RAM

Focus on Absolute permeability

Characteristics

- Permeability estimation from skeleton
- Paralleled calculation
- Similar method to Pore Network Modeling





Rocks	Image size	Permeability	Computation time
Mallorca	1 Gb	14 mD	276 sec
Berea	2,5 Gb	104 mD	11 min
GD15	6 Gb	100 mD	39 min
Bentheimer	21 Gb	2270 mD	1h 45 min

Hardware setup: HP Z840 workstation 32 cores / 256 GB RAM

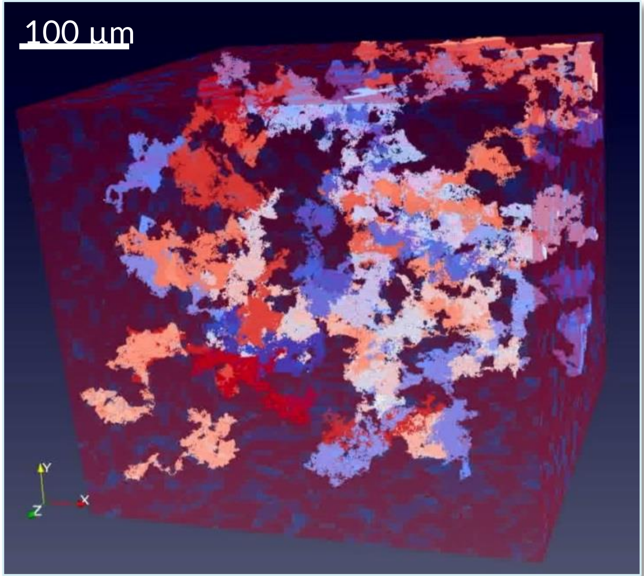
Focus on Effective diffusion

Characteristics

- Diffusion simulation based on Time Domain Random Walk method (Dentz, Russian, Dweik, Gouze et al.)
- Paralleled algorithm
- Semi-automated post-processing

Rocks	Image size	Diffusive tortuosity	Computation time
Mallorca	1 Gb	9	10 sec
Berea	2,5 Gb	7	10 sec
GD15	6 Gb	30	500 sec
Bentheimer	21 Gb	5	295 sec

Hardware setup: HP Z840 workstation 32 cores / 256 GB RAM

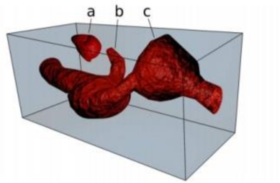


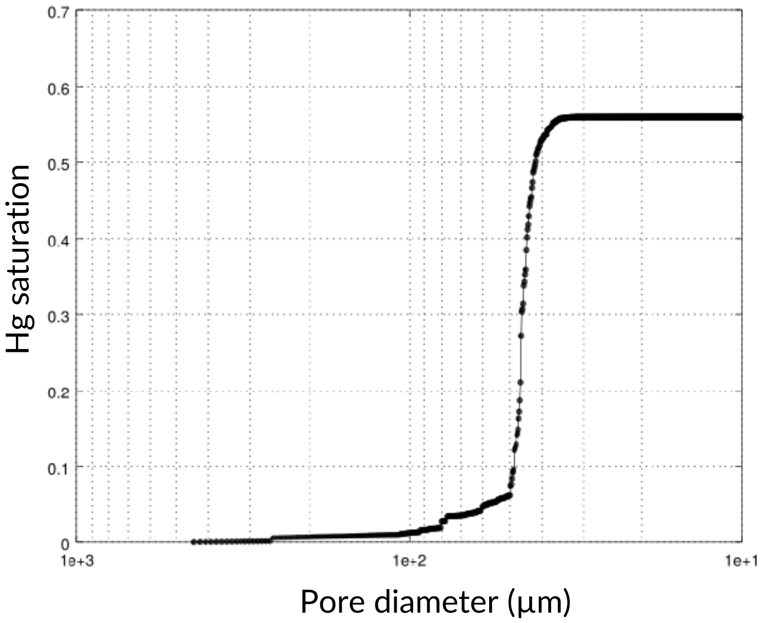
Diffusion process in a sandstone pore network

Focus on Capillary pressure

Characteristics

- Drainage process modelisation
- Based on the skeleton: hydraulic radius per node
- Non-wetting phase
- Trapping possibility





Rocks	Image size	Pore entry diameter	Computation time
Mallorca	1 Gb	7 µm	296 sec
Berea	2,5 Gb	4 µm	13 min
GD15	6 Gb	5 µm	42 min
Bentheimer	21 Gb	3 µm	1h 48 min

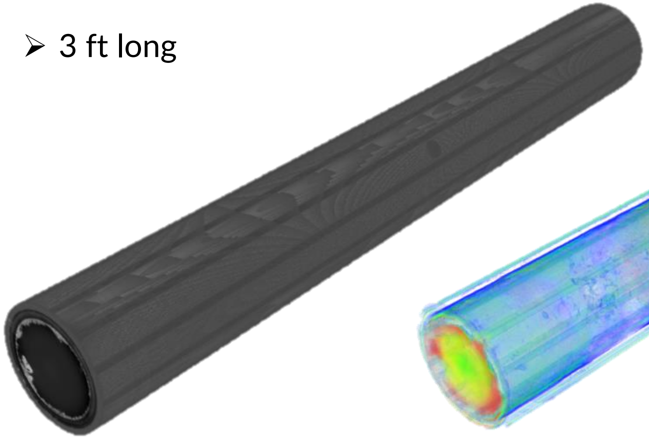
Hardware setup: HP Z840 workstation 32 cores / 256 GB RAM

Porosity & Permeability estimation

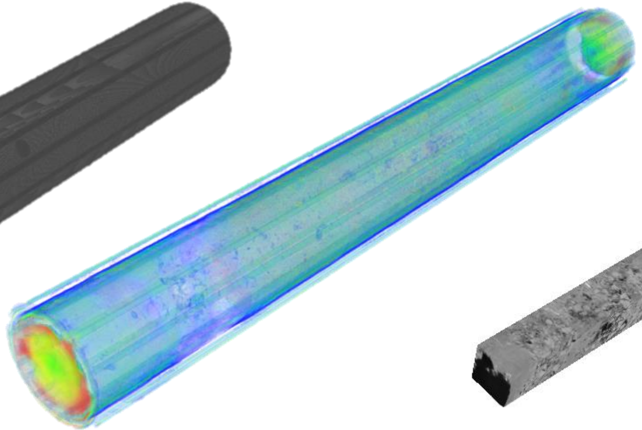
From digital core

Digital core Visualisation

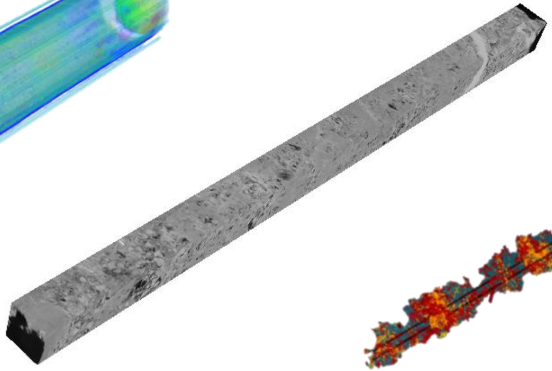
- CT scanner imaging
- Voxel size: 0.5 mm
- 3 ft long



Core into PVC tube



Inner structure
through PVC tube

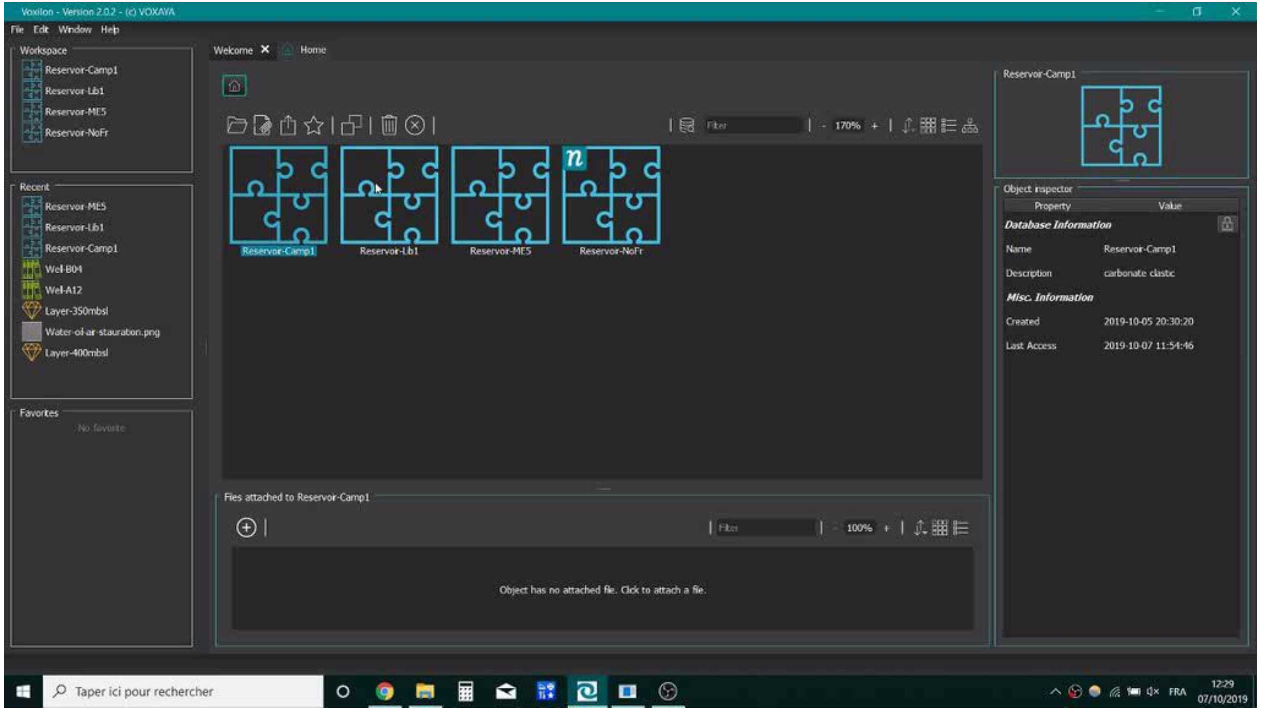


Core extraction

Main structural features

Digital core Screening

Video link: https://youtu.be/a3dBb0DIl0k

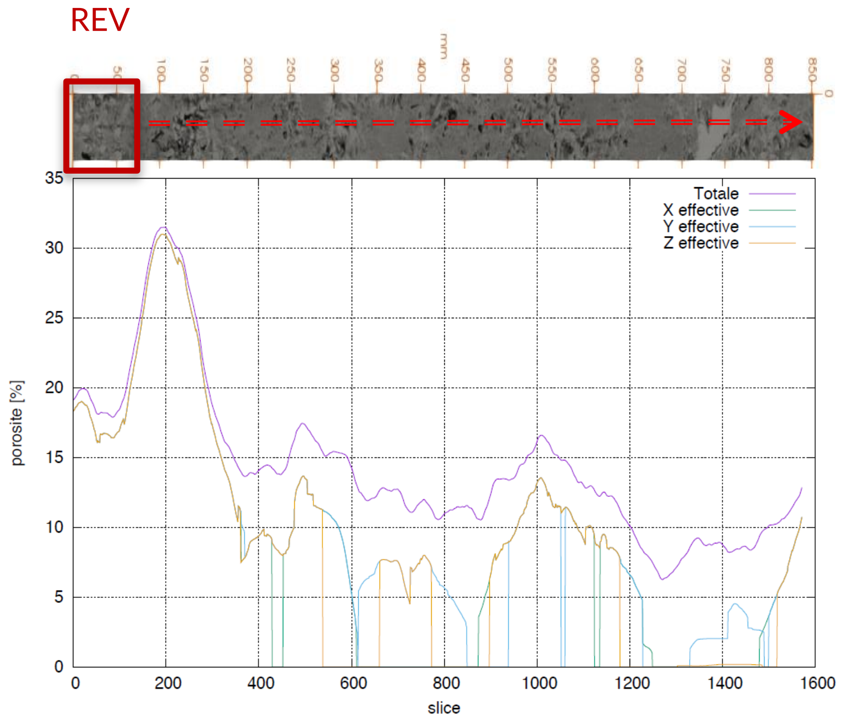


Porosity screening from REVs

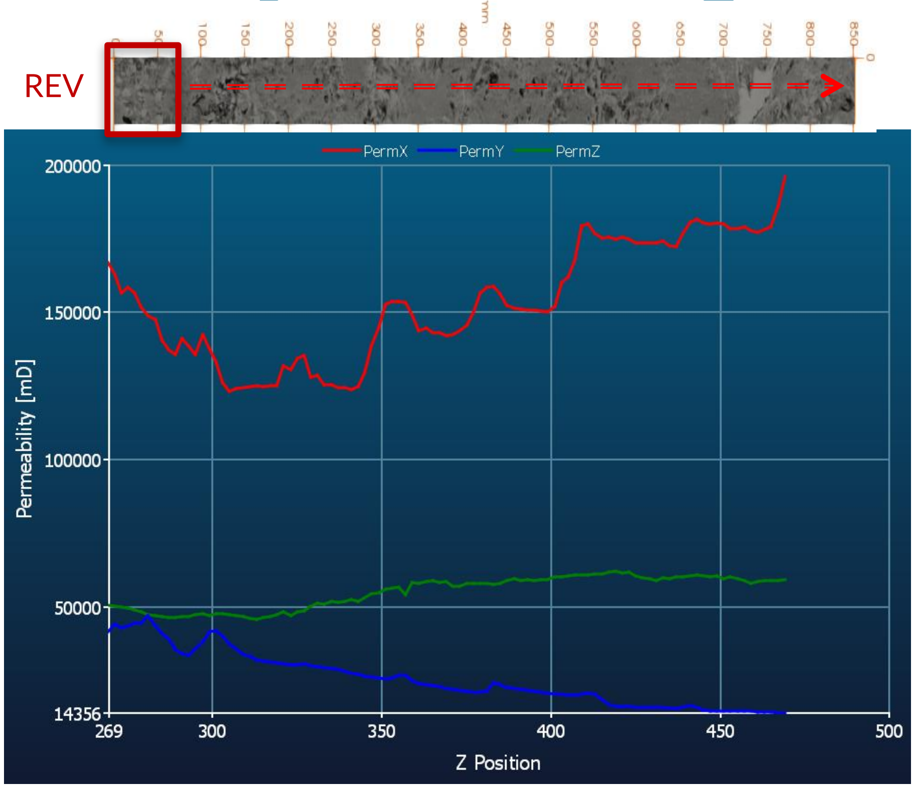
Digital core screening by Representative Elementary Volume displacement

→ **Porosity profiles**

- ❑ Total porosity
- ❑ X-direction (horizontal plane) effective porosity
- ❑ Y-direction (horizontal plane) effective porosity
- ❑ Z-direction (vertical plane) effective porosity



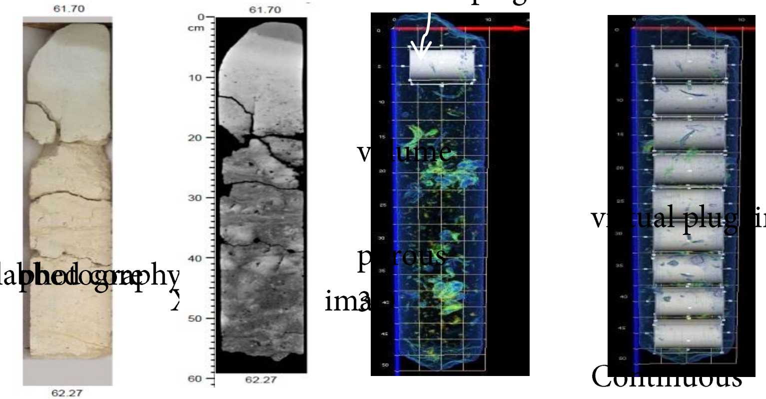
Permeability screening from REVs

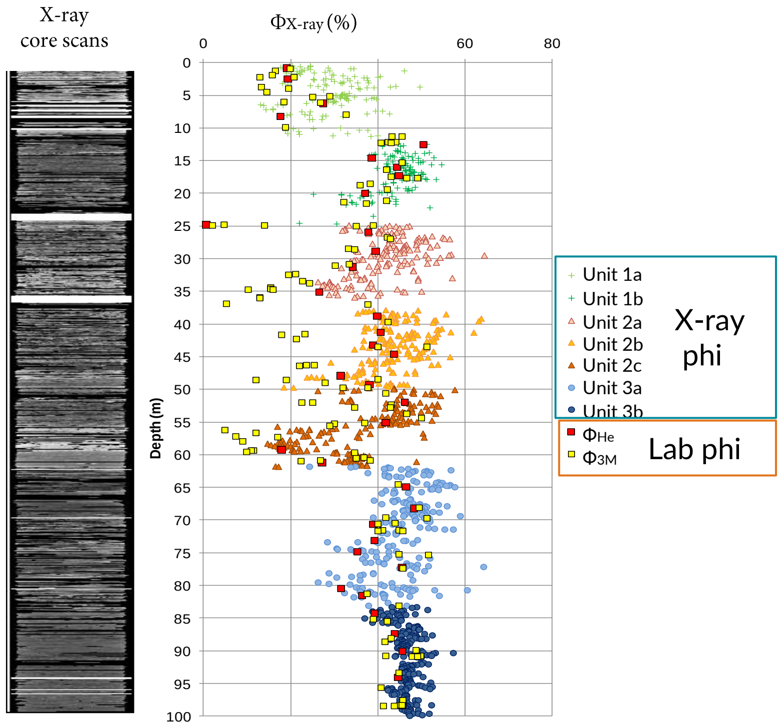


Digital core Screening

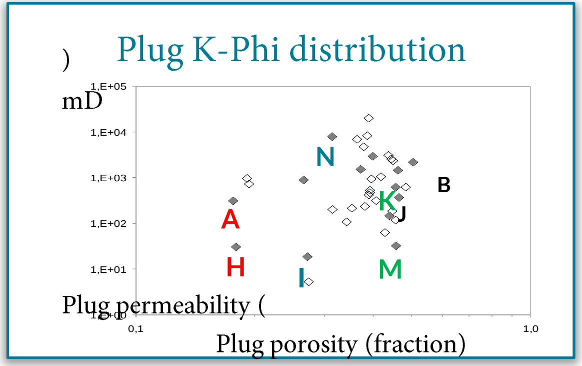
1200 virtual plugs sampled along 100m long "Full core" 3D scan

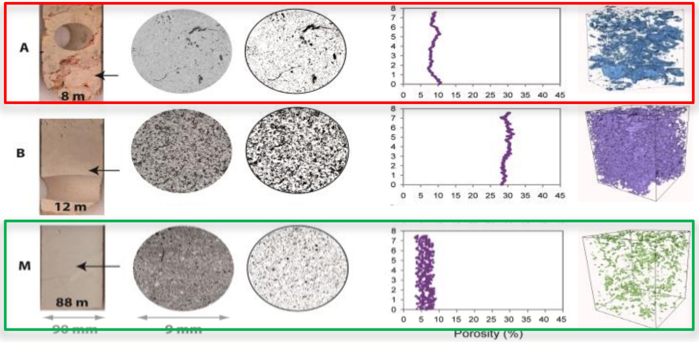
→ **High resolution porosity profile**



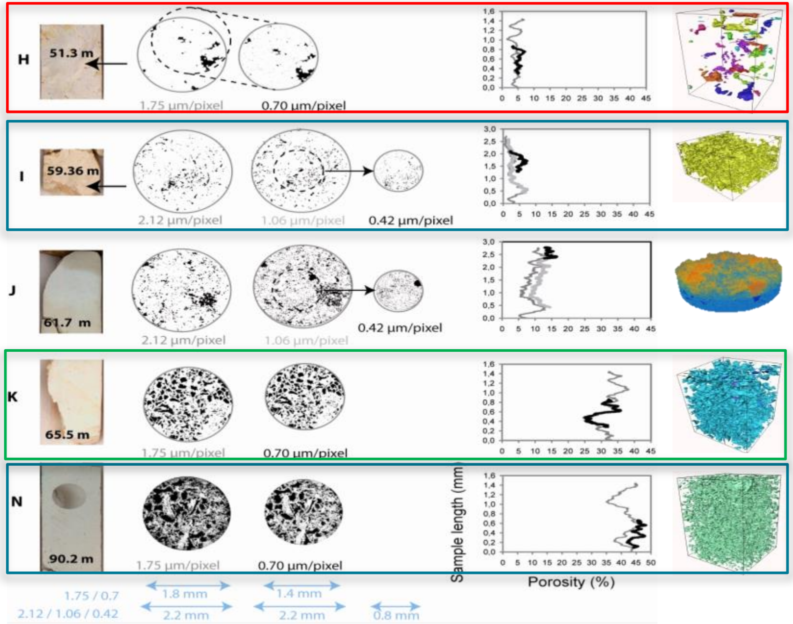


Phi-K relationship - microplug analysis





Multiscale pore network quantification: porosity vs connectivity



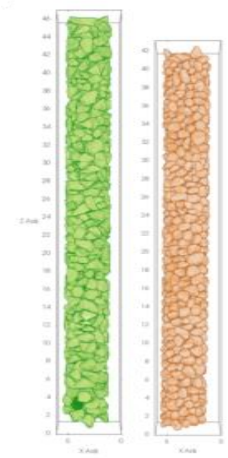
Challenging characterization

through sediments & cuttings

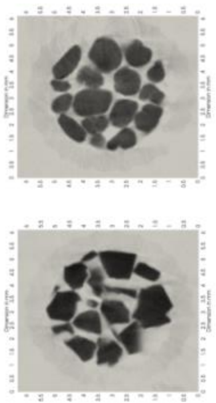
Unconsolidated sediments Analysis

Column fulfilled with rock grains and fluids

→ Numerical quantification is possible through tube

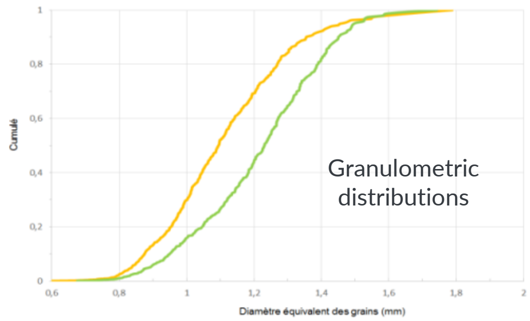


3D volumes
of grain columns

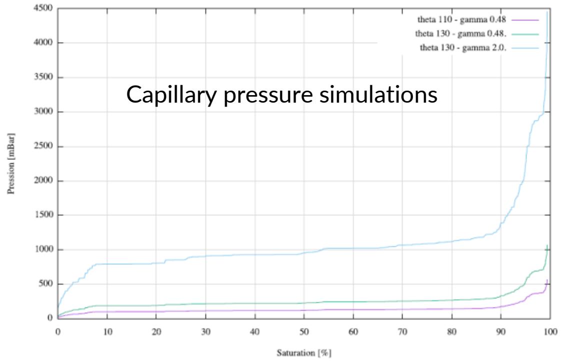


2D cross-sections

Characteristics	Column A	Column B
Number of grains	444	608
Intergranular porosity	52%	46%
Mean grain volume	0.8 mm3	0.6 mm3
Reactivity surface	2324 mm2	2284 mm2
Mean grain sphericity	2.2	1.4



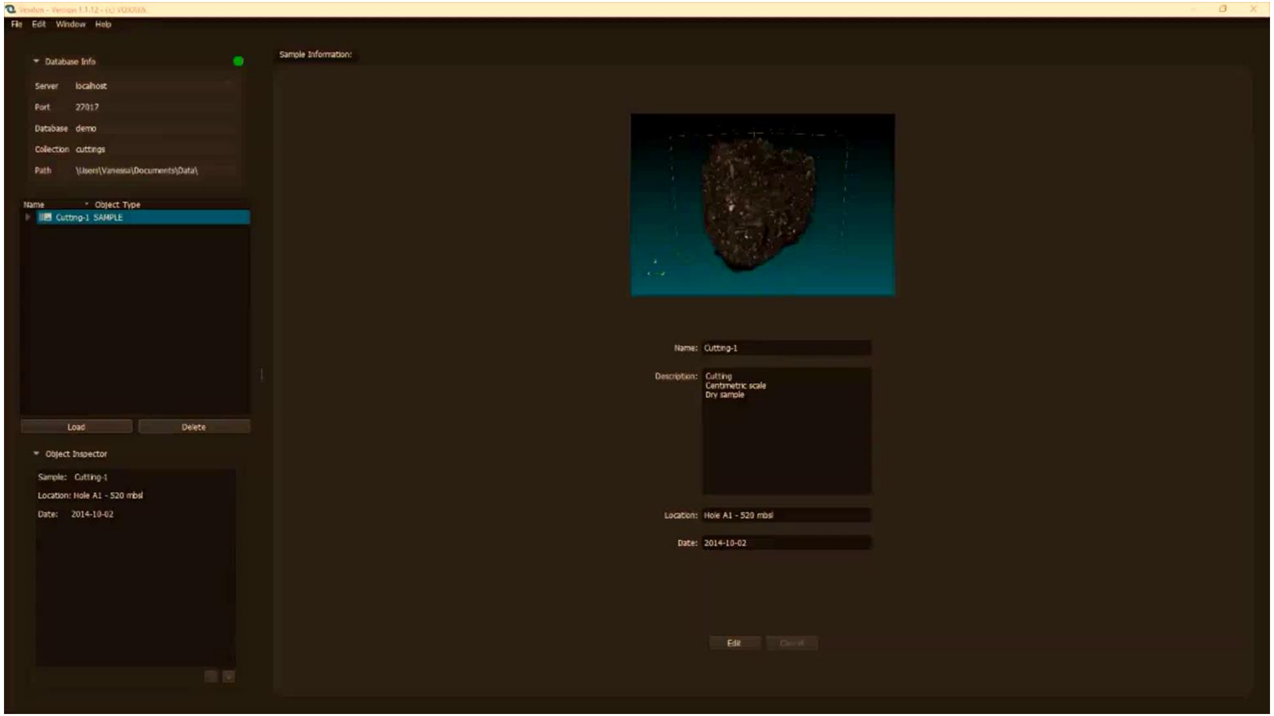
Granulometric distributions



Capillary pressure simulations

Digital cutting Visualisation

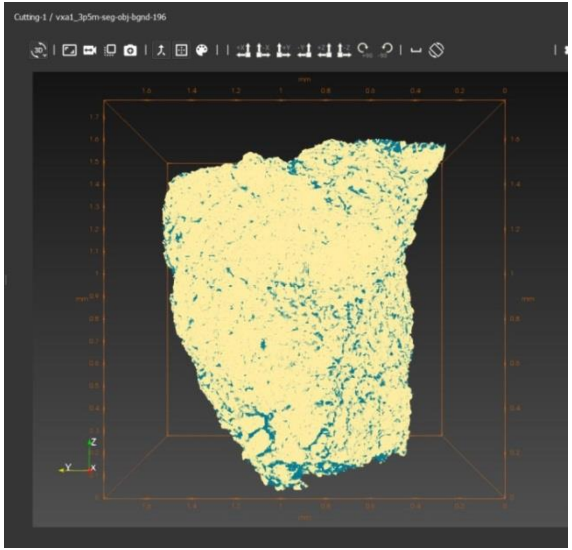
Video link: https://youtu.be/wVXZnMhscUM

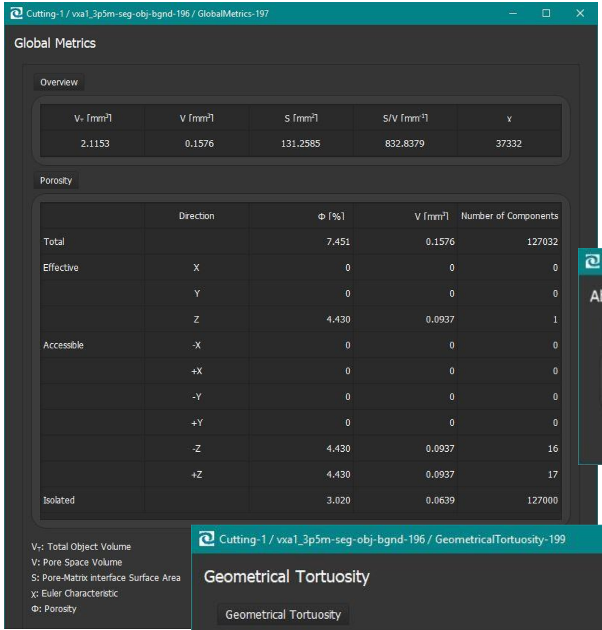


Digital cutting Analysis

Digital cutting

→ **Numerical quantification into each cutting**




Cutting-1 / vxa1_3p5m-seg-obj-bgnd-196 / GlobalMetrics-197

Global Metrics

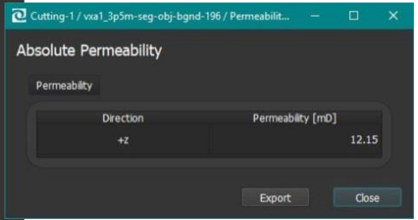
Overview

V_T [mm³]	V [mm³]	S [mm²]	S/V [mm⁻¹]	χ
2.1153	0.1576	131.2585	832.8379	37332

Porosity

	Direction	Φ [%]	V [mm³]	Number of Components
Total		7.451	0.1576	127032
Effective	X	0	0	0
	Y	0	0	0
	Z	4.430	0.0937	1
Accessible	-X	0	0	0
	+X	0	0	0
	-Y	0	0	0
	+Y	0	0	0
	-Z	4.430	0.0937	16
	+Z	4.430	0.0937	17
Isolated		3.020	0.0639	127000

V_T: Total Object Volume
V: Pore Space Volume
S: Pore-Matrix interface Surface Area
χ: Euler Characteristic
Φ: Porosity

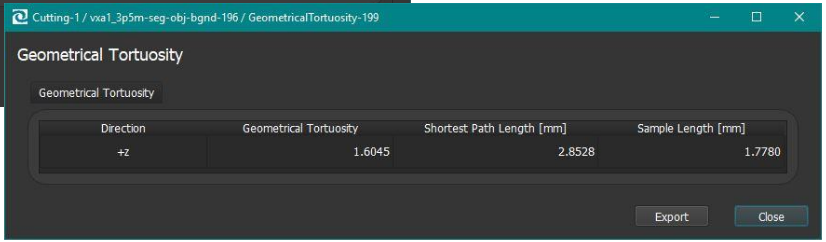

Cutting-1 / vxa1_3p5m-seg-obj-bgnd-196 / Permeabilit...

Absolute Permeability

Permeability

Direction	Permeability [mD]
+z	12.15

Export Close


Cutting-1 / vxa1_3p5m-seg-obj-bgnd-196 / GeometricalTortuosity-199

Geometrical Tortuosity

Geometrical Tortuosity

Direction	Geometrical Tortuosity	Shortest Path Length [mm]	Sample Length [mm]
+z	1.6045	2.8528	1.7780

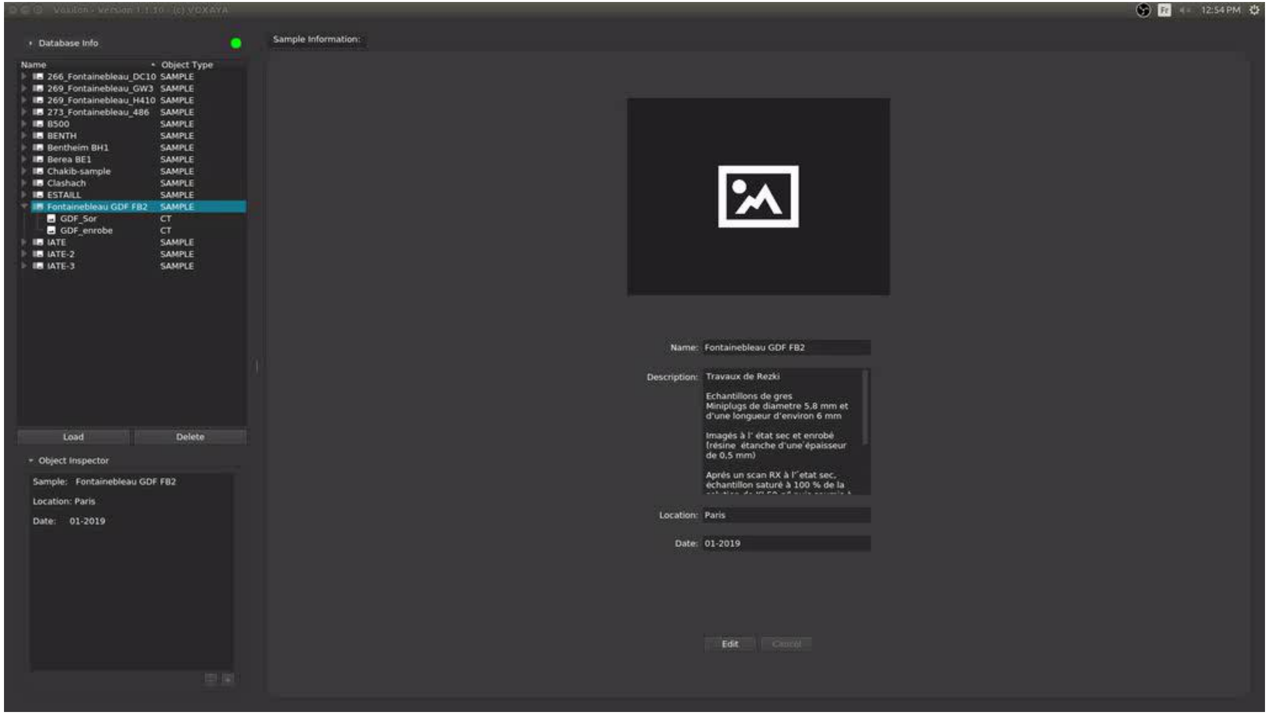
Export Close

- Voxel size: 3.5 µm
- 4 mm long

Saturated sample

Digital saturated plug Analysis

Video link: https://youtu.be/5Bg7qqKR4T8



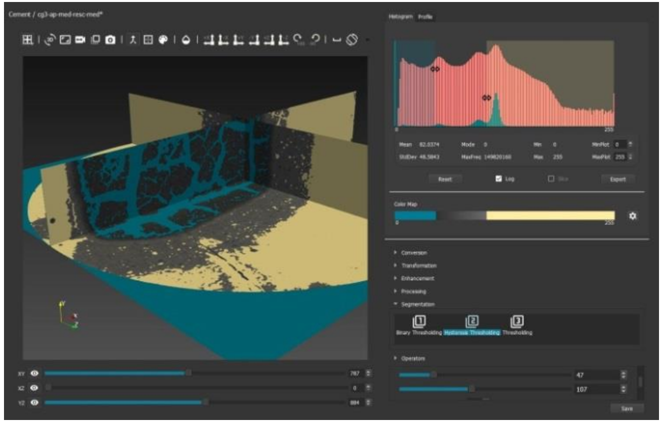
Porosity Estimation by Machine Learning

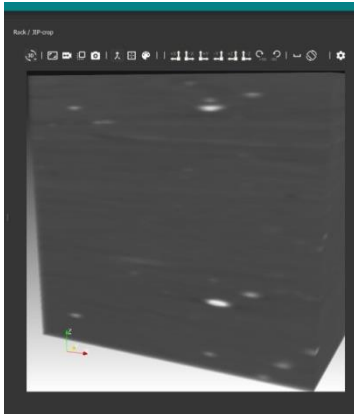
SCA2019-025 paper

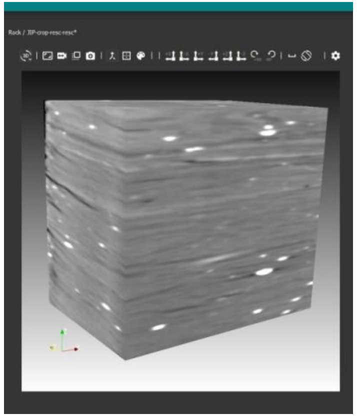
Universität Konstanz

Segmentation step Flaws

Sensitive & crucial step of the image analysis workflow → **Direct impact on quantifications**







Isolate & labelize each component.

Several segmentation tools: binary, hysteresis, gaussian mixture thresholding.

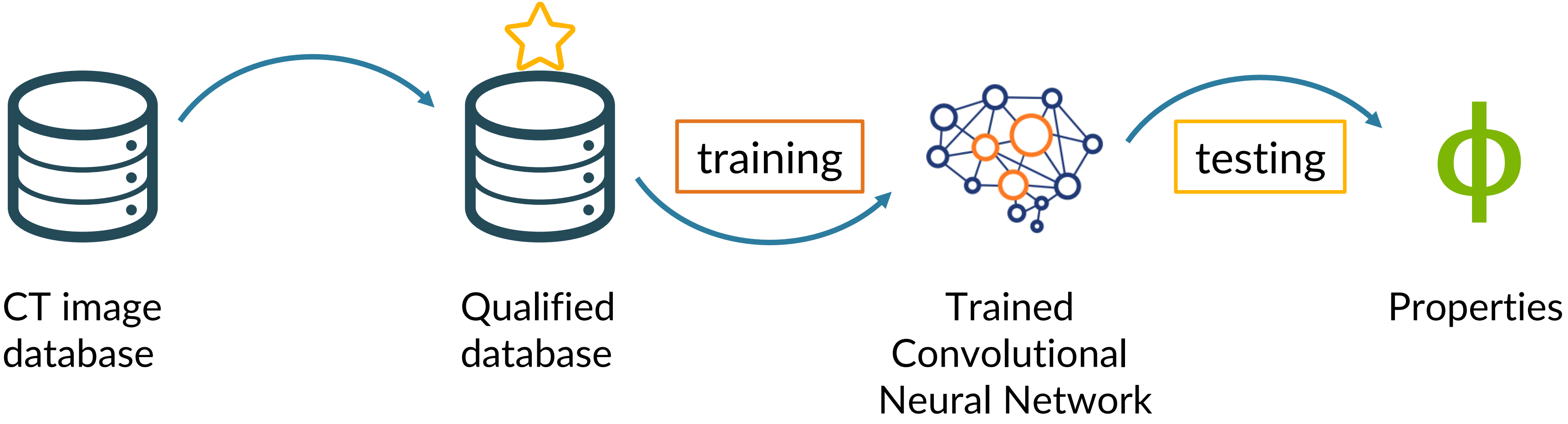
Resulted image depending on the operator.

Enhance by filter combination.

Pre-processing : artefact, beam-hardening reducing, signal/noise ratio increase.

Distorted initial information.

Machine Learning Workflow



Experiments with CNN

RockClass

Rock classification

Grayscale image to rock type

RegPhi

Direct porosity estimation

Grayscale image to porosity

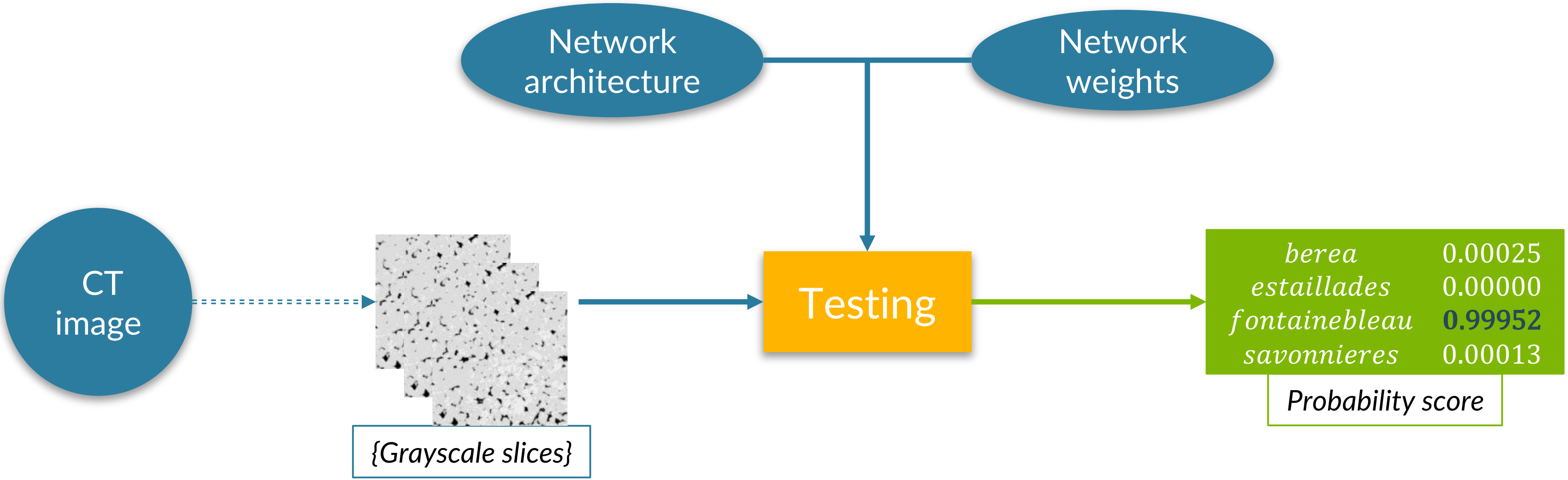
AutoEnc

Explicit porosity estimation

Automatic segmentation

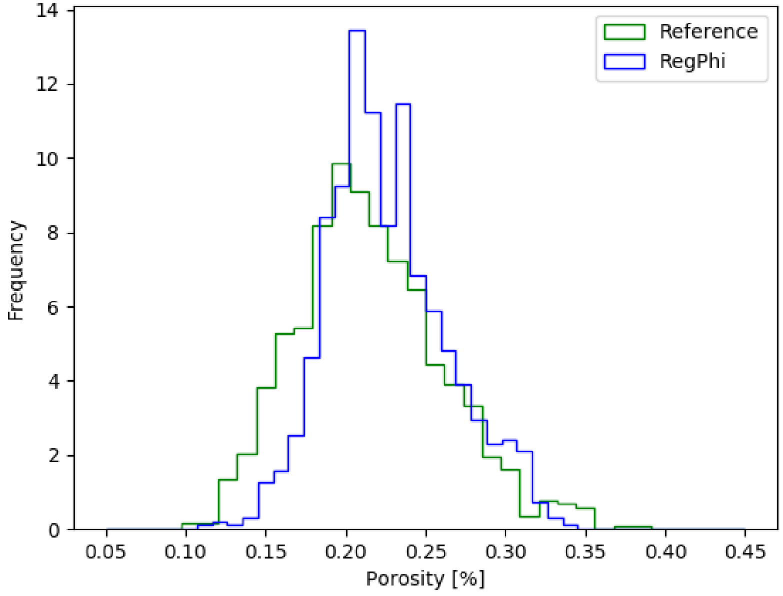
Hardware setup: HP Z840 workstation, *Intel Xeon CPU 3.20 GHz (32 cores), Nvidia Quadro M6000, 256 GB RAM*

Testing Rock Classification

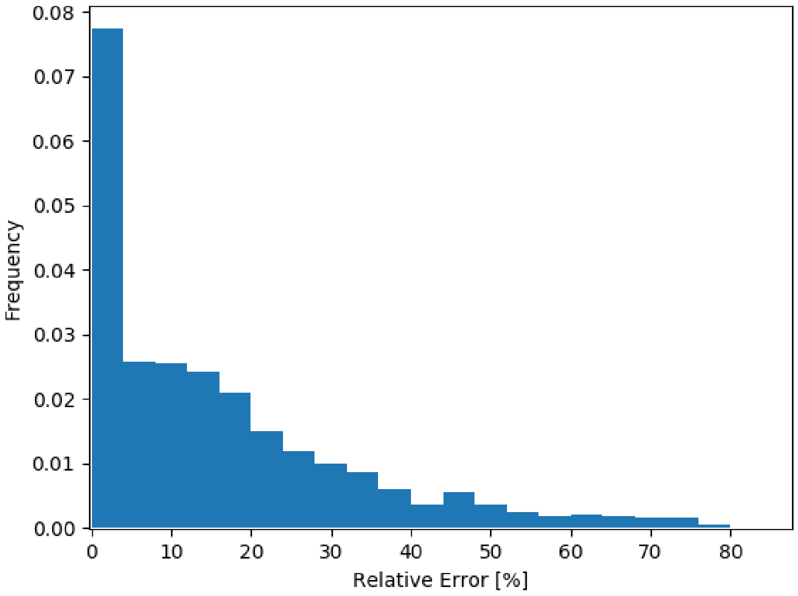


Global recognition accuracy> 99.9%

Testing Direct porosity estimation



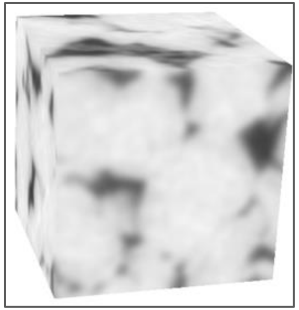
Porosity distribution from RegPhi on Berea



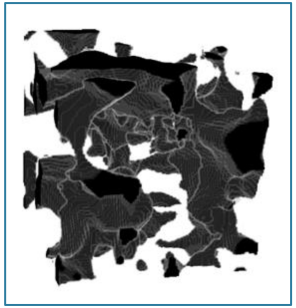
Relative error between RegPhi and reference on Berea

Architecture based on *Sudakov 2016*

Segmentation by IA



$100 \times 100 \times 100$ voxels

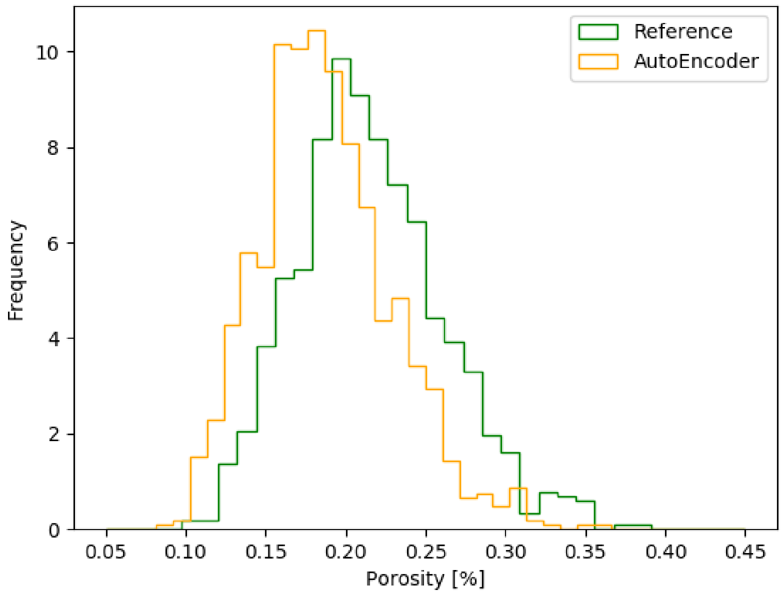


User segmentation

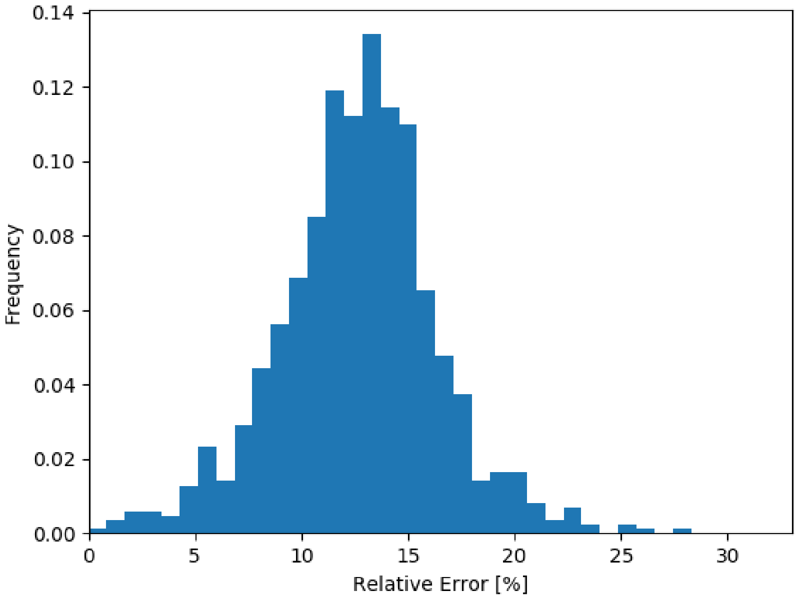
Hysteresis Thresholding
with Voxilon

AutoEnc segmentation

Testing Explicit porosity estimation

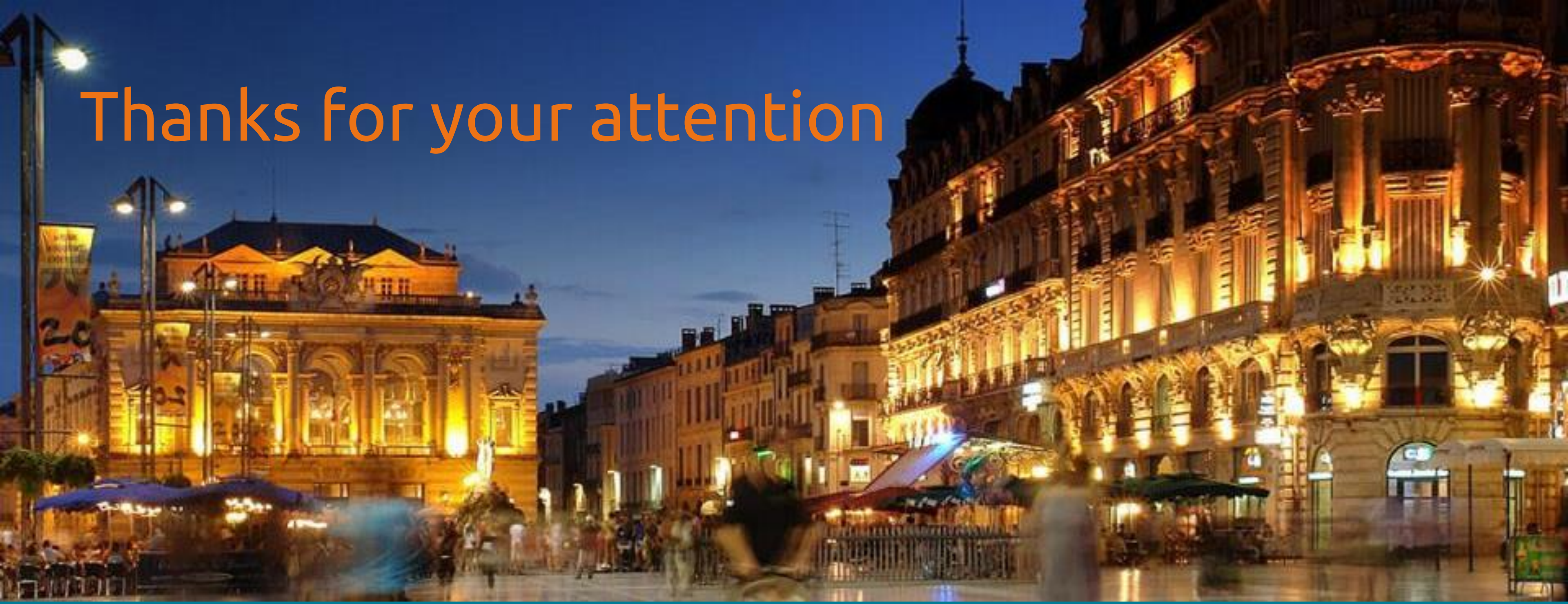


Porosity distribution from AutoEnc on Berea



Relative error distribution between AutoEnc and Reference

Thanks for your attention



hebert@voxaya.com

+33 669 086 843

www.voxaya.com

Cap Omega – CS 39521
Rond-point Benjamin Franklin
34000 MONTPELLIER
FRANCE